Can radiographer musculo-skeletal trauma radiograph interpretation re-position the profession in Australian healthcare?

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Summary

Literature review

The literature review examines the socio-historic context of why radiographer interpretation has been hampered in Australia. Interpretation performance measurement methods are analysed allowing methodological corrections to be applied in this study. Literature also establishes whether current healthcare and political developments will enable radiographer image interpretation.

Method employed

Development of a consensually agreed (3 of 4 radiologists) image test bank, balanced according to injury prevalence, rates of injury according to body region, age and gender is described. Sixteen volunteer radiographers with 2+ years of experience from radiology services imaging emergency department patients including children but not major trauma from across Victoria interpreted the images before and after an educational input. Sixteen final year medical students from a single medical school in Victoria also voluntarily interpreted the test bank. Participants provided interpretations using home computers with widely available software and a standardised response form. Radiographers completed surveys before and after an educational input to establish if radiographer attitudes changed about perceived interpretation ability and the structures needed to support radiographer interpretation. Medical students were questioned if undergraduate image interpretation education was adequate and to identify difficult to interpret images. They were also asked whether radiographer interpretation would help, if they knew radiographers should give verbal opinions on images when required or about international radiographer interpretation. Illustrative examples of radiographer interpretations in clinical situations to add study depth were given.

Statistics demonstrating numerical inter-group variation from scores generated using a tick box and free text comments against the test bank are given. Participant abilities were compared using all images, appendicular only and adult only images. The Mann Whitney U non parametric test was used to establish statistical significance between the performance of radiographers post education test, radiologists and medical students.

Conclusions

Radiographers overcalled more frequently than radiologists but ROC values showed least difference between this pairing. Radiographers missed fewer positives than medical students. Radiographer ROC values were significantly better than medical students. Depending on the comparison statistic used, a radiographer interpreting role is possible, though a longer period of education assimilation is advised. It is opined the educational paradigm for radiographers is currently inappropriate for diagnostic decision making and is supported by radiographer educational needs commentary and the medical students' belief that radiologists' interpretations are best. This is despite contradictory examples of health system failure and radiologist performance variation shown during the image test development. Analysis of radiographer registration, and professional and governmental body perspectives, provides an opportunity to develop radiographer interpretation if universities change their teaching paradigm. However, the Medicare reimbursement scheme to healthcare providers limits this. Corrective measures accounting for earlier Australian investigation flaws are successful in this study however further examination to extend the knowledge to understand the performance of radiology interpretation by non-radiologists is needed. An internet based system of benchmarking is proposed to achieve this. In the light of recent coronial comments and failures to report images, federal and state/territory governments should consider ways to re-position the radiographer in Australian healthcare.

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STATEMENT OF ORIGINALITY

The material submitted within this thesis has not been accepted for the award of any other degree or diploma in any university or other institution. This statement affirms to the best of the student's knowledge the thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Name (print) [redacted]

Signature [redacted]

Date 8TH JUNE 2015

Abbreviations

AC1	The AC1 Statistic – a version of Kappa
AHPRA	Australian Health Professions Regulatory Agency
AIR	Australian Institute of Radiography
AMA	Australian Medical Association
APAP	Advanced Practice Advisory Panel
APWG	Advanced Practice Working Group
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
AUC	Area Under the Curve (the ROC curve)
ASA	Australian Sonographer's Association
BI	Bias Index
BMA	British Medical Association
BPK	Bias and Prevalence adjusted Kappa value
CoR	College of Radiographers (UK)
CoRA	Confederation of Regulating Authorities
CPD	Continuing Professional Development
CPSM	Council for Professions Supplementary to Medicine
CT	Computed Tomography
DICOM	Digital Imaging and Communication in Medicine
DHHS	Department of Health and Human Services
DHS	Department of Human Services
ED	Emergency Department
ESR	European Society of Radiology
FN	False Negative
FP	False Positive
FROC	Free-response Receiver Operator Characteristic curve
HARP	Hospital Admission Risk Program
HCPC	Health and Care Professions Council
HWA	Health Workforce Australia
IPAT	Inter-professional Practice Advisory Team
IRMER	UK Ionising Radiation (Medical Exposure) Regulations
ISRRT	International Society of Radiographers and Radiologic Technologists
KSF	NHS Knowledge and Skills Framework
LR-ve	Negative Likelihood Ratio
LR+ve	Positive Likelihood Ratio
LROC	Localisation Receiver Operator Characteristic curve
MBA	Medical Board of Australia
MRPBA	Medical Radiation Practitioners Board of Australia
MRPBV	Medical Radiation Practitioners Board of Victoria
MRTBQ	Medical Radiation Technologists Board of Queensland
MSK	Musculo-skeletal Trauma
NHSBSP	National Health Service Breast Screening Programme (UK)
NPV	Negative Predictive Value
NRAS	National Registration and Accreditation Scheme
NZIMRT	New Zealand Institute of Medical Radiation Technologists
NZMRTB	New Zealand Medical Radiation Technologists Registration Board

PPV	Positive Predictive Value
PACS	Picture Archiving and Communication System
PI	Prevalence Index
Pneg	Proportion of answers given as negative also interpreted negative
Post Odds	pre test odds x likelihood ratio
Post Odds	
Probs	Post test probability of having the disease, based on the test results
Ppos	Proportion of answers given as positive also interpreted positive
QA	Quality Assurance
QH	Queensland Health
QUDI	Quality in Diagnostic Imaging
RANZCR	Royal Australian and New Zealand College of Radiologists
RCR	Royal College of Radiologists
RCT	Randomised Controlled Trial
RDS	Red Dot Signalling/System
RMIT	Royal Melbourne Institute of Technology
ROC	Receiver Operator Characteristic curve
ROC emp	The calculated area under the curve of the empirical ROC curve
ROC fit	The calculated area under the curve of the smoothed/fitted ROC curve
ROF	Radiographer Opinion Form
SCoR	Society and College of Radiographers
TAFE	Technical and Further Education Institute
TN	True Negative
TP	True Positive
UK	United Kingdom
US	Ultrasound
USB	Universal Serial Bus
VLE	Virtual Learning Environment
Wtd Kappa	Weighted Kappa value

The layout of the thesis

Radiology began its life in the late 19th century and gained impetus as a medical specialisation in the first two decades of the 20th century. With a history now extending to 120 years many developments have been seen both in radiological techniques as well as the workforce in Australia and internationally. One of the drivers for this investigation was to establish whether the Australian radiographers could contribute to the provision of some form of radiograph interpretation service as has been seen in UK .The UK developments are perceived to be world leading, with one function being to support the newly qualified medical practitioner in his/her early years of practice in the Emergency Department (ED) so that mistakes in diagnosis from radiological examinations are reduced. To allow a full understanding of how pertinent aspects contribute to the understanding of why Australia differs from the UK and to analyse whether Australian radiographers can perform this role, the thesis is divided into several sections. Chapters within each section expand on features of the study, with the thesis being divided as below:

Part 1	Introduction/background considerations, project aims and socio-historic context
Part 2	Methodological critique and proposed study investigation method
Part 3	Quantitative and qualitative results
Part 4	Discussion
Part 5	Study limitations, conclusions, recommendations and further work

This thesis is supported by pilot work that was completed in 2010 – 2011 in Queensland which used material developed as part of this study. This work demonstrated the value of radiographer input to adult appendicular trauma image interpretation in two Brisbane based hospitals. This resulted in the creation of a report for Queensland Health (QH) the major funding body, and the Medical Radiation Technologists Board of Queensland (MRTBQ). Two papers were published in 2012 and 2013 within the UK peer reviewed journal 'Radiography.' A commentary critiquing the statistical approach adopted by a team of Emergency Nurse Practitioners aiming to show their ability to interpret trauma plain radiographs at the Alfred Trauma Centre in Melbourne was also published in the International Journal of Nursing Studies in January 2014. These papers are included at the end of the appendices.

PART 1

INTRODUCTORY BACKGROUND CONSIDERATIONS, PROJECT AIMS, AND SOCIO-HISTORIC CONTEXT

'Radiographers tend to function somewhat below the level of accomplishment reached by their colleagues who work in pathology or other laboratories.'

K Swinburne, Radiologist
The Lancet, March 20th, 1971 p 589

Chapter 1 Background considerations and reasons why the study was performed

1.1 Initial Considerations

Medical Imaging is the backbone of the modern health care system. Its practice is at the heart of the diagnostic process and patient management. However the health care system is facing ever increasing demands upon its capacity to meet public expectations. An increasing population size and workforce expectations in terms of work-life balance have also contributed to a need for greater numbers of doctors to be trained [1-4]. Indeed recent reports in the Australian media have suggested the system is in crisis. In respect to the delivery of radiology services, turnaround times can be large and there is potential for pathology to be missed [5-7]. The situation is compounded by the fact that according to Zhou et al [8] inappropriate and inadequate imaging referral knowledge and practices amongst junior medical staff is the norm.

This should not be a surprise given that radiology receives a low level of teaching averaging 85 hours in Australian undergraduate medical curricula [9]. Furthermore, when medical students receive radiology teaching it is not generally provided by radiologists, particularly in the clinical setting, with the result of an ongoing undervaluation of the specialty [10]. Medical students fail to learn the complexities surrounding image interpretation from the recognised expert namely the radiologist.

Plain radiographic interpretation forms one of the baseline capabilities of the newly qualified doctor and is a key performance expectation of the medical practitioner working in the Emergency Department (ED) [11]. This ability is representative of expectations of the medical practitioner who seeks registration by the Medical Board of Australia (MBA) following completion of their internship [12].

It is during their internship that new medical graduates are expected to develop a broad range of skills, including image interpretation, through access to senior medical staff [13 p5]. This requirement is in accordance with the supervisory expectations promulgated by the national accrediting body, the Australian Medical Council (AMC) [14].

Significantly, several authors have indicated that when clinical demand is high, close supervision is not always available to interns despite AMC expectations [15, 16 - 20]. The need for more doctors has also placed pressure on medical schools and internship providers resulting in a change to the format of the internship. Previously there was an expectation for an 8 week ED placement within all internships. Owing to the further pressure on available placement experience, defined as 'terms' by the AMC, the 8 week ED experience in medium/large hospitals has been substituted by small hospitals or GP lead emergency service placements [13]. As a result the period in ED that was a prime focus for plain radiograph interpretation is reduced. The lack of serious attention to developing undergraduate competency in image interpretation within medical education has the potential to affect patient care and management. Instead of stipulating interns interpret a finite number of images to prove their level of skill, the internship assessment process relies on the mentor attesting candidate competence [11]. If appropriate foundations in image interpretation are not laid during the undergraduate period [9, 21, 22] this could leave junior doctors at a significant disadvantage for their future practice development. Furthermore this potentially exposes the public to possible error that, due to radiology reporting delays, may not be corrected in an acceptable timeframe [5, 6].

Cowling reports the International Society of Radiographers and Radiologic Technologists (ISRRT) and the European Federation of Radiographic Societies (EFRS) is pursuing recognition of radiographer status as a full allied health professional [23]. It is envisaged this will achieve equivalence with nursing and physiotherapists and as such flag radiographers as the professional, other than radiologists, to provide an image interpretation. It is further suggested that experienced radiographers with advanced education operating in a specialised area would benefit the developing intern/junior doctor. For the purposes of this thesis the reader should assume radiographers are diagnostic radiographers or medical imaging technologists.

Thus we have a situation where junior doctors appear to be underprepared for their role in relation to image interpretation, there are delays in radiologists reporting images and there is underutilisation of radiographers who create the image.

This study describes and analyses the historical, socio- political and educational factors that have led to this situation and investigates the potential of a multi-disciplinary approach to the delivery of medical imaging services in the 21st century in Australia. A mixed quantitative/qualitative approach to the research is used. The quantitative arm measures the ability of final year medical students and further educated qualified radiographers to interpret musculo skeletal (MSK) trauma plain radiographic images. This was achieved using an image test bank the content of which was consensually agreed by several consultant radiologists. It also explores qualitative aspects of each participant group from perspectives of perceived image interpretation confidence, perceptions of medical students regarding a radiographer interpretation and radiographer experience of use of their skills by medical staff in their clinical environments. Accordingly the results are analysed and discussed in the light of the known socio-historical factors that have influenced radiographer practice to date, to establish if a multidisciplinary approach to medical imaging services delivery is appropriate.

1.2 Project aims

This investigation explores whether, after a short course of education, experienced radiographers from the state of Victoria can identify and interpret abnormalities on plain images of musculo-skeletal (MSK) trauma to support the junior doctor.

Any work of this nature to date internationally has examined radiographer interpretive capability relative to qualified doctors or other health professionals [24, 25, 26-30]. The Australian educational model that leads to a medical internship expects internees to be able to recognise plain radiographic pathological and traumatic changes in images of the chest, abdomen and skeleton. Moreover, the ‘Intern training – guideline for terms’ document [31] makes it clear that the foundational knowledge obtained in the undergraduate medical course of study should be appropriate for building upon during internship, to reach fully qualified status. It is therefore pertinent to ask if the soon to be intern doctor possesses this capability to an acceptable standard. There were difficulties in recruitment of qualified doctors (post internship in 1st year qualified) or as interns due to this component of practice being beyond university medical school control. Consequently it was believed that access to medical students in their final year was feasible and those recruited should be at a similar level of preparation, thus minimising the potential for inclusion of variables that could not be controlled.

Likewise, the Medical Radiation Practice Board of Australia (MRPBA) has recently issued within its 'Capability Framework' a list of image appearances/pathologies that radiographers should be able to identify [32] on completion of the undergraduate degree. An ability to recognise these appearances within the MSK system, forms part of this investigation amongst a group of further educated experienced diagnostic radiographers. Prior to this study these capabilities were not specifically requested by MRPBA or its predecessors the State Registration Boards where they existed. As such this necessitated a need to provide a baseline level of education amongst radiographer participants, similar to that purported in undergraduate medicine prior to internship, was also available to radiographers as the medical student received a minimum of 85 hours of specific radiology training [9]. Consequently it was also inappropriate to compare final year radiography and medical students. The investigation also explores through the objectives listed below whether radiographer input can provide a supportive contribution to the image interpretation process for MSK trauma events. In the past radiographers have been prevented from contributing to the patient pathway through image interpretation and content description [33-38]. This investigation identifies potential educational requirements and areas of concern for radiographers and final year medical students by evaluating the objectives listed below:

1. literature to identify the factors that have hindered radiographers from participating in musculo-skeletal trauma image interpretation;
2. the ability of further educated experienced radiographers and final year medical students capacity to interpret appearances seen in musculo-skeletal trauma radiographs in order to establish if each group has accuracies close to that seen amongst radiologists;

3. the ability of further educated experienced radiographers and final year medical students to describe incidental findings on an examination and express whether further investigation(s) is/are warranted ;
4. the number of requests for further imaging between further educated experienced radiographers and final year medical students in comparison with radiologists;
5. whether final year medical students are aware of and open to input by radiographers via image interpretations to the emergency department (ED) to aid their own performance and if radiographers believe they are able to do this.

To reiterate and clarify within the PICO format of study design; population is that of further educated experienced radiographers from the State of Victoria compared against final year medical students. The intervention was one of the radiographers having received a short course in further education so they were at a knowledge level of injury mechanism and image interpretation capability that is purported to be the expected starting point of final year medical students about to enter their internship. This enabled comparison between the two groups relative to the gold standard of a consensually agreed radiologist reported image test bank. Further information to add depth to the sociological components was gleaned through use of a series of surveys before and after the baseline image test for the radiographers, and before the image test for medical students. Outcomes were expected to show that due to the wider radiographer experience they would perform at a higher ability level than the medical students but lower than the radiologists. Improved radiographer performance was also envisioned due to the intervention and further details regarding the perceptions and process of image interpretation in this field by the two groups could be extracted.

1.3 Discussion of the aims/objectives

The main aim of this study was to establish whether experienced radiographers from the state of Victoria can aid junior doctor interpretation of MSK plain radiographs following a short course of education. Several objectives were also investigated to extend the understanding associated with MSK trauma image interpretation by radiographers and its potential use by medical students who will soon be practising. As such section 1.3.1 adds information underpinning the ideas explored in the key aim and objectives 1 – 5. Objectives

2,4 and 5 are further considered in section 1.3.2 with objective 5 receiving more underpinning thoughts in section 1.3.3.

1.3.1 Australia relative to the international scene

The literature shows that Australia has not progressed down the same path of radiographer reporting and commenting as seen in the UK. The radiological examination request and subsequent radiology consultant interpretation in this study is driven by the content of a patient history following a trauma related event [39]. The Royal College of Radiologists (RCR) in the UK indicated in 2006 that the trained nurse or allied health practitioner without a medical degree should, following education, be able to correctly describe images with a single pathology. This suggests in the application to trauma related referrals a *'…yes/no answer…'* is expected [39 p11] to align with Thomas' UK approach of the three D's that would support multidisciplinary working. His proposal identifies that the practitioner, in this case the radiographer, would

> '*Describe, Diagnose (in this case is there a fracture or other abnormality?) and Direct for further examinations/projections that may be required'* [40 p16].

The outcome of trauma related reports can be affected by the amount of clinical detail provided to the radiologist [41]. Often other irregular appearances are evident and of dubious significance with respect to answering the clinical question in the radiological report. Thomas [40] suggests these should be ignored if they do not contribute to the imaging outcome of the trauma experienced by the patient that he/she attended radiology for. On this basis Thomas suggested that the interpretation that could be offered by a radiographer would be equivalent to those given by radiologists. Furthermore the radiographer could provide appropriate information for the ED team to act upon [7], in a timeframe that is classed as immediate. It should be noted though that the radiographer can elicit further information beyond that on the referral form through patient interaction during the imaging process [42] thus potentially improving the interpretive process.

It has been shown that [42] through investigating the impact of interacting with the patient during the examination that an advantage may be revealed by radiographers making clinical observations. These are often not written in the histories received via request forms. The radiographer and patient interaction with provision of an immediate interpretation of radiographic appearances improves surety of diagnosis by the receiving doctor and enhances examination quality outcomes [42]. In the State of Queensland [24], a pilot investigation in Brisbane demonstrated that when radiographers had access to the patient, the overall performance accuracy rate improved compared to a standardised test component of the same study where patients were not available to influence image interpretations [25]. Participants showed that they could operate at a level not statistically significantly different to the ED doctor and radiologist. By working together the overall accuracy rate of ED doctor and radiographer was enhanced in the two ED departments in the project. A further project in Ireland [43] evaluated junior ED doctors and radiographers without additional training in their interpretations of single view wrist radiographs and head CT. This work showed statistically significant diagnostic improvement when radiographers and junior doctor interpretations were merged ($p \leq 0.008$ for wrist fractures and $p \leq 0.0026$ for CT head) indicating the team approach was of value. These pieces of research demonstrate how the clinical component is important and outline how the testing regime can impact on the results obtained in an investigation. The method employed in this thesis ensured all participants underwent the same test format that was outside the clinical contact setting, so direct performance comparison was possible.

Willis and Sur [44] suggest the junior doctors' interpretive ability is aided significantly by employment of initial triage through abnormality flagging using a 'red dot system' (RDS). This is where an abnormality is indicated but with no further interpretive input by the radiographer. They extend their argument to suggest the radiographer takes on an advanced role to include a reporting responsibility in ED. Australian radiologists currently reject interpretation and reporting by radiographers, as the radiologist report is perceived to be the medical component to patient management. Recently radiologists, through the vehicle of their professional body the Royal Australian and New Zealand College of Radiologists (RANZCR), responded negatively to the MRPBA's capability proposals for the diagnostic radiographer's scope of practice [45]. The RANZCR argued that the capability proposals are beyond the role or ability of those without a medical degree. These factors are discussed in greater depth later in the thesis; however the MRPBA has defined the expectation of appearance interpretation by a newly qualified radiographer [32]. Prior to this, the RANZCR [46] and van der Weyden [47] argued that a lack of medical education prevents the radiographer from participating in an interpretive clinical service role. This position is taken despite radiologists expecting radiographers to be aware of abnormality appearances and to raise concerns with them [45, 48]. The RANZCR and Van der Weyden suggest that insufficient medical knowledge is possessed by radiographers and that the risks of litigation are too great for a delegated role of an interpretive nature. This contradicts the research findings supporting radiographer reporting in overseas countries and from the pilot study performed in Queensland [24, 26 - 30].

1.3.2 Can radiographer interpretation support radiologist reporting?

Berlin [49 - 53] explores the issues of report content, phraseology, timeliness and further imaging needs from a malpractice perspective. He also offers suggestions to avoid litigation through attentive practice. Other authors support his position [54] and ask the question, as does Berlin, with whom does the final responsibility for ensuring the message about image content is sent and received as intended rest? [53] Alternatively it is suggested that if urgent information transmission has been attempted then it is documented as such [39, 55 - 57]. The concept of safe practice by an alternative practitioner, in particular the radiographer, was proposed in Australia by Smith and Baird [58]. They suggested that an immediate response to the referrer after interacting directly with the patient being examined would provide an enhanced and safer diagnostic event. Considering Berlin's ideas, Smith and Baird's proposal also forms a more robust litigation defence position. Furthermore this idea aligns with the four tier skills escalator approach adopted by the UK National Health Service, which addressed its workforce shortages crisis through a skills base approach [59, 60].

Some of the approaches employed by the UK are reflected in the Victorian Government's Hospital Admission Risk Program (HARP) [61] that provides a 3R's management principle of **R**ight person, **R**ight place, **R**ight time. Human resource problems for healthcare delivery are recognised locally by the Victorian Department of Health and Human Services (DHHS) - formerly the Department of Human Services (DHS) - prompting an analysis of the workforce and workflow between radiology and ED [62]. The DHS report noted that radiology reporting workload was a concern, but reported the belief of radiologists that newer digital technologies would make the reporting process easier and timelier. If concerns expressed by authors over a long time period, are indicative of excessive pressure on the radiologist workforce then access to images of a digital nature will have minimal impact on reducing workload [1-3]. This is further compounded by population rise and radiologist workforce stagnation if not reduction, as identified in the 2010 RANZCR workforce study [4].

In the UK, the National Health Service Breast Screening Programme (NHSBSP) is an example of how double reporting by radiographers alongside a radiologist ensures a high sensitivity and specificity at a reduced cost to the imaging department [28]. UK authors persuasively demonstrated how the radiographer can contribute to the trauma service if not other areas [63 - 68] such as through reporting images. Since 2010, an extension of the Red Dot Signalling (RDS) approach with commenting was advocated by the UK College of Radiographers [69] (CoR). The CoR has required change to the content of undergraduate programmes of study to support commenting as the normal scope of practice expected of radiographers. Through generating interpretations of the images they produce Australian radiographers would be taking a step beyond the triage suggestion initially made by Swinburne [70] but aligned with the reporting capability seen amongst UK advanced practice radiographers. Using a controlled and measured approach an exploration of the potential of Australian radiographers to safely perform an interpretation role, at a level acceptable to radiologists is feasible.

Where radiographers have participated internationally in studies of MSK trauma reporting, study participant numbers have frequently been at low levels; this raises questions about result validity. However, higher participation numbers where radiographers only had to identify abnormalities in images [71 - 73] using marking techniques have been achieved. Studies of these types published in Australia are discussed relative to the methodological concerns raised by Brealey and co-workers in Chapter 3 ‘International Methodological Critique’. Of particular importance is the concern raised by Brealey et al about flawed measurement methods used in the UK. These have been copied in Australian investigations, necessitating a need for careful consideration of the method used to perform image interpretation measurements before any claim about radiographer interpretive abilities. The impact of flawed methodology on Australian studies is critically analysed in Chapter 4 ‘Australian Radiographer Reporting Investigations’.

1.3.3 The role of education

Thurstan-Holland [74] in the UK first highlighted the absence of radiology in medical education courses in 1917. With this in mind and considering more recent work from Kourdioukova, Subramaniam and others [9, 21, 75], aspects of education for both participant groups is investigated and discussed. In this investigation surveys were used to identify educational issues for the further educated experienced radiographers participating in a role not currently traditionally associated with their profession in Australia. A survey was also used to establish whether those about to embark upon their medical careers are aware of the potential of a radiographic input within ED and if they felt it would be a resource they could use. Medical student participants were asked whether they believe they have received sufficient radiology education prior to starting their internships. They also consider what areas of plain radiography in MSK trauma they found most difficult to interpret.

1.4 Overview and some further considerations

Much of the research that measures radiographer performance has been gathered in the UK. Australia's healthcare system differs in that there is a greater proportion of private radiology service provision compared with the UK's mainly publicly provided National Health Service (NHS). Australian radiology provision, particularly publicly funded services, relies upon the provision of the report by the radiologist as the point where revenue is paid to hospitals [76]. Furthermore, patients who pay for their service through a private provider are likely to expect a consultant radiologist to generate the report. Therefore there is a clear connection with revenue, the patient and the radiologist that contributes to the difference in perception about Australian radiographer interpretation when compared with the UK.

This study invited participation from experienced radiographers in the State of Victoria, working in the public or private radiology service sectors where an ED facility was available. Invitations of to all eligible participants ensured randomisation of response from radiographers of differing service provision environments. The radiographer participants were analysed as a uni-professional group working in the ED setting and were assumed to be of an equal performance capability. The arguments for radiographers to perform a trauma MSK description function have been identified. Private radiology providers as well as the public sector will gain by freeing up radiologist time to concentrate on more medically challenging cases, for which radiologists have received advanced education after their initial medical degree.

Final year medical students from a single medical school in Australia were invited to participate. This group of healthcare personnel has not previously been assessed in the area this study investigates. Neither had they been approached about whether they believed their education was sufficient to perform this role and if help from a non-doctor multi-disciplinary team member would be appropriate. Although participants were from one university, the revelation that across Australia that radiology teaching averages at 85hrs over the degree period acts as a common denominator within this participant group.

This study explores whether radiographers can provide an interpretation to the standard of a radiologist in comparison with final year medical students about to begin their internship. Further the study seeks to answer which of the further educated experienced radiographer and imminently qualifying doctor groups performs best. The investigation also considers how they differ from each other and what their concerns are about performing this role? Hardy et al have shown cost savings to be evident and timeliness of service provision may improve [77] with radiographer reporting; both are factors that contribute to operational efficiencies in public and private radiology service provision. These aspects are of importance to the overall direction of the investigation but not evaluated in this research as their work looks at full radiographer reporting and initial interpretation.

Chapter 2 considers the historical aspects that have driven the development of radiology, the radiographic workforce and its relationship with the rest of the radiology department. It also critically discusses whether or not that relationship might change. Further, the study considers the educational aspects of the radiologist and radiographer workforce and the undergraduate educational needs/delivery from an international comparisons perspective. The chapter draws on current developments to indicate how the radiological workforce may or may not be able to change and what that relationship may be with its client base in the form of the employment relationship. Finally the chapter considers the role of political expediency and how this has impacted on the radiologist – client relationship.

As in any other field of medicine we may delegate part of the technical manoeuvres required to obtain information on which we base our opinion, but we cannot shirk the responsibility for the giving of that opinion.

J. R. Young, Radiologist in response to the assertions of Swinburne
The Lancet, April 10th 1971, p757.

Chapter 2 The socio-historical context in understanding why radiographer interpretation has not developed in Australia.

2.1 Introduction.

Chapter 1 outlined how this study evaluates whether further educated experienced radiographers from the State of Victoria and final year medical students from a single medical school interpret plain MSK trauma radiographs. The study also identifies if radiographers and final year medical students interpret image content at significantly different levels to each other and to radiologists. The investigation further establishes whether there are particular educational issues for each participant group and if medical students would value an input by qualified radiographers when working as interns in the ED. This chapter critically evaluates the sociological and political forces that have contributed to the current position of Australian radiographers, and whether their educational abilities in image interpretation could contribute to a required workforce change in the near future.

Australian radiographers look on as colleagues in other countries practice roles that include image interpretation. The MRPBA have now detailed the expectations of the newly qualified radiographer that demands image interpretation as a skill expectation. Evens was quoted by Stiles and Belt 1991 to ask in 1982 'Can history predict the future?' [78 p828] In 2008 Steketee [79] identified the difficulties the then Minister of Health, Nicola Roxon would face, in the quest to change the way in which healthcare and Medicare operate in Australia. This followed a long campaign by Duckett who highlighted inefficiencies brought about by private healthcare and the health insurance rebate [80, 81]. He worked in the Victorian health system for a number of years from 1983 including as Regional Director and subsequently Director of Acute Health for the Victorian Department of Health and Community Services. He was responsible for introducing case mix funding to Australia where healthcare services in a publicly funded sector. Duckett became the departmental secretary to the Australian

Government Department of Human Services and Health for the Keating government in 1994 until 1996.

Duckett discussed potential ways forward that require more funding to be focused on public health provision, as he showed public sector delivery is more efficient. He suggested the public healthcare system could become more capable in delivering services by making changes to the way system is organised; ultimately he proposed new roles for current staff levels with assistants to make up any shortfall in service delivery [82, 83].

This chapter considers the historical perspectives, including the relationship with the UK that have acted as barriers to Australian radiographers' inability to practice an interpretive role and asks; '*has anything changed recently to impact on the socio-historical position with respect to radiographers providing interpretations in the ED?'*

2.2 The evolution of the radiologist in Australia.

2.2.1 Some UK underpinnings.

Some background of the UK perspective on the evolution of the radiologist has to be considered before the Australian position can be discussed. Larkin [84] and Price [33] have both written in depth about the origins and development of radiography in the UK following the 1895 discovery of the X-ray by Röentgen. Larkin [34, 84] identified the potential available to an open market for the provision of imaging services, which included acquisition and interpretation. Disputes ensued until the mid 1920s in the UK as various groups working under the title of radiographer laid claim to their share of the marketplace. Subsequently the Society of Radiographers formed with a role to regulate practice; this organisation was constituted predominantly by members from a medical background. Eventually the Society of Radiographers received ultimate direction for its incorporation as a body from the British Medical Association. Earlier doctors, via the BMA, had taken the stance that;

> *"The practice of medical radiography by a lay person, except under the direct instruction of medical practitioners, ought not to be encouraged." (BMA 1917) [85]*

This position was maintained in the UK until the Council for the Professions Supplementary to Medicine (CPSM) [86]changed its stance in 1994 and is discussed later on p21.

In Australia, the very early years of radiology were driven mainly by either the [medical] radiographer (skiagraphist or radiologist) or by physicists. Hamersley [35] explored the social constraints placed on the Australian scientific community between 1896 and 1914, to explain how the medical fraternity gained control of Röentgen's discovery. His analysis suggests that several factors contributed to this position. They are summarised in figure 2.1 p16.

Australia produced its first radiographs between February and March 1896 [87]. The developmental timeline and key protagonists are seen in figure 2.2 p17. Several images published in the Australian Medical Journal between 1896 and 1897 demonstrated that radiography was used to diagnose bone and joint abnormalities, foreign body retention and physiological symptoms [88]. Father Slattery at the St Stanislaus Seminary College held a significant skill set. These enabled interpretation of the German discovery reports to allow incorporation of geological knowledge (responsible for early experimentation in phosphorescence to generate early fluoroscopy – see figure 2.2 p17) into the self built equipment required to produce early X-rays. However, even at this early stage, doctors preferred to call themselves 'radiologists', the suffix 'ologist' claiming them as '*…a specialist in a particular area of scientific study*' [89] .

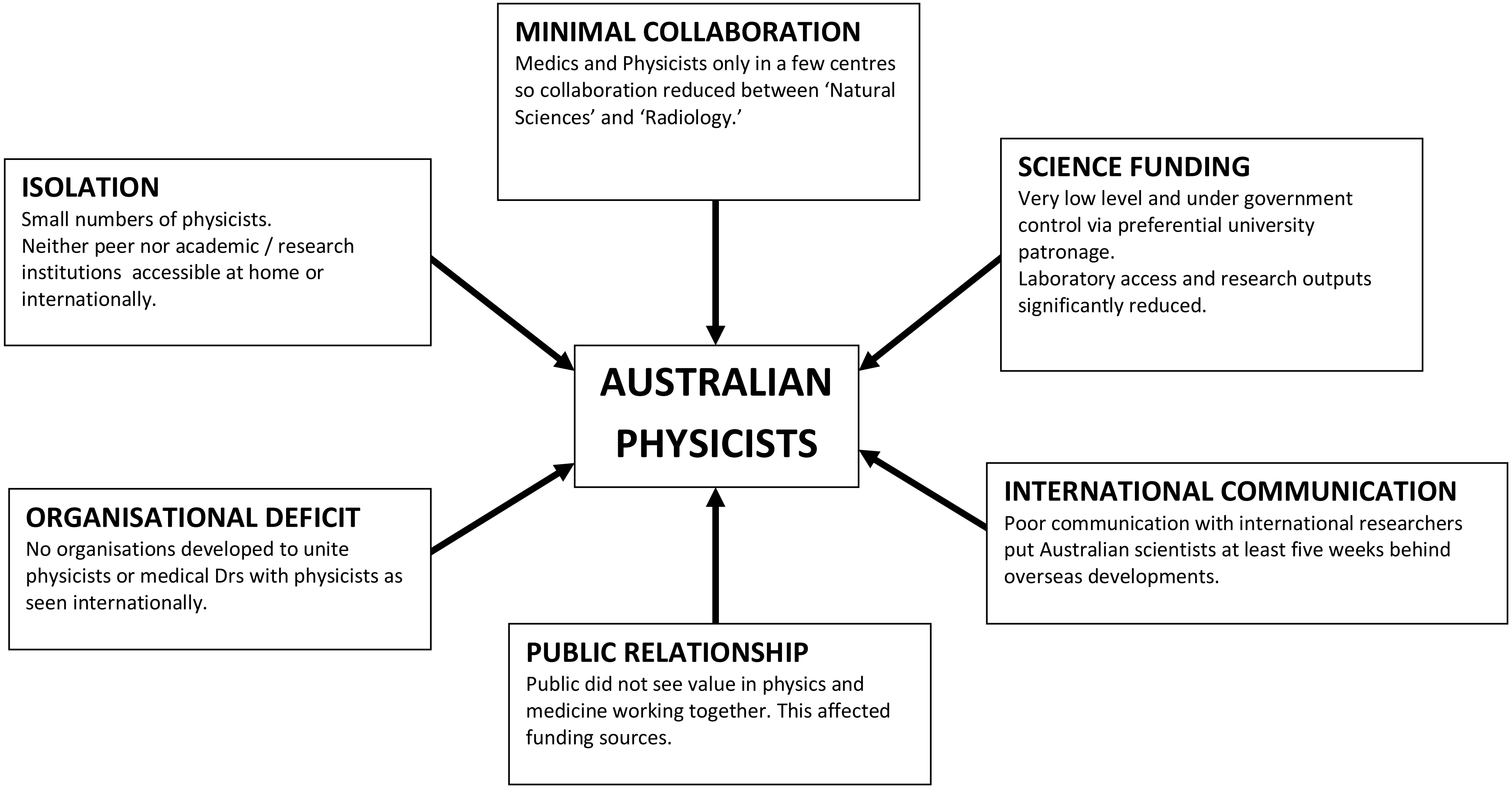

Figure 2.1 Factors impacting on early Australian physicists according to Hamersley (1980) [35]

LYLE

Lyle
University of Melbourne
Final week February 1896

+

Public demonstration
March 3^{rd} 1896
Melbourne Argus reporter present

FILMER

Walter Filmer
New South Wales
Pre 15^{th} Feb 1896
X-ray of son's hand
Personal communication only

+

Foreign body demonstration
Possibly 2^{nd} week February 1896
FB in foot demonstrated for Dr Eames to remove

+

Walter and Ethelbert Filmer
Awarded positions of 'Honorary Electricians' Newcastle Hospital
October 1896

SLATTERY

Slattery based at St Stanislaus College linked to St Charles Seminary, Bathurst, New South Wales
Skills of glass blowing, spoke German, taught physics, studied geology and photography

+

Credited with being either 1^{st} or 2^{nd} to produce a radiograph – Lyle and Filmer evidence suggests otherwise

+

Produced images of an arm wounded in shooting incident to enable successful surgery

+

Experimented with phosphorescence to produce real time images as a precursor to fluoroscopy probably post July 1896

Figure 2.2 Key incidents in the early development of Australian radiography.

2.2.2 Development of the Australian radiologist's position

Figure 2.3 gives multiple quotes from UK and Australia in the claim for ownership to reporting on radiographs. Furthermore radiologists with medical education argued that they provided a significant contribution so that other doctors would refer to and pay only them for an image production and reporting service. This relationship created a new medical specialty that was seen in the UK and followed by other countries [90 – 92].

In 1904, an Australasian Medical Gazette (AMG) editorial [93 p253] warned of the impact of the "*...intrusion of laymen into medical practice..."* that was contemporaneous with UK medical journal reports. Harris [94] (1906) advocated that medical practitioners were the ideal personnel to produce and read the radiograph (figure 2.3 p19). He quoted Thurstan-Holland who complained in 1905 that 'non-specialists' dabbling in image taking retarded radiology's recognition as a medical specialisation. Morris [95 p400], at the 1908 Australasian Medical Congress called for "*...the radiographer, if possible, to be a medical man...*"

The link between the UK and the colonies remained strong and the medical press of the 'mother country' was frequently applied to the Australian situation to claim advanced skills by the 'radiologist.' In contrast however, early radiological equipment manufacturers W. Watson and Sons of Melbourne, advertised that within their premises the client "*... will discover in the clever radiographer, Mr Baker, one who is able to enlighten and illuminate.*" Evidently the Watsons believed the imaging practitioner did not need to be hold a medical qualification[96 p508]. Later, Clendinnen [97] addressed the Australasian Medical Congress in 1911 to rebut the scepticism of radiology by other specialists and how surgeons now often used radiologist interpreted radiographs pre-treatment. Clearly the doctors experimenting in these areas were gaining recognition amongst some of the wider medical fraternity.

Pasveer [36] discussed how medicine claimed the interpretive upper hand by suggesting the radiographic image to be equivalent to other clinical tests. By arguing that it is through the use of the two knowledge bases of medical and physics based science Pasveer was able to identify radiology's claim as a medical specialisation. However, McKeown reports Morton's

The Lancet 1896	*'We cannot see any objection to a medical man skilled in recent photography, devoting himself to the application of it in medical and surgical cases and announcing to medical men his intention of doing so through ordinary channels. Of course we assume that he entirely dissociates himself from any treatment of the case and works only at the instance of the practitioner in attendance.' Hall Edwards, The Lancet 1896: 904*	**The claim of radiography and radiotherapy for medicine**
The British Medical Journal 1903	*'There is no reason for professional prejudices against the practice of radiology by lay-men, so long as they confine themselves to the mere mechanical act of producing a picture and abstain from assuming scientific knowledge of their bearing of their radiographs on diagnosis or prognosis.' Salt C.E. BMJ 1903: 831.*	
The Australasian Medical Gazette 1904	*'The knowledge of electricity and electrical instruments possessed by the ordinary medical practitioner is necessarily very meagre; hence unless special attention has been directed to this subject, a[n ordinary] medical man is not able to manipulate the apparatus necessary for therapeutic application of these powerful forces' Editorial AMG 1904: 354. Parentheses added.*	**The claim by medicine that radiation control deserves merit and recognition as a specialisation**
The Australasian Medical Gazette 1906	*"...there remains a field for the x-ray expert who is ready and competent to use the x-rays properly for any and every class of case to which they can be applied; and this man ought necessarily to be a qualified medical man." Harris, AMG 1906: 85*	
The Australasian Medical Gazette 1906	*"Large numbers now 'dabble' with x-rays. They order a good apparatus and do not trouble to get proficient at the work; as a consequence their x-ray work is most inefficient...the results they show are quite worthless and tend to bring x-ray work into disrepute among those physicians and surgeons who depend on others for this work." Harris quotes Thurstan Holland (1905) AMG 1906:85*	
Archives of Radiology and Electro-therapy 1919	*"To organise and educate the various classes of lay helpers. To see that their status, remuneration and prospects are such as to make them contented. To educate the public as to why such people are at one and the same invaluable as helpers, and extraordinary dangerous when they seek to practise independently." Hernaman-Johnson 1919:186*	**The claim for medical dominance over a sub group**
Archives of Radiology and Electro-therapy 1919	*"We should welcome lay assistance, and seek to organise and guide it. It is too late in the day to make a mystery out of taking plates but the interpretation is ours forever." Hernaman-Johnson 1919:187*	

Figure 2.3 'Medical radiologist' quotes used to claim specialist status and create the radiographer, a UK and Australian developmental timeline.

reminiscences in the Alfred Hospital's Clinical Reports [98] that indicated there was reliance by student doctors to use X-rays to provide the diagnosis. This suggests that good imaging would replace clinical evaluation and so contradicts the medical knowledge based argument doctors had used to claim interpretive superiority over non-medically educated personnel.

Murphy [37] argues that medical control was enabled through association with electrotherapeutics or radiotherapy. She suggested that initially image acquisition and interpretation could be defined as a technical skill, whereas therapy required medical referral and direction. Thus it was argued that by linking therapy with the need to provide medical oversight the scene was set for the affirmation of the need for medical control in the diagnostic field. Through gradual technological improvement doctors were enabled to control X-rays equally as well as scientists. Consequently this allowed for the employment of medically directed assistants who ultimately became known as radiographers [33, 34]. Not only did the medical fraternity create a lower order workforce, but as early as 1898 physicists were also separated from Australian radiology development. It is suggested this was due to radiology departments being mainly hospital controlled and hence medically directed (Eddy 1946 cited by Daly and Willis) [38].

In 1919 Hernaman-Johnson [99] defined the future professional hierarchy of radiology in the UK through role differentiation. He proposed the need for a sub group of workers to produce but not interpret images, formed of those without a medical degree. Consequently, as Larkin [84] and Daly and Willis [38] have demonstrated, the 'non-medical' health care worker or lay-worker was deskilled by being prevented from interpreting. Thus radiologists were able to enhance their position by detaching themselves from the technicalities of image acquisition. Effectively therefore, scientific and service efficiency drove labour division. This created a hierarchy led by those with medical degrees that included contemporaneous knowledge of anatomy and pathology. It was ultimately through the collegial process between branches of medicine, that medically educated radiologists in the UK claimed full responsibility for the reporting of radiographs [33].

Doctors therefore achieved autonomy through legitimising an occupational ideology in the 1920's [38]. Radiology's evolution showed global similarities in a short timeframe, with UK, French, American and Canadian referral and reporting practice alignment resulting in [100, 101] the medical regulation of radiographers. Australia and New Zealand replicated the changes seen in the UK. However, in Australia a direct employment relationship with the patient through payment for services to include performance of the examination and its interpretation has subsequently protected the radiologists' professional autonomy. This was supported by radiologists later rejecting employment through Friendly Societies. They also resisted government salaried positions, as seen in the UK NHS, by successfully arguing in 1949 that salaried medical service contradicted the Australian constitution as it represented conscription! [38] Effectively this protected the Australian medical practitioners right to private practice within a publicly funded, state based healthcare system.

2.3 Radiographer Registration

In the mid 1920s the newly constituted UK Society of Radiographers employed its registration and investigative powers to eject from its register those radiographers without a medical degree who provided reporting services. This came about via a requirement of the Board of Trade to consult with the General Medical Council (GMC) following a wish to become an incorporated body. The GMC had no jurisdiction over radiographers but expressed concern about medical practitioners receiving reports from the non-medically qualified. This invoked a situation between government and the medical council from which the non-medically qualified could not escape. The final position that ensured medical control was the need for funding for the Society. This was sourced from the British Institute of Radiology (BIR) that as an organisation would not countenance non-doctors providing reports. To complete the capitulation of non-doctors the Society then produced a statement in 1923 (below) to differentiate radiologists from radiographers:

> *"In order to put an end to the confusion with regards to the terms 'radiographer' and 'radiologist', it has now been generally agreed that the term 'radiologist' shall be applied to members of the medical profession who undertake radiographic diagnosis and treatment by means of X-rays and radium, while the term radiographer be applied to their trained non-medical assistants." Society of Radiographers BMJ 1923:416*

Furthermore, in 1925 the GMC prevented doctors from using radiographers as the interpreter by threatening the doctors professional position if this did occur and is quoted below:

> *"Medical practitioners are prohibited from associating with unqualified persons who may assume medical functions, but the General Medical Council has no other power of restraining the unauthorised activities of lay diagnosticians and healers. It is therefore incumbent on medical practitioners, in the interests of their patients as well as for their own professional security, to see that the line between radiographers and radiologists is honourably observed." BMJ 1925:855.* [90]

The inception in 1960 of the UK Council for Professions Supplementary to Medicine (CPSM) reaffirmed the medical dominance of the professions it registered, through an imbalance of the inaugural council membership. All nine medical colleges and the General Medical Council were represented with just one representative from each allied health profession permitted. The remaining membership comprised lay members with no representation from professional associations [86]. Prior to 1994 the CPSM in the UK only permitted radiographers to verbally discuss the content of images with the referring doctor [86] but only if their opinion was sought. However a combination of factors including the implementation of a degree based education for radiographers, the numbers of patients flooding the NHS and shortages of radiologists, required the CPSM to change its position on allowing UK radiographers to provide interpretations. Interpretation of images by radiographers could only be achieved when they had received further education. At this time even with degree level education, UK radiographers were not expected to interpret radiographs and proffer a diagnostic opinion. Of interest to this thesis the CPSM was reconstituted as the Health Professions Council (HPC) in 2003 under the National Health Service Reform and Health Care Professions Act 2002. Since 2012 the HPC became the current Health and Care Professions Council in 2012 (HCPC) [102] to recognise Social Workers within the Health and Social Care Act of 2012. As a result, all registered health professions outside nursing and medicine in the UK now fall under a single registering body. This has similarities with the recent developments seen in Australian health professional registration.

The Australian Institute of Radiography [103] (AIR) as the professional body held a similar position to the one espoused by the former CPSM until recently. The AIR promulgated the view that a radiographer should express to the referrer any concerns that may be evident on the images and which the radiographer believes may not be seen or interpreted without their direct input. The AIR further advocated that radiographers should suggest supplementary imaging to enable correct diagnosis of abnormalities. Until recently there was no explicit expectation that formal discussions have to take place or interpretations are written by a radiographer and offered to the referring practitioner. The AIR also forbade a radiographer to confirm the presence of an abnormality to the patient.

In comparison with Australia, the New Zealand Institute of Medical Radiation Technologists (NZIMRT) as the professional body formally supported in 2010 a move towards radiographers having a role in image interpretation (personal communication D. Morris Secretary NZIMRT). As well, the New Zealand Medical Radiation Technologists Registration Board (NZMRTB) has recognised the need to '*provide an informed opinion to medical staff as appropriate*' thus acknowledging that radiographers can identify abnormality that is relevant for the referral [104]. Prior to the formation of the National Registration and Accreditation Scheme (NRAS) in Australia, and subsequently for radiographers the MRPBA, verbal information giving was previously supported by the state and territory registration boards of Australia where they existed. The national position was supported through recognition of the AIR as the accrediting body of undergraduate courses [103] and as such was a professional expectation of registrants in all states and territories. Since July 2012 the provision of 'verbal information giving' to medical staff [103] and those involved with patient treatment is recognised within the regulations of MRPBA, and has since been strengthened through the Capability Framework and subsequent radiographer graduate expectations. This was confirmed through a period of stakeholder consultation in 2013 [105]. Of note during deliberation of the capability framework strong opposition to a radiographer's interpretive position was made by the RANZCR [45 pp10, 16-17]. They indicated that any kind of interpretive information giving is beyond the capability of the newly qualified radiographer. The capability framework requirements have been developed with recognition of stakeholder contributions by the MRPBA in their subsequently published standards [106, 107].

The MRPBA standards are now used to judge the capability of individual radiographers and the courses that educate them. It also appears that the AIR takes a stronger position within their response to the MRPBA registration capability consultation by stating that radiographers *'should alert medically significant findings to the medical personnel responsible for the treatment of the patient.'* [108 p6] This position is a development from the verbal only approach that was previously advocated by the AIR as a professional body. The AIR apparently believes there is now a legal prerogative that may require written notification to medical staff, though how this is transmitted to the recipient is not discussed within the AIR's submission to the MRPBA. However, it is through the stance of the Capability Framework and how the requirements of the practitioner are interpreted that the subservient position discussed by Larkin [84] and Daly and Willis [38] may now be overcome. The capability framework now allows the Australian radiographer's registered role or its development to be more flexible and open to change as individuals and education institutes find ways to align with standards.

Practice limitations of verbal information giving only to appropriate staff are therefore examples of state or political patronage. This is the control through recognition of medicine by the state as being the holder of expertise. Perpetuation of control by one group that limits the role of another is defined as 'authority' by Daly and Willis [38]. They further suggest that licensing laws often reflect previous power brokerages. If the medical position can be successfully argued, it is politically expedient to follow direction by the dominant profession. Thus sponsorship by government strengthens the medical position to enable control and subordination of other professional groups. This is a position that has shifted to achieve a more inclusive multidisciplinary team in the UK due to service demands and the pressure brought to bear by the public on politicians to ensure access to health services are enabled.

2.4 The educational contribution to radiologist recognition and radiographer training.

2.4.1 Radiology education in undergraduate medicine.

By way of ensuring doctors from other specialties accepted the role of the UK radiologist, Thurstan-Holland in 1917 [74] highlighted the absence of radiology education in medical courses. He further suggested its inclusion would aid recognition of the new specialisation of radiology. The lack of recognition of the clinical importance of radiology remains in Australia today, evidenced by an average of only 85 hours undergraduate radiology teaching in medical curricula [9]. A similar phenomenon was also reported recently in a westernised medical school in Ethiopia [109]. Goergen [10] complained about this teaching insufficiency compared with the clinical employment levels of imaging, and is discussed in section 1.3 'Discussion of the aims' p6. At first glance the figures quoted by Subramaniam et al [9] appear to be low. However, the 2010 European study by Kourdioukova et al [21] was the only reference employed by the European Society of Radiology (ESR) in their white paper of 2011 [75] that addressed the urgency of improving and standardising undergraduate radiology education. Kourdioukova et al [21] investigated the undergraduate radiology education position across Europe by approaching 34 countries for information. From these 31 provided data to the study. The findings showed the mean amount of undergraduate radiology teaching was 89 hours, median of 76 hours and a range between 19 and 212 hours. As with the Australian/New Zealand study [47] the focus for radiology education is during the later years of the medical degree i.e. years 3 to 5 with year 4 being the most important year for teaching radiology. In Europe subjects like imaging anatomy, radiation protection and referral practices are taught as theory aspects in first and second year pre-clinical sessions.

McKeown's 1983 thesis [98] and post doctoral work [96] describes radiographer educational development in the State of Victoria. A significant demand for radiographers was noted in 1920 as few were employed in hospitals or private practice. In Victoria, radiographer education formalisation was achieved by 1930. Previously most personnel were apprenticed to non-radiologist staff with prior equipment knowledge who passed on the 'know-how' without medical supervision. As imaging technology improved and the examination range widened, a tailored radiographer education programme was necessitated [96].

2.4.2 Professional diplomas for Radiographers

An inaugural Australian radiography training course began in Victoria through the Melbourne Working Men's College in 1929/30, with radiologist support and input into the teaching and programme development. In 1936, as radiographic practice developed, an increase in the academic length of the course and a defined, medically guided clinical period was added. Figure 2.4 below compares the courses. Radiologist teaching contributions increased supporting an argument that input at the educational interface enabled an opportunity to inculcate the trainee radiographer to expect radiologist control and fits with the control/dominance perspectives discussed earlier [38].

	1929/30 Programme	**1936 Programme**
Time frame	2 years	2 years
Academic	2 hours evening class per week	2 x 2 hours evening class per week
Content	Year 1 = Sciences Year 2 = Radiographic positioning	Year 1 = Sciences Year 2 = Radiographic positioning
Clinical	To be working in the clinical environment	A 3 month acceptable practice period under medical guidance after course completion
Education rationale	Melbourne radiographers wanted the British Institute of Radiologists 1917/1918 training course for armed services and civilian radiographers. Certification would lead to recognition of good standards across the profession.	
Designed by	Radiology section of the Victorian Branch of the British Medical Association and the Melbourne Technical College (MTC)	
Teaching contributors	Radiologists and scientific staff from MTC. Radiographers of long standing.	
Other delivery methods	Also available as a correspondence course across Australia and as an alternate to the British Diploma in New Zealand.	

Figure 2.4 Early radiography course designs in Melbourne

The professional diploma was the international education standard until the State of Victoria implemented the world's first radiography bachelor degree in 1986 at the Royal Melbourne Institute of Technology (RMIT). At this time Bentley and Watson [110] campaigned strongly for UK degrees, arguing they would protect the professional role, and enable advancement. Consequently, Australia and the UK were the first to achieve degree based education as the national standard for radiographers.

2.4.3 *Impact of the degree and Australian radiographer registration.*

Bentley and Watson argued, albeit accepting that overall content was less than a medical programme, that an honours degree would provide registered radiographers with educational principles equivalence with newly qualified doctors. They believed that exposure to research techniques is a common denominator of professional learning [110]. This belief is reinforced within the accreditation statements of the AIR and is included in the MRPBA Capability Framework [106, 107]. The UK became the first country to deliver degree only based radiography education for radiographers, in advance of Australia by approximately 18 months. This was mainly because Australian state and territory governance support and drive towards degrees for radiographers was nationally unequal, which stalled the educational conversion process.

In Australia two parallel educational models for radiography have been followed. One is the three year bachelor's degree plus an intern or clinical year, recently termed the National Professional Development Programme [111]; the second is a four year program that incorporated the further clinical time that has been perceived to be necessary to achieve competency on graduation. The original four year program awarded graduates honours status based upon meritorious academic performance. This does not follow the traditional university based honours year that would normally be wholly research focused.

Whichever approach is adopted by a specific University, the now defunct AIR accreditation process, which ended in 2013, required radiography degree courses to incorporate teaching and development of research techniques or its critical application for professional practice accreditation. The four year Australian degree when compared with the equivalent UK course shows no significant difference in outcomes as a three year honours programme is delivered over eight trimesters to achieve the same degree status. UK courses also require clear research technique learning and application as an expectation of the newly qualified radiographer [112]. However, by allowing a choice of educational pathways in Australia, the intent of the AIR as the undergraduate education accreditation body might have been diluted. This occurs because graduating radiographers are exposed to differing capabilities in the research arena between states/territories due to opting for the three or four year systems. Consequently there is potential to directly affect the ability of a profession to develop and drive its own research philosophy and so limits its capability to generate evidence to support an argument for a change in practices. The advent of the MRPBA

Accreditation Board has provided an opportunity for universities to address this within the Capability Framework via the Code of Conduct that came into force in 2014 [106, 107, 113].

It could be suggested that without an undergraduate degree framework in the UK, role change amongst the professions of the NHS would not have been possible. Although struggling today the NHS would have significantly failed to meet its targets, caused by ageing population demographic of both patients and workforce [114 - 116]. The main change that came about with the introduction of degrees in the UK was the move to the university sector from local NHS Schools of Radiography. This was facilitated through Colleges of Health that were ultimately absorbed into either the universities or the polytechnic sector, which itself was granted University status in the early 1990's. Recognition of radiography as a subject worthy of university support in its own right resulted in a move away by academic staff from medical direction and radiologist control. Students could receive a wider education to include a research base to develop evidence supporting their own professional capability. Since then, postgraduate education for radiographers in the UK has evolved to support advanced practice working across a range of aspects of radiology. In Australia, despite a desire to move in this direction through coursework masters provision by universities such as Sydney and Monash, most postgraduate courses focus on academic rather than a clinical orientation. However strong aspirations for postgraduate development via the support of the AIR the Advanced Practice Advisory Panel (APAP) [117, 118] is seen.

A further deterrent to enrolment into higher degree professions based programmes in Australia is a lack of recognition by the Commonwealth Government, which funds the higher education sector. Most students studying at postgraduate level are able to apply for a loan to pay fees but this has to be repaid and is capped. Beyond the maximum loan level the student pays fully unless a commonwealth supported course in the area of study is available. Without government post qualification education being supported, then forward movement of a profession becomes more difficult.

In comparison, the UK College of Radiographers collaborated with the UK government to develop the NHS through proposals such as the NHS plan [114 – 116]. This enabled alignment with the '4-tier' system that made working at advanced levels possible. As a generalisation this enabled universities in the UK to develop educational programmes that would be subscribed to as there were sufficient students to make courses financially viable. Students from the NHS were also supported through contractual agreements between workforce confederations and local higher education providers with study time off work to attend courses also made available by employers. Developing the radiographer workforce supports the aims and objectives of the local healthcare provider and as such forms a key part of NHS hospital mission drivers, thus attracting employer encouragement. A pathway from postgraduate certificate to Doctorate now exists [119, 120], which also employs a strong clinical basis in its teaching. As indicated earlier, the student in Australia pays for postgraduate education either outright or as a loan and has few periods of study time from the work place made available. Occasionally however, financial support for the remote and rural radiographer has been provided [121]. Generally there has been a failure within the federal and state health ministries to recognise the wider gains for healthcare through supporting postgraduate health practitioner education by the provision of Commonwealth Supported Places (CSP).

In 1997 Finch wrote about the global understanding the ISRRT had about the wide-ranging roles of radiographers [122]. She reported results from their survey that showed there were differences between role expectations between countries but also indicated what should be the radiographers remit. This went beyond the definitions received from countries responding to the survey that outlined the tasks of the radiographer. Further, she questioned the role of the bachelor degree and other educational levels within radiography such as professional diplomas, and asks whether this makes a difference to the radiographer's role or ability from an international perspective. She concluded that the undergraduate degree potentiates wider radiographer input to health care systems, but that some radiographers insist that clinical decision making is not their role. She further suggests that some radiographers preferred to operate under radiologist control despite the evidence supporting ambitious practitioners' capabilities to work in a professionally autonomous fashion. Because of this respect for a medically based leadership by some radiographers in key roles themselves, she suggests that abrogation of decision making would continue to restrain radiographer professional growth.

Recently Cowling [123] wrote an editorial piece that considered later work performed by the ISRRT and whether the situation had altered since the investigation of 2008 [124]. Although variations in radiographers' roles still exist globally, there has been a gradual move towards advanced practice. This includes radiographer reporting, particularly in remote areas, such that this has driven the development of advanced practice radiography educational programmes. She reinforced the idea that a profession gains recognition when it can produce its own evidence base/research to back its assertions of its professional capability. She also points out that Australia, though lagging behind with radiographer role development, has begun to make strides towards improving this position. The unfolding of that process is the subject of the next section.

2.5 Recent Australian radiographic practice debate.

In 2004 Rouse reported to the annual general meeting of the AIR the findings of the 2002 'Future Directions' working party, tasked to identify the profession's trajectory by 2012 [125]. Several unpalatable findings of the investigation were revealed:

- *Radiographers have a significant inferiority complex;*
- *Many radiographers feel it is beyond their realms of practice to participate in role development i.e. decision making was not for them and radiologists should take the lead;*
- *Senior clinical staff often undermine the enthusiasm for change amongst more recently qualified radiographers;*
- *There is a failure to recognise role expansion as the perceived baseline clinical skills and knowledge expectation of the new graduate and all those in practice;*
- *There are concerns about cost to the individual and what recognition would be given for taking further responsibility i.e. what's in it for me;*
- *The AIR was 'out of touch' and 'unresponsive' to requests from its membership in enabling change to occur;*
- *Without proactive leadership from the professional body, role change was not likely to happen.*

The attendant membership indicated that radiography would miss an opportunity to position itself in a stronger professional stance without immediate action. Lewis in her thesis [126] and in a later paper indicated that poor identity, subservience and workplace culture had resulted in low levels of responsibility acceptance and associated professional autonomy [127]. Smith and Lewis [128, 129] also align with many of the key elements expressed in the 'Future Directions' investigation. Smith and Lewis stated that, from post employment feedback to their universities, new graduate boredom results in high profession attrition rates as graduates are *'...generally not challenged and are generally undervalued and unappreciated.'* [128 p162] Smith and Lewis further suggest that the Medicare Benefits Schedule (MBS) prevents referral to radiographers, as service payment is only for a radiologist's interpretation. This is defined in the MBS as:

> *'a procedure for the production of images… for use in the rendering of diagnostic imaging services' …* and *'…the rendering practitioner is the medical practitioner who provides the report.'* (MBS) [76 p30]

Essentially as Lewis et al [127] argue, the link between private radiology referral and money has eroded the radiographer-patient relationship. They further believe this has introduced other, potentially unethical practices into *'…the radiographer-radiologist-referring practitioner relationship.'* [127 p90] Although Lewis et al [127] take the stance that private radiology undermines the position of the radiographer's role, Smith and Lewis had previously asserted in 2003 [129] that the process of appropriate imaging rather than formal interpretation has greater importance. They argue that treatment frequently begins based on the clinical knowledge of the requester of imaging or through following standard protocols. This means that treatment starts without the radiologist report or the report follows in a clinically unhelpful timeframe. Smith and Lewis [129] suggest that radiologists are not always clinically necessary and they go as far as to argue for the introduction of an assistant layer beneath the registered radiographer. Using an assistant to perform supervised radiographer roles at a lower level that require an educational ability below the degree enables a hierarchically superior position to be attained. This echoes the dominance position noted when radiology as a specialisation occurred; it would appear that Smith and Lewis believe the introduction of a new layer to the radiographic workforce generates a space for radiographers to take on more demanding, traditionally medical roles. Smith tried to extend this theory in 2006 [130] by outlining his thoughts for how this could operate. However, many Australian radiographers warned that radiologists or department managers may attempt to reduce radiographer numbers through increasing the assistant role. In this way radiologists gain power and managers reduce costs by employing a lower educated and therefore less expensive workforce.

2.5.1 The situation since the Future Directions report.

Since 2004, the AIR has attempted to define the future role of the radiographer. The Advanced Practice Working Group (APWG) indicated the aims of the profession in 2009 [117]. During 2009 the Victorian State Government Health Department also held wide-ranging discussions about role change and task substitution within medical imaging. The author was present at the meeting and witnessed the radiologists rejection of radiographers participating in image interpretation. At the same meeting, the chair of the Victorian Branch of the RANZCR education committee encouraged image interpretation by other professions such as nursing and physiotherapy, offering college support to achieve this, but not to radiographers.

Since the 2009 National Health and Hospitals Reform, set up to investigate new ways of delivering Australian healthcare [131], and the Productivity Commission [132 - 134] investigations, initial federal health ministry impetus to change health service delivery through task substitution by health professionals other than doctors has shown minimal progress. However, the AIR pressed ahead and published the APWG 2009 discussion paper [118] resulting in the creation of the Inter-professional Practice Advisory Team (IPAT). Consequently the IPAT final report was created [135] following discussions between the RANZCR, the AIR, other professions and the Australian universities offering undergraduate radiography education. This group recommended a three tiered structure similar to the UK College of Radiographers (CoR) model [112]. The CoR model is now in its 3rd iteration (2013) and is closely linked to the NHS Knowledge and Skills Framework [KSF] used to define roles and development of staff within the health service. Stepping away from the UK situation, the definition of advanced practice roles for Australian radiographers still requires multipartite agreement. Australian radiologist resistance to radiographer advanced practice through image interpretation was evident with Fabiny [48 p42-43] quoted in the IPAT document as stating:

> *'…a radiologist would appreciate a communication from a radiographer if they noted an abnormality or placed a comment such as identifying a fractured radius, for example. However, a distinction exists between an identification of an issue of this kind or an*

observation and the conduct of a clinical examination which is the role of the radiologist and the task of formal reporting, the traditional purview of radiologists.'

Recently in the UK a poorly evidenced communiqué released by the RCR [136] expressed an air of reticence toward radiographer interpretation. Paterson gave a strong evidence based response from the CoR [137] demonstrating the research that radiographers can draw upon to support their position from an educational [138 - 140], regulatory framework [141 - 143] and safety / performance aspects when compared with radiologists [144 - 146]. In an air of reconciliation and need to ensure good team working, both articles have recently been withdrawn with a conjointly written team working document published to replace the earlier polarising literature [147] suggesting that a multidisciplinary team approach is the best way forward.

A further example of radiographers potentially failing to appreciate their capabilities was revealed in a recent paper published by Emergency Nurse Practitioners from a major trauma centre in Victoria [148]. Analysis by the author of this thesis showed significant over reaching by emergency nursing colleagues in terms of understanding how to measure their performance [149]. The paper, which was supported by radiologist input, supports the idea of the multidisciplinary team of radiology and the ED. However for service delivery it is evident that radiographer involvement should be part of that approach but the paper fails to recognise this. If radiographers do not rise to the challenge of providing interpretations then they will be overlooked, and the position highlighted by Fabiny [48] will be maintained.

2.5.2 Recent radiologists *attempts to use Australian legislation to control the radiographic workforce.*

During June 2011, a private radiology provider approached a Technical and Further Education (TAFE) Institute in Melbourne to set up a radiographer assistant program, in which these students would learn to perform some diagnostic radiography procedures (M Baird personal communication). The radiologists would rely upon the supervision arrangements within the MBS whereby, with appropriately licensed radiologists on site to supervise, any trained and government licensed person may generate medical images using X-rays. This effectively reduces the need for radiographers, thus lowering staff overheads. Use of licensed assistants is possible within the Use of Radiation Licence Regulations if supervisory clauses are manipulated. This appears to be the cynical perspective identified in response to Smith's 2006 position as a reaction to radiology task substitution aspirations by radiographers [130]. Although this could enable radiographers to participate in more demanding imaging procedures, it might be argued that being supported by the radiologists, staff licensing would reduce the need for degree educated personnel. Alternatively a name and apparent role change would be a different way that services might be provided to avoid registration legislation and is discussed later

Proposals from the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), to direct the way in which departments of radiology operate through the "Safety Guide for Radiation Protection in Diagnostic and Interventional Radiology 2008' [150], identified three worker categories in a radiology department. They were the '*responsible person, operator and medical practitioner.*' The responsible person - radiologist, physicist or manager - manages the facility or radiation source; the operator produces images by operating equipment with clinical supervision by the medical practitioner. The medical practitioner adopts responsibility for report generation while radiographers, as operators, control dose factors and change imaging according to initial findings or suspicions about whether the referral is justifiable from a radiation protection perspective. The referrer of tests is not mentioned at all.

This document appears to support medicine as the dominant profession while shadowing the UK Ionising Radiation (Medical Exposure) Regulations (IRMER) ideas developed in 2000 (reviewed in 2007) [151, 152]. However in Australia, an attempt to secure the medical position by naming one of the roles as 'medical practitioner' rather than 'practitioner' is apparent. The IRMER guidelines are not as profession role prescriptive as the ARPANSA proposal. IRMER definitions enable speedy transit of patients through the radiology department because increased autonomy for radiographers is achieved by role switching between operator, referrer and practitioner where employer agreements allow. Through these employer agreements, UK radiographers are effectively empowered to adjust requests by changing the imaging routine as evidence necessitates or by suggesting and arranging with consultation for a patient to move to another radiological modality. As a result the healthcare system therefore achieves greater flexibility and is patient focused rather than service controlled. Consequently the system is able to respond to the public expectation demands for service delivery as discussed in section 1.1 p2. This is not possible if the radiographer cannot interpret the image or referral, so that the ARPANSA proposal perpetuates radiologist control over radiographers as change to the imaging routine is effectively blocked. As Hicks observed in the context of a meeting of the Confederation of Regulating Authorities (CoRA - pre AHPRA working group) [153],

> *'...the defining of the professional role of radiographer as "operator" ultimately demeans the dignity of the radiographic profession and narrows the professional scope.'*

Furthermore, this proposal goes against the scope of practice of the radiographer as defined by the AIR [103]. However until a radiographer is able to cite a Medicare number that enables money to flow with the patient for services performed, this position is likely to remain [76].

Radiologists seem unaware that radiographer advanced practices, outside of interpretation, are already widely enacted clinically [48] within Australia. It appears they do not believe radiographers should be part of the image interpretation chain, which is supported by the fact that most Australian undergraduate courses prior to the recent Capability Framework expectations [32] do not prepare radiographers to perform such a role. Further there are few clinically oriented postgraduate qualifications [154] available to support radiographer interpretation or reporting. Similarities abound with the UK position in 1999 where Thomas reports the comment *"Radiographers reporting? Over my dead body."* that was overheard at the RCR headquarters [155]. In 2007, Smith and Baird suggested that radiographer role development would be possible and appropriate for the profession and Australian healthcare provision [58]. The RANZCR responded with an unsupported rebuttal [156] however Rodger, a Scottish clinical oncologist, diluted the RANZCR's perspective by outlining that task substitution is about team working for the good of the client [157]. Rejection of radiographer interpretation was not a new position for the RANZCR [46] who had responded to the Quality in Diagnostic Imaging (QUDI) report that supported radiographer interpretation. They attempted to debunk the evidence available internationally by quoting Donovan and Manning's paper [158] that stated reporting by radiographers could only be task specific and is therefore limited to prescribed examinations. This position is recognised by radiographers in the UK; they support the principle that good professional standards require individuals to recognise when working beyond their clinical capability and refer on to the person with appropriate skills [141, 147]. A similar safety net employable by all professions has been demonstrated in Queensland [24] as a pilot to this work. Findings in that investigation showed interpretation performance overlap between ED doctors and radiographers results in fewer missed abnormalities. This supports the suggestion made in the aims of the study that further educated experienced radiographers are able to describe abnormalities on plain images of MSK trauma to support the junior doctor.

2.6 Recent Australian federal government initiatives. How does this affect the potential for radiographer interpretation?

2.6.1 *Change in leadership approach.*

Health Workforce Australia (HWA) in 2012 proposed a move away from the heroic and profession focused tradition i.e. single person most frequently doctors, to delivering healthcare to one replaced by an organisation and client based system [159, 160]. Duckett [161] opines however that there needs to be a wholesale change in attitudes and points out the health service copes with technological advances but not its social ones. Duckett quotes Perkins (2008) [162] who notes that medical students are taught in old ways to maintain their superior's perspectives and become less team oriented as they progress through their studies. However, being positive, through the HWA proposals, new ways of working are possible that will generate a practitioner acceptable to all health professions whether medical, allied health or nursing. This could be along the lines of the physician assistant seen in America. A practitioner of this nature would have additional responsibilities to meet the future demands of Australian healthcare, in particular radiology, using today's skill base as a foundation. However variation in response, particularly by the radiologists, is likely to hamper this development [45]. Universities delivering radiography undergraduate degrees have to work within the expectations of the MRPBA *'Medical radiation practice accreditation guidance material v1.1'* and code of conduct documentation [32, 113]. Through this new ways of producing future radiographers or other workers in the imaging profession may be possible or need to be found. Furthermore postgraduate opportunities become feasible as they are an extension of current baseline practice. The outlook of the professional body, managers of healthcare facilities and the radiographers themselves will influence this development. Compared with current approaches to workforce structure a wider ranging professional who might be specialisation focused e.g. on trauma rather than imaging modality aligned is possible. As such the newly qualified student operates at what is now perceived to be advanced level working, becomes the norm. An approach such as this is likely to gain political patronage, as it produces a workforce to meet the increasing demands made on the imaging department. Furthermore it has the potential to reap greater output from the degree educated individual and could enable a change in the career structure healthcare workers.

2.6.2 The changing position of the medical profession and how this influences health care policy development

Healthcare developments occurring currently in Australia match the seismic changes noted when the Medibank and the eventual Medicare Benefits Schedule came into being. DeVoe and Short [163] examined this period and suggested that the pre Medibank alignment between the Australian Medical Association (AMA) and the previous non-Labor Federal governments had enabled a corporate, mutually beneficial relationship to develop. This stemmed from the need to legitimise the medical profession in Australia in the 1850's that was achieved through aligning as colonial chapters of the British Medical Association (BMA), which eventually merged to form the AMA. This strengthening then gave political potential as a medical lobbying group that eventually developed into the corporate arrangement of medicine before the creation of Medibank. Eventually political strength was enhanced so that when the Medibank developments occurred there was a swing away from the corporate beneficial relationship to one that showed the AMA to be a powerful political pressure group. For the reasons identified earlier [46, 47] and the fact that the previous minority Labor Federal government attempted to change healthcare delivery, it is now apparent that the AMA or specialist groups within the medical profession have returned to being pressure groups. As such this poses a significant problem for government to navigate, whichever political party is in power at the time, as the doctors hold a strong position. Until a situation acceptable to the medical profession echoing aspects of medical dominance discussed previously are achieved, attempts to move the agenda of radiographer interpretation forward are likely to fail. This may now be affected further by the 2013 change to a conservative Liberal/National coalition majority government that also looks in a strong position to maintain power in 2016. Historically this party has a different outlook on how it supports healthcare delivery, closing down the HWA in August 2014. This suggests that there may be a return to the medico-political relationship that was seen pre Medibank.

2.7 Summary

Radiography's history in Australia has been as eventful as that seen in other countries and was detailed in sections 2.2 p13 and 2.3 p20. An early move by radiologists to claim the area as a medical specialisation was successful to the extent that physicists were excluded as potential leaders in the field of therapy and imaging. Registration approaches similar to other countries cemented this position as far as radiographers in Australia were concerned. Early educational approaches ensured radiologist control or at least direction of a lower grade workforce to continue. The employment relationship between radiologists and their patients has ensured that without their input through the report, money does not flow to healthcare facilities. This ensures that involvement of personnel without a medical doctor title in the reporting of images is not viable, unless changed by government, thus preventing any transformation in service delivery.

Differences in the approach to higher education for radiographers may have held Australia back. Australian radiographers are now developing the confidence and expertise to proffer convincing and evidence based arguments in support of role development. Nevertheless, despite anecdotal examples of role extension, continued failure by successive governments to partially divert political allegiance with the medical profession hampers radiographer role development in Australia. Some radiographers maintain the perception that '*radiographers should know their place in professional life*' [103, 106] as decision making related to image interpretation is the radiologist's responsibility. Through these limitations, often professionally self imposed and perpetuated, radiography professional development is hampered. This is not just for advancing roles, but also ensures perpetuation of the hierarchical relationship of Australian radiology, as clinical, strategic or managerial decision making is left to radiologists.

Examples of role extension seem to be occurring on an ad hoc basis, despite some anecdotal evidence published in the likes of the AIR submission to the Garling report. [164 p4] Continued failure by successive state and federal governments to partially divert allegiance with the medical profession restricts radiographer role development in Australia. Until recently, the radiographers' professional body (AIR) has provided insufficient directional drive to steer radiographer role development. Without that leadership being evident then it is natural to expect radiographers to be unable to press forwards. This has recently changed significantly and positively for the quest of radiographer interpretation through HWA initiatives to move towards an organisational patient focused structure rather than maintaining the status quo. Radiographers have felt professionally subservient thereby maintaining the dominance of radiologists, though there is now also evidence that this position is changing.

Smith and Lewis [128, 129] have argued that recently qualified radiographers are frustrated by the lack of potential professional development in Australia. Evidence of this frustration becomes apparent in this study amongst participants who have witnessed or practised at an advanced level in other countries. The evidence has shown that in Australia, radiologists wish to maintain control over all image interpretation to the point where other professional groups rather than radiographers are supported. This position has been demonstrated publicly and in documentation by senior radiologists. Furthermore, the generation of a new radiography assistant workforce may appeal to public sector cost cutting in the current financial climate, to undermine the current radiographer position. The post graduate educated radiographer who provides a radiographic opinion is a necessity for the provision of timely, reliable imaging services to the ever expanding healthcare sector. This is especially true in remote and rural areas of Australia where radiology services can be difficult to secure due to staff recruitment issues. However the argument for an assistant grade of staff also provides an opposite perspective as a body of advanced radiographers could fill gaps currently evident in radiology service provision in the urban as well as rural settings. Recognition by government is apparent in this situation where financial help is provided to secure postgraduate education, which is not evident in urban Australia, and so acts as a barrier to radiographer development.

Perhaps the answer comes from working within or around current thinking with respect to practitioner registration and healthcare leadership to generate new types of imaging or healthcare personnel? Through a change in government patronage or by altering health care delivery approaches to meet increasing demand within finite resources, a shift in the politico-professional trajectory is possible, assuming the medical lobby can be negotiated. Duckett has been a key voice in arguing the need for these developments in light of the wasteful approach of healthcare insurance relative to an appropriately funded, efficient public provision. However, much remains to be seen of the impact on healthcare through the recent change in political ideology with a move from a minority Labor led government to a more conservative Liberal-National coalition that holds a large majority in the hose of representatives.

This chapter has reviewed the historical perspectives of radiology and radiography development, the impact of education and how politics plays its part in developing workforce relationships. The chapter has shown the contribution that the registration process has on the workforce to suggest how professional body leadership can cement a workplace relational position, be it a dominant or subservient one. Educational comparisons have been made between radiographers, radiologists and the undergraduate medical curricular content limitations in Australia and further afield have been discussed. Focused radiology training is required to produce new doctors who are able to function fully when they join the healthcare workforce. Necessarily international comparisons have to be drawn in the understanding of the methods used to investigate radiographer or any other professional groups' interpretative capability. The next chapter explores and analyses international methodological strengths and shortcomings in the measurement of image interpretation performance. This enables a critique of the research performed by Australian radiographers and academics that has occurred to date in this field (chapter 4) so that limitations can be identified and corrected in the methodology detailed in chapter 5.

PART 2

METHODOLOGICAL CRITIQUE AND PROPOSED STUDY INVESTIGATION METHOD

'A large scale RCT [randomized controlled trial] that compares the film reading performance of two professional groups would protect against…biases. However such studies are expensive and may not be amenable to a rapidly evolving political climate.'

S. Brealey and A.J. Scally
The British Journal of Radiology 74, (2001) p307

Chapter 3 Radiographer interpretive performance measurement; what is understood internationally?

3.1 Introduction.

Chapter 2 examined the socio-historical and educational contexts that have prevented Australian radiographers from providing interpretive descriptions on MSK trauma plain radiographic images. At the same time it was argued that under the pressure from an ageing population and workforce [1 - 4], politically sanctioned opportunities for role extension within radiography will increasingly become available. Nevertheless, as the previous chapter suggested, these opportunities will only be realised if research into radiographer interpretive performance demonstrates that radiographers can provide a safe and appropriate service.

The majority of radiographer interpretation performance measurement to date has emanated from the UK. However as the work of Brealey and colleagues has demonstrated, many of the studies that support the claim that radiographers are capable of providing interpretive descriptions on general radiographic images have methodological shortcomings. [165 - 168] This chapter reviews this work to link to chapter four, which critiques published Australian studies, so that the methodology chosen for this investigation detailed in chapter five can be justified.

3.2 A return to the history to reveal some key points.

Some key points in the more recent history of radiographer interpretation potential is now revisited to set the scene. Starting with Swinburne's triaging idea in 1971 [70] studies in the UK followed, with subsequent investigations into highlighting RDS systems [169]. These were then succeeded by papers asking whether radiologists need to report all plain radiographic images from the ED as suggested by Wardrope and Chennells [170] and Saxton [171] amongst others. These claims were supported by Renwick et al's limited but ground breaking support for interpretation by radiographers [172]. During 1994, Loughran [26] published his initial paper detailing how, with appropriate education, radiographers could match radiologists very closely in interpretive capability in the field of MSK trauma. Calls for change in models of service provision and concern about a lack of immediate radiologist input, were further supported by the warning from McLauchlan and Guly [173] about the very low interpretive ability of junior medical staff in the emergency department. Authors such as Hallas and Ellingsen [174] in Norway identify more recently that the ability of emergency department doctors is still less than ideal with at least 3.1% of fractures being missed. This is despite the introduction of tailored education amongst this group of medical staff.

Loughran [26] was the first to report measurement of radiographer reporting performance, beating the grant winning bid by the then Leeds College of Health, to investigate the potential for radiographer interpretation. Robinson, a senior radiologist with colleagues at St James' Hospital also in Leeds, embarked upon a series of reports highlighting the interpretive capability of radiographers. These studies were initially performed with Jackson, a junior radiologist and later Culpan and Wiggins [175, 144] who became reporting radiographers. Robinson examined the nature of image reporting [176] and also discussed reporting variation amongst experienced radiologists [177]. In this respect he discovered up to 11% discrepancy in the content of MSK reports between radiologists reporting the same images. Robinson's open support for radiographers often led to invited appearances in radiography journals and text books, suggesting his allegiance was a key factor in advancing the cause of radiographer reporting in the UK. As a generalisation there was a belief amongst radiographers that his and colleagues research was well executed. Later, authors from a radiographic background [178], contributed to the radiographer interpretation deliberations by analysing change in radiographer reporting ability over the period of a program of study. This introduced the radiographic readership to the use of predictive values and the Kappa statistic as methods of performance comparison.

In 2000 there was the realisation that the RDS was taking place without any performance evaluation across the UK, neither was there any educational support for these radiographers. This resulted in a short study by McConnell and Webster [64] who developed a radiographer teaching program showing a short course can have a significant improvement in descriptive performance. This development was mainly delivered by radiographers trained to report at postgraduate level with some radiologist input. The approach indicates that radiographers have confidence in their abilities and that self driven teaching with new knowledge by the profession was possible. This takes us to the point when Brealey began his work, initially as a PhD student but later to become an acknowledged expert in the field.

This summary of the key points between 1994 and 2000 gives insight into the trajectory of research followed by the embryonic investigative processes into radiographer interpretation. It further sets the scene about the methodological difficulties that have been encountered over time and enables analysis to be made such that a method corrected for any limitations is employed in this study.

3.3 A discussion of bias types.

Brealey and Scally [165] identified that the randomised controlled trial (RCT) was the best form of investigative approach. They continued by outlining the difficulties of performing the RCT in the field of radiographer reporting from the perspective of cost, finally proposing that political change would be the most likely barrier to such involved studies ever occurring. In continuing their discussion they went on to create and assign titles of form that might be given to plain radiograph interpretation studies. To this they continued by indentifying types of bias that could be evident in these investigations. In reviewing potential causes of bias amongst investigations of reporting performance measurement, Brealey and Scally listed and defined a series of bias types. These are defined and reviewed in table 3.1 p46 paraphrased from their work. In 2002, Brealey, Scally and Thomas [166] discussed methodological standards amongst radiographer image reading studies that had been published in the UK to that date. Ultimately they devised 10 standards to evaluate radiographer image reading studies aligned to image selection, study design and results presentation and are quoted over:

Selection of subjects (films)

1. *Was an appropriate sample size considered?*

Study design

2. *Was a normal/abnormal report adequately defined?*
3. *Was the observer's performance placed in the context of the diagnostic sequence?*
4. *Was the contribution of individual groups determined if the combined performance of two (or more) different groups of observers were assessed?*
5. *Was an appropriate (valid) reference standard ("gold" or "criterion") used?*
6. *Was an appropriate (valid) arbiter used to compare radiographers' reports with the reference standards?*
7. *Was an appropriate control used?*

Presentation of results

8. *Were films appropriately analysed for pertinent sub groups?. Was the data presented in enough detail to allow for the re-calculation of performance statistics e.g. sensitivity, specificity and confidence interval?*
10. *Were indeterminate i.e. equivocal, missing data, non-diagnostic results appropriately presented? (Brealey, Scally and Thomas [166 p109]).*

A further paper in 2002 by the same authors [167] went on to discuss the extent to which bias was present amongst the studies examined earlier. Thirty studies from the UK were identified and assigned study categories namely;

- ***Diagnostic accuracy studies*** where the radiographers report on a bank of validated images as part of a postgraduate qualification;
- ***Diagnostic performance studies*** that audited radiographer image reading performance in the clinical setting;
- ***Diagnostic outcome studies*** where radiographers would be compared against emergency department doctors in their plain image reading capabilities.

Understanding the various forms of study is important as differing biases may affect an investigation without the researchers realising it.

The UK experience is held in high regard with research outcomes often being quoted in Australian work, in the form of review articles or the basis for submissions to government [58, 133, 164, 179, 180]. However, the work of Brealey and various colleagues has shown that there were potential issues with aspects of research performed by a range of investigators, if the criteria developed by Brealey et al are adopted for critique purposes. Rejection of some of the ideas expressed in the UK or Australian papers suggesting radiographer task substitution, whereby radiographers would take on a delegated radiologist role, is noted within the RANZCR response to the discussion paper on role evolution [46]. Whether this was

Bias type/title	Comments
Group 1: Patient or image selection bias	
Referral bias	Can occur when comparing observers from differing centres where their clinical departments deal with (for example) emergency department cases. Due to the experience of differing referrers studies that deal with images on an on-going nature are impacted. Studies may also be affected by 'hot reporting' or 'red dotting' by radiographers as the comparator emergency department doctor decision could be altered by these inputs.
Film/Image cohort bias	The criteria used to include given images in a study affects the characteristics of the selected sample. This impacts on-going evaluations in particular, as spectrum and population bias is directly affected.
Spectrum bias	Limitations to the disease type, severity and clinical demographics. Spectrum bias is seen in testing radiographer ability in postgraduate course assessments as images may be unrepresentative as the assessment format tries to establish an overall capability. Stratification to show an effective higher prevalence and variety of pathology is required to overcome this.
Population bias	This is the converse of spectrum bias where a performance comparison against other clinical readers is the focus. Because a reference standard of a single radiologist may be used to establish the disease status of the patient then the study effectively is showing the radiographer's ability to match the radiologist who could be incorrect. This means sensitivity and specificity calculations are impacted by the disease prevalence, which means a random sample of images from clinical practice at the same prevalence level should be used.
Film/Image selection bias	Occurs when radiographers do not read all images that can be included in the study or opt to choose those images they wish to interpret. As a result radiographer confidence and time availability controls which images are selected to enhance performance levels when calculations are performed.
Group 2: Observer selection bias	
Observer selection bias	Images selected for a study should be carefully chosen as any conclusions drawn can only be for those images. This is further impacted if only selected radiographers in a department are assessed as wider generalisation to other radiographers should not be made. A record of these selection criteria should be kept so appropriate inferences can be made about the results.
Observer cohort bias	To avoid external validity impact the number and level of experience or further education of radiographers involved in the study should be noted to estimate any influence these factors may have had on the results.
Observer cohort comparator bias	Occurs when two or more observer groups are compared without sufficient matching criteria being applied. In this way control and intervention groups should be carefully matched to ensure changes occur due to the intervention rather than any other unforeseen process.

Table 3.1
Types of bias in plain image reading studies paraphrased from Brealey and Scally 2001[165].

Group 3: Reference standard application bias	
Verification bias	This bias occurs when the images interpreted by the radiographers are not interpreted by the same reference standard.
Work up bias	This bias occurs when the reference standard is not applied when the comparator responses are the same and assumed to be correct. This would mean the two groups being assessed would apparently perform better than the reference standard would suggest. Likewise if only abnormal readings receive comparison with the reference standard an artificially inflated sensitivity due to reduced false negative recognition would be the result. In an on-going study the reference standard should not know about the opinions of others reading the images to avoid a further incorrect reference standard being generated.
Incorporation bias	Occurs when the observer being measured also contributes to the generation of or is used as the reference standard.
Group 4: Result measurement bias	
Disease progression bias	This would occur if the radiographers report was referenced against a repeat examination in the future as a standard of performance. To avoid a problem a consensus review of the initial radiographer report should be performed to establish if an abnormality had been previously missed. If an occult injury was present only on subsequent images then this bias would not apply.
Withdrawal bias	If images are excluded from a test sequence non-randomly then withdrawal bias is evident. Withdrawal prior to receipt of the reference standard will cause work up or verification bias according to the exclusion reason adopted.
Indeterminate results	A form of withdrawal bias where equivocal images are not included in the final calculations. This may cause bias in the performance calculation and should be included if for example radiographers want further imaging to make a decision when the radiologist made this decision without those extra images. This will have economical impacts when comparing radiographers with radiologists. Frequency of equivocal reports should be noted in studies as assuming negative or positive outcomes will artificially change the relative sensitivity and specificity scores.
Loss to follow up	In on-going studies images may be lost so that a reference standard cannot be applied.
Observer variability	Reliability of a study is influenced greatly by observer variability due to the judgement component and comparison with the standard. Two forms of observer variability impact on plain image reading studies: *Inter observer* – observers in different groups should independently report the same or at least similar images to enable comparison of consistency or evaluation of variability between groups. *Intra observer* – is the measurement of reproducibility by a single observer at different times. Individuals within groups could re-interpret a smaller sample of a set of images at a later time to establish which cohort performed more consistently Inter observer variation is usually greater than intra observer and can be measured using the kappa statistic.
Arbiter variability	Consistent application by arbiters is a requirement even when explicit criteria for decision making about individual's interpretations are available. This means the assessment criteria should be applicable by different people if necessary or consistently applied by the same arbiter at differing time points in the study. Failure to correctly apply and interpret criteria can impact reliability. Arbiter variability can also be measured using the kappa statistic. Two forms exist: *Inter arbiter* – where two independent arbiters consistently apply the criteria to a sub set or interpretations in a matched way. *Intra arbiter* – a single arbiter compares a sub set of interpretations by a reader(s) to see if the criteria can be consistently applied at different times by that individual.

Table 3.1 continued

Group 5: Plain image reading performance study biases.	
The purpose of a study will impact on whether a form of bias becomes evident. True reading performance measurement should be conducted blindly with no conferring or access to other reports due to the impact that prior knowledge can have. If done in clinical practice environments i.e. on-going studies, then this other material may be allowed. Clinical judgement can impact on the assessment by the arbiter. As such the arbiter should be blinded to who generated the reports due to preconceptions of the observer tending to sway a response towards concordance with the reference standard. Brealey and Scally suggested terms for forms of bias that may be encountered in performance studies.	
Observer review bias	Occurs if the radiographer is aware of the reference standard content. Observer should be blinded to this information.
Reference standard review bias	Occurs when the radiographer reports are known to the reference standard report generator. Again this person should be blinded to any external information of this nature that may bias the reference standard report.
Observer bias	Occurs if individual radiographers in the same study do not interpret images independently of each other i.e. blinded. This bias is not applied if normal clinical practice suggests radiographers would communicate with colleagues during interpretations.
Observer comparator bias	Occurs if the radiographers being tested do not interpret the same images or a comparable sample. This enables comparisons to be made and attribute according the individual differences amongst participants rather than the image mix.
Co-image bias	Occurs when other images beyond those being used for testing are available to the observers and as such may add to information to enable correct decisions to be made on the original image. If simulation of clinical practice was an aim of the study then this would be permissible.
Arbiter review bias	Impact of arbiter review bias changes according to whether they are under evaluation themselves or responsible for generation of the reference standard. The first type impacts more severely on the result.
Arbiter bias	This bias impacts when the arbiter is aware of the interpreter who generated the report. Blinding between reference standards and the 'other' reporter navigates this issue when comparisons are being made over an extended period.
Film/image access bias	This occurs when the arbiter can also see the images when judging if interpretations are concordant. Arbiter judgement could be influenced by his/her interpretation or being affected by an incorrect report when looking at the images.
Clinical review bias	The influence of clinical information should be accounted for in studies as minimal information such as age, gender and symptoms/history enables interpretation to meet a clinical context. There is debate about the value of clinical information availability on the interpretation and so should be considered when evaluating the outcomes of the study. Understanding the clinical question requiring an answer however is a key requirement to the direction of the report that is generated.
Cohort comparator bias	This bias arises when two groups do not interpret images independently i.e. each group should be blind to each other reports as suggested in the reference standard review bias. The same or comparable batches of images should be used to evaluate two groups.
Co-image comparator bias	This occurs if one group has access to more images than the other e.g. radiologists have CT images to add to the plain radiographs interpreted by the radiographers. A potential unfair advantage to one group that could artificially depress the scores of the other.
Arbiter comparator bias	This bias is seen when the arbiter is aware of which group provided which reports. As such it may be perceived the radiologists as a pre conception should perform better than radiographers, again unfairly enhancing one group score over another.

Table 3.1 continued

due to recognition by the RANZCR that bias was present in studies is unclear, however the RANZCR's position was inadvertently supported in the UK by Donovan and Manning [158] in 2006. Through indicating that the nature of radiographer reporting will be limited by task specificity and is therefore less useful than the radiologist performing the role, the RANZCR claimed a superior position without needing to concern themselves with bias in reader performance studies.

As indicated earlier, Brealey and his co-workers reviewed 30 UK studies within the field. Their findings pinpointed recurring research design faults that inadvertently introduced forms of bias into the range of material that was published, or available as grey literature, but used for the development of radiographer roles nonetheless. Not only has this biased research been used for the development of radiographer roles, political expedience at the time and pressure on managers to provide services probably led to some degree of risky acceptance of the results from the research that had been performed. Radiographer reporting systems that were initially adopted tended to have the safety net of continued radiologist input and therefore could be considered to be less risky. When examined from governance perspectives, 'risky acceptance' with associated on-going practice audit was considered to continue to demonstrate safe levels of performance acceptable to delegating radiologists and health service managers.

Forms of bias, where present in the studies identified by Brealey et al, based on those definitions supplied in table 3.1 p46, are quoted in table 3.2 p50. The studies were split into the three forms indicated above (p45), namely; diagnostic accuracy studies, diagnostic performance studies and diagnostic outcome studies. In examining table 3.2 it becomes apparent that observer and arbiter sources of bias are most common. In testing regimes that are more controlled, such as for postgraduate assessment or audit of radiographer reading performance where the comparison is directly with the radiologist, then these are the key forms of bias. When an on-going clinically oriented testing system is put in place (diagnostic outcome studies) a range of biases should be considered. These include aspects such as image selection, access to other images, the generation of the reference standard; verification and work up bias also become problematic when results are calculated and generalised from an incorrectly applied reference standard.

Diagnostic accuracy studies n=11		**Diagnostic performance studies n=11**		**Diagnostic outcome studies n=8**	
Type of bias	Number	Type of bias	Number	Type of bias	Number
Image filtering	1	Centripetal	1	Population	3
Observer cohort	1	Population	2	Image filtering	1
Inter-observer variability	10	Image filtering	2	Image selection	4
Intra-observer variability	11	Image selection	1	Verification	3
Inter-arbiter variability	11	Verification	1	Work up	3
Intra-arbiter variability	9	Work up	1	Loss to follow up	1
Observer	1	Incorporation	4	Inter-observer variability	7
Arbiter review	1	Indeterminate results	2	Intra-observer variability	7
Arbiter	8	Inter-observer variability	11	Inter-arbiter variability	8
Image access	1	Intra-observer variability	9	Intra-arbiter variability	8
Arbiter comparator	5	Inter-arbiter variability	10	Reference standard	5
		Intra-arbiter variability	9	Arbiter review	4
		Observer review	1	Arbiter	6
		Reference standard	7	Image access	6
		Arbiter review	8	Cohort comparator	1
		Arbiter	10	Arbiter comparator	6
		Image access	6		

Table 3.2
Major types of bias present in plain image reading studies according to Brealey et al 2002 [166]

Brealey et al [167] conclude that greater scientific rigour can be achieved if investigators are able to recognise sources of bias and that these are easily negotiated by adopting techniques such as blinding observers and arbiters.

3.4 Using methodological standards to define study validity.

Brealey, Scally and Thomas [166] also applied their list of methodological standards against the 30 studies they investigated to establish how much control was achieved. This is because multiple influences can affect the outcomes of performance studies and that some level of control should at least be attempted by the researchers. The most poorly applied standards are discussed below as those not expanded upon were performed as required.

By far the weakest applied of the standards listed on p44 was **standard 1**; assuring an appropriate sample size was taken based on the research question/performance measurement to be answered. In slightly under 60% of studies due recognition of various standards was not taken and as a result the value of the work is reduced.

The image sample size should be sufficient to answer the question being posed, because if this is too small there will be an impact on study precision. Studies that are used to measure radiographers, or another single group, by way of sensitivity and specificity scores should have a sample size calculated according to the precision level that measures the performance in those factors. If groups are being compared, such as radiographers against radiologists, clinically important effects of different interpretation capability within an image sample should be defined using an appropriate power calculation. Scally and Brealey [181] and later Naing [182] outlined methods based on Daniel's (1999) calculations showed how to establish confidence intervals and hence sample size for appropriate study power.

Standard 4 (p45) asked: Was the contribution of individual groups determined if the combined performance of two or more different groups of observers were assessed? This meant that if each group that contributed to study results was not measured independently and the ability of all groups is compared against another, then the performance one group has over the other cannot be assessed i.e. it is impossible to tell who performed best. **Standard 6** (p45): Was an appropriate (valid) arbiter used to compare radiographers' reports with the reference standards? This suggests that the best results in terms of marking responses by given observers, is achieved with a panel of arbiters. Arbiter problems arise particularly if the radiographer without education is used as an arbiter without reference to a radiologist, or if the radiographer is in training and used as an arbiter. **Standard 7** (p45) asks if an appropriate control was used. Study validity can be affected by failure to use a control as this makes explanation of unexpected results impossible without a baseline to compare against. Ideally the control should closely match the study sample population.

An examination of the chosen image sub groups pertinent to the study is **standard 8** (p45). This is a detail that could be missed if the study only reports an overall measure, as the images used should be representative of a normal workload. Further analysis of sub group failure e.g. extremity compared with axial musculo-skeletal radiographs, is also possible when this standard is adhered to. In the example given this may be used to identify within a group of radiographers that images of given body areas may or may not be interpreted well. The final poorly performed standard from p45 is a function of result presentation. In

standard 9 only 59% of studies presented results in such a way to allow re-calculation by readers external to the work. This aligns in particular with study scores or creation of confidence intervals if they haven't been presented. Participant results are used for a range of values that a true performance lies across i.e. can we be sure what the upper and lower limits of acceptable performance are?

In summary, Brealey, Scally and Thomas [167] demonstrated that there has been, in the UK literature, a wide variation in the ability of studies to align with the standards they defined. Their message is that appropriate sample size generation methods should be adopted and an apt marker, arbiter or method of marking should also be chosen. Reference standard generation is also a variable that can impact on measurement outcomes and should be multi-partite in nature if at all possible. This may be harder to achieve in diagnostic outcome studies due to the fact that radiologists of varying experience may report a range of images and often only a single radiologist is used to generate an opinion that is used for measuring against. Most importantly for study validity is that if a reference standard is generated incorporating the opinion of the observers being measured, then 'reference standard review bias' is generated. In this situation the radiologist uses the impression of the one being tested to inform his/her opinion [166] so that the reference standard (radiologist report) becomes strongly influenced by those being measured. In the 2002 paper [167] Brealey et al conclude that even when reference standards are carefully chosen in diagnostic outcome trials, attempting to establish the ideal reference standard may not be feasible. In these cases, inter and intra observer variation between groups in comparison with a radiologist judged to be the standard in a given department, will generate sufficient information to suggest under or over calling by different observers or groups. In these cases, statistical comparisons of sensitivity, specificity, accuracy and use of the kappa statistic will be sufficient to provide an indication of whether various groups are performing at acceptable levels

3.5 Statistical strengths and weaknesses.

Statistical measurements that are suggested above are the key assessment elements for the studies evaluated by Brealey et al [167]. Most common values that are used to test the performance of image interpretation studies are listed over (p53):

- Sensitivity, specificity and accuracy
- Predictive values and likelihood ratios
- Receiver Operator Characteristic curves (or areas under these curves)
- Kappa statistics

The relative capabilities of these evaluative techniques will now be considered so that the strengths and weaknesses of their use can be discussed in association with the results data generated for this investigation.

3.5.1 *Sensitivity, specificity and accuracy.*

These are the building blocks on which all image interpretation performance statistical analysis can be developed. Sensitivity describes the proportion of true positives identified by the observer and likewise the specificity describes the proportion of true negatives [183]. They are linked in that variations in either sensitivity or specificity will necessarily impact on values obtained by observers and the final accuracy figure that may be generated. Studies should not make it possible for the participant to know how many abnormal and normal examinations are present within the make-up of the test, as this will tend to encourage observers to err on the side of one or other interpretation when there is doubt (refer to section 3.6 Bias in clinical decision making, p61).

3.5.2 *Predictive values and likelihood ratios.*

Sensitivity and specificity are respectively proportions of true positive and true negative identified by a test or in this case the reader of a test. They are used to establish the ability of the test to provide diagnostically reliable results, however being able to predict abnormality is a more useful outcome from a test. To establish this, predictive values are used where the positive predictive value (PPV) is the ability of the test to correctly identify those patients with the abnormality. Conversely the negative predictive value (NPV) is the ability to confirm that a person does not have the problem. Altman and Bland [184] make the point that prevalence impacts significantly on the relative values of predictive values, thus influencing the validity of the result. Where prevalence varies the impact on the predictive value changes; higher prevalence will result in higher PPV and lower values will enhance the NPV. However, where the abnormality prevalence is very low, achievement of a PPV close to 1 is not possible. As such this tends to elevate the false positive rate even if high sensitivity and specificity scores are obtained by the test. In recognising the impact of prevalence, PPV and NPV should be calculated with prevalence as a recognised factor and is shown as follows in equation 3.1:

$$PPV = \frac{\text{sensitivity x prevalence}}{\text{sensitivity x prevalence + (1- specificity) x (1 – prevalence)}}$$

$$NPV = \frac{\text{specificity x (1 – prevalence)}}{\text{(1 - sensitivity) x prevalence + specificity x (1 – prevalence)}}$$

Equation 3.1 – calculating formulae for predictive values (Altman and Bland 1994) [184 p 102]

Prevalence suggests the likely probability a person may have a problem before the test is carried out. Predictive values therefore are post test probability indications and estimate the likelihood the individual has or is clear of an abnormality. If the difference between the prior and post probabilities (prevalence and predictive value) is taken, then the test usefulness can be better gauged.

The likelihood ratio by comparison measures the probability of the positive result if the patient had the abnormality compared with the probability if the person was healthy. As such the likelihood ratio indicates *'...the value of the test (radiographer reading images) for increasing certainty about a positive diagnosis.'* [184 p102] Positive likelihood ratios of values over 1 indicate likely presence of the abnormality and those with a value over 10 suggesting a strong association. Values under 1 indicate the problem is not likely to be present with a value below 0.1 being very strong for a negative outcome [185] or a good negative likelihood ratio. The likelihood ratios are calculated as below (equation 3.2):

$$\text{Likelihood Ratio +ve} = \frac{\text{sensitivity}}{1 - \text{specificity}}$$

$$\text{Likelihood ratio –ve} = \frac{1 - \text{sensitivity}}{\text{specificity}}$$

Equation 3.2 Likelihood ratio calculation formulae

The post test odds and therefore post test probability of having the disease, based on the test results, can also be calculated by multiplying the pre test odds by the likelihood ratio. Equation 3.3 below gives details:

$$\text{Post test odds} = \text{pre test odds} \times \text{likelihood ratio}$$

$$= \frac{\text{prevalence}}{1 - \text{prevalence}} \times \frac{\text{sensitivity}}{1 - \text{specificity}}$$

$$= 0.192 \times \text{likelihood ratio}$$

$$\text{Post test probability} = \text{post test odds} / 1 + \text{post test odds}$$

Equation 3.3 Calculation formulae for post test odds and post test probability

Deeks and Altman [185] have produced a nomogram to calculate post test probability of abnormality presence when the pre test odds, post test odds and likelihood ratio are known. A caveat should be considered in all these calculations from the perspective that a high likelihood ratio may suggest the test is useful in detecting an abnormality. However, there is no guarantee that a positive test definitely indicates the presence of the abnormality [184].

3.5.3 *Receiver Operator Characteristic curves (or areas under these curves [AUC]).*

The ROC is a plot of sensitivity against the false positive fraction (1-specificity) when a binary response (yes/no) of abnormality presence is considered. This enables the diagnostic accuracy of a procedure or individual reader to be measured. The binary response of the reader is measured against a reference standard that is considered to be a true indication of the result of the test [186 - 189].

In the real world setting, decision making is affected by individual reader thresholds to labelling a finding positive or negative. The effect of this is described by signal detection theory [190] and further discussion regarding causes of decision making bias will be given later (section 3.6 p61). Normally the AUC defines the overall accuracy of the reader. As indicated earlier, sensitivity and specificity values trade off against each other. This is seen as an individual's temptation to under call (high threshold = false negatives) or over call (low threshold = false positives). This gives the first reader low sensitivity and high specificity while the low threshold reader will have high sensitivity but low specificity. Both of these outcomes will reduce the overall accuracy according to the prevalence of abnormality in the test bank, and may have other deleterious effects for the patient. However, the AUC of the ROC curve is independent of the threshold chosen by an individual when they decide an image outcome is positive or negative. The ROC therefore effectively adjusts for this to give an overall value of ability of one reader or test against another, as it is independent of the threshold chosen by the reader when a decision is made [186, 189].

ROC values of 0.5 or less suggest that the reader demonstrates abilities no better than random guessing that an abnormality may be present. A typical ROC curve that demonstrates strong accuracy will operate by showing initial rapid gains in sensitivity score on the left hand side of the graph with a gradual flattening as it plots to the right and further along both axes (figure 3.1).

In addressing the problems of thresholds and decision making confidence Eng proposes several systems of data gathering [189]. One proposal uses a six point scale from which 3 lean

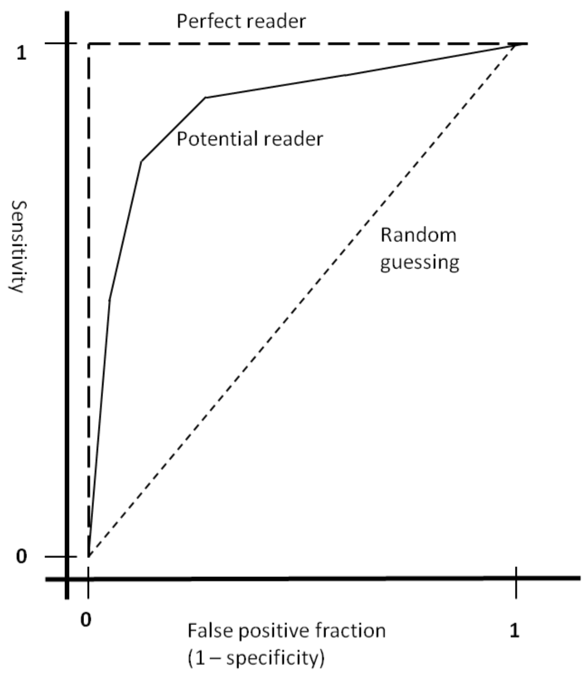

Figure 3.1 Features of the ROC curve

toward abnormality, and 3 to normal thus retaining an overall binary positive/negative response. The reader chooses one value for each radiograph viewed and results are collected as sensitivity/specificity pairs that are plotted on an ROC graph. This will create an empirical graph with points plotted for the reader much like the potential reader line in figure 3.1. A fitted version of the ROC curve can be constructed if the plot points for each threshold or certainty of response level are applied to the graph. This then allows a smooth, best fit curve to be applied across the range of possible confidence levels.

The AUC for the empirical curve is calculated using the trapezoidal rule for each trapezoidal section of every curve segment. By comparison the fitted ROC curve AUC uses a bi-normal model to calculate the area. This is based on the supposition that observer confidence ratings are from two normal distributions of responses, around normal and abnormal decisions [190], which means the spread of responses overlap as seen in signal detection theory diagrams. However, it should not be assumed that the curve smoothness represents greater precision by the reader or that the graph would always follow the line towards the false positive fraction of 1 in exactly the path delivered on the output plot. Eng warns readers of ROC curves presented in the literature and to be wary of smoothed graphs as this may give a false impression. He further suggests the empirical plot should also be made available to enable true performance understanding to be revealed [189].

ROC curves suffer from two key problems; firstly the fact that they fundamentally rely on binary responses for the presence or absence of an abnormality, so cannot be used where there are more than two outcomes to the test. Secondly, the ROC requires a reference standard that is reliable in its definition of a given state for the patient i.e. positive or negative. As with sensitivity and specificity calculations, inaccuracy in this aspect would impact significantly on the ROC analysis. The AUC also gives an average of the performance over the specificity and sensitivity values selected by a reader. As such it does not account for shape variation in the pair of empirical curves generated by two observers, even though the area beneath them may be calculated to be the same. It should also be remembered that the ends of the ROC demonstrate unequal importance clinically as diagnostic tests are not likely to be found with close to zero sensitivity or specificity as they would have no significance [186 - 189].

ROC curves also fail to some extent because they are unable to take account of the location of an abnormality. The image reader may be credited with a correct response of the presence of abnormality even though the correct location is not given and so performance is overestimated. To combat this, the Localisation ROC (LROC) was developed so that the reader should both correctly identify an abnormality and give the appropriate location. Specialised software is required for this approach and at the time of data collection was not widely available. Swensson [191] discusses the statistical procedures for combining localisation information with the normal ROC output. Not only is location an issue but also multiple points of abnormality within a radiograph also limits the ROC capability; this has been addressed by the Free-response ROC (FROC). Where more than one abnormality event is seen in an image a variation in the ROC axes has been devised. The vertical axis counts sensitivity scores for all true positive locations when more than one positive point is contained in an image; the horizontal axis counts the average number of false positives per image or case as there are multiple points in the image where a diagnosis can be made. Again software availability and an assumption by measuring systems that all abnormalities are distinct, reduces the ability of this approach to use in evaluation. Work is on going to address this [192].

3.5.4 *Kappa statistics.*

Cohen's Kappa statistic is commonly used in medical research to establish the degree of agreement between two or more observers when the data is expressed using a binary format [193 - 197]. The weighted Kappa statistic was developed as it corrects for agreement that could occur by chance [176] and is calculated as follows:

$$K = \frac{po - pe}{1 - pe}$$

po = proportion of observed agreement (some of this will be due to chance alone)
pe = agreement expected by chance (a correction factor to allow for inflated po)

Equation 3.4 Weighted Kappa calculation equation

Although a popular statistic, several investigators have identified problems from prevalence and bias sources [194, 196]. The impact of prevalence and bias was discussed in section 3.5.2

Predictive values and likelihood ratios, to indicate that where the abnormality prevalence is very low, achievement of a PPV close to 1 is not possible. Feinstein and Cichetti [194] discuss Kraemer's discovery that with observers who have a constant accuracy, the prevalence value affects the Kappa calculation for each individual. This is due to differences in observer selections of true positive and true negative as a proportion of the overall total of responses. A bias effect occurs due to the frequency of 'Yes' choices made between observers, that is *'...the differences in proportions of "Yes" for the two observers...'* [196 p424-5]. These variations will generate differences in marginal totals in a 2 x 2 square even though the overall accuracy may be the same. A 2 x 2 square showing the relations between true and false responses and marginal totals is shown below in Table 3.3:

	Observer 1		Marginals
Observer 2	Yes	No	
Yes	TP a	FN b	a + b *g1*
No	FP c	TN d	c + d *g2*
Marginals	a + c *f1*	b + d *f2*	Tot

Table 3.3 Demonstrating the relationship between true and false responses relative to marginal totals.

The 2 x 2 table can also be used to demonstrate sensitivity, specificity, accuracy, predictive values and likelihood ratio

Byrt et al [196] showed that as the bias index (BI) or relative proportions of 'Yes' choices and the prevalence index (PI) or relative probabilities of 'Yes and No' choices changes, the following relationship would be evident:

as BI ↑ then *pe* ↓ to cause κ ↑ and

as PI ↑ then *pe* ↑ to cause κ ↓

This phenomenon was also suspected by Feinstein and Cichetti [171] however, Byrt et al [196] described methods for adjusting Kappa to take account of bias and prevalence. In a worked example these authors made the following assertions about marginal totals and how they affected the Kappa statistic. Relating back to the 2 X 2 square above they state when *po* = 0.6:

Marginals are uniform	f1 = g1 = f2 = g2	κ = 0.467	No prevalence or bias effect
Marginals are equal but not uniform	f1 = g1 and f2 = g2	κ = 0.444	Prevalence but no bias effect
Marginals are unequal	No match	κ = 0.474	Prevalence and bias effect. Bias = stronger to cause raised κ

Table 3.4 Worked example by Byrt et al [179] showing the impact on Kappa when bias and prevalence vary

They also recommend that the bias index should be discussed when reviewing results to establish whether a given level of bias would be important in the context of a test being performed. Bias effects can be large when there is poor agreement between observers and the Kappa value is also weak. Byrt et al [196] also state that Kappa values of between 0 and 0.2, slight agreement if the Landis and Koch [197] descriptors are used, are linked to a large bias index. Knowing the magnitude of bias is useful for its own sake but is also important where observers are believed to be matched and therefore interchangeable, as bias should be absent. In these cases should bias be evident to a large value then responses should be investigated further to establish a cause.

Byrt et al [196] further recommend that Kappa values should be evaluated by considering the effect of prevalence when the bias index is small. They also suggest the use of Feinstein and Cichetti's [196 p428] indices of positive and negative agreement. These values will aid researchers through:

1. Understanding consistency of observers when choosing opposite responses i.e. sensitivity and specificity through choosing yes and no respectively. This allows the researcher to understand individual results better;

2. Enabling elimination of the high *po = low* κ due to demonstration of the relative positive and negative values that contribute to changed κ so the reader can see why the results have occurred;

3. Realising when there is less than perfect symmetry between the marginal totals κ tends to be raised if *po is* relatively high. When neither *po* nor κ is high the researcher may tend towards suggesting the observers have not produced good results. This may make the researcher look at the experiment and make changes – the indices will enable a decision about where and how much improvement is required.

Gwet [198] deconstructs Cohen's derivation of Kappa stating that the assumptions used to calculate the level of chance assumed within it are flawed. He compared Kappa with Pi (π) statistics that are both used to calculate agreement between observers while allowing for chance agreement. Through analysing how chance agreement may occur in Kappa and Pi, Gwet comes to the conclusion that a probability for chance agreement should not exceed 0.5 in value, if both observers randomly come to a decision that they both agree on. In debunking the Kappa derivations assumption, Gwet argues for an alternative value he terms the AC1 – statistic. Chance agreement is defined by Gwet as the *'...simultaneous occurrence of random rating (by one of the raters) and rater agreement...'* [198 p4]. This statistic appears to take account of the marginal values on a 2 x 2 square to produce an outcome that would be appropriate, if Feinstein and Cichetti [194, 195] and Byrt, Bishop and Carlin's [196] approaches were also considered in the same situation.

3.5.5 *Why are these statistics important?*

Section 3.5 has analysed the statistical measurement approaches that can be employed. A full understanding of the impact of each of these values is important to appreciate where other research may be incorrect. It also demonstrates why the adoption of one method over another to identify relative reader performance may not reveal the whole picture i.e. there is some form of result reporting bias. There has been a tendency to apply simple statistical reasoning in most research published so far; however to correctly report the results of this investigation it is understood that the comparisons identified earlier need to be made so that a full picture of performance can be gleaned. In this way if questions are raised about the reported performance by radiographers and final year medical students the outcomes can be argued from a range of statistical positions.

3.6 Causes of bias in clinical decision making.

Christensen [190] discusses decision making in terms of relative value ascribed to a decision and illustrates his assertions by suggesting that:

> *'...the radiographer will have to weigh up the relative value of a false alarm (a worried patient is unnecessarily recalled for another test) versus a false negative (the condition may be much worse when it is finally diagnosed correctly).'* [190 p34]

He continued by suggesting regret and the impact of emotion in these decisions when incorrect, which results in image readers favouring the false positive approach. He also talked more widely about everyday decision making and discussed cognitive theories that have been used to underline decision making. The rational model supports the idea that the rational decision maker prefers to maximise the utility outcome of a decision and that he or she is able to equally view loss (incorrect diagnosis) at the same level as a gain (correct diagnosis). A perceived value bias against wrong decisions often has a psychological comfort component, and as a result individuals are risk averse. Kahneman and Tverski [199] used this thinking to develop their prospect theory, which over values bad choices and under values good ones. This is the kind of situation that tends to result in a hedging approach to report content and hence clinical decision making, especially where there is some doubt about the image content. As such it will directly impact on sensitivity and specificity values in a study.

It was stated in section 3.5.1 (p53) that radiographer reading studies should not disclose the number of patients/images that may be positive for abnormality in the test being performed. The probability of a given number of individuals being positive for an abnormality from a given population sample is termed the prevalence [200]. Period prevalence i.e. the prevalence over a given period of time, which relies on knowing the incidence of an abnormality in a given population, can be calculated (equation 3.5) as follows:

$$\text{Prevalence} = \frac{\text{Incidence}}{\text{Population}} \times 100$$

Equation 3.5 Calculating period prevalence

Knowing the prevalence of the disease in a given population may encourage the reader to interpret one way over another. However, although prevalence has been suggested as a form of potential bias [201 - 203], Ethell and Manning [204] revealed a statistically significant impact on sensitivity and specificity was seen only at 83% prevalence levels. Gur et al [205] confirmed no significant difference to abnormality identification in laboratory conditions could be linked to prevalence. Prevalence, according to Obuchowski, can therefore be regarded as less problematic as once thought [206]. Interestingly though Pusic et al [207] found that prevalence within a test bank can influence how individuals learn about normal and abnormal appearances. However, with the assertions of Gur and Ethel and Manning [204, 205], prevalence should be used to calculate the required number of examinations to be included in a test and is applied in section 5.2.1 p84

A person/practitioner's experience often results in an intuitive judgement about the outcome of a test. These are the 'rules of thumb' or heuristics that are applied by an individual based on past events and how they have been lodged within memory. Christensen [190] discusses several heuristics that people often apply. These are discussed in box 3.1 below. It therefore becomes apparent that even when statistical considerations may be accounted for there are psychological aspects that could impact on clinical decision making that are difficult to explain on an individual basis, especially in the clinical context.

HEURISTICS

Representativeness

Probability judgement based on how much object/subject A resembles B. As more information is available the chances of A representing B fall. However, how we imagine the connection (i.e. apparent likelihood) increases with more information. This can lead to assumptions about abnormality despite the baseline position indicating otherwise.

Availability

Individuals judge the probability of an occurrence based on recall of previous instances. Common events being common then this works appropriately as do recent events. This means more recent events attract a greater likelihood and hence probability than occurrences of older ages.

We may review our decisions to ask ourselves whether we have made good decisions, assessed the evidence appropriately or was something missed especially if the outcome of a decision was perceived to be negative.

BIAS

Regret

People control their actions to minimise the impact of a decision that may have negative outcomes. A causative link is often made for things done rather than not done so that inaction tends to be favoured over the chance of a bad outcome because of an action carried out. As a result people show signs of caution. This is termed **omission bias**.

Confirmation bias

This occurs when an individual searches out information that would support or confirm their beliefs and reject information that undermines their position. This leads to satisfaction of search or may be linked to the clinical history supporting the findings made resulting in ceasing further image scrutiny. In a negative sense following a mis-reading of images, this could result in hindsight bias.

Box 3.1 Heuristics and Bias paraphrased from Christensen 2005 [190]

3.7 Conclusion

This chapter illustrates there are several potential sources of bias that can be labelled psychological in nature rather than bound in fact. These sources of decision making mistakes must be considered when a review of observer agreement performance is undertaken. It is possible too, that when a multiple radiologist consensually agreed test is developed there may still be sources of bias in-built that can result in image reporting measurement being incorrect. This is despite further patient management having not been initiated at the traumatic event that would act as a confirmatory piece of evidence to suggest no abnormality was present in the images. A definitive gold standard is often impossible to generate, however the best possible reference standard that can be developed must be used in this kind of testing. The degree of alignment between the radiologists should also be considered before using their interpretations unquestioned as the comparison for other observers/viewers. Blinding of radiologists, other observers and the final marking arbiter to each other are key elements in attempting to ensure good research outcomes are reported.

The chapter has also shown the statistiscal analyses that may be employed to evaluate the strengths and limitations within observer performance studies. It is therefore important that researchers use the best statistical representation possible while also being cogniscant of limitations that may be inadvertently incorporated into a testing regime. In this investigation, the reporting of each value by a researcher is key to defining the capability of radiographer or medical student descriptive abilities, when compared with what could be an imperfect gold standard.

The next chapter will critically analyse the Australian research that has been undertaken to measure radiographer interpretive performance. It evaluates these studies relative to the standards that have been described here and ascertains the extent to which policy makers can have confidence in the conclusions made by the researchers.

'As a general observation, it is evident that those countries with a longer history of formal radiography education combined with recognition through regulation have progressed further along the role boundary continuum.'

C Cowling
Radiography (2008) 14, e29

Chapter 4 A critical examination Australian radiographer image reading investigations

4.1 Introduction.

The previous chapter reviewed research methods that have been employed internationally (mainly in the UK) to measure radiographer interpretive performance. Chapter 3 also identified best practice in performance measurement and demonstrated that there were significant shortcomings in some of the work performed in the UK. This chapter critically examines the Australian research that has been published, employing the standards and definitions developed by Brealey and his colleagues. It identifies where the strengths or limitations of these studies are evident and offers reasoning to explain where errors are apparent through analysis of the choice of methodology in each piece of research.

4.2 Who, what and when?

Over the 12 year period between 1997 and 2009, there has been limited radiographer reporting investigations within Australia. Of those published no determination as to their value or otherwise as a piece of scientific research has been made. As the previous chapter illustrated, researchers interested in determining the extent to whether a radiographic opinion has accuracy equal to a radiologist can now draw upon studies that have increased the collective understanding of the sources of bias. This means that the investigative weakness during the developmental phase for research of measurement of radiographer interpretive capability is now possible. This section critiques the four Australian reports that exist and outlines their positive and negative attributes [208 - 212].

In the Australian literature, five investigations have been found:

- Orames 1996 [208]
- Hall, Jane and Egan 1999 [209]
- Smith and Younger 2002 [210]

- Cook, Oliver and Ramsay 2004 [211]
- Smith, Traise and Cook 2009 [1212]

Three of these papers focus on RDS performance and two on radiographer interpretation. Orames [208] produced the first report in an attempt to show that radiographers could compare favourably with emergency department doctors, through the flagging of abnormality on images requested by those doctors.

An overview of whether the forms of bias identified in radiographer interpretation studies by Brealey and Scally [165] are evident in the Australian work is presented in Table 4.1 below. Although not all the forms of bias recognised by Brealey and co-workers [166 - 168] are apparent, the identifiable forms are demonstrated for easy review by the reader. Consequently it could be argued that, if radiologists had read the outcomes of these studies, then a degree of scepticism would not be inappropriate.

Types of bias detected (other forms may be present but not detected due to reporting approach)	**Orames 1996**	**Hall, Jane and Egan 1999**	**Smith and Younger 2002**	**Cook, Oliver and Ramsay 2004**	**Smith, Traise and Cook 2009**
Referral bias	✓		✓	✓	
Film/Image cohort bias		✓	✓	✓	✓
Spectrum bias					✓
Film/Image selection bias		✓	✓		
Observer cohort bias	✓	✓	✓		
Verification bias	✓	✓	✓	✓	
Indeterminate results		✓	✓	✓	
Arbiter variability					✓
Reference standard review bias	✓				
Arbiter review bias		✓			
Arbiter bias		✓	✓	✓	✓
Arbiter comparator bias	✓	✓	✓	✓	✓
Publication bias	✓	✓	✓	✓	
Total number of bias forms in each study	6	9	9	7	5

Table 4.1
Detected forms of bias in Australian studies as defined by Brealey and Scally [165]

4.2.1 *Orames (1997).*

Orames [208] used a methodological technique that matched methods reported by Renwick [172] (1991) despite the known issues with his approach. Faults included no control over radiographer experience, no radiographer education and acceptance that the radiologist report as a reference standard was always correct whatever the level of experience of this individual. Although assessment of radiographer's performance against radiologists was possible, Orames' work was executed on the relatively small number of 541 cases that generated 736 radiographic studies, divided amongst *'about 20 radiographers'* [208 p53]. Of these radiographers, seven were in their first year of practice. The aim of the study was to compare the relative capability of emergency doctors, the radiographer and the radiologist. However, only 106 cases equating to 136 radiographic study interpretations were made by the emergency doctors that could be followed up thus further limiting this evaluation between them and radiographers/radiologists.

Despite these limitations, Orames went on to show overall levels of accuracy between the radiographers and emergency doctors (89.1%/89.9% respectively) compared with 87% agreement of radiographers with radiologists. She added detail by identifying a 79% accuracy rate with the radiologist interpretation of the chest radiograph, 89.7% agreement on paediatric images and 98% on spinal examinations. In the main, Orames identified a tendency to generate false positive responses which reflected the findings of Renwick's study [166]. Nonetheless, the low red dot interpretation numbers in the study could also have contributed to this reported variation. She accepted that radiographer performance was not as strong as that noted either by Renwick's study [172] or in the 1985 red dot study by Berman et al [169]. She mitigated this by suggesting the reasons for the UK studies would cause the discrepancies. It is not clear how the 'reasons for the UK studies' impacts, as the relationships are not discussed but are mentioned as a way to reduce the potential for ED litigation and to lessen the time radiologists have to spend reporting trauma images.

It appears that the main reason for performing the study was one of team support to the emergency department by radiographers, as Orames reports some of the medical staff working at her department had encountered the UK system and had found it a positive experience. Team support may also explain why so many radiographers interpreting so few images were combined to give accuracies that appeared potentially better than one could be certain about for an individual's performance. Little else is suggested as a gain from implementing the RDS and Orames suggests that the radiologist would not be replaced. This ran contrary to the acknowledgement of the advanced position in terms of activity and reporting by radiographers then apparent in the UK. It would seem that, despite an effort to provide a baseline data set, there was insufficient enthusiasm to push the agenda for radiographer interpretation forwards in Australia. By following a flawed methodology sufficient performance capability could not be demonstrated, thus ensuring the argument for radiographers to provide interpretations alongside radiologists in this field could not be progressed. Furthermore, the decision of the journal to publish the material does not aid the thrust of the argument as publication bias is apparent and should be taken into account. This was possibly prompted by the fact that Orames' work was the first such investigation in Australia and therefore was looked upon favourably by the professional body responsible for publication of the journal this paper featured in [213]. Furthermore, a review of the editorial make up of the journal revealed a single editor with responsibility for acceptance of material. It was only later that an editorial board became the norm, with inclusion to the board reliant on membership of the AIR. This limited the knowledge base of the editorial board and lead to potential furtherance of the biased article selection for publication, if it was perceived that research met with the ideals of the professional body that the journal represented.

4.2.2 *Hall, Jane and Egan (1999).*

Hall, Jane and Egan [209] described how the RDS was being employed in 'outback' Australia. They evaluated performance of all examination modalities on offer at the time to include computed tomography (CT) and ultrasound (US). Three trial periods of approximately one month in length were held in 1992, 1994 and 1997, and included all radiographers. Participant experience ranged between three and 20 plus years and consisted of all but four Australian educated personnel. The aim was to establish whether radiographers could identify normal from abnormal examinations using a red dot flag and provide a provisional diagnosis in the 1997 period. However the way the results were reported in the paper is confusing. Normal/abnormal comparison was made against the single radiologist report produced for the examination and no further radiographer education took place. Three responses of 'normal', 'abnormal' or 'don't know' were collected each time.

Radiographers completed 940 examinations across the study collection periods, which is significantly fewer than the workload figures would suggest are available for interpretation. Potentially over 2100 examinations could be available suggesting image selection bias may be evident unless only a very small proportion of referrals came as plain radiograph referrals. A reported mean of 91.2% accuracy in normal/abnormal and correct provisional written diagnosis of abnormalities in 85% of cases is given for the 1997 trial period. False positive rates gradually fell across the trial periods from 5.9% to 4.4% and 4.1% respectively, though the false negative rate grew to 4.2% in 1997. The authors again discussed the impact that prevalence may have had in decision making between normal and abnormal due to the majority of examinations being referred from the emergency department. Taking this argument forward would not support the increased false negative report in the final study trial of 1997 as, despite recent disagreement between authors, higher prevalence would favour a bias towards false positive interpretations [205, 208].

The authors continued their report by breaking down the results into chest radiographs and all other examinations, indicating 51% (480 cases) of all examinations were requests for the chest. Accuracy for this area was 79% meaning 21% (100 cases) of all chest X-rays seen by radiographers were incorrectly interpreted. Clearly, the reported accuracies indicated by the authors must be incorrect or they chose to highlight the stronger performance in the remaining 49% of cases that generated a 91% mean accuracy. Evidently it would appear there is result reporting bias to support the radiographer background of the authors. Once again, airing flawed results in the professional journal chosen for this report, with no evidence of further review of the article beyond acceptance date, demonstrates publication bias [213]. Though as noted previously an editorial panel had not yet been convened for this journal.

It is probable that the underlying imperative guiding the authors was to suggest a possible solution to the growing delay in plain film image reporting resulting from an increasing radiologist workload. A further advantage of an adoption of the RDS suggested by Hall et al would be an increased job satisfaction. Hall et al further intimated this could be a boon in staff retention in the rural/remote setting of healthcare delivery. Delays in half of the cases seen in the researched department meant reports were given up to one week after the examination with up to 1.5% of examinations having no radiologist report. Based on the workload figures quoted for the study department, this non-reporting rate would equate to 383 studies receiving no radiologist input per annum.

There was recognition by the authors of the need for more education to improve the results. They cited multiple pieces of work performed internationally to illustrate improvements are feasible when education occurs. The authors failed to take account of the potential that not having a fixed staff base could also impact on the performance across the 3 years that data was gathered. Hall et al also attempted to disguise some performance issues by discussing inaccuracy rates amongst radiologists. This discussion is appended to the unreported rate in their hospital to suggest radiographer input is better than that suggested in the study. This infers that the team was looking for ways to account for mixed ability in a relatively low number of examination evaluations, spread across several staff. The case mix used in the study demonstrated varying examination types that were investigated at differing time intervals with no recognition of body part proportionality/injury types that could impact on the study performance. This indicates there was weak control of confounding variables to undermine the validity and reliability of the research.

4.2.3 *Smith and Younger (2002).*

Evaluation of radiographer capability and bridging the divide in terms of weaknesses of the RDS without added commentary, are the foci of the work by Smith and

Younger in 2002 [210]. They devised a system whereby a tick box approach with further commentary by the radiographers could be applied to their emergency department referrals for plain radiographic examinations of the MSK, chest and abdominal regions. It is unclear whether cranio-facial examinations were included however, the tick box listings on the Radiographer Opinion Form (ROF) developed for this investigation does not appear to have categories that would underpin interpretations of the skull and face.

The paper begins with a comparison between studies performed in this arena to demonstrate radiographer accuracy, and where possible sensitivity and specificity against the radiologist opinion. Where data was available, the ED Drs interpretive ability was also compared with the interpretations by the radiologists. Approximately 22,000 examinations are performed through the emergency radiology department used as the study base with 15,500 being plain radiographic studies of areas that match the ROF criteria. The study was performed over a three month period, ostensibly making 3875 examinations potentially available for the research. This assumes a mean monthly value is calculated from workload figures provided for the department involved in the investigation.

There were 34 radiographers on staff of whom 26 agreed to participate. It was reported by the authors that specialist staff e.g. CT radiographers would not work in the emergency setting and thus intimated the participation rate was high; it was not reported how many specialist staff made up for the reduction in participants and if those not participating were the specialist staff. In other words were the participants a true reflection of staff normally participating in this field of work i.e. were there 26/26 participants none of whom were from the specialist staff base? No exclusion criteria on individual participants was set meaning radiographers with 27 years experience down to those recently qualified from their academic programs, and currently on their professional development year, contributed to the research. Academic qualifications possessed by the radiographers included associate diploma (6), diploma (11) and bachelor degrees (9) showing a spread of education and experience amongst participants. Individuals were anonymised using a randomly allocated alphanumeric system known only to the individual. This was delivered to each radiographer in the study through a third party who kept demographic details linked to the codes so that results could be returned to individuals on completion of the study. This research approach received approval from the local research ethics committee to proceed subject to the receipt of informed consent from each participant.

Over a three month timeline, 820 plain radiographic examinations of the MSK system, chest and abdomen from the emergency department were commented upon using the ROF. Completed forms were placed in a sealed box, not to be seen by referring doctors or radiologists so that appropriate comparison could be made at the end of the study. As with previous studies, this would suggest only a very small number, in the order of 33 cases per participant if mean values are taken, were tackled by individual radiographers. Over a three months period this is very low and evidently rostering dependent, as this equates to approximately one examination every three days. No time of day discussion was presented to indicate whether certain points in the day produced a greater number of radiographer opinions. In a three months timeline, public holidays are also a possible criterion to consider that could impact on radiographer involvement in the study. Previous authors have argued there have been delays in radiologist report receipt due to the impact of holidays; there could have been an impact of this nature in this study which is not considered by the authors.

Finally, and most seriously, the authors reported image selection bias by the participants during the generation of the radiographer opinions. This feature was ignored and lack of intervention on the part of the researchers gravely undermines any reporting of results from the study, even if statistical calculations demonstrate positive outcomes. Selection bias may also account for the overall low numbers of completed ROFs from the potential number of examinations that could have been contributed to over the period of data collection.

In analysis of the results, the Kappa statistic of 0.86 for all reports merged together suggested almost perfect agreement according to Landis and Koch [197]. No Kappa statistic range is offered across individuals. Imaging areas showing better performance are revealed namely MSK presentations in comparison with the chest and abdominal examinations that demonstrated lower levels of capability. Paediatric opinions were also less accurate. Education background and inferentially the potential experiential timeline of participants – associate diploma/long clinical experienced; diploma/mid range clinical experience; degree/least clinical experience, did not demonstrate any significant difference in performance. Again selection bias is evident with low numbers of participants in the study being likely to have impacted upon this.

The authors concluded this work by analysing the performance of the ROF and attempted to convey strong performance without having collected data to secure these comments. Selection bias by participants undermines the results, such that the stated inference that the ROF increases the likelihood of an accurate diagnosis being made at an early stage of management must be rejected. The authors also state the ROF gives radiographers a check list against which to evaluate images. This has some value however there was no indication that this information was gathered in a systematic way, so it can only be an assumption on the part of the authors.

Concerns from the participants that were expressed about the medico legal position of their opinions and the added responsibility this brings for radiographers are addressed. However, Dimond's discourse on red dots and radiographer liability [214] was not incorporated into the deliberations by the authors, as they abrogate responsibility by suggesting any opinion by radiographers carries no diagnostic weight. Clearly, as Dimond expands [214], if this position is taken then there is no point in a radiographer contribution. Alternatively participants should be aware they need to match radiologist performance and be prepared for a court of law to direct its judgement against poorly performing interpreters who are not doctors. This is clearly the opposite viewpoint of Smith and Younger when they say in regard to radiographer opinion *'… that responsibility rests with the clinician who has full* *clinical appreciation of the patient's condition.'* [210 p31] The same position could also be argued for the radiologists input to reporting that raises the question of whether a radiologist is required. However, a referral to radiology is also a request for a radiology opinion that may influence the decision making by the referrer even though Morton [98] identified over reliance on imaging was not a sound approach to diagnosis.

The journal that published the article is probably again guilty of publication bias for the reasons previously indicated. This journal represents the professional body that actively supports the pursuit of radiographer role development. The article attempts to positively spin the outcomes by making bold associative statements of the merits of the ROF, despite the deep flaw in data generation. Furthermore, no follow up research was proposed to answer the questions posed by these statements as conveniently they were not raised by the authors.

4.2.4 *Cook, Oliver and Ramsay (2004).*

A more carefully controlled study was performed by this group in 2004 [211]. Two senior radiographers were used as the study sample. One had prior experience in reporting from another country and the other was studying to an advanced level in reporting in Australia. As such a more reliable investigation was performed by controlling some of the variables identified as limitations in other papers in this section. Further education equating to 30 hours of direct teaching with the professor of radiology over a 12 month period was undertaken as part of the investigative approach, though detailed content of this approach is not provided.

The exact numbers of examinations each radiographer interpreted from a total of 540 patients over 10 weeks is not presented. The approach to describing the methodology does not give the impression that each radiographer was tested with the same images; rather the total reported was the sum of all examinations tackled by both radiographers. No images on patients under 14 years were reported by radiographers in an attempt to exclude paediatric variations. Reports by the radiographers were marked using a third party so that an unbiased comparison could be made. Mechanisms of review were put in place with the same professor of radiology providing the education input, reviewing all images where radiographers disagreed with the reporting radiologist or where an equivocal response was obtained. The equivocal responses were removed from the study to create a binary 'yes/no' dataset. Five percent of the reported images assessed by the third party including those believed to be incorrect were reviewed by the radiology professor to act as a marking standard, from a final reporting data set of 527 examinations. Ethics considerations were taken, however this local approach was believed to be an audit of practice and as such did not require full ethical approval.

The radiographers demonstrated (presumably averaged) sensitivity of 98.97%, specificity of 96.49% for an overall accuracy of 98.48%. Two false positive (FP) and six false negative (FN) reports were given, with three FN diagnoses being significant clinically. Insignificant FN mistakes included failure to mention minor degenerative changes and two cases identifying an abnormality initially missed by the radiologist that were seen in the review by the professor of radiology. With this latter point in mind, the decision to evaluate 5% of the images inclusive of the incorrect radiographer reports suggests more examinations should have been re-assessed. Furthermore no rationale was given for the selection of 5% of images as being sufficient to act as a checking mechanism. Positive and negative predictive values of 99.32% and 97.40% respectively, were obtained along with a likelihood ratio of 99.11%. The positive posterior odds, which is the chance that a positive radiographer report is given when a fracture was evident, was 99.32% with a prior odds ratio of 1.32:1. The latter value, when multiplied by the likelihood ratio, gives the positive posterior odds and considers whether the report is correct, rather than the likelihood ratio on its own that demonstrates the radiographer is correct. This gives an effective balance of reporting approaches so that accusations of bias cannot be levelled based on the statistical types used. This supports the arguments communicated earlier in this thesis.

Corroborating statistics, such as the ones highlighted above demonstrate the authors have a grasp of the relationships between the figures generated from the data. Despite this there was no attempt to establish appropriate power in terms of the numbers of examinations that the radiographers should report prior to beginning the study. Scally and Brealey [181] and the work of Naing [182] since, have outlined methods based on Daniel's (1999) calculations to establish confidence intervals and hence sample size for appropriate study power. As such Cook et al could have established the necessary number of reports required to gain 95% confidence to add to this study. With the suggested prevalence calculated (56.93%) from the cases examined, Cook's participants should for a 95% confidence level examined 377 examinations each. Furthermore, although useful statistics supporting the radiographic performance are presented, direct comparison using the Kappa statistic is not shown as discussed by the authors and mentioned in the previous section. Use of the ROC curve was also not attempted [186, 187, 215]. The area under the curve as defined by the ROC and Kappa comparison statistics would have further strengthened the results and removed any doubt generated by the limited image assessment carried out by the radiology professor to support the third party marking.

In addition to this the authors did not consider whether a consensus image test, where examination content is agreed amongst several radiologists, would also be of value. This study appears to have re-reported previous images from the ED and did not follow the method of immediate interpretation by radiographers prior to later verified radiologist reports. Immediate interpretation of examinations performed by radiographers would enable direct contact with the patient, which in itself is not wrong but does have a potentially 'unfair' perspective that the radiologist would not have access to when reporting images later. By following the described approach a reasonable comparison is made between radiographers and radiologists who only have request information available to link to the image and make appropriate interpretations from. Possession of this feature shows this paper has greater strength as it ensures participant comparison is matched to avoid observer cohort bias and clinical review bias.

When discussing the limitations of the work, the authors acknowledged that the study assesses the radiographer reporting of a group of images that includes MSK plain radiographs of the limbs, shoulder girdle and hip. This control is not defined at the beginning of the methodological discussion. The authors also suggest more information about the ability of radiographer performance in given areas of image interpretation is possible such as achieved by Smith and Younger [210] discussed earlier. Finally, there was no control for the radiologist experiential level, which could have impacted on the results, especially as only 5% of images were re-assessed by the professor of radiology.

Literature from sources with good research control is considered at the start of this paper and the statistics generated by this group appear to support a position for workforce change though this is not clearly stated. As such the authors begin to wander further in their discussion than is warranted by the depth of the research and the stated aim of the study. Indeed, the further discussion brings in new information about workflow and extending the radiographer contribution to this pattern of operation. Little is discussed of the education program undertaken, even though experience and external course participation are suggested at the beginning of the paper to be important attributes of the participating radiographers. A comment in the conclusion does, however, call for a controlled program of study and investigations into the impact of such an intervention. Most importantly, further controlled research into radiographer interpretation was suggested if Australia is to keep apace of practice such as that seen in the UK. Although these comments have value, in the sense of well controlled research the points the authors made could have been developed as a result of further investigation as is evident in a systematic literature review. By the time this investigation took place many lessons had been learnt in the UK, and it seems had not been embraced in Australia. On balance however, this study has many attributes that put it in the lead from a perspective of Australian research published in this field to date. It should be noted that by this time an editorial panel now existed within the journal chosen for publication, though it was still curtailed by the need to be a member of the professional body thus limiting the expertise available to advise on research content in this field.

4.2.5 *Smith, Traise and Cook (2009).*

This piece of research attempted to show the impact of a continuing education program on the ability of rural radiographers to interpret a small image test before and after an educational intervention. The education intervention took the form of weekly self guided Microsoft © power point presentations, directed learning and self test case studies. Portable document file (PDF) style readings were e-mailed to participants and teleconferencing sessions were supported by internet web sites.

The test batch used 25 images selected by a radiologist and 16 radiographers participated in the study. Radiographer interpretations were submitted through the ROF developed from previous work by Smith [210], one of this study's authors. In this investigation three levels of response were possible to include; a general opinion of whether an abnormality was present or not; observations of the nature of the abnormality with a list to select from, and a final level with open comments to enable a brief written description of the appearances seen. Three grades of complexity and hence interpretation difficulty was incorporated into the test bank. The lowest level were those cases as defined by the radiologist a new medical graduate would be expected to interpret (3 examples); 17 examples of cases that would be seen in the radiology fellowship examination and 5 cases that a specialist MSK or experienced general radiologist should be able to interpret.

The images in the test bank were all positive for abnormality i.e. no normal or normal variant images with which to evaluate specificity of the interpreters were included. Four months elapsed between the first test, delivery of the educational support and the second test in an effort to prevent memory influences contributing to scores. The scoring system that was adopted varied from other published methods seen to date in that *"To attain an accuracy of 100% a radiographer had to correctly identify and describe most, but not necessarily all of the abnormal radiological signs in all 25 cases."* [212 p3] A target score of 85% was set either, it is inferred, as a pass mark for the education program or alternatively as an indicator of performance that suggests an acceptable accuracy level was achieved. The aim of this grading structure is not clear. Either way, it is stated marking was performed by the same radiologist who set the test.

Improvements in accuracy performance post education intervention of the second and third level cases was demonstrated; strong interpretive performance at the lowest level of images was apparent throughout, however an overall mean radiographer score of 85% accuracy was not achieved. For the more difficult interpretations, a scoring system that could be aligned with the image content and clinical significance was developed.

The fundamental limitation in this study was the decision to establish description capability through the use of a test batch of images with only abnormal images in it, even though the radiographers did not know if this was the case. A truer evaluation of the performance of the radiographers could have been gleaned had normal or normal variant images been included in the test. The limited number of images also reduces the power of the test however it does provide information about the skills and knowledge base of radiographers, who frequently provide verbal support to referring medical staff due to a lack of radiologist availability.

Further limitations of the study are discussed by the authors including the belief that use of a limited number of radiographs more than once is problematic. This is not the case and was discussed as appropriate in the work of Brealey and his colleagues [165, 166], especially when no feedback is given to participants between tests. Ryan et al recently confirmed the value of this approach in their study of chest radiographs and intra vascular line placements [216]. Due to the sample size adopted it may be suggested that the radiographer cohort used for this study is small. This is refuted by Obuchowski who advocates that more than 10 observers from several centres constitutes an appropriate base for an advanced or *'Phase III'* [217 p868] study, which is evidently met by this investigation.

The authors accepted the statistical limitations of the study due to the decision to collect data in the way described, however the notion that ROC curves can be calculated without a major change in the data generation method is mistaken. An ROC curve plots sensitivity/1-specificity; however with this data set specificity cannot be calculated. Thus for given cut off points of performance on a graph using the labels sensitivity and 1- specificity for the Y/X axes respectively a curve is plotted, which clearly is not possible. As indicated in section 3.5.3 Eng [189] indicates application of a fitted ROC curve has a closer clinical performance value. Here the ROC curve accounts for degrees of uncertainty by using confidence levels allocated by the image observer to account for potential decision ambiguity. If it is believed that a subjective allocation by a third party makes it possible to generate a specificity score, such as that suggested in the scoring mechanism in this study, then any results produced would be highly dubious.

Finally, and disappointingly, it was reported by the authors that the radiologist involved in the study relinquished participation in the investigation part way through due to the negative perceptions of his colleagues. This action appears to confirm the the effect of medical dominance upon radiographer role advancement as discussed in part one. A question does arise from this decision however; did the radiologist mark all the results for both tests and if not is the reader sure the ‘model answers’ he provided were correctly applied by an alternative arbiter? Either way there must be further doubt about the scores attained by individual participants especially if the marker/arbiter differed at a point part way through the investigation.

4.3 Conclusions

A limited number of investigations have been published in Australia across a period of 12 years. This suggests significant difficulties have been encountered in achieving any valid research to indicate whether radiographers can contribute to image interpretation. Furthermore it is difficult to infer whether their opinion is perceived worthwhile to the treatment process. In addition to this, there have been significant weaknesses evident in those studies that have been completed and reported, indicative of a failure to perform research systematically and account for sources of bias. Researchers in Australia should learn from the ideas of others by wide reading and search for appropriate help to enable strong research approaches that may withstand robust scrutiny within the scientific paradigm. However inspection is also driven by political expediency and a blinkered attitude towards healthcare delivery, the so called 'silo' mentality, can lead to bias in evaluation of research as it fits with a political need. In other words make the research results fit the problem to generate an acceptable solution. Finally, authors should seek publication media where bias cannot be levelled through the avenue chosen to bring the message to others. However, gaining access to journals reviewed by the medical profession in the climate suggested above is not an easy prospect. Poor selection of appropriate media can effectively damage the message being sent or limit its audience to those with a biased interest; just as much as weak research techniques impair the credibility of the researcher.

The next chapter describes the method employed for the research performed in this thesis. As the discussion will demonstrate, attention has been given to the many and varied issues critically discussed in the preceding chapter and especially in relation to bias. The chapter will detail those aspects where careful consideration has been necessary to avoid weaknesses becoming a major component of the research. This sets the scene for the discussion to explain how successful these approaches have been in achieving a balanced outcome to the investigation and whether the results support or refute the aims of the study.

In common with other developed nations, Australia's health workforce is under tremendous pressure and must undergo significant transformation to meet the rapidly rising demands for healthcare.

For Australia to continue to have a high quality healthcare system that is sutainable and affordable, we need to look at how the health workforce can provide health services differently.

Statement on the home page of Health Workforce Australia website announcing its closure in 2014

https://www.hwa.gov.au/ accessed May 2015

Chapter 5 Best practice methodological design to demonstrate radiographers meet the interpretive standard within the diagnostic process for MSK trauma.

5.1 Study method ethics and investigation calendar.

5.1.1 Ethics approval.

Low risk ethics approval was sought and granted by the Monash University Standing Committee for Ethical Research in Humans and allocated with the identifier CHF11/0213 2011000077. This research involved the issuing of an invitation to final year medical students and radiographers with 2 years or more experience working in a radiology department with ED provision. As materials were supplied by the University there was no need to seek multicentre ethics approval.

5.1.2 Investigation calendar.

The project was performed using the approach detailed in the Gant chart (table 5.1 over) over. Initial work prior to confirmation of candidature and final ethical clearance included the scanning of images that were randomly selected from the clinical archive from between December 2000 and June 2003. These were re-reported by radiologists in preparation for the image test bank generation. Recruitment of radiographer participants could not take place until ethics clearance had been obtained, which occurred at the beginning of February 2011. An amendment to the initial ethics clearance was submitted and confirmed in August 2012 to enable recruitment of final year medical students due to difficulties experienced in recruiting first year intern doctors. This new participant group was used to establish if nearly qualified doctors, compared against the radiographers already tested, have differing abilities to interpret MSK trauma radiographs. Using

Year	Component of study	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
2009	Application for PhD Study	■											
	Literature review reading		■	■	■	■			■	■	■	■	
	Archived image selection		■	■									
	Image scanning			■	■	■	■	■	■				
	Radiologist re-reporting												■
	Draft writing					■	■				■	■	
2010	Radiologist re-reporting	■	■		■				■	■			
	Image test bank selection and test created									■	■		
	Literature review reading	■		■				■					
	Pilot work with Queensland		■	■	■	■				■			
	Ethics development & application											■	■
	Candidature confirmation preparation												■
	Draft writing		■	■									
2011	Candidature confirmation presentation	■											
	Ethics approval		■										
	Pilot work with Queensland	■				■							
	MRPBV approached and radiographers recruited			■									
	Education sessions constructed		■	■									
	1st image test, survey and education sessions delivered				■	■	■						
	2nd image test and survey to radiographers								■	■			
	Radiographer image tests result collation and feedback						■	■		■	■	■	
	Draft writing											■	■
2012	Ethics clearance for medical student recruitment								■				
	Queensland pilot paper 1 published								■				
	1st group of medical students recruited									■			
	1st medical students image test and survey										■	■	
	Draft writing		■	■	■	■		■		■			■
2013	Feedback to 1st medical student group	■											
	Queensland pilot paper 2 published		■										
	2nd group of medical students recruited							■					
	2nd medical students image test and survey								■	■			
	Feedback to 2nd medical student group											■	
	Commentary submission to IJNS re- ENP methodology											■	■
	Draft writing	■	■	■	■				■	■	■	■	
2014- May 2015	Commentary to IJNS re- ENP methodology published	■											
	Draft writing to submission	■	■	■	■	■	■	■	■	■	■ End May 2015	■	■

Table 5.1 Gant chart demonstrating points of the investigation and thesis generation.

this approach the ability of radiographer interpretation is measured against a medical education baseline.

5.2 Development of the image test bank.

5.2.1 *Test size and content development.*

Between December 2000 and June 2003 a representative, retrospective sample of plain radiographic images of MSK trauma referrals from the ED with radiologists reports were collected from the archive of a tertiary referral hospital in Melbourne. These dates were chosen to ensure several periods of similar annual referral activity were searched for image examples. The date spread also represented referral variation that may be apparent due to weather or likely activities of the patients attending the ED. Court – Brown and Caesar [218] argued that fracture incidence values change rapidly and many variations have been documented since Buhr and Cooke [219] first described fracture patterns in the UK in 1959. Several authors have contributed to the discussion since, often with contradictory findings [220 - 222]. A full analysis of fracture patterns is currently described in Bucholz et al's text [223] where there is comparison between several studies that culminates in supporting the position that the Court-Brown and Caesar [218] methodology produces the most reliable results. As such the image sample selection enabled the construction of an image interpretation test with its make up being dictated by the proportions of abnormalities seen within a population.

Court-Brown and Caesar [218] identify two key incidence bands in the male population; during the twenties and thirties years of age where fracture rates are seen to range between 14 to 22/1000 population/year respectively. The fracture incidence then rises in men from the mid seventies age onward to approximately 22/1000/year. These are identified to be linked to age related osteoporotic skeletal change. Females by comparison show low fracture incidences until the mid fifties age group after which the incidence rises from 8/1000/year to 40/1000/year by their nineties. This latter rate is strongly influenced by the impact of osteoporotic skeletal change.

A library of 435 patients containing 650 examinations was identified by randomly selecting ED referred studies from the radiology archive. These cases were re-reported by three consultant radiologists so that four radiologists had passed comment on the images. The initial radiologist could not be guaranteed to be at consultant level however these reports were verified by a consultant before issue from the radiology department. Using the average injury incidence of 14.2/10,000/year described by Bucholz et al [223], a period prevalence of injury of 16.13% was calculated (equation 5.1) as follows:

$$\text{Prevalence} = \frac{\text{Incidence}}{\text{Population}} \times 100$$

$$= \frac{14.2/10000/\text{year}}{880000} \times 100$$

$$= \frac{14.2}{88} \times 100$$

$$= \mathbf{16.13\%}$$

Equation 5.1 Calculating the period prevalence for this study

The number of images required for test generation was calculated with the following formula [165] (equation 5.2):

$$n = \frac{Z^2 P(1-P)}{d^2}$$

Z = constant for confidence level
= 1.96 for 95% Confidence interval

d = precision = 5% = 0.05

P=prevalence presented as decimal of 1

***n* = 208.8**

Equation 5.2 Calculation of images required for the test with 95% confidence and 0.05 precision [182]

Based on calculations from Daniel cited by Naing [182] using the calculated period prevalence of injury in equation 5.1, an image description test was created. The test was constructed so that each body area identified by Bucholz et al [223] was proportionately represented. Appendicular and axial skeleton plus paediatric presentations for radiography of MSK trauma used for patient management made up the initial library of images. Two hundred and nine images were finally selected to account for conjoint examinations amongst case files with 61 being abnormal and 148 normal. This represent 16.13% injury prevalence from the body areas identified by Bucholz et al [223] or 29.2% of images consensually agreed abnormal. In this way whole patient presentations were still available for selection i.e. examinations were not removed from a case, and body areas as defined [223] were correctly represented. No-one to date has described an image test bank generation approach that follows the principles described. If these principles are not followed then the research can be questioned with respect to the impact of abnormality prevalence. These points are further discussed in section 8.1.1 p175.

The 650 examinations created sufficient redundancy in the image library to enable random selection of appropriate images that were representative of injuries to the range of body areas and age groups as discussed by Bucholz et al [223]. Consensus was accepted when three out of four of the radiologists making the report comments agreed in terms of image content. The size of the initial library and level of redundancy ensured random choice of body area plus adult or paediatric representation was possible. Where there was a lack of consensus between radiologists' reports an alternative examination of that type could be included, as a sufficient range was available to choose another example from. Figure 5.1 p87 shows the flowchart that was developed to explain the method used to create the image test.

The images for the test were taken randomly from batches of radiographs from that body area as adults or paediatric examples as noted by Caesar and Court-Brown [218,] and Bucholz et al [223]. For example, one batch of images, such as the ankle area, was allocated to an abnormal decision and a second batch as normal decision by the radiologist consensus method as discussed. In recognising that 209 examinations made up the test, then each body area had an expected total number of that body area image divided into proportions of normal and abnormal. Each combined radiologist report for an examination in a batch was randomly allotted a number. Every 3rd case was chosen until sufficient normal and abnormal consensually reported images were selected for the test from that body area to avoid radiograph

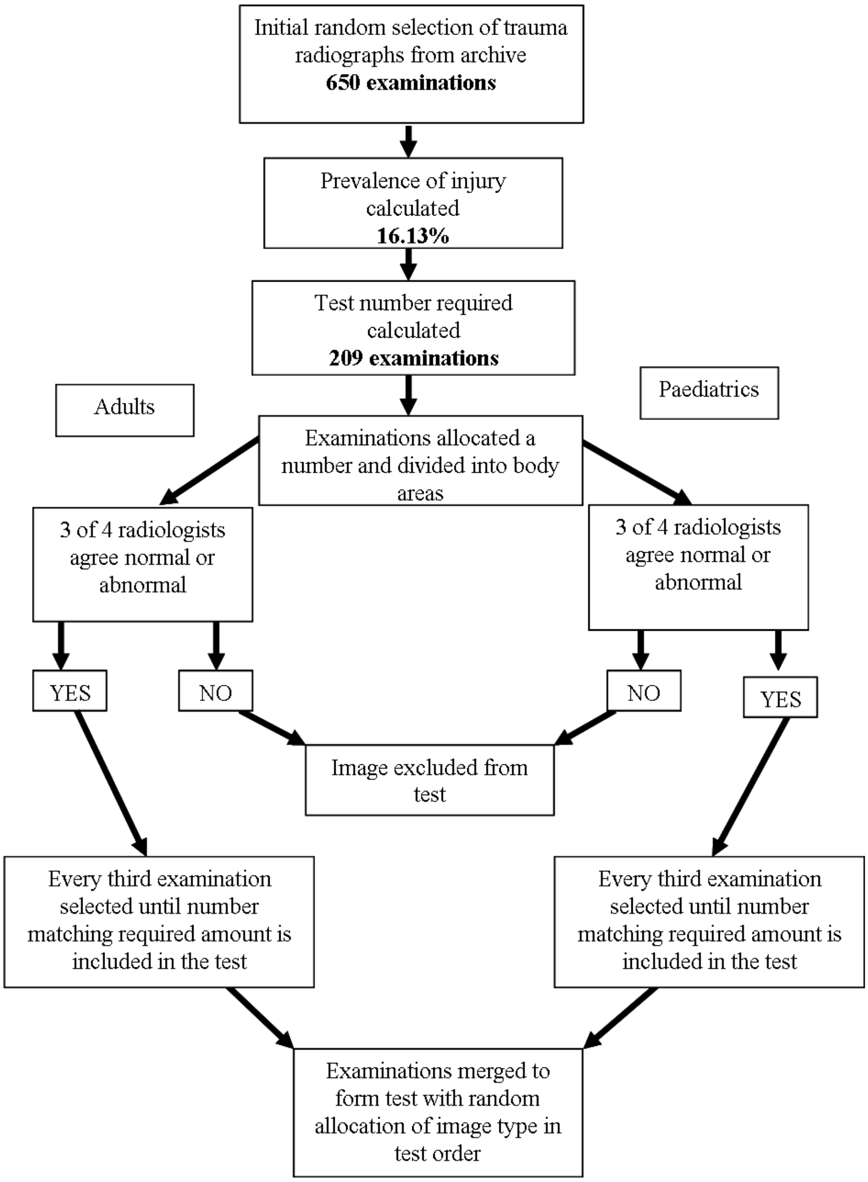

Figure 5.1 – Image test generation flowchart

selection bias. The image test order was representative of a typical ED referral background where attendance would have been random in nature. This meant that the test format did not merely present, for example, all ankle examinations then all wrists, but randomly presented radiographs from differing body areas. As such this represented the typical pattern of work noted in an ED. The image test is included on the CD ROM attached to this thesis.

5.2.2 *Image digitisation and consensus report creation.*

The radiologists invited to re-report the radiographs did so between December 2009 and August 2010. Each radiologist had an interest in MSK radiology and held either the fellowship of the RANZCR or the RCR. The radiologists were also from imaging departments similar in nature to those where the radiographer participants were invited to join the study i.e. have an ED department but not a specialist trauma centre and also delivered a service to children.

The radiographs that were randomly selected from the image archive were in laser film format. These were re-scanned on an Epson Perfection V700 Photo© digital scanner at 600 dots per inch (dpi) using transmitted light and saved as minimally compressed jpeg file format using Adobe© Photoshop Elements 6 software. This was done to minimise a moiré sampling artefact that could be generated on screen due to the scanning pattern of the computer monitor and excessive magnification when saved as tagged image file format (.tif file). Excessive magnification also meant that beyond a certain resolution power the actual laser light impaction points were visible indicating that the scanning level was beyond the initial resolution capability of the laser printer that produced the film based image.

The images for test in this study were provided to the re-reporting radiologists with a history available supplied on a worksheet containing the same tick box components as those given later to the radiographer and medical student participants (figure 5.2 p89). The free hand commentary was later added by the researcher from a dictated report. The radiological request was anonymised with respect to patient name, hospital/radiology service identifying number and date of birth. An age and gender was supplied so that any chance of identification is minimised but these factors relative to image findings is maintained, as image appearances may be typical of a given patient age group. Verbal comments, recorded on a Sony© ICD-BX700 digital voice recorder, were transcribed by the researcher who has appropriate medical terminology knowledge and context understanding. This data was entered onto the matching worksheet and into a database to enable comparison between radiologists with respect to report content. The radiologists were blinded to each others reports

Male

28yrs

Hyperextension injury to thumb following fall onto outstretched hand. No ASB tenderness

Confidence in decision Case 1 (please mark 1 box per area)					
Area	Definitely Normal	Probably Normal	Unsure – further investigation advised	Probably Abnormal	Definitely Abnormal
Thumb					
Hand					

Further imaging required (please mark appropriate modality(ies) for each area if necessary)					
Area	Further radiography views	Computed Tomography	Ultrasound	Magnetic Resonance Imaging	Nuclear Medicine
Thumb					
Hand					

Figure 5.2 The radiologist re-reporting worksheet

and the initial report to prevent inadvertent introduction of biases such as verification bias, observer review bias, reference standard review bias and observer bias. No further images were available to the radiologists so that co-image and co-image comparator biases could feature in the study.

The newly transcribed radiologist reports were reviewed to ascertain whether a reported image could be included or rejected based on a pre-defined acceptable level of agreement between the radiologists. Where consensus could not be made by three out of the four radiologists the image was rejected from the test bank as unsatisfactory for inclusion. The re-reporting radiologist was asked to include in his/her report, considerations of the need for further imaging, whether incidental pathology is present and if that pathology has any bearing on the patient management. Each image thus possessed a consensus report that has key elements that any observer would be expected to include in the future reporting test. This information contributes to localisation and characterisation aspects of the participant response so that the researcher was certain that correct recognition is made of the abnormality and where it is perceived to be. This allows a yes/no binary response to be applied so that an ROC curve can be plotted (see discussion section 3.5.3 p55). As indicated above, significantly larger numbers of images than those finally employed in the test were re-reported to account for rejection of reports when consensus could not be achieved and to ensure random allocation to the test was possible.

5.2.3 *Image viewing.*

Use of the jpeg file format allowed easy interaction with Microsoft© Picture Manager computer software. This software was chosen so images could be viewed on a non-radiologist or high definition monitor. This would be similar to the monitor type available in a clinical department at a non-reporting viewing console, typical of that used by radiographers or remote viewers in image viewing stations outside radiology. Instructions of how to use 'Picture Manager' to view the images was provided to participants in a Microsoft© Power Point presentation and a printed file version (see *appendix 1).* Changes to magnification and brightness/contrast are possible using 'Picture Manager' with the software usually available within a standard Microsoft© Office package. This software was also chosen to enable viewing at home on a standard 1.3k x 1k monitor, so that participants can interact with the material as a professional development program. Spigos et al [224] demonstrated that use of a monitor of this resolution did not present significant issues in terms of image viewing potential compared with a high resolution, radiologists reporting monitor. Monitors available on home computers closely align the findings of Spigos et al and match the capabilities defined by the RCR in their guide to diagnostic display systems for Picture Archiving and Communication Systems (PACS) [225] where they indicate that:

> *'…at a normal viewing distance (60cm) normal human viewing performance is well matched to a screen with 0.25mm pixels (pixel pitch). This is equivalent to a native screen resolution of 1280 x 1024 (≈1.3 MP) on a 42cm (17") display…'* [225 p4].

With Microsoft© Picture Manager, radiograph magnification is possible to a level that would enable resolution of subtle lesions. Radiologists reported on images using both monitor formats i.e. clinical reporting or home based computer system, and did not report perceptions that the lower resolution system was an issue. One comment was received though whereby mouse control of window/level/magnification/image rotate was harder to achieve than at a PACS workstation so could slow the viewing process compared with a clinical workstation. To offer PACS capability on all participants' home computers would however require a Digital Imaging and Communication in Medicine (DICOM) file reader that would necessitate more specialised software not available on the standard personal computer.

5.2.4 *Radiographer worksheets.*

Worksheets were generated (figure 5.3 over) to make it possible to establish the level of confidence of an interpretation such that ROC curves can be plotted from the data produced taking into account the ideas of Eng [189]. Participants were asked to state:

- whether an abnormality was present or not;
- if present the likely form from a range of tick box options;
- suggest if further imaging is required to confirm the problem or further evaluate;
- indicate the level of confidence as a scalar response between 1 - definitely normal and 6 - definitely abnormal in the decision being made, using a tick box approach.

So that in combination cross checking was quickly achievable and enabled use of the open format comment section for deeper analysis of responses. This component allowed the researcher to mark the image responses with further understanding about the choice of tick box response that was made. Use of this approach also allowed the researcher to allocate a positive or negative impression when an examination, believed to be equivocal or closely equivocal, should be perceived positive or negative for abnormality. As a result correct positive or negative allocation was enabled to ensure correct ROC curve generation was achieved.

Worksheet

CASE 1			DATE Performed
Your participant code number	**Patient gender** **Male**	**Patient age.** **28yrs**	**Attendance history** Hyperextension injury to thumb following fall onto outstretched hand. No ASB tenderness

Normal or abnormal? Indicate all boxes that apply to the area

Area	No Abnormality Detected		Fracture	Soft tissue sign of fracture	Dislocation	Soft tissue injury only	Foreign body
Thumb							
Hand							

Further imaging required (please mark modality boxes you deem necessary)

Area	Further radiography views	Computed Tomography	Ultrasound	MRI	Nuclear Medicine
Thumb					
Hand					

Confidence in decision
(please mark 1 box per area)

Area	Definitely Normal	Probably Normal	Unsure Normal	Unsure Abnormal	Probably Abnormal	Definitely Abnormal
Thumb						
Hand						

Describe location and appearances (box extends as you type).

Figure 5.3 The Radiographer and Medical Student Worksheet

5.2.5 *Selecting the radiographers to participate*

Experienced radiographers working in the State of Victoria who were two years or more post qualified were invited to participate in this study. Addresses, obtained with permission from the public component of the now disestablished Medical Radiation Practitioners Board of Victoria (MRPBV) website [226], for radiographers registered on the general portion of the register, were contacted after ethics approval was obtained. Ideally 20 but more than 10 radiographers who have been qualified and on the register for at least two years were sought to meet the phase III level study requirement [217]. Potential participants were initially asked if they participated in ED radiography of adults and children as a regular component to their work activity and if they were interested in joining the project. This was advertised through a recruitment poster (*appendix 2*), in which participants were asked to contact a third party administrator who would confirm that each applicant met the inclusion criteria. This was achieved by using a recruitment survey (*appendix 3*). A total of 439 invitation posters were sent to individual radiographers across all service providers identified as likely to be working with the defined patient type. This was facilitated through the MRPBV mailing list that identified the place of work to approach participants. Individuals were given further information verbally beyond that on the poster when they contacted the administrator. Each contact was also sent more in depth information about the project and contributions expected from each participant. As attendance for a study period may not have been possible for some at the suggested delivery dates, this excluded them from selection. Further information about participant backgrounds and a contact method for the study administrator to use were also obtained via this initial contact. This approach enabled randomisation of participant selection and ensured anonymity from the image researcher; observer selection bias was also avoided by adopting this method and by ensuring blinding of participants to the researcher so that arbiter bias was also circumvented.

5.3 Testing the radiographers.

5.3.1 *Sample and test format.*

Twenty four radiographers who self identified using the above criteria confirmed they were able and wished to participate. They completed and returned the consent form that was accompanied by an information sheet that detailed the investigation approach (*appendix 4*). Each participant completed a questionnaire to establish their concerns and confidence in performing a descriptive role for the emergency department (*appendix 5*) prior to receiving the education via the program detailed in box 5.1 p94, and included as material on the enclosed CD ROM with the thesis.

Two sessions of education were provided to maximise participant inclusion as this project relied upon donation of personal time by individuals, who also had to consider on-call commitments as clinical practitioners. Images were sent on a Universal Serial Bus (USB) memory stick to each participant who was allocated a number by the third party administrator so anonymity and blinding was assured.

The education package

Book contents

Part 1 Radiographic appearance of skeletal disease
Introduction
Soft tissues
Bones
Joints

Part 2 Plain radiograph interpretation in skeletal trauma
The upper limb
The lower limb
The spine
The cranio-facial skeleton

Workshop presentations with image description sessions in order of delivery over the studyweekend and copied to CD ROM for further reading after attendance

Power point presentations
Mechanisms of injury
The ABCs system of musculoskeletal interpretation
Upper limb ABCs + image viewing/discussion workshop
Lower limb ABCs + image viewing/discussion workshop
Spine and pelvis injury imaging + image viewing/discussion workshop
Cranio-facial interpretation pointers + image viewing/discussion workshop
Guidelines for describing/reporting

Further presentations linked to activities in the book
Bone infection radiological patterns and further imaging
Bone tumour radiological patterns
Introduction to the arthritic radiological patterns
Stress fracture radiological patterns and further imaging
Paediatric trauma radiological patterns
Justification principles for imaging

Reading to support book
McKinnis L.N. (2010) Chapter 2 Radiological evaluation, search patterns and diagnosis pp 39 – 51 in *Fundamentals of Musculo-skeletal Imaging* F.A. Davis, Philadelphia USA.

Box 5.1 The education package

A period of one month was allocated from receipt of images to attendance at the education session to describe the image content using the worksheet. As indicated for the radiologists, the worksheet contained the patient age, gender and history as well as a case number. The participating radiographers were asked to mark the tick box sections for presence or absence of abnormality, a likely form e.g. fracture, dislocation and to indicate their level of confidence in their description again through tick boxes. In addition, radiographers were asked to indicate where they believed further imaging was necessary using another tick box component of the worksheet. Finally where a description of the abnormality or area of concern was necessary, participants were asked to add details in the comments section. The pre and post education intervention tests used the same response form that enabled comparison between tests to be possible and facilitated coding for statistical analysis.

5.3.2 *First radiographer test.*

No further education was provided at this point; the performance of radiographers was dependent purely on prior experience and therefore acted as a control. Participants were asked about any professional development they had participated in prior to the invitation to join the study to establish if they had previous knowledge of image interpretation. This allowed their performance to be evaluated accordingly. A questionnaire that established the radiographers' opinions about the project was completed before description of the images was attempted (*appendix 5*).

As indicated above the worksheet (figure 5.3 p92) has several data collection formats in it. An open comments section was also provided to allow full description of the appearances so tick box selection could be confirmed by cross referencing with the narrative provided by the radiographer.

All participants described image content for the test received, when there was a perceived abnormality or if there was uncertainty of radiograph content. Each description was used to elicit correct identification of any trauma based lesion, whether further images or imaging types are required and if associated pathologies are present on the images. If other lesions were noted on the images then radiographers were assessed through their free hand description content whether they believed these lesions would impact on patient management or not and as such affect the yes/no response i.e. there was no contradiction between the tick box and written impression that would change patient management. In this instance patient management includes suggestion of whether further imaging such as alternative modalities or further projection radiography is required. Confidence in the description provided by the radiographer was also gathered and this contributed to the creation of ROC calculations using Eng's [189] ROCFIT calculator, established as a measurement principle in section 3.5.3 p54, and available on the internet at http://www.rad.jhmi.edu/jeng/javarad/roc/JROCFIT.html .

Use of the descriptive section of the worksheet enabled localisation and characterisation comparison between radiographers' descriptions and the radiologists, and to affirm the tick box selections that were made. The tick box section of the form enabled comparison of report content in a binary sense thus enabling allocation of a normal or abnormal label to generate TN, TP, FN and FP responses. This facilitated the generation of sensitivity, specificity and accuracy levels for each participating individual from either background. The availability of TN, TP, FN and FP values also allows generation of a wider range of comparator statistics detailed below in the data analysis section, 5.6 p100.

5.3.3 *Education package.*

After completion of a first test sequence, radiographers attended for an education package to be delivered. Content is detailed in Box 5.1 p94, and available for viewing via the CD ROM supplied with the thesis. The education package was delivered to the radiographers to support their interpretation and decision making of images and to underpin style development for the writing of descriptions to include in the second test. The education program supporting the radiographers participating in this research was initially developed through clinical experience gained by the researcher as a reporting radiographer in the UK between 1995 and 1997 and published in McConnell and Webster's 2000 paper [64]. This experience culminated in the co-authorship of the book 'Interpreting Trauma Radiographs' published by Blackwell Science in 2005 [227]. The study as described used a combined distance education and short attendance package based upon materials previously developed at postgraduate level in Australia and the UK and delivered in pilot format in Queensland in 2010 [25]. The education package was delivered by the researcher who had over 14 years of teaching experience at the time of delivery and has taught similar sessions internationally. A weekend delivery period was employed with other materials available for study by distance methods supplied.

The education program was a specially prepared amalgamation of material to serve the needs of the research project. Its length and lack of assessment in a formal sense, though the image viewing test could be construed as a form of assessment, meant that the material could not replace any named award of postgraduate education offered by Universities within Australia, nor was it intended to. The participants who contributed to this study did so in a professional development sense.

5.3.4 *Second radiographer test.*

Following completion of the course, the radiographer participants were requested to re-sit the initial test using the same format as employed before the education input. The second test took place eight weeks post attendance at the education session. The test was delivered by distance methods through the USB memory stick method described previously. The timescale to completing the test reflected a time component required for radiographers to incorporate their new knowledge into their work practices so change measurement recognises the time taken for learning to take place. This time span also reduced the recall potential of cases. As no feedback was provided to participants until both tests had been taken, participants remained blind to image content thus avoiding potential cohort comparator bias. A second questionnaire was made available on the same memory stick for participants to complete to establish if the radiographers' attitudes had changed as a result of contribution in the research. This questionnaire also asked the radiographers about any anecdotal aspects linked to this project such that further qualitative components could be included in the final reckoning of the study.

5.4 Testing the final year medical students.

The final year medical students were invited to participate through poster advertisement via their Moodle © website, the internet Virtual Learning Environment (VLE) platform used for faculty teaching and communication at the university delivering the MBBS degree programme. Due to difficulties with enrolling participants, two methods of returning responses were adopted in recruitment exercises held in the latter halves of 2012 and 2013. In 2012 the medical students followed a process similar to the radiographers using USB memory sticks to return their data. In 2013 the third party administrator was able to collect responses from the Moodle website and pass these on for analysis after applying an anonymity code.

Twenty four final year medical students self identified they were prepared to participate in the study using the above criteria and confirmed they were able and wished to participate. The participants completed and returned the consent form that was accompanied by an information sheet that detailed the investigation approach (*appendices 6 and 7*). Each participant was asked to complete a short questionnaire detailed in *appendix 8* prior to receiving the same test that was supplied to the radiographers. Instructions about how to interact with the test was supplied in the same format as the radiographers. Response sheets, also in the same format as the radiographer's, were made available. The approaches described for the radiographers were applied by the researcher to the medical student responses. This enabled evaluation and feedback about performance given as an individual mark to each participant and relative to how the whole recruitment group from that year performed. This enabled a self applied gauge of ability was possible for each individual. Students were allowed to retain the images on the USB so all the radiologist reports to the images that were also provided could be aligned enabling full feedback to occur.

5.5 Participant Surveys

Questionnaires were also administered to each participant group so that the study followed a mixed methods approach using quantitative and qualitative techniques [228]. The radiographers received a survey for them to complete before they began the first image test and after completion of the second test. These were returned with the responses on the USB memory stick for analysis. The medical students received a single survey which was completed and returned either on a USB memory stick or via the VLE. Open and closed ended response questions were developed to gather further and in depth information using a mixture of tick box replies and by allowing space for participants to type into a box where an open response was requested. This also allowed clarity to be obtained where there might be ambiguity and to act as a cross check with the closed question responses [229]. Questions were piloted three times using a radiographer lecturer to establish whether changes needed to be made to the survey content or layout [228, 229]. Finalised surveys were included in the ethics application. Questions that may be linked with respect to likely content were deliberately separated in an attempt to avoid the participant identifying any kind of pattern. This was done to avoid generating responses that were not true reflections of respondent understanding, but arose due to pattern recognition generating an expected response within the survey [230].

Open ended questions were analysed across the participant groups to establish common themes thus enabling thematic analysis [228, 229]. These are detailed in chapter 7 and summarised to show key themes that may have changed or become more detailed through the types of questions used.

5.5.1 Radiographer questionnaires

Radiographers were asked questions about why they decided to participate, their confidence levels in image interpretation before and after the tests. Radiographers were also asked about whether they believed an input by radiographer interpreting would enhance the patient pathway and what kind of educational support would be required to enable them to perform this role. The post 2nd image test survey asked if the radiographers believed anything had changed with respect to confidence, areas they could interpret and if they now believed that they could always perform as well as the radiologist. They were also asked again if their attitudes towards describing while the patient was still present in the department had changed, whether new knowledge had impacted on their radiography practice and to provide examples of when their input was accepted or ignored and the consequences of this. These responses were cross checked with the medical student responses to establish aspects of parity of difference of opinion regarding potential radiographer interpretation.

5.5.2 Medical student questionnaire

Medical students were also questioned about their reasons for participating in the study, if they had any particular concerns regarding their interpretation ability in given areas of plain radiography and whether they received enough image interpretation education earlier in their undergraduate careers. They were also questioned as to whether their experience to date enabled them to interpret images at a level similar to the radiologist. Medical students were asked about their knowledge with respect to the expected scope of practice of radiographers both nationally and internationally. They were also asked if they believed radiographers could contribute positively to the patient pathway through interpreting with respect to enhancing their own diagnoses or improving imaging modality choices by advising on their use.

5.6 Data storage

All data was stored on password protected computing equipment and only anonymised results are presented as required in the ethics regulations of Monash University [231]. Only the researcher and main supervisor had access to the data, which meets the requirements of ethics approval by way of storage, or retention for future investigation that is possible from this data set. As part of consent, individual participants had the right to view and discuss their performance compared with the group as a whole. The summarised whole group report provided information to individual participants as mean, median, range values with appropriate statistical results presented as detailed in the data analysis section.

5.7 Data analysis

Participant performance was assessed by evaluating responses to establish the levels of TN, TP, FN and FP. From these figures the statistics detailed below were calculated. The results from the study were expected to demonstrate a non-parametric nature. To enable further comparison with the radiologists several other statistics were calculated based on the background review in the earlier sections of this thesis. The statistics that were calculated included:

- Sensitivity, specificity and accuracy (raw and percent values) [183]
- Positive and negative predictive values [184]
- Likelihood ratios (relative positive and negative values) [185]
- Post test odds and post test probability [186]
- Kappa
  - Cohen's weighted [193]
  - Byrt et al's prevalence and bias adjusted weighted kappa value (BPK) [196]
  - Feinstein and Cichetti's indices of positive and negative agreement [194, 195]
  - Gwets AC-1 statistic (adjusted chance for marginal values) [198]
- Receiver operator curves with AUC in empirical and fitted forms [189]

The various forms of kappa statistic with checking calculations and ROC AUC comparisons were employed. This ensures the fullest performance understanding is possible due to the variations in validity of these statistical methods identified earlier. The outcomes of these calculations have been considered and will be discussed in later sections of the thesis.

It was envisaged that following the education package, participating radiographers would demonstrate higher equivalence with the radiologist report than that seen prior to training. As such the spread of results between the two groups was expected to be skewed, therefore indicating the Chi Squared test had less value as this test is essentially designed to also demonstrate the degree of normality of spread between two groups [71]. With this in mind the Mann Whitney U statistical test for independent non-normally spread results was employed to establish significance. This test has been used in before and after trials in other studies [64, 71] and is suggested by Marshall and Jonker [232] as the appropriate test to use and confirmed in consultation with a statistician.

Where multiple lesions may be evident in the image and in using the free text approach to indicate this, the response was considered from the perspective that appropriate aspects in the image were discussed so that patient management would be correctly initiated i.e. is there presence or absence of injury. The descriptive section of the worksheet enabled allocation of an appropriate response for ROC generation and reinforced the decision confidence level that had been selected by the participant when completing that part of the worksheet. The Weighted Kappa statistic [193] is used as a comparator between individual participants and radiologists, and between participant groups, along with further informative statistics such as PPV, NPV and the likelihood ratio (LR) [183 - 185]. The positive posterior odds ratio [185] is used to calculate the degree of positivity a description may have when provided by the participant. For reasons discussed earlier, calculations of the positive and negative proportion indices [194, 195], the prevalence and bias adjusted kappa statistic [196] and the AC1 statistic [200] are performed to clarify the results discussion.

The responses from the questionnaires to radiographers and final year medical students were analysed to establish whether any qualitative themes from the participants were present. These themes were reported back as being evident before and after the education intervention for radiographers and compared with the single medical student survey responses. It was anticipated that any concerns regarding performance of image interpretation may be expressed by radiographers and medical students. The questionnaires aimed to establish what these concerns may be and if there were any common themes between the two participant groups such as areas of difficulty in interpretation for example paediatric presentations of given regions of the anatomy.

PART 3

QUANTITATIVE AND QUALITATIVE RESULTS

'A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it. '

Max Planck 1858 – 1947
Scientific Autobiography and Other
Papers Translated by F. Gaynor (New York, 1949)

Chapter 6 Quantitative results

6.1 Project aims

At this point it is worth reiterating the aims and objectives of the project to act as a reminder to the reader within the results section. This will enable alignment between results and the expectations of the investigation.

This investigation explores whether, after a short course of education, experienced radiographers from the State of Victoria can identify and describe abnormalities on plain images of MSK (axial and appendicular) trauma to support the junior doctor.

Internationally radiographer image interpretation research has examined capability relative to qualified doctors or other health professionals [24 - 30]. The Australian educational model expects medical internees expects to be able to recognise plain radiographic pathological and traumatic changes in images of the chest, abdomen and skeleton. The 'Intern training – guideline for terms' document [31] makes it clear that the undergraduate medical course of study should provide a foundation for building image interpretation skills during internship. It is therefore pertinent to ask if the final year medical student possesses this capability to an acceptable standard.

Radiographers are now expected by the MRPBA to recognise, interpret and act upon radiographically visible MSK abnormalities. A group of 16 further educated experienced diagnostic radiographer's image interpretation skills are evaluated relative to 16 final year medical students who are about to become interns. The investigation also explores whether radiographer input can provide a supportive contribution to the image interpretation process for MSK trauma events. History shows that radiographers have been prevented from contributing to the patient pathway through image interpretation and content description [33 - 38]. This investigation also explores and identifies potential educational requirements and areas of concern for radiographers and final year medical students with respect to performing image interpretation. To establish this, the study evaluates the objectives listed below:

1. literature to identify the factors that have hindered radiographers from participating in musculo-skeletal trauma image interpretation;
2. the ability of further educated experienced radiographers and final year medical students capacity to interpret appearances seen in musculo-skeletal trauma radiographs in order to establish if each group has accuracies close to that seen amongst radiologists;
3. the ability of further educated experienced radiographers and final year medical students to describe incidental findings on an examination and express whether further investigation(s) is/are warranted ;
4. the number of requests for further imaging between further educated experienced radiographers and final year medical students in comparison with radiologists;
5. whether final year medical students are aware of and open to input by radiographers via image interpretations to the emergency department (ED) to aid their own performance and if radiographers believe they are able to do this.

Chapter two previously established the socio-historical context of radiographer interpretation nationally and internationally; the influence of this will be incorporated into the discussion and conclusions. This chapter, along with chapter seven, reveals the data produced by the testing regime and the pre/post image describing test questionnaires that were delivered to the participants. The range of results discussed in the method and methodological considerations is listed below:

- Sensitivity, specificity and accuracy (raw and percent values)
- Positive and negative predictive values
- Likelihood ratios (relative positive and negative values)
- Post test odds
- Kappa
    - Cohen's weighted
    - Byrt et al's prevalence and bias adjusted kappa value

    - Feinstein and Cichetti's indices of positive and negative agreement
    - Gwets AC1 statistic (adjusted chance for marginal values)
- ROC curve AUCs in empirical and fitted forms

Relationships between components will also be highlighted within this chapter and chapter seven. It should be noted that individual performance scores for the various values that were calculated for radiologists, radiographers and medical students can be viewed in appendices 9 – 12.

6.2 Participant sample information.

Contributors to the study included three radiologists with an interest in musculo skeletal radiology as well as a range of radiologists providing the original report. Inclusion of images in the final image test bank required three of the four radiologists who reported the radiographs to agree the content. Comparison between individual radiologist's performances, to demonstrate the degree of variability in report as suggested by Robinson [177] is important to consider within the results and will be shown in section 6.3.

The final year medical students who contributed to the study came from a single university MBBS degree programme and were self selecting. All the medical students were in the second half of the final year with recruitment coming from the 2012 and the 2013 cohort, generating seven and nine participants respectively, a reduction in the initial 24 consented students, the remainder of whom chose not to participate further.'

Consent forms were returned at each recruitment drive after the students had read the information letter explaining the requirements from them. In 2012 a memory stick with the image test and initial survey was mailed to the 2012 cohort. This cohort of recruits returned the electronic memory stick in a reply paid envelope with the survey also completed. In the 2013 cohort the Monash University virtual learning environment (Moodle©) was used as the vehicle to transfer responses that were all dealt with by the administrative officer assistant. This person forwarded the information for collation and analysis after application of an anonymity code, to maintain participant separation between the arbiter and participants.

After seeking permission from the now disestablished MRPBV, radiographers were invited to participate in the research after being contacted via the professional register. Addresses that individual practitioners indicated should be their contact point found in the MRPBV register were used to send invitations. The register was scrutinised to exclude those radiographers that indicated that they worked in a major trauma centre. These radiographers were excluded as their work either avoided contact with children or acted as the only type of patient that was worked with. The research was interested in finding the image interpretation ability of radiographers and medical students across all age ranges attending the ED department. As such regular access to all ages of patients was a necessity.

Initially 434 invitation letters to participate were mailed to individual radiographers. Twenty two were returned due to the address being incorrect. During the following one month response period, 44 radiographers contacted the third party administrative officer responsible for ensuring participant anonymity. After receipt of further information about the expectations of the study 26 respondents returned their consent. Due to reasons linked to their work patterns that would prevent completion of the image test or attendance at the radiographer education session, eventually 16 radiographers completed the study. They, as with the first medical student cohort, returned their responses to the image tests and surveys via the electronic memory stick that had been provided to them. The image test content is included in the CD ROM at the back of the thesis. Two study sessions were held to maximise the uptake of participants. The memory sticks from test one were gathered as the radiographer participants arrived for the study sessions. The follow up re-test took place after completion of the education with an eight week gap to allow the information to be applied in the clinical setting as well as to give participants time to assimilate new information. The radiographers were requested to return their responses to the second test and survey between four to six weeks after receipt making a total of 12 – 14 weeks post attendance for the education session.

Radiographer participant make up was as seen in table 6.1 that shows the current working experience and time since qualification each participant had. In chapter seven the survey response results will be given. However, one radiographer made a clear point that he/she believed that axial interpretation and paediatric referrals would be more difficult and perceived this might give an unfair comparison. With this in mind all results are reported for the full test (test 1 and test 2 – pre and post educational intervention for the radiographers) and values achieved for appendicular images only or adult images only.

Years qualified	No of radiographers		Radiology department provider type	No of radiographers
>2 – 4 yrs	4		City Public	6
5 – 9 yrs	5		Country Public	5
10 – 14 yrs	2		City Private	2
15 – 19 yrs	1		Country Private	3
20+ yrs	4			

Table 6.1 Radiographer participant demographic.

6.3 The radiologist's performance.

The study aimed to identify whether radiographers described images to a level not statistically significantly different to that of the radiologists. To understand what this meant, the individual radiologists who re-reported the images and the initial reporting radiologist group had their individual performances measured relative to the consensus test finally used. This allowed pooled consensual values to be compared with the radiographer and final year medical student performances. The wide number of radiologists involved in the initial reports, when added into the consensual test bank, gives strength to the system due to the greater number of individuals that effectively contributed to the agreement process to generate the image test. Table 6.2 below shows the radiologist results for the full test with table 6.3 p110 the appendicular skeletal images only and table 6.4 p110 revealing the adult only interpretive results. The key for all subsequent tables for all participant groups is shown over:

TN – True negative
TP – True positive
FN – False negative
FP – False positive
% Sens – sensitivity score as a percentage
% Spec - specificity score as a percentage
% Acc – accuracy score as a percentage
PPV – Positive predictive vale
NPV – Negative predictive value
LR+ve – Positive likelihood ratio
LR-ve – Negative likelihood ratio
Ppos – Proportion of answers given as positive also interpreted positive
Pneg - Proportion of answers given as negative also interpreted negative
Post Odds - pre test odds x likelihood ratio
Post Odds Probs - post test probability of having the disease, based on the test results
Wtd Kappa – Weighted Kappa value
BPK – Bias and Prevalence adjusted Kappa value
AC1 – Gwet's AC1 statistic (kappa value accounting for misconceptions in Wtd Kappa)
ROC emp – the calculated area under the curve of the empirically plotted ROC curve
ROC fit - the calculated area under the curve of the smoothed plot (fitted) ROC curve

Radiologists	TP	TN	FP	FN	Sens %	Spec %	Acc %
Original radiol	142	58	3	6	95.08	95.95	95.69
Radiol 1	143	57	4	5	93.44	96.62	95.69
Radiol 2	127	60	1	21	98.36	85.81	89.47
Radiol 3	142	59	2	6	96.72	95.95	96.17

	PPV	NPV	LR +ve	LR -ve	P Pos	P Neg	Post Odd	Post odds probs
Original radiol	0.91	0.98	23.45	0.05	0.928	0.969	4.503	0.818
Radiol 1	0.92	0.97	27.66	0.07	0.927	0.969	5.311	0.841
Radiol 2	0.74	0.99	6.93	0.02	0.845	0.920	4.581	0.821
Radiol 3	0.91	0.99	23.86	0.03	0.937	0.973	4.660	0.823

	Wtd Kappa	BPK	AC1	ROC emp	ROC fit
Original radiol	0.897	0.883	0.926	0.948	0.980
Radiol 1	0.896	0.842	0.926	0.947	0.969
Radiol 2	0.768	0.963	0.809	0.935	0.945
Radiol 3	0.909	0.923	0.934	0.964	0.986

Table 6.2 Radiologist performance results (full test)

Variation exists in all viewers of images hence the need to compare the radiologists as a baseline so that the expected range of performance can be established for numerical and statistical comparison. With 3 out of 4 radiologists having to agree image content for inclusion in the test bank, then the images added to the test enabled generation of a gold rather than merely a reference standard.

Radiologists	TP	TN	FP	FN	Sens %	Spec %	Acc %	
Original radiol	126	55	2	3	96.49	97.67	97.31	
Radiol 1	127	54	3	2	94.74	98.45	97.31	
Radiol 2	111	56	1	18	98.25	86.05	89.78	
Radiol 3	124	56	1	5	98.25	96.12	96.77	
	PPV	**NPV**	**LR +ve**	**LR -ve**	**P Pos**	**P Neg**	**Post Odd**	**Post odds probs**
Original radiol	0.95	0.98	41.49	0.04	0.816	0.900	7.966	0.888
Radiol 1	0.96	0.98	61.11	0.05	0.817	0.901	11.732	0.921
Radiol 2	0.76	0.99	7.04	0.02	0.796	0.841	1.351	0.575
Radiol 3	0.92	0.99	25.35	0.02	0.813	0.895	4.866	0.829
	Wtd Kappa	**BPK**	**AC1**	**ROC emp**	**ROC fit**			
Original radiol	0.937	0.918	0.953	0.964	0.983			
Radiol 1	0.936	0.876	0.953	0.964	0.983			
Radiol 2	0.778	0.961	0.812	0.964	0.982			
Radiol 3	0.926	0.959	0.943	0.981	0.993			

Table 6.3 Radiologist performance results (Appendicular images only)

Radiologists	TP	TN	FP	FN	Sens %	Spec %	Acc %	
Original radiol	106	37	2	6	94.87	94.64	94.70	
Radiol 1	107	36	3	5	92.31	95.54	94.70	
Radiol 2	98	39	0	14	100.00	87.50	90.73	
Radiol 3	109	37	2	3	94.87	97.32	96.69	
	PPV	**NPV**	**LR +ve**	**LR -ve**	**P Pos**	**P Neg**	**Post Odd**	**Post odds probs**
Original radiol	0.86	0.98	17.71	0.05	0.964	0.902	3.400	0.773
Radiol 1	0.88	0.97	20.68	0.08	0.900	0.764	3.969	0.798
Radiol 2	0.74	1.00	8.00	0.00	0.848	0.731	1.536	0.606
Radiol 3	0.93	0.98	35.42	0.05	0.937	0.776	6.800	0.871
	Wtd Kappa	**BPK**	**AC1**	**ROC emp**	**ROC fit**			
Original radiol	0.866	0.870	0.912	0.936	0.972			
Radiol 1	0.926	0.802	0.913	0.936	0.972			
Radiol 2	0.783	1.000	0.839	0.975	Degenerate Sens 100%*			
Radiol 3	0.914	0.867	0.946	0.975	0.990			

Table 6.4 Radiologist performance results (Adult images only)
* A high or zero sensitivity or specificity score can impact on final values due to the unlikely event that this would normally occur clinically. See ROC discussion section 3.5.3 p69

The radiologists, as expected performed to a high level and demonstrate relatively close values between each other. One radiologist showed a large variation from the remainder however, as the reports provided in this case were frequently equivocal because of excessive content or suggesting more imaging. This affected the numerical performance, however the general trend of this individual appears to be similar to other radiologist participants.

6.4 Full test performance values.

A separate group of radiographers to act as a control was not used. The pre-education intervention values are employed as the baseline and therefore represent a control function. Appendix 12 shows the individual scores for radiographer test 2 and medical students.

6.4.1 *Radiographer Sensitivity.*

Sensitivity is the measure of the proportion of positive results the observer gains

Radiographers TEST 1 n=16	**TN**	**TP**	**FN**	**FP**	**% Sens**	**% Spec**	**% Acc**
Mean	122	56	5	26	91.79	82.22	85.02
Median	124	56	5	24	91.80	83.79	86.84
Range	61	10	10	61	16.39	41.22	26.79
Minimum	80	50	1	7	81.97	54.05	66.99
Maximum	141	60	11	68	98.36	95.27	93.78
Radiographers TEST 2 n=16							
Mean	120	57	4	28	94.25	81.35	85.11
Median	125	57	4	23	93.44	84.46	87.08
Range	33	8	8	33	13.11	22.75	15.79
Minimum	100	52	1	15	85.25	67.11	74.64
Maximum	133	60	9	48	98.36	89.86	90.43
Medical Students n=16							
Mean	121	53	8	27	87.50	81.80	83.46
Median	115	53	9	33	86.07	77.70	81.34
Range	30	10	10	30	16.39	20.27	14.83
Minimum	107	50	1	11	81.97	72.30	76.08
Maximum	137	60	11	41	98.36	92.57	90.91

Table 6.5 Comparison of performance – Sensitivity, Specificity and Accuracy between **both full tests** of Radiographers and Medical student single test

relative to the true positive labelled images noted in the radiologist consensus reports. The performance of the radiographers is shown in table 6.5 p111.

6.4.2 *Radiographer Specificity.*

Specificity is the measure of the proportion of negative results the observer gains relative to the true negative labelled images noted in the radiologist consensus reports. The performance of the radiographers is shown in table 6.5 p111.

In remembering that there is a relationship between proportions when specificity and sensitivity are compared and combined as a total score, it is clear that as sensitivity increases then specificity is likely to fall. The lowest specificity score in test 2 is 67.11% performance in test 2. In test 1 a single participant scored at a lower level of 54.05%. Overall therefore the specificity score for radiographer's test 2 is more tightly grouped together (22.75% range in test 2 compared with 41.22% in test 1) even if not reaching as great a maxima as seen in test 1 (89.86% test 2 compared with 95.27% test 1) .

6.4.3 *Radiographer Accuracy.*

Accuracy is the measure of the proportion of correct results (positive and negative for abnormality) the observer gains relative to the radiologist consensus reports. As noted earlier it too is a piece of data controlled by the relationship between sensitivity and specificity. The performance of the radiographers is shown in table 6.5 p111. As noted with the specificity scores the accuracy range is smaller (15.79% test 2 compared with 26.79% in test 1) with a greater lower value score and reduced upper value (74.64% test 2 compared with 66.99% test 1 and 90.48% test 2 as opposed to 93.78 test 1). It should be noted though that numerically the overall mean and median scores for accuracy in test 2 were slightly greater than those delivered in test 1 (85.11% mean/87.08% median accuracy test 2 against 85.02% mean/86.84% median accuracy test 1).

6.4.4 Medical student sensitivity, specificity and accuracy values.

Apart from the mean specificity value for the radiographers in test 2, the medical students performed less well. The medical students generally demonstrated mean and median values lower than both test results for the radiographers. This is despite the higher minimum specificity score and greater than radiographers test 2 maximum score. The range of scores for specificity by the medical students is narrower and the same pattern appears to be apparent, due to the sensitivity/specificity relationship described earlier. This is seen in the accuracy results as well. The difference in scores though is reduced due to the effects of better performance on the sensitivity component by the radiographers. The narrower range of values in accuracy when compared against the mean and median values obtained compared with the radiographers indicates that the scores within the range for the medical students have tended to be lower overall. This is supported by higher radiographer true negative/positive and lower false negative/positive results.

6.4.5 Predictive values, likelihood ratio calculations and proportion values.

Predictive values are used to establish the ability of the test to provide diagnostically reliable results. However being able to predict abnormality is a more useful outcome from a test. The PPV is the ability of the test to correctly identify those patients with the abnormality and the NPV the ability to confirm that a person does not have the problem. The calculations for the predictive values for the full test for both radiographers and medical students are shown in table 6.6 (p114).

Between tests 1 and 2 for the radiographers the positive predictive value falls slightly, however the mean value in test 2 for the radiographers is the same as the medical students and better as a median score (0.72 radiographers against 0.62 medical students). By comparison there appears to be very little change in the negative predictive values between the two tests for the radiographers across all statistics presented though test 2 for the radiographers demonstrates slightly better performance than the medical students. The range and minima/maxima are similar thus leading to the conclusion that the overall number of medical students scoring lower in test 2 occurs more frequently than for the radiographers.

Radiographers TEST 1 n=16	**PPV**	**NPV**	**LR+ve**	**LR -ve**	**Ppos**	**Pneg**	**Post Odds**	**Post odds probs**
Mean	0.71	0.96	7.58	0.10	0.789	0.882	1.455	0.528
Median	0.70	0.96	5.62	0.10	0.809	0.899	1.078	0.519
Range	0.42	0.07	16.92	0.19	0.261	0.257	3.249	0.502
Minimum	0.47	0.92	2.14	0.02	0.635	0.699	0.411	0.283
Maximum	0.89	0.99	19.06	0.21	0.896	0.956	3.660	0.785
Radiographers TEST 2								
Mean	0.68	0.97	5.64	0.07	0.790	0.884	1.056	0.503
Median	0.72	0.97	6.10	0.08	0.807	0.903	1.171	0.540
Range	0.25	0.06	6.22	0.16	0.176	0.139	1.292	0.310
Minimum	0.54	0.93	2.84	0.02	0.679	0.791	0.447	0.325
Maximum	0.79	0.99	9.06	0.18	0.855	0.930	1.739	0.635
Medical Students								
Mean	0.68	0.94	6.08	0.15	0.760	0.873	1.167	0.506
Median	0.62	0.94	4.01	0.17	0.745	0.854	0.769	0.435
Range	0.27	0.07	8.61	0.20	0.176	0.124	1.653	0.321
Minimum	0.56	0.92	3.08	0.02	0.675	0.811	0.591	0.371
Maximum	0.83	0.99	11.69	0.22	0.851	0.935	2.244	0.692

Table 6.6 Comparison of performance – Predictive values and likelihood calculations between **both full tests** of Radiographers and Medical student single test

Likelihood ratios (LRs) are used to inform about the performance of a test when there is a positive or negative outcome for the individual. This means for a positive LR the result indicates how well the test (in this case the viewer or radiographer) performs when a condition is known to be present, as agreed through the consensus radiologist reports. Absence of disease is confirmed with measurement of the negative LR. The comparison values are shown in table 6.7 below.

Probable result	*Positive LR*	*Negative LR*
Large	>10	<0.1
Moderate	5 - 10	0.1 – 0.2
Small	2 - 5	0.2 – 0.5
Tiny	<2	>0.5
Minimal	1	1

Table 6.7 Positive and negative likelihood ratio interpretations [184]

According to table 6.7, higher values for positive likelihood ratios and conversely lower scores for negative likelihood ratios indicate better performance respectively. This translates into showing that, when compared against test 2 for the radiographer's, the medical students appear to perform better in the positive likelihood ratio measurement. However the lower median value for the medical students would suggest this is not the case. The radiographer negative likelihood ratios are generally lower and therefore indicators of better performance in this measurement than the medical students. This appears to be the opposite suggestion made about the mean specificity values within table 6.5 (p110). However it should be remembered that the median specificity performance was greater by the radiographers, which supports an overall expectation and finding that the negative likelihood ratio should be performed better than the medical students.

The proportions positive and negative values achieved by the two groups showed the radiographers numerically achieved better results with higher mean and median values in both tests 1 and 2. The range of scores achieved by the medical students was equal to or less than those shown by the radiographers, with minimal difference between the highest and lowest scores achieved. This would again indicate that the medical students as a group had results that were, numerically, generally lower as revealed by the mean and median values, even if the score range was less. As a generalisation therefore, this suggests that the medical students scored lower on the proportions of positive and negative for an abnormality being correctly identified in the full test.

The post test odds and therefore post test probability of having an abnormality present, based on the participants test results, can also be calculated. Clinically post test probabilities may even be a guess especially if a pathognomic sign is evident e.g. a lipohaemarthrosis in an occult intra-articular fracture. Rarely is there a binary outcome, 0 or 100% certainty result for a test to a disease, due to the subjectivity of the reader of test results or the signs/symptoms demonstrated. The probabilities of a test being correct in its diagnosis, or in this case the reader of the test, can be estimated using post test probability when the positive likelihood ratio and pre test odds (0.192) are known. Calculation of these factors is described in chapter 3, section 3.5.2 p53; larger post test odds give greater security that there is presence of an abnormality (in this case MSK trauma) and this is also true of the post test probability; the latter is represented as a decimal of one.

Tests 1 and 2 for the radiographers showed the post test odds and post test probabilities median values achieved are greater than the medical students, though the students gained higher maximum values than the radiographers in test 2. Again, however, for the radiographers' second test results, the range of values obtained is lower suggesting that the scores within the group err more towards the higher scores of the range. Mean values for the medical students are slightly greater when compared with test 2 for the radiographers but less than test 1. This lends support to the spread of radiographer results, even if lower, tending towards the upper end of the range to produce a higher median value. It should be remembered that an outlier value can significantly skew mean values.

6.4.6 Kappa and performance comparison statistics.

Kappa statistics are used to compare two sets of observers. Table 6.8 p117 shows the performance of the radiographers in both tests and the medical students when compared against the radiologists' performance.

Weighted Kappa (Wtd Kappa) calculates comparative performance taking into account chance selection of the correct response. Bias and Prevalence adjusted (BPK) Kappa [196] makes adjustments for the proportions of times the observer selects a positive response (bias) when compared against the original observer and the number of times a positive and negative response is selected (prevalence). The AC1 statistic [198] applies Gwet's idea that Kappa cannot be calculated as a value based on a maximum score of 1.0. He argues that due to an answer being either yes or no then the maximal available score for calculation must be 0.5. Numerically the radiographer's performed slightly better than the medical students in both tests apart from the maximum score for radiographers in test 2 for the AC1 statistic.

Radiographers TEST 1 n=16	Wtd Kappa	BPK	AC1	ROC emp	ROC fit
Mean	0.683	0.817	0.724	0.927	0.949
Median	0.714	0.812	0.760	0.941	0.955
Range	0.441	0.299	0.548	0.113	0.098
Minimum	0.410	0.665	0.346	0.851	0.875
Maximum	0.851	0.964	0.894	0.964	0.973
Radiographers TEST 2 n=16					
Mean	0.680	0.816	0.725	0.928	0.955
Median	0.712	0.834	0.767	0.942	0.964
Range	0.294	0.297	0.317	0.122	0.093
Minimum	0.491	0.667	0.514	0.854	0.893
Maximum	0.785	0.964	0.831	0.976	0.986
Medical Students n=16					
Mean	0.639	0.715	0.694	0.896	0.912
Median	0.608	0.681	0.652	0.898	0.917
Range	0.284	0.395	0.314	0.156	0.148
Minimum	0.499	0.568	0.529	0.816	0.836
Maximum	0.783	0.963	0.843	0.972	0.984

Table 6.8 Comparison of performance – Kappa statistics and ROC curve AUC values between **both full tests** of Radiographers and Medical student single test

The ROC curve AUC calculations as either fitted or empirical (ROC fit, ROC emp) for the radiographers in test 2 were better than those in test 1. The mean and median scores for the radiographers in test 1 were greater than the medical students though the actual minimum and maximum numerical results for the medical students were lower and greater respectively than the radiographers. The greater mean and median values therefore suggest the radiographers in test 1 performed with more results closer to the maximum. The radiographers in test 2 performed better than the medical students with greater scores in the ROC statistics provided, and with a much narrower score range suggesting support for the notion of stronger radiographer performance than that seen in test 1.

The comparison statistics allow various ways to describe the relative performance of each group; each one takes account of slight variations in calculation. The ROC AUC calculations are now accepted as the best approach to clinical performance measurement as it allows wider appreciation of the choice variables that an observer may select.

6.5 Appendicular only images performance values.

As previously indicated in this chapter, one radiographer made a clear point that they believed that axial interpretation and paediatric referrals would be more difficult and he/she perceived this might give an unfair comparison with the radiologists. To allow this to be further explored the image test results were reconfigured. This allowed performance to be demonstrated when only appendicular images of all patient age groups made up the test bank. It also allows further comparison when paediatric images, those where the skeleton demonstrated incomplete maturity and epiphyseal lines might still be visible, or those images in patients aged 16 and under were excluded. This reduced the image test banks to 186 appendicular images and 151 adult or skeletally mature images. The appendicular image performances are discussed below.

6.5.1 Appendicular images only sensitivity, specificity and accuracy.

Table 6.9 p119 shows the performance of the radiographers in both tests and the medical students in their single test. Clear patterns in the results become evident on closer analysis. As with the full test it can be seen that the radiographers numerically performed better than the medical students in their mean and median values of sensitivity, specificity and accuracy as a percentage correct value. The medical students showed a smaller or equal range of maximum and minimum scores compared with the results from both radiographer tests. This suggests that the radiographers had weaker specificity scores, but as a group they have higher mean and median values. The inference from this is that in the overall performance scores sensitivity were equal to (test 1) or higher (test 2) than the medical students though all tests showed that at least one participant in a group identified or possibly guessed all the radiographers had more participants scoring higher. The radiographer's minimum for abnormal images in the test. Remembering the relationship between sensitivity and specificity described earlier, a stronger

Radiographers TEST 1 n=16	TN	TP	FN	FP	% Sens	% Spec	% Acc
Mean	107	53	4	22	92.68	83.29	86.22
Median	110	53	4	20	92.98	84.89	88.71
Range	52	10	10	52	17.54	40.31	26.34
Minimum	71	47	0	6	82.46	55.04	68.28
Maximum	123	57	10	58	100.00	95.35	94.62
Radiographers TEST 2 n=16							
Mean	106	54	3	23	95.40	82.36	86.36
Median	109	54	3	20	94.74	84.50	88.44
Range	30	7	7	30	12.28	23.26	17.74
Minimum	87	50	0	12	87.72	67.44	74.73
Maximum	117	57	7	42	100.00	90.70	92.47
Medical Students n=16							
Mean	105	50	7	24	88.38	81.59	83.67
Median	101	50	8	29	86.84	77.91	81.99
Range	30	10	10	30	17.54	23.26	16.67
Minimum	91	47	0	8	82.46	70.54	75.27
Maximum	121	57	10	38	100.00	93.80	91.94

Table 6.9 Comparison of performance – Sensitivity, Specificity and Accuracy between both tests of Radiographers and Medical student single test for **appendicular** images only

performance in the sensitivity component will lift the overall accuracy result. This is supported by the higher values for true negative/positive and lower false negative/positive when considered across the radiographer's two test performance.

6.5.2 Predictive values, likelihood ratio calculations and proportion values.

As stated predictive values measure the ability of a test or its observer to give a correct positive or negative outcome. The likelihood ratios also show the ability of the test or its reader to give a correct answer of the presence or absence of a disease/trauma. Comment was also made earlier about the proportions positive and negative as well as post odds ratio and post odds probability of the presence or absence of disease/trauma. Table 6.10 p120, shows the results of the appendicular only image test between the two non-radiologist groups.

Radiographers TEST 1 n=16	PPV	NPV	LR+ve	LR -ve	Ppos	Pneg	Post Odds	Post odds probs
Mean	0.73	0.97	8.55	0.08	0.813	0.885	1.641	0.561
Median	0.74	0.97	6.36	0.09	0.837	0.892	1.221	0.549
Range	0.41	0.08	17.80	0.21	0.259	0.255	3.421	0.497
Minimum	0.49	0.92	2.19	0.00	0.655	0.706	0.419	0.296
Maximum	0.90	1.00	19.99	0.21	0.914	0.961	3.840	0.793
Radiographers TEST 2 n=16								
Mean	0.71	0.98	6.15	0.06	0.814	0.892	1.181	0.525
Median	0.74	0.97	6.39	0.06	0.837	0.911	1.226	0.551
Range	0.27	0.06	7.20	0.15	0.200	0.156	1.382	0.308
Minimum	0.55	0.94	2.80	0.00	0.689	0.787	0.538	0.349
Maximum	0.82	1.00	10.00	0.15	0.889	0.943	1.920	0.657
Medical Students n=16								
Mean	0.68	0.94	6.08	0.15	0.760	0.873	1.167	0.506
Median	0.62	0.94	4.01	0.17	0.745	0.854	0.769	0.435
Range	0.27	0.07	8.61	0.20	0.176	0.124	1.653	0.321
Minimum	0.56	0.92	3.08	0.02	0.675	0.811	0.591	0.371
Maximum	0.83	0.99	11.69	0.22	0.851	0.935	2.244	0.692

Table 6.10 Comparison of performance – Predictive values and likelihood calculations between both tests of Radiographers and Medical student single test for **appendicular** images only

From the table it can be seen that the radiographers obtained greater mean/median PPV and NPV values along with better positive and negative likelihood ratios. The medical students demonstrated a narrower score range in the proportion positive and negative values though again a lower mean and median score than the radiographers in both tests 1 and 2. This indicates that the mean, median and range scores (test 1) for the positive and negative predictive values as radiographer scores tended toward the higher values within the group as a whole. In the post test odds and post test probabilities it is evident that some medical students performed better than the radiographers in test 2 achieving higher minimum and maximum scores, though once again the mean and median values are higher for the radiographers suggesting overall skewing to greater scores for the group as a whole.

6.5.3 Kappa and performance comparison statistics.

Table 6.11 p121 shows the values for the Kappa based statistics and the ROC AUC values obtained when the appendicular only images were considered. From the results presented it can be seen that the radiographer performance in test 1 was slightly better in the weighted kappa and BPK statistics though a slight improvement became evident in test 2 for the AC1 and ROC values. As a generalisation however, it is evident that the mean and median numerical results for all the performance comparison statistics of this nature were greater for the radiographers. There was narrower result spread than the medical students, although the maximum value obtained by the medical students marginally exceeded the empirical and fitted ROC

Radiographers TEST 1 n=16	**Wtd Kappa**	**BPK**	**AC1**	**ROC emp**	**ROC fit**
Mean	0.708	0.842	0.743	0.934	0.955
Median	0.756	0.845	0.791	0.949	0.957
Range	0.458	0.349	0.536	0.122	0.108
Minimum	0.417	0.651	0.370	0.851	0.875
Maximum	0.875	1.000	0.906	0.973	0.983
Radiographers TEST 2 n=16					
Mean	0.706	0.816	0.745	0.936	0.963
Median	0.750	0.844	0.787	0.951	0.972
Range	0.336	0.537	0.352	0.122	0.079
Minimum	0.497	0.463	0.512	0.859	0.913
Maximum	0.833	1.000	0.864	0.981	0.992
Medical Students n=16					
Mean	0.650	0.740	0.697	0.901	0.917
Median	0.627	0.704	0.662	0.904	0.923
Range	0.318	0.409	0.330	0.165	0.153
Minimum	0.493	0.591	0.529	0.814	0.831
Maximum	0.811	1.000	0.859	0.979	0.984

Table 6.11 Comparison of performance – Kappa statistics and ROC curve AUC values between both full tests of Radiographers and Medical student single test for **appendicular** images only

results for the radiographers in test 1. This suggests that not only did the radiographers perform better but they had generally higher scores with less spread between them as a group, thus indicating an overall higher performance numerically when compared against the medical students.

6.6 Adult only images performance values.

There were 151 adult or skeletally mature images in the full test. These are now reported as a sub set of performance as discussed earlier.

6.6.1 Adult images sensitivity, specificity and accuracy.

Table 6.12 (p122) shows the performance of the radiographers in both tests and the medical students when only adult images are considered. From the table it can be seen that, as has been noted earlier, the radiographer mean and median values were in excess of the medical students except for test 2 mean specificity. The range of results for the radiographers in test 1 was wider though maximum scores were greater, indicating the minimum scores were the same as the medical students. The medical students achieved higher minimum and maximum scores than radiographer test 2 results for accuracy and specificity.

Radiographers TEST 1 n=16	**TN**	**TP**	**FN**	**FP**	**% Sens**	**% Spec**	**% Acc**
Mean	93	36	3	19	91.67	83.43	85.56
Median	95	36	4	17	91.03	84.82	87.09
Range	42	7	7	42	17.95	37.50	25.83
Minimum	65	32	0	5	82.05	58.04	68.21
Maximum	107	39	7	47	100.00	95.54	94.04
Radiographers TEST 2 n=16							
Mean	93	37	2	19	94.55	82.76	85.80
Median	97	37	2	16	94.87	86.61	89.07
Range	27	345	6	27	15.38	24.11	17.22
Minimum	75	33	0	10	84.62	66.96	74.17
Maximum	102	378	6	37	100.00	91.07	91.39
Medical Students n=16							
Mean	93	34	5	19	88.45	83.04	84.47
Median	91	34	5	21	87.18	80.81	83.78
Range	25	6	6	25	15.39	22.32	17.89
Minimum	81	32	1	6	82.05	72.32	74.83
Maximum	106	38	7	31	97.44	94.64	92.72

Table 6.12 Comparison of performance – Sensitivity, Specificity and Accuracy between both tests of Radiographers and Medical student single test for **adult** images only

However, the overall mean and median values across all measures are higher for radiographers except the mean for test 2 specificity. Once again this indicates that the scores, as in previous results sets, were toward the higher end of the scale in more cases than the medical students. This is supported by the greater number of false positives/negatives displayed as mean and median scores of the medical students.

6.6.2 Predictive values, likelihood ratio calculations and proportion values.

The predictive value, likelihood ratio, proportion positive and negative as well as the post test odds and post test probability calculations for adult only images are shown below in table 6.13 below from which a mixture of result performance becomes evident.

Radiographers TEST 1 n=16	**PPV**	**NPV**	**LR+ve**	**LR -ve**	**Ppos**	**Pneg**	**Post Odds**	**Post odds probs**
Mean	0.69	0.97	8.59	0.10	0.777	0.892	1.649	0.560
Median	0.68	0.97	6.00	0.10	0.792	0.906	1.152	0.535
Range	0.43	0.07	17.78	0.21	0.276	0.230	3.414	0.486
Minimum	0.45	0.93	2.32	0.00	0.613	0.730	0.446	0.308
Maximum	0.88	1.00	20.10	0.21	0.889	0.960	3.860	0.794
Radiographers TEST 2 n=16								
Mean	0.67	0.98	6.42	0.07	0.779	0.895	1.233	0.532
Median	0.71	0.98	7.28	0.06	0.809	0.922	1.397	0.583
Range	0.28	0.06	7.47	0.19	0.196	0.146	1.434	0.310
Minimum	0.50	0.94	2.87	0.00	0.655	0.794	0.551	0.355
Maximum	0.78	1.00	10.34	0.19	0.851	0.940	1.985	0.665
Medical Students n=16								
Mean	0.68	0.94	6.08	0.15	0.760	0.873	1.167	0.506
Median	0.62	0.94	4.01	0.17	0.745	0.854	0.769	0.435
Range	0.27	0.07	8.61	0.20	0.176	0.124	1.653	0.321
Minimum	0.56	0.92	3.08	0.02	0.675	0.811	0.591	0.371
Maximum	0.83	0.99	11.69	0.22	0.851	0.935	2.244	0.692

Table 6.13 Comparison of performance – Predictive values and likelihood calculations between both tests of Radiographers and Medical student single test for **adult** images only

For the predictive values the mean and median scores for both tests for the radiographers is greater than the medical students except test 2 PPV mean score. With PPV the range of scores between minimum and maximum is greater for the radiographers with lower minimum scores. A higher maximum by radiographers is seen in test 1 but lower in test 2 compared with the medical students. The range in the NPV is the same for medical students and radiographers in test 1 but the minimum and maximum scores for the medical student's is slightly lower. In the radiographers test 2 the range is lower and scores for minimum and maximum are higher than the medical students.

For the likelihood ratios it can be seen that for the positive ratio the radiographers in test 2 gained a higher mean and median value than the medical students with a narrower range although the minimum and maximum scores were lower. For the negative likelihood ratio the mean and median values are lower in both tests for the radiographers that indicate better performance than the medical students; the LR-ve value is lower when indicating greater performance. The range is narrower for radiographers with lower minimum and maximum scores indicating that the radiographers performed better.

The mean and median proportions of positive and negative values obtained by the radiographers in both tests are greater than the medical students, although they have higher minimum and maximum scores with a narrower range. This again shows that the scores overall within the radiographer tests are made up of a higher number of results towards the better performing values.

Mean and median values for the radiographers in both tests for the post test odds and post test probability are greater than the medical students. Test 2 for the radiographers demonstrates a narrower range but the minimum and maximum values obtained in both radiographer tests shows the medical students performance to be greater. However as noted elsewhere, the higher mean and median values for radiographers indicates they have a greater proportion of participants performing toward the higher value end of their results continuum.

6.6.3 Kappa and performance comparison statistics.

The Kappa and other comparison of performance statistics are shown in table 6.14 p125 and demonstrate, through the range of methods described, the relative performance of each professional group. The medical students performed with better minimum values and a narrower range of scores compared with both radiographer tests for Wtd Kappa though the maximum value was lower. This pattern is repeated in the AC1 statistic with all other values in table 6.14 p125, when compared against the radiographers, being lower. As a generalisation therefore, the radiographers numerically performed better than the medical students. With radiographer values within the group once again tended to be proportionately skewed to the higher side of the continuum than the medical students.

Radiographers TEST 1 n=16	**Wtd Kappa**	**BPK**	**AC1**	**ROC emp**	**ROC fit**
Mean	0.675	0.801	0.742	0.930	0.953
Median	0.704	0.781	0.774	0.950	0.962
Range	0.454	0.368	0.519	0.132	0.123
Minimum	0.396	0.632	0.384	0.846	0.865
Maximum	0.850	1.000	0.903	0.978	0.988
Radiographers TEST 2 n=16					
Mean	0.681	0.823	0.747	0.934	0.954
Median	0.739	0.822	0.811	0.949	0.964
Range	0.313	0.364	0.341	0.126	0.094
Minimum	0.478	0.636	0.514	0.853	0.895
Maximum	0.791	1.000	0.855	0.979	0.989
Medical Students n=16					
Mean	0.639	0.715	0.694	0.896	0.912
Median	0.608	0.681	0.652	0.898	0.917
Range	0.284	0.395	0.314	0.156	0.148
Minimum	0.499	0.568	0.529	0.816	0.836
Maximum	0.783	0.963	0.843	0.972	0.984

Table 6.14 Comparison of performance – Kappa statistics and ROC curve AUC values between both full tests of Radiographers and Medical student single test for **adult** images only

With greater mean and median values across all scores it is evident that individual radiographer values within the group once again tended to be proportionately higher than the medical students.

6.7 Further examination requesting.

A further way to establish the performance of each group was to compare the radiologists' number of requests for more examinations with those suggested by the radiographers and medical students. As previously noted, comparison is made between test 1 and test 2 for the radiographers, but for this aspect the whole of the image viewing test is used as the comparator. Table 6.15 p126 shows the total request numbers made by the radiologists that performed the second reports. Not surprisingly the radiographers and medical students made more requests for further examinations.

Radiologist	Further radiography	CT	US	MRI	NM
1	11	6	1	0	2
2	14	21	6	17	5
3	6	6	0	1	0

Table 6.15 Further requests made by second reporting consultant radiologists

The amounts are presented with a differentiator titled 'No of times minimum selected'; this was done to draw attention to the number of participants that selected the minimum value. The figure allows demonstration of the proportion of that observer group who selected fewer examinations for repeat or other imaging to confirm or exclude the presence of abnormality. Table 6.16 shows these figures, however it can be seen that the radiographers increased the request for further examinations or extra modalities in test 2, and asked for further imaging more than

Radiographers TEST 1	**Mean**	**Median**	**Min**	**No times minimum selected**	**Max**	**Range**
Radiography	23	22	5	1	38	33
CT	13	10	4	1	28	24
US	3	3	0	5	12	12
MRI	3	1	0	7	27	27
NM	1	1	0	8	6	6
	43			**22**		
Radiographers TEST 2						
Radiography	20	20	4	1	39	35
CT	15	14	2	1	53	51
US	4	2	0	5	24	24
MRI	4	4	0	3	8	8
NM	2	1	0	6	9	9
	45			**16**		
Medical Students						
Radiography	12	11	0	1	33	33
CT	18	14	0	1	82	82
US	1	0	0	9	5	5
MRI	4	1	0	7	26	26
NM	1	0	0	12	4	4
	35			**30**		

Table 6.16 Further imaging requests made by radiographers and medical students

the medical students overall. It is evident in both groups however, that the ionising radiation based modalities are asked for more frequently. Common reasoning given for these requests appears to follow the pathway amongst radiographers that they either felt the radiographic positioning was insufficient to make a judgement for a description or that they knew of a further projection that they had experience of that would add to the diagnostic process. Some medical students appreciated the need for aspects of the imaging in plain radiography to be correct, however they tended to relate the request for further imaging to initial examinations that would benefit from confirming whether there was injury, for example, to the spine that is not always revealed on plain radiographs. This is a standard protocol to follow in the trauma setting and is supported by the high range in scores seen for CT further requesting. Radiographers by comparison, and this may be due to the mix of the participants in the radiographer group, erred towards non ionising imaging modalities, primarily ultrasound, for the detection of foreign bodies or to look at soft tissue injuries in a readily accessible and less expensive way than MRI would demand.

6.8 Statistical significance testing.

Figures reported thus far are descriptive and essentially numerical in nature. To ascertain whether the difference in performance between groups has statistical significance, test 2 by the radiographers was compared with firstly the radiologists and secondly the medical students. As the radiologists, radiographers and medical students reviewed the same images, comparison of performance between the numerical values given earlier is possible. The results are not normally distributed but are continuous and independent in nature so therefore can be analysed for statistical significance using the Mann Whitney U statistical test. The second radiographer test was compared with the radiologists and medical students; results are indicative of the influence of the educational input whether better or worse than the initial baseline, pre education test Table 6.17 p128 shows the Mann Whitney U test values for the radiologists against the second radiographer test result.

	TN	TP	FN	FP	% Sens	% Spec	% Acc
Full test	0.385	0.005	0.007	<0.001	0.385	0.005	0.002
Appendicular only	0.385	0.011	0.211	<0.001	0.437	0.011	0.005
Adult only	0.820	0.007	0.007	<0.001	0.819	0.007	0.005

	PPV	NPV	LR+ve	LR -ve	Ppos	Pneg	Post Odds	Post odds probs
Full test	0.003	0.211	0.003	0.249	0.002	0.003	<0.001	<0.001
Appendicular only	0.007	0.249	0.011	0.290	0.682	0.437	0.011	0.008
Adult only	0.003	0.750	0.005	0.385	<0.001	0.016	0.005	0.005

	Wtd Kappa	BPK	AC1	ROC emp	ROC fit
Full test	0.002	0.148	0.003	0.554	0.249
Appendicular only	0.005	0.099	0.007	0.030	0.011
Adult only	0.002	0.499	0.003	0.494	0.080

Table 6.17 Statistical significance comparisons: P values using Mann-Whitney U measuring between radiologists and radiographers **TEST 2**

From the results presented in table 6.17 it is clear that the radiologists demonstrated no statistical significance less frequently in their scores when compared with the radiographers' second test results. Only the True Negative (TN), the percentage sensitivity, the negative predictive value, the negative likelihood ratio and the BPK values across all three image groupings demonstrated no statistical significance in the scores obtained. Other non-statistically significant values included the appendicular only false negative, proportions positive and negative, and the full test plus adult only test ROC empirical and fitted results.

The impression from the radiographers compared with the medical students differs. Table 6.18 p129 shows the calculated probability values. There was no statistical significance between the radiographers and the medical students across all three image groupings for True Positive, False Positive, percentage specificity and accuracy, positive predictive value, positive likelihood ratio, proportions positive and negative, the post test odds ratio, weighted Kappa and the AC1 statistic. No statistical significance was found in the adult true negative values, with all other results demonstrating significant differences below the $p=0.05$ value as a two tailed test.

	TN	TP	FN	FP	% Sens	% Spec	% Acc
Full test	<0.001	0.763	<0.001	0.763	<0.001	0.763	0.486
Appendicular only	<0.001	0.777	<0.001	0.777	<0.001	0.777	0.213
Adult only	0.584	0.734	0.001	0.706	0.001	0.720	0.584

	PPV	NPV	LR+ve	LR -ve	Ppos	Pneg	Post Odds	Post odds probs
Full test	0.865	<0.001	0.970	<0.001	0.220	0.665	0.763	0.018
Appendicular only	0.572	<0.001	0.572	<0.001	0.142	0.299	0.572	0.039
Adult only	0.895	0.002	0.954	0.003	0.356	0.624	0.955	0.004

	Wtd Kappa	BPK	AC1	ROC emp	ROC fit
Full test	0.346	0.018	0.598	0.043	0.003
Appendicular only	0.214	0.039	0.291	0.035	<0.001
Adult only	0.546	0.004	0.678	0.035	0.012

Table 6.18 Statistical comparisons: P values using Mann-Whitney U measuring between radiographers **TEST 2** and medical students.

The statistical results help to reveal where the numerical values have greater meaning that are not due to chance. However the numerical values cannot be ignored even if not demonstrating statistically significant differences. This is because although a test may not reveal statistical significance the actual values obtained demonstrates a difference in ability and so should be viewed in this light.

With the numerical based results available the next chapter moves on to reveal the responses to the surveys carried out with the radiographers and medical students to allow recognition of the qualitative aspects in this investigation. These responses give insight into perceptions of overall performance and how the users of a radiographer provided service such as the medical student about to move into their internship, feel about this option. Alternatively, the surveys can be employed to reveal how radiographers perceive their ability and if they feel safe in interacting in this way in the clinical setting through providing a describing role? Once these aspects are known the results will be considered and discussed in chapter eight.

'The experience of radiographers is largely unrecognized yet they provide an understated interface with junior clinicians at the place and time of patient care.'

N Brayley, ED Consultant
Editorial, Radiography (2000) 6, 229.

Chapter 7 Qualitative Results

7.1 Results from the radiographer pre and post test surveys.

The radiographers who provided responses to the image tests were also asked to complete a short survey before test one and after test two. The surveys were designed to elicit further information about their professional situation, ability before and after the short course, and provide examples of situations where a radiographer's image description input was employed in either a positive or negative sense. The radiographers were also asked about their thoughts and feelings of their performance before and after the investigation.

In the second survey radiographers were asked whether the patient's presence may alter the radiographer's perceptions of performing at a level equivalent to the radiologist. The second survey also establishes whether receipt of the short course enhances perceptions of radiographer's descriptive ability and had an impact of their radiographic practise. Impressions about the test and its size were also sought.

Where comments can be aligned with particular participants his/her participant number is included in parentheses at that point [...]. The questionnaires are included as *appendix 5.*

7.2 Radiographers pre image test 1 survey responses.

Eighteen radiographers responded to the pre test survey before attending for the study weekend. Not all respondents ultimately attended the education session to contribute to the study, however their comments have been incorporated into the results below to give as full an appreciation of radiographer attitudes as possible. Of those radiographers who initially thought they would be able to attend the study weekend and participate in the testing component of the investigation, work commitments allowing, 11/16 of the tested radiographers completed the first pre-test survey.

Question 1

In this questionnaire, the first question asked radiographers what drove them to participate in the study. The following themes emerged as listed below:

- Rural *(2 comments)*
- Working overseas *(2 comments)*
- Advancing the radiographers role in Australia *(5 comments)*
- Greater use to medical staff *(3 comments)*
- Workforce enhancement *(5 comments)*
- Maintaining knowledge base with new student learning *(2 comments)*

Not all participants commented and some gave thoughts that may be applicable to more than one theme that was generated. The participants to whom the comments could be ascribed are included in parentheses at the end of the comment.

Rural

The radiographers highlighting this theme indicated that they wished to know more about interpretation, because they did not have a radiologist or even another colleague on site to discuss image findings with [1]. The second comment made it clear that;

> *'…I perform on call after hours radiographs I am often asked for an opinion by doctors over the phone and by senior emergency nurses within the hospital.' [10]*

Working overseas

Both respondents discussed their work in the UK where they had become familiar with the RDS (Red Dot Signalling) methodology of highlighting abnormalities on trauma images. The aim of participating in this study for them was to be part of a study of this nature and to have a greater contribution to the patient's diagnosis. [2, 26]

Advancing the radiographers role in Australia

Three of the five respondents were very clear in their belief that radiographers should contribute to an advancement of the role in Australia and believed this approach to be the way forward [4, 7 and 16]. They were clearly future oriented by way of attempting to drive the direction of their profession. One response was a little more circumspect in that his/her comment reflected that the radiographer's role should include interpretation to some degree in the job [20]. The final comment recognised that data needed to be collected in order to generate the potential for radiographers to participate in this kind of role [21].

Greater use to medical staff

These responses centred on the diagnostic process. One reply indicated that this radiographer believed they could be of more immediate use to the emergency department when medical staff sought verbal commentary. Immediate describing was felt to avoid the need to seek an opinion from other radiographers who probably had not participated in the examination, and therefore was unable to comment in a directly linked way [6]. Furthermore it was suggested that having the diagnostic knowledge would enhance the radiographic performance as the individual has a stronger understanding of the diagnostic role of the examination [17]. The final comment indicated that this participant felt he/she would be able to help more with the diagnostic process [27].

Workforce enhancement

Multiple facets were revealed from these responses. They were probably best represented in the following quote by participant 8:

> *'The 'Body Radiographer' represents a much underused resource within the Health Sector and with appropriate training, funding, recognition and support can both assist further in imaging delivery and attract and retain a competent, well trained work force.'*

This sentiment is evident in the other responses whereby the individuals indicated that they believe they could offer more to the workplace by being trained to interpret and this would aid recruitment and retention of staff through enhancing the role of the radiographer [13, 26]. One reply indicated that he/she felt that improving interpretation skills would lead to an overall work performance improvement [9]. The final comment appeared to be of a self challenging nature in that participation in the study would be good measure of that radiographer's ability to confidently interpret emergency images [24].

Maintaining knowledge base with new student learning

These two responses recognised that the practising radiographer may not necessarily have kept up with the level of education now being received by undergraduate students. They both recognised there were times when their knowledge base had probably declined and saw participation in the study as a method to update [11, 27]. Furthermore through the continued use of interpretation skills, this knowledge would be of value to students as the following quote from participant [11] identifies:

> *'With different subjects and methods currently being taught, I find I cannot always answer the student's queries. Their grounding in pathology and film interpretation is far more in depth than mine. This is an opportunity to evaluate my current knowledge but more importantly improve my image interpretation.'*

Question 2

Question 2 in the pre test questionnaire asked radiographers about their anxieties and concerns about providing an interpretive function before receipt of the educational input. A wider range of response themes became evident from the replies to this question, including:

- No concerns *(4 comments)*
- Lack of confidence *(3 comments)*
- Performance anxiety *(4 comments)*
- Implications to patients and others *(6 comments)*
- Responsibility levels *(2 comments)*
- Legal/ insurance perspectives *(2 comments)*
- Reporting ability *(2 comments)*

No concerns

Participants 9, 13, 26 and 27 replied that they had no overall concerns about the project other than the time it might take [9] or the realisation that there would be things he/she didn't know [13], but the course would help rectify this. A general impression was one of excitement about participation.

Lack of confidence

Responses indicated a level of low confidence and risk of appearing foolish at the lack of knowledge possessed to enable discussion of the content of images [1]. Lack of confidence was also indicated within particular areas of practise such as skull images or those from paediatric patients [4]. One participant had concerns about difficult images and how well he/she might perform [20].

Performance anxiety

Some of the responses here could cover more than one of the devised themes they have been placed in, however the main thrust decided which grouping the comment was placed in. Generally there was anxiety about how well each of the radiographers would perform. This worry emanated from the perceived skill set an individual possessed being sufficient for a complex task, or belief that the image reader has insufficient experience, or has not seen enough radiographs [21 and 24 respectively]. A further anxiety from participant 6 was:

> *'There may be an expectation that we will be correct all of the time and that there may be ramifications if we get it wrong.'[6]*

Participant 2 drew together the above thoughts:

> '*There is the anxiety to perform well, the expectation that a radiographer who has worked in a specific field should have a sound knowledge in emergency/trauma radiography but is/has never been tested.'[2]*

Clearly the spectre of being tested honed the thought processes of some of the participants.

Implications to patients and others

Two main points can be merged under this theme; being incorrect and negative impacts on the profession. These were; a fear of incorrect interpretation and its direct negative impact on the patient's well being, or missing a significant finding when providing an early interpretation before radiologist input. This results in misinformation going to other healthcare practitioners to affect patient treatment and was raised as a specific concern. Alternatively, confusing patients due to inaccuracy or simply missing an injury or other injury with potential life threatening consequences [4, 10, 17 and 24] was perceived as a further apprehension.

Two responses indicated that the incorrect interpretation due to an inappropriate skill set or causing patient confusion might have a negative impact on the profession or perceptions of radiographers from other professions, such as emergency doctors, radiologists and interestingly other radiographers [16, 21].

Responsibility levels

Two considerations within the theme of level of responsibility as an anxiety about performing a description role were raised by participants 6 and 7 respectively and are quoted below:

> *'Would the radiologists be happy about us giving opinions and would they help and support us if we had questions about cases or trouble with ED doctors?' [6]*
> *'I would be concerned about the amount of responsibility taken on by radiographers: is the radiographer ultimately responsible if the diagnosis was wrong; would extra insurance be required etc.' [7]*

Evidently there are some doubts how the team might work and who holds final responsibility for the description. Although not listed as responsibility levels, the quotes above link well with the next aspects revealed from the survey responses.

Legal/ insurance perspectives

Concerns are evident amongst some of the participants [6, 16] who raised the following questions about performing a descriptive role:

> *'Would we be covered legally for performing these interpretation functions?' [6]*
> *'Concerns that mistakes might be made and the ramifications of those.' [16]*

These aspects should be addressed if radiographers are to move into a future describing role.

Reporting ability

Some further comments that add to the idea of '*Implications to patients and others'* are revealed in comments from participants 8 and 11 below:

> *'It is very easy to i) comment on obvious pathology and ii) to have an informal guess at more obscure pathology. It is a different matter to record your interruption [interpretation?]'* [8]
> *I can usually recognise there is an abnormality but am often unable to put a name to it.* [11]

Clearly, appropriate descriptive expression and being able to build a significant knowledge base to enable good working abilities are upper most in the minds of some of the radiographers.

Question 3

Question 3 asked: Are you aware of any professional body input to furthering role development for radiographers? 12 of the respondents were unaware of specific professional development input by the AIR at the time of the survey, to support an interpretive role. Interestingly, where a response of knowledge enhancement in support of radiographer interpretation was mentioned, only one participant acknowledged the professional body as below:

> *'The AIR sometimes run seminars on specific parts of the anatomy which I try to attend if possible. On call replacement is an issue.'* [1]

Participant 2 indicated from his/her international experience that:

> *'I am aware of role extension in the UK, axial/appendicular reporting, CT reporting (only brains when I left in 2006), now I have heard of fistulograms, PICC insertions and soon to be fistuloplasties.*
> *I am aware of educational development in Australia but not a great deal can be implemented as role development from a Masters program, lots can be learned but I am a sceptic on how much can be used to extend the radiographic role. I do not think grade 2 - grade 3 for a Masters constitutes this role development.' [2]*

Clearly this participant had seen a wide range of potential role development involvement in the UK but, importantly, was aware of Masters level programs to support education in aspects that would lead to radiographer role development. The main point however, was that the re-grading potential available for someone investing in his/her own education to this level. Currently minimal reward or support is evident with and could be questioned as being financially insufficient for radiographers to self fund themselves through an expensive Masters degree.

One participant [11] knew of an image interpretation course offered by Charles Sturt University in the State of New South Wales – even though several others were available at the time of the survey. Participant 21 saw the UK College of Radiographers as being the professional body that supported radiographer interpretation internationally in advance of the AIR. This respondent was also a sonographer so indicated the Australian Sonographer's Association (ASA) as being a professional body that supported interpretation by radiographers. The nature of and operator dependency of sonography, plus lack of radiologist contact during the dynamic scanning sequence, has enabled sonographers to incorporate into their regular activity a level of interpretive capability. This is often supported by the ASA in its activities.

Question 4

Question 4 asked about the participants' expectations for support should musculo-skeletal describing become part of their role in the future. Several themes emerged to include:

- Educational courses *(6 comments)*
- Computer/internet based education *(3 comments)*
- Support from staff *(8 comments from 7 participants)*
- In house updating *(8 comments from 7 participants)*
- Performance feedback *(4 comments)*
- Miscellaneous *(5 comments)*

Educational courses

It is evident from the participants' responses that they value further education in this field. The theme detailed what six different participants felt they would require educationally to enable them to perform a describing role. This included significant educational input from Universities, external providers possibly through an interest group sponsored by the professional body and on-going refresher courses. It is interesting to note that there is a belief amongst participants that University provision should be a Bachelor's level programme or diploma, indicating that there is a lack of understanding about educational provision at advanced level offered by Universities. Audit of performance was mentioned in the same comment from one participant suggesting the realisation that a checking mechanism should be in place. One participant indicated that a degree of experiential/professional seniority plus attendance on a recognised but non award bearing course was a requirement in his/her experience whilst working in the UK. This would set a minimal standard expected of those offering image describing as part of their professional role. Finally one of the refresher course suggestions was for *'A course (1 – 2 days) every year covering new methods of image interpretation.'* It is not clear what was meant by this as once an individual has developed a working scheme or routine that is successful then what kind of 'new' methods of interpretation might there be? It would appear that international experience by some participants or alternatively operating in a further imaging modality such as ultrasound (US), has influenced the thought processes of those participants.

Computer/internet based education

As a sub-set of comments offered by participants computer based education programmes were suggested by two individuals, to support the radiographer wishing to provide an image describing service. Participant 9 indicated that training updates to cover aspects of more unusual pathologies or less common radiographic projections to suggest for further examinations would be helpful. Further, this participant indicated that protected time for reading current/new journal articles would be helpful alongside more reference material being available in the department where they were providing descriptions. Participant 13 made a useful point that computer based tutorials could be provided to ensure he/she stayed confident with regions or aspects of practice to which he/she does not always have significant and regular exposure to. This would occur as a result of the nature of work undertaken at his/her workplace. It would seem that computer based support is an aspect of on-going radiographer knowledge reinforcement that could have value.

Support from staff

There was variation between participants in their comments about this aspect. Participant 2 discussed the need for multiple staff to be able to offer describing so that a team of radiographers were able to support each other as had been experienced in the UK. The remaining participants expressed a need for on-going support from staff mainly recognising the need for this help to come from doctors. This is best represented in the following quotations:

> *'If I was not confident on reporting an exam I would hope there would be support available to assist with the interpretation.' [4]*
> *'Close co-operation with emergency dept consultants and follow up would add certainty to one's efforts and provide validation to the exercise.' [8]*
> *'Support for the new role and how you will then fit into the [radiology] department and the Emergency Department.' [16]*
> *'RANZCR-recognition ? Registration as div 2 image interpreter?' [22]*
> *'Need support from the staff at work e.g. Doctors. It is not something a radiographer should be taking on, on their own. I think it is important to have the backup of the radiologists in decision making.' [27]*

Evidently there is a degree of uncertainty about undertaking the role without backing from doctors and extra help being available either from the radiologist or, as a stop gap position, the emergency department medical staff. In particular participant 27 appears to have strong concerns about whether the radiographer should be undertaking the role at all. Participant 22 promotes the idea of a lower grade interpreter that would have the support of the RANZCR.

Participant 6 suggests that sitting with the radiologists while they report certain images or when radiologists provide verification of the image content would be a good teaching and learning opportunity. This could occur during or after initial training for radiographer describing. This is not an unusual component in UK initial training programmes and is seen as an audit technique there as well.

In house updating

In house updating is seen as an important aspect to on-going practise. One suggestion [participant 2] supported the need for annual updating with on-going competencies assessed by the radiologist. He/she stated that the onus for doing this rests on the individual – presumably to maintain currency? Participants indicated that on-going tutorials and case discussion with radiologists would be useful and regular skills updating to ensure radiographers standards were maintained at a high level. These would also serve to revise difficult areas that individuals identify. [4, 13, 16, 17 and 20] There could also be regular fortnightly or monthly radiographer led meetings where presentations are made about pathologies [and trauma – added comment] encountered during their work.

Participant 21 makes some insightful comments that recognise the role of the wider team. He/she suggests that the local health network including emergency department educators should meet with the radiographers in feedback sessions to discuss how well the system is working. A second comment indicates that the HMO, RMO and Nurse Practitioner meetings are also appropriate areas where extended radiographer role contributions and performance could be discussed.

Performance feedback

As indicated earlier, performance feedback was recognised as a key element in the on-going capability identification amongst radiographers. Feedback about results, especially false positives and negatives and guidance from the radiologists appear to be of value to these participants at this stage [4, 7 and 10]. Participant 11 felt that having access to the radiologist to obtain an explanation about incorrect diagnoses in the early stages of study/performing a describing role would be of importance.

In house peer review

Participants 8 and 9 were keen to receive regular peer review with associated staff meetings to discuss cases to provide continual feedback and education. Radiologist and supervisor input with respect to missed pathologies and accuracy rate calculations are also stated to be of value. Participant 13 suggested random audit of his/her performance would be especially useful from a perspective of highlighting any weaknesses he/she may have in his/her describing approach. Clearly these participants are keen to ensure they perform to the best of their ability with a view to providing the best service to the patient.

Miscellaneous

Participants making comments that were classified as miscellaneous indicated that they believed there was no need for further monetary reward as he/she felt that describing formed part of their duty of care to comment or inform a senior (?) doctor about any trauma. This was in the light that he/she felt that this is already performed [2]. There was recognition that more time may be required by the radiographer to perform the duty so managers ought to recognise this [7]. Most clearly two different participants to those answering question 2 (p132) identified that liability insurance needed to be increased to support the radiographer [8, 21].

Again, participant 27 wished to raise the recognition of the role of the medical staff in this process by stating *'It is really the doctor's responsibility in making the final diagnosis.'*

Question 5

Question 5 was concerned with the participants' thoughts about the intensive nature of the testing regime for this study. As with previous questions several themes emerged and are detailed on p141:

- Time *(7 comments – 7 participants)*
- Confidence *(1 comment)*
- Prior knowledge *(5 comments 4 participants)*
- Difficult cases *(2 comments)*
- Performance level *(5 comments)*
- Approach to describing *(2 comments)*
- Coming to the University *(1 comments)*

<u>Time</u>

These participants all commented on the time it could take to participate in an intensive study such as this. Most quoted finding the time amid busy lives and the current demands around their working situation with one radiographer indicating he/she covered three radiology departments in the rural setting [1]. One participant stated that he/she might be challenged to complete the test before attending for the study session as it was perceived that he/she would be *'...quite particular with each image.'* [9] The general opinion though was time would be found.

<u>Confidence</u>

One participant was very concerned about the image description test. This radiographer [1] felt that:

> *'The other challenge is lack of confidence and feeling as though I will fail the initial test miserably and probably not do very well in the second test.'*

It would seem that loss of face is part of the challenge faced by this radiographer at least.

<u>Prior knowledge</u>

The level of prior knowledge or the ability to recall previous information was the cause for concern with these radiographers. Even with a *'... reasonable experience of acute skeletal injuries...'* [10], one participant felt there was a need to have more experience with chronic pathological appearances as well as in the chest image although this was not part of the investigation. Participant 17 felt he/she had inadequate experience and education to be able to make the correct diagnosis and participant 26 was fearful of not recognising a given pathology because he/she had not come across it and did not know the accurate names of pathologies.

Difficult cases

Participant 4 expressed concerns about being able to recognise and correctly interpret paediatric and skull/facial skeleton images. A recurring concern, that of missing a life threatening injury, was expressed by participant 24.

Performance level

Being able to perform at an adequate level that is consistent appears to be an area that the radiographers had concerns about. Participant 2 was particularly keen to be consistent in his/her interpretations between tests. Participants 4 and 9 expressed concerns that they would not be able to interpret the images to levels they believe they can now i.e. when being measured by an external arbiter. They also believed that their recognition of pathology may not come up to self expectations.

One participant felt he/she was too old for the task and joked that his/her computer and concomitant operating skills would not be sufficient [9]. Participant 21 had concerns about fatigue with a large test and that his/her dictation, writing and terminology skills would not be sufficient for the test.

Approach to describing

These two participants expressed some thoughts on their approach to interpreting the images. They are quoted below:

> *My current approach to interpretation is based on clinical notes however I assume that radiologists use a more methodical approach to interpretation which reduced the chance of missing significant pathologies. [10].*
> *When compared to a radiologist, I don't have a trained set pattern on how to systematically assess an image. I feel that I may miss vital indicators because of this. [13]*

This suggests that radiographers believe that radiologists follow some schema in their interpretation of images, which may be an incorrect assumption on their part.

Coming to the University

A comment made by participant 1 adds a further facet not considered in depth when the study was constructed. He/she stated

> *Another challenge is getting accommodation in Melbourne near the University for the weekend course. I will need to get down to the city on Friday night ready to begin early on Saturday morning. This necessitates money for travel and accommodation, which I will ask the hospital to help out with.*

Even though the course was provided free of charge it is evident that some staff groups would have difficulties with participating in research like this. It does suggest though, that feelings are strong in the radiographic workforce that individuals are prepared to extend themselves to enable participation in this study.

Question 6

Radiographers were asked if they believed they can describe the content of an emergency musculo-skeletal radiograph at a level matching the radiologist. Of those participants that replied to this question 13 said yes and 4 said no.

Question 7

Question 7 provided the stem "By indicating YES or NO in the appropriate box, do you think commenting on the images while the patient is still present:.." to attempt to elucidate features that might influence image describing if the patient was still present. The responses and questions are shown in table 7.1 below. Clearly the majority of radiographers responses suggest that describing, and features about the process, will enhance the patient and professional position in a positive way.

Comment	**YES**	**NO**
Will enable you to interpret the images more confidently.	11	6
Gives you an interpretive advantage over the radiologist.	15	2
Will be helpful for the emergency department doctors.	17	0
Will encourage better quality radiographic technique.	16	1
Will enhance your status amongst radiology and emergency department colleagues.	15	2
Will improve the patient experience.	14	3

Table 7.1 Potential interpretation influencing features from radiographers describing

Question 8

Question 8 asked whether interpretation of images by radiographers while patients were present in the department may be affected. A range of themes became apparent including and are listed over:

- Time in a busy dept *(3 comments)*
- Workflow *(4 comments 3 participants)*
- Patient experience *(5 comments)*
- Other staff experience *(7 comments 5 participants)*
- Radiographer autonomy in examinations *(11 comments 6 participants)*
- Radiologist impact *(2 comments 1 participant)*

Time in a busy department

This aspect concerned itself with the amount of time that might be available for radiographers to perform a descriptive role on top of providing the normal imaging service [1, 6 and 24]. The comments focussed on the perception of how busy a radiographer was as this could not only put pressure on the radiographer but would subsequently negatively impact on the patient. Three quotes below are useful to consider in this light:

> '*Time is always a big factor, as my patients have appointments every 10 or 15 minutes and there is always not much time between patients.' [1]*
> *'Depends on how busy your shift is and whether you have the time spare to analyse all images to the detail they want. Some weekend shifts are busy enough without the added stress and pressure to accurately assess and diagnose images.' [6]*
> *'The time constraints on the radiographer, with usually many patients waiting for x-rays in emergency.' [24]*

Workflow

In contrast to the previous comment, improved workflow and patient through put are cited as major gains in following the radiographer role change. This could reduce waiting times and potentially achieve earlier discharge [4, 17]. Participant 4 believed patient anxiety could be reduced as the waiting time for results would be reduced coupled with improved radiographer autonomy to inform the patient at the time of the examination. Participant 16 made the point that there could be a negative impact on workflow due to the way in which radiographers with a different skills base would interact with the other members of the radiographic team, suggesting that challenges would arise but that these could be overcome. The impression from participant 16 appeared rather elitist. The comment suggests that those with an advanced role might perceive themselves and their role differently and would not work within the radiographic team to the same extent.

Patient experience

The comments from this theme echoed some of those discussed under the workflow heading. Most participants' [2, 7, 13 and 17] projected a positive outcome and are revealed in the quotes below from some of the respondents:

> *'It will also allow faster treatment of these emergency department patients and assist in triaging.' [7]*
> *'It may shorten the time the patients are present in the emergency department by either discharge (NAD) or booking a theatre slot sooner (Fracture diagnosed). [13]*
> *'Increased patient satisfaction.' [17]*

Participant 2, although appearing positive to begin with, sounded a warning in that in the false positive scenario an excessive wait may be generated resulting in patient dissatisfaction. Participant 6 made an insightful comment:

> *'Some patients may be unhappy with "non doctors" assessing their films. If we get it wrong would this affect how professional radiographers seem?' [6]*

It would appear that this group of participants recognised gains and also those aspects where there could be issues from radiographer describing.

Other staff experience

It was perceived by the participants [7, 13, 17, 26 and 27] who made comment that other staff would in general feel a benefit from the enhanced role of radiographers. When a radiologist was not available, radiographer describing was perceived to be of value, particularly to ED where inexperienced medical staff may be working outside office hours. A faster response time was also noted as a key aspect to performing this function with the added benefit of improving relations between ED and radiology. Participant 26 felt that the radiologist might not have to be consulted at all if a trained describing radiographer was available, which was supported by participant 27 who said:

> *'Faster patient diagnosis. For example the emergency doctor can have an idea of what is wrong with the patient before the images are reported by the radiologist.' [27]*

Radiographer autonomy in examinations

This theme was a significant development from question 8. From the responses it is clear this group of radiographers have some strong views about having some level of autonomy to perform further radiography without referral to a radiologist, and that this would be reinforced by the potential to examine the patient whilst performing the radiographic examination(s). This is illustrated by the quotations below:

> *'Extra views are more easily obtained. / Physical examination of the patient with regard to radiographic pathology (or lack of) may assist in some difficult interruptions [interpretations?]' [8]*
> *'I think interpreting the images while the patient is there provides an opportunity to ask about old injuries or related incidents that may aid in diagnosis.' [9]*
> *'The opportunity to provide supplementary views based on what is interpreted is a great advantage and increases the chance of correct interpretation not only by the radiographer but by the radiologist as well.' [10]*
> *'Like ultrasound, peripheral pathology may be noticed unrelated to clinical question and exam expanded to accommodate this therefore more streamlined for the patient.' [21]*
> *'Any extra views can be taken if needed to visualise the pathology better.' [26]*

Despite the positive comments noted above, there were caveats indicated by some participants [9 and 21] as revealed below:

> *'Although I would never doubt a patient's pain I feel personally there could be potential to be misled by their descriptions of the affected area rather than keeping an unbiased opinion as the radiologist does, leading to radiographers looking for pathologies that are not present.' [9]*
> *'Problem in that diagnosis is made in light of patient contact information rather than image interpretation alone i.e. making the images fit a diagnosis.' [21]*

Some participants also felt that the radiographer could have excessive pressure placed on them to produce a report if the public knew this service was available. This would be especially problematic if the request was made about an examination outside the radiographer's scope of practice. One participant suggested that he/she might be distracted by the inquisitive patient who would ask many questions to try to gain an answer that couldn't be provided. Participant 26 though was assertive about the role of the radiographer as he/she believed:

> *'I think it is about time that radiographers get more respect in their line of work, and I believe this would achieve that.' [26]*

Clearly this radiographer was proud about his/her role and believed that due recognition was required. He/she felt that this role might enable greater esteem for his/her colleagues for the service provided to the healthcare team.

Radiologist impact

Participant 13 was clear in his/her assertions about how a radiographer description role would aid the radiologist. He/she opined that the correct further imaging option would be chosen if radiographers were enabled to perform this descriptive function, to reduce unnecessary imaging and reduce patient dose. This participant also believed that the radiologists' role would be enhanced as his/her radiologist workload would be reduced, freeing their time up for more involved procedures that they would be better suited for.

7.3 Radiographers post image test 2 survey responses.

From the 16 participants who completed the second image reading test, 14 offered comments to the survey that was developed from the pre test one questionnaire. The second survey attempted to elicit if any changes to attitudes or responses had occurred. Questions for this survey were reconstructed to enable reflections from the participants to be collected with further details being requested so that change could be evaluated or an initial explanation could be built. The two non respondents completed an initial pre test survey.

Question 1

Question 1 asked participants to state why they wanted to participate in this study. Several sub components became evident in their responses including:

- Role change *(5 comments)*
- Knowledge extension *(6 comments from 5 participants)*
- Interpretation skill testing *(6 comments)*
- Radiographer improvement *(1 comment)*

Role change

Participants 2, 3, 7, 9 and 27 commented in this vein. They expressed a need for radiographers in Australia to participate in role change and that they believed this aspect of advancement was appropriate for them. They also made the points that the course had enhanced their knowledge base with respect to appreciating the skeleton more and its response to trauma as injury mechanism knowledge added a further dimension to their understanding. Furthermore the course had exposed them to a wider comprehension of pathologies that might be evident as co-morbidities on images in patients attending a trauma related event. Participant 9 highlighted the fact that being at the beginning of his/her career then a wider role would be a challenging development to be involved with and therefore would enhance their jobs.

Knowledge extension

A few different perspectives became evident from participants 1, 4, 5, 6 and 7. Two main foci from participation became apparent, namely that radiographic technique would improve along with the knowledge base associated with imaging pathologies and paediatric patient image content recognition. All participants in some way mentioned that the course had enhanced their personal radiography knowledge as well as improved their ability to identify abnormalities in the radiograph produced following trauma.

Interpretation skill testing

Although participants responding to this question mainly concentrated on commenting on the fact that they believed their interpretation skills would be improved through contributing to this research, there were also sub themes within their observations. Participants 6 and 10 saw their ability to aid medical staff as being key:

> *'I wanted to be more confident in helping the emergency dept staff with a diagnosis after hours [6].*
> *As I currently work in a small rural hospital without a radiologist in attendance I am often asked by GPs for my opinion regarding radiographs. I see this as an opportunity to gauge and improve my skills in interpretation.'* [10]

Participant 17 added a further facet to this through the recognition of improved radiograph provision:

> *'To increase my image interpretation skills in the hope that this knowledge would be able to assist me in making decisions regarding image quality or additional images that would be useful.'* [17]

Evidently there are aspects to the participation in an interpretive or descriptive role that can add to the overall quality of service provision beyond the obvious offer of an opinion on images following trauma.

Radiographer improvement

Participant 16 recognised the need for research to occur in this aspect of healthcare practice, stating:

> *'Because I believe that Radiographers' have something to offer in this area and I am willing to give up my time to bring research backing into this area.'* [16]

There is an interesting sub text here however, with the participant indicating that he/she is prepared to give up time to participate, raising a concern that perhaps most radiographers are unwilling to do so?

Question 2

Question 2 asked participants if any anxieties/concerns that were evident before participating in this study about performing an interpretation function had changed. Three sub themes emerged from this question including:

- Performance level anxiety *(8 comments)*
- Legal perspectives *(2 comments)*
- No changes *(1 comment)*

Performance level anxiety

Eight participants gave comments with this aspect in mind [1, 2, 7, 9, 10, 16, 17 and 27]. The majority of responses appear to indicate that these participants either retained a concern that they would not perform at an adequate level or that completion of the course with the second test has indicated to them that their knowledge level is insufficient. This stance came from the realisation of how little they knew. Comments included:

> *'If anything I am probably more anxious now as there is just so much that I don't know and I just haven't found the time to improve myself.' And 'I work fulltime in a small rural hospital so it is very busy. In saying that, I do feel more confident in my informal reporting, and have certainly taken much more care in looking at images, and knowing what I am looking at.' [1]*

> *'If anything my anxieties have increased because I am aware now that there is a lot more that I am now aware that I don't know and before I was oblivious to this. I will be able to learn though as required.'* [16]

> *'No. My main concern was that despite my experience as a radiographer I would not have all the necessary skills to be able to correctly interpret images. I feel that although I have increased my confidence I feel that there is a lot more that I need to learn before I would be confident in image interpretation which would impact on patient treatment.'* [17]

'I don't believe they have, I still need to gain confidence in my decision making however am more confident to seek out information to help with any interpretations I attempt to make.' [9].

'I am still not confident with paediatric reporting but I have improved in this area.' [7]

'My anxiety is about performing at a low standard, making too many false positives and any false negatives at all. To me the false negatives create the most anxiety for me because I want to avoid them at all costs.' [2]

In comparison participant 27 identified that there is a need to get approval from radiologists to perform this role especially when they are paid per report as private providers and that the radiographer's role may be limited:

'My main concern is getting approval from radiologists. This may be very difficult especially in the private sector where radiologists are paid per report. They may not be willing to allow radiographers take on such as role. Radiographers may only be able to assist in image interpretation at hospitals where there are limited radiologists or practices that are too busy where more urgent reporting is required. Thus, the assistance of radiographers reporting images may be required.' [27]

It would appear that this participant believes there could be an acceptance of two levels of working and therefore the performance levels may be acceptably different according to the centre being worked in.

Participant 10 by comparison felt that his/her confidence had improved in the assessment of radiographs but added the caveat that perhaps a concomitant interpretive skill level improvement may not be evident. This would only become apparent when the results of test two were made available.

Legal perspectives

The legal aspects were separated from comments made by participants 5 and 6. Participant 5 indicated that legal issues were of concern though no details are given. This observation was made alongside a concern about workflow issues, which again were not clarified though it is assumed that this participant believed the time it would take to perform a descriptive role would impact heavily on the patient throughput from ED. Participant 6 identified legal issues as a concern within the context of his/her ability to correctly interpret the findings in radiographs of children:

'I feel a little more confident with giving my opinion but there are still so many normal variants especially with children. Our radiologists have not given an opinion on us, as radiographers, having a say in the diagnosis, but we can still help out the emergency doctors if they ask. Also still not sure where we stand legally about performing the interpretation function in our hospital. I feel I am more concise in describing the site of injury.' [6]

Some uncertainty is clearly demonstrated here.

<u>*No changes*</u>

Participant 18 indicated he/she had no anxieties or concerns except about the time taken to complete the programme and image viewing tests.

Question 3

Question three asked about changes in attitude for the need for on-going support that would be required to enable the performance of the interpretive duty. Three themes emerged from the responses:

- Education support *(5 comments)*
- Colleague support and attitudinal change *(9 comments)*
- Time concerns *(1 comment)*

<u>*Education support*</u>

On-going support was again highlighted as a requirement to provide radiographer descriptions. Participant 2 remarked that:

'A small amount of education has helped immensely into changing my attitude of "Can radiographers comment to an acceptable standard" but I believe this is ongoing and education and support from colleagues and radiologists will be a key.' [2]

There was further recognition by participant 5 that constant Continuing Professional Development (CPD) and Quality Assurance (QA) would be necessary to ensure participants maintain performance at an acceptable level. Participant 9 made similar recommendations but added that there would most likely be a need to tailor CPD to individuals rather than providing generalised information as seen in the education programme developed for this study.

Participant 18 remarked that the approach adopted is a great start and that with proper training radiographers with experience will be able to fulfil this role. The inference taken from this is that a longer course of study would be better.

Colleague support and attitudinal change

Participants 1, 2, 3, 6, 10, 11, 16, 17 and 27 made comments within this theme. All participants had some observation to make that suggested that without the input of the radiologists, radiographer describing was unlikely to be successful. Furthermore, there was the recognition that acceptance by radiographer colleagues and medical staff and to some extent nursing colleagues from areas such as ED would be needed. Again, without this, success in the performance of and training for such a role would be curtailed. Comments are shown below. Particularly insightful are those of participant 2:

> *'I believe ongoing support will amount to at the very least, (1) radiographers who mentor junior commenting staff to have post grad qualifications, (2) accessible resources and protected study time in the clinical setting, (3) Radiologist support with either in house training, discussions on false positive/negative cases when compared against gold standard.'* [2]

Participant 3 took a service improvement stance in his/her comment:

> *'Need better support from radiologist and clinicians (eg: respect etc) Need to abolish scepticisms from clinicians on radiographers' assuming their roles but to remind them that this will enhance patient care.'* [3]

Participant 6 had a more circumspect impression of the needs that would be required from colleagues. He/she stated:

> *'We would need the full support of the radiologists. It would be good to sit in on tutorials they give to medical students, sit in with the radiologists themselves as they report, go to orthopaedic meetings, have legal support from the hospital, and be supported and respected by those in the emergency department. It would be good to have in-house presentations by other radiographers about interesting and difficult cases, as all exposure to normal and abnormal images is vital.'* [6]

This participant evidently has a wider perspective and recognises the multidisciplinary components that are likely to impact on radiographers to achieve the aims of role development in a describing responsibility. Participants 10, 16 and 17 reinforced the perspectives of participants 3 and 6, clearly outlining the need for the wider team involvement and acceptance, whilst also identifying that the radiologist retains the expert position due to the earlier and wider medical degree and subsequent specialisation:

> *'I still feel that the opportunity to seek guidance/an opinion from radiologists is very important. The opportunity for further study and testing would also be of great value.'* [10]

'I have realised that we would need the support and backing of the radiologists and the support of ED staff that they would be willing to accept our interpretation of the images. Before I felt that we could go at it alone.' [16]

'Lots of support from radiologists. In addition, nurses and medical doctors themselves would need to increase respect towards radiographers on the whole.' [17]

Participant 11 indicates that he/she found the work difficult, especially when it came to formulating a comment or in his/her terms a 'report.' Essentially however, the same message appears to be coming through as identified by other participants:

'I completed this exercise using only the information provided in the course, text books and the internet. At times I became "bogged down" in the diagnosis and wording of the report. Discussion with radiologists and colleagues would have been a tremendous help. I am sure with this backup and regular reporting opportunities, reports would become more accurate and appropriate.' [11]

Participant 27 raises again the need for radiographers to be accepted into the team so they will be recognised and allowed to perform this role. He/she said:

'*Radiographers need the support of radiologists and emergency doctors. They need to approve the idea of radiographers performing image interpretation and be willing to work with radiographers as a team.' [27]*

<u>*Time concerns*</u>

Participant 2 made some further comments about the impact of the time required to perform this 'extra' duty within his/her usual role. After performing a short audit whilst on duty over one week this participant made the following observation:

'I still don't have the answers for 'time' which this additional radiographic duty will encroach on existing duties meaning more 'handovers' at end of shifts. If radiographers can save time at the discharge end of emergency then perhaps this equates to an additional EFT radiographer to assist at the clinical level. I imagine we will need to prove the prior before being recognised with the additional staff member.
I did perform a weekly analysis of commenting [on] appendicular cases within our hospital recently and found (only including appendicular cases from 5pm – 7am) that approximately 3 cases would require an abnormal comment and 6 require a normal comment, not a significant increase in work load I felt. So this may help us locally to reduce radiographer anxiety, at least until our workload increases.' [2]

It would appear that this participant is aware of wider practices, probably because of his/her time spent working in the UK. Clearly this individual wants the project to work and is investigating ways in which arguments about workforce shortages within the radiographer ranks could be addressed to enable the development to go ahead.

Question 4

Question 4 asked "As part of the study you have participated in 2 tests and completed 135 interpretation cases (209 exams) in each test to compare against the radiologist. Have the challenges you felt before completing test 1 changed?" This question focussed on the participation in the project and considered the participants asking if the challenges felt before completing test 1 had changed. The themes emanating from the question are listed below:

- Time *(4 comments)*
- Confidence levels *(6 comments)*
- Work system *(1 comment)*
- No change *(3 comments)*

Time

Participant 2 clearly had some strong feelings about finding the time to join in with the study due to the required input to complete the study/education programme. He/she did remark that the second test was completed more efficiently though it was also identified that no time limit was placed on the participants, which might not be representative of the clinical requirement.

Participant 16 also remarked that the expected time input was large however, the overall enjoyment felt about participation meant that he/she felt that '...it wasn't too burdensome.'

Confidence levels

The majority of comments revealed that the participants had increased confidence levels in their abilities. There was a perception of improved specificity ability [6] however this participant retained concerns that he/she was over analysing image content as more was now visible in the examination. Description content was also improved as a self reported outcome:

> *' I feel more confident in saying "definitely normal". I would have said "probably normal" beforehand just to be on the safe side. I feel I have a better technique at looking at the films, but I don't know whether I "see" more now, and am picking up things that I didn't see before and over-analysing things. Paediatrics is still a challenge, knowing what is normal and what is not. I feel I have more concise*

answers and can describe pathology and location better, rather than saying i.e. fractured thumb.' [6]

In contrast however participant 1 still felt uncomfortable about missing some pathologies, even though this respondent believed that self reported performance was improved.

Participants 7 and 10 supported the increased confidence perspective and participant 18 supports the notion that more information is visible in the radiograph now as:

'Yes. After the 2 days briefing I am able to see the images from different angle and able to describe better.' [18]

Participant 9 made the remark that following the education programme he/she had higher performance expectations; otherwise no changes were discussed.

Work system

Participant 2 found working with the software in the format used was tedious, though '...it's not a big hassle...' He/she drew comparisons with software from a UK university that was provided with a postgraduate course this participant signed up with just as the second reading of the image test came around.

No change

Participant 3 indicated there were no changes in his/her perceived challenges from before the first image viewing test as did participant 5, though he/she also stated that his/her confidence levels were slightly higher than test one. Participant 17 also felt that there was no change in his/her perceived challenges adding that following the study weekend he/she perceived that there was:

'...after attending the information session I feel I have a better understanding of descriptive terms and key things to look out for.' [17]

Questions 5 and 6

Questions five and six gave participants an opportunity to offer an attitudinal, scaled response (question five) about whether radiographers could match radiologist reporting of ED images. A yes/no reply to question six was constructed to align with a series of details in describing that could be affected by the patient still being present. The responses to these are demonstrated as tables 7.2 and 7.3 over.

Always	Mostly	Occasionally	Rarely	Never
	9	5		

Table 7.2 Question 5: Since participating in the study do you believe radiographers can always describe the content of an emergency musculo-skeletal radiograph at a level matching the radiologist?

It would appear that radiographers have adjusted downwards their ability judging from the spread of the answers received, when compared with the pre test 1 survey.

Comment	**YES**	**NO**
Will enable you to interpret the images more confidently.	12	2
Gives you an interpretive advantage over the radiologist.	13	1
Will be helpful for the emergency department doctors.	14	0
Will encourage better quality radiographic technique?	13	1
Will enhance your status amongst radiology and emergency department colleagues.	13	1
Will improve the patient experience.	13	1
Will be difficult to achieve due to pressures on your time.	9	5
Will require support in forms of liability insurance beyond that provided by your place of work.	12	2
Can only be provided in fixed areas of the body.	10	4
Requires significant further education and on-going performance audit.	13	1

Table 7.3 Question 6: Radiographers impressions on their description performance when the patient is still present

The weighting of responses in comparison with those elements asked in the pre test 1 survey shows understanding of the depth of radiographers' concerns or considerations. This becomes evident when the test 2 survey question responses are looked at alongside those matching questions seen in test 1 and scrutinised for any changes.

Question 7

Question seven asked if participation in this study had changed participants thoughts about the acquisition and interpretation of emergency musculo-skeletal appendicular skeletal plain radiographs? The themes generated included:

- Enthusiasm *(7 comments)*
- International experience *(1 comment)*
- Australian need *(2 comments)*
- Education and support *(2 comments)*
- Radiograph acquisition standards/self critique *(3 comments)*

Enthusiasm

There appears to be some divergence of perspective based on the responses from those who answered this question to generate this theme. Participants 3 and 11 firmly believe in the role radiographers have to play in the '...*interpretation of X-rays*...' [3] and '*I have always believed radiographers have a role here and still believe this, perhaps now I am more confident about offering a diagnosis on a wider range of examinations* [11].'

As a contrast however, participant 2 is more cautious indicating that '... *it [radiographer describing - parentheses added] will require some careful planning and assistance before it is implemented*...' Participants 5 and 16 express the need to have more experience and to realise there is more to this role than is first apparent:

> *'I would like to do it, however at a later date, once I have more experience.'* [5]
> *'I now am certain that not all radiographers would be suited to this role, but there are many who could be excellent. I feel that it is more of a challenge that what I had first anticipated.'* [16]

Participant 1 took a different perspective indicating:

> *'We definitely have an advantage over the radiologist as we are right there to see the patient and the injury. Talking with the patient is always helpful. I am now more aware of the usefulness of really good images to help interpretation.' [1]*

International experience

The international experience of participant 2 had resulted in contact with radiographers who performed a reporting role. This participant was keen to ensure that Australian radiographers were aware of UK practice and that '...if they can, I know I can...' attitude was evident amongst radiographers working in Victoria at least.

Australian need

Participant 2 again spoke up with a further perspective:

> *'The correct geographical, radiologist short supply and a 24/7 emergency department with the need from emergency a radiographer commenting workforce which needs this comment to assist with discharges or admittances.'* [2]

Although unclear, possibly due to trying to express his/her ideas succinctly, this is likely to be read as a demand exists due to geography, a lack of radiologists and the need to supply 24 hour cover requires a comment from someone [radiographer – parentheses added] to enable patients to be sent home or admitted for appropriate care. Effectively then, being able to comment or describe image content will enhance service provision most probably in regional, rural and remote areas. Participant 27 supported this perspective and added in that there were examples of the approach working internationally that could be adopted in the Australian healthcare environment.

Education and support

Strong, on-going educational support is a key criterion that should be fulfilled to enable radiographer describing to take place [6 and 17]. Participant 6 makes several important points linked to this sub theme:

> *'It [the study – parentheses added] has definitely made me realise how important good radiography is to a more accurate diagnosis, and the need for good clinical notes and talking to the patient. I have a higher appreciation of the knowledge that the radiologists have, and would be keen to further my studies, but am unsure that I could ever do as good a job as them without a heap more study, legal and hospital support.'* [16]

Radiographic acquisition standards/self critique

Three participants made a connection with improved radiographic technique (also suggested by participant 16) to enhance the potential outcome of the examination. This stems from the range of accepted images that found their way into the test to make the radiographer reader aware of the difficulties that could face the radiologist or other reader, medically educated or not:

> *'Yes in that due to the variability in the projections provided between cases there needs to be more uniformity and protocol enforcement of the essential projections needed in emergency examination. I also feel that it has made me critique my images to a higher standard as I was more aware of the need for the radiologist viewing them to be able to create a report of what was seen.'* [9]

Participants 10 and 18 looked at this feature from the position of knowing injury mechanisms or appreciating where else to look for potential evidence of injury informs the radiographic standard or the necessity to produce appropriate further projections.

> *'I have always felt that a better appreciation of the injury process and understanding of anatomy and injury interpretation would ensure better radiographs from the technician.'* [10]
> *'Yes. Has taught me to provide the extra views and images where necessary for accurate reporting.'* [18]

The use of the technician identifier is pertinent as this appears to suggest the self confidence and professional labelling issue discovered by the Rouse study [125] for the AIR in 2004 still carries weight. Alternatively it may be a term this participant uses freely as it is their working title.

Question 8

Question eight was devised to obtain examples of events where participants believed their input through direct contact with the patient and subsequent interpretation was not acted upon by the emergency department doctor. The intention was to establish whether some of the patterns that might be beginning to emerge from the perspective of team position or enhanced level of knowledge results in a helpful contribution by the radiographer. These can then be linked to earlier statements that had been made. Several themes became evident and will be discussed over:

- Responsibility to inform *(2 comments)*
- Teamwork *(3 comments)*
- Failure to use radiographer input *(1 comment)*
- Recall due to radiographer input *(2 comments)*
- Over treatment *(2 comments)*
- Expectations of Radiographers *(3 comments)*

<u>*Responsibility to inform*</u>

Participant 2 made the following point even though he/she did not provide an illustration of an event that was affected by radiographer input:

> *'I make our emergency doctors aware if I see a **subtle abnormality** to avoid this happening at our hospital. I feel the doctors in emergency listen to me if I have something to say, that is probably because of my experience in emergency and that my opinion is worthy of hearing.'* [2]

As a further point, participant 2 also identifies that any examples he/she indicated that were subtle in nature were usually seen in the orthopaedic clinic the next day or fracture clinics the following week. Appropriate treatment according to ED protocols having already been put in place. In addition participant 27 highlighted how the lack of radiologist cover at night necessitated radiographers' input to include pointing out plain radiograph abnormalities as being a key role.

Teamwork

Participant 1 drew upon rural experiences to illustrate how team working would be supported by radiographer describing. He/she gave the following examples:

> *'I had a patient who presented with an injured finger due to netball. I diagnosed a fracture, sent her back to the doctor who dealt with it correctly. When the report came through from the radiologist as NAD, I asked that the films be re-reported, which subsequently happened and showed an injury.'*
>
> *'I can't think of any situation when the doctor has ignored what I have had to say. In my experience, they are usually only too willing to be advised on the films in front of them. Perhaps in rural situations it is different to big city hospitals. As medical staff we are all on the same level because we all live together and often know each other socially. There is much respect between all areas.' [1]*

Participant 2 made the following comment:

> *'I feel the doctors in emergency listen to me if I have something to say, that is probably because of my experience in emergency and that my opinion is worthy of hearing. This has not always been the case in my career for example emergency physicians don't listen too much to locums but they do to experienced radiographers. I believe it is learned respect from time spent in the same emergency department where people get to know each other and have had many case opinions reinforced by emergency physician peers against what my opinion has been, OK enough.'* [2]

Participant 11 believed that the medical staff he/she works with is receptive to the radiographers' thoughts and suggestions. He/she illustrates with some examples:

> *'I don't believe there are many missed diagnoses in this area of emergency medicine in our ED department. Most of our doctors are receptive to radiographer's diagnoses or seek seniors or radiologists opinions on our suggestion. I am pleased to be trusted in assisting in diagnosis and helping to reduce unnecessary radiation.*
>
> *Since starting this course, while reviewing images, I diagnosed a Salter Harris Type 2 fracture of the finger (on a patient not x-rayed by myself). When comparing with the radiologist report, no abnormality was diagnosed. Cross checking with another radiologist the fracture was confirmed and the patient followed up. Recently after x-raying a cervical spine on a 31yr old footballer a follow up CT was requested for a C5-6 fracture. Not believing that I had mis-diagnosed this patient I queried the need for a CT. The doctor pointed out an anterior osteophyte fracture and after consultation with the radiologist the CT was cancelled.'* [11]

Failure to use radiographer input

This radiographer [11] points out the danger of the medical staff not applying the radiographer input:

> *'Many years ago in a small hospital a patient walked in with a painful hip following a fall. I diagnosed an impacted NOF and notified the requesting doctor. The doctor would not believe my opinion and sent the patient home awaiting the radiologist's report. Before the radiologist could see the films the patient's hip "gave way" and he returned to the hospital with a displaced NOF fracture.'* [11]

Recall due to radiographer input

Participant 3 had two examples to give and made a strong point that whoever makes the diagnosis doesn't matter. He/she states that it's about a team approach due to the service being for the patient and not the personnel. He/she adds that a waste of capability is evident if the same approach continues to be taken and that a four year degree course is excessive if all radiographers will do is to take images:

> *'A few years ago after completion of an afternoon shift, I met a gentleman who I had x-rayed earlier that day, walking with crutches , and a crepe bandage applied to his ankle. After a friendly chat I was made aware that no fracture was present on the x-ray as advised by the emergency room doctor. I was able to contact the emergency consultant, and make him aware that there was a fracture present. The patient was then recalled, and POP was applied and referred to the orthopaedic clinic.'* [3]

> *'On another occasion, a patient had a large pneumothorax present on the x-ray. This patient was still in the waiting room. After discussion with the emergency room doctor, the patient from the waiting room was upgraded to the emergency treatment room.'* [3]

Participant 5 made the following point, based on a perceived poor capability of the ED team for reasons that have not been disclosed:

> *'It happens occasionally, furthermore our ED department is not efficient at evaluating patients, many pts have multiple visits to radiology throughout their few hours in ED.'* [5]

Over treatment

Participants 6 and 10 made comment about over treatment. In participant 6's experience there also appears to have been a failure on the part of ED to acknowledge the radiographer's input. Participant 10 gives a detailed account of how a young child and her parents were put through undue worry, though the position about litigation, noted by the radiographers themselves earlier, has probably come into play in this example:

> *'I can recall a time I told a patient I thought they didn't fracture their wrist but that the emergency doctors would assess it. The patient came past with a cast on and told me that I was wrong. I looked up their report later to find that there was no fracture seen, so I didn't feel so bad. They probably plastered it and re-xrayed them in 10 days ? scaphoid injury.'* [6]

> *'I have been fortunate in that the doctors I work with take my suggestions seriously and they have generally been acted upon. In one instance however I was called in after hours to take a cervical spine series on a ~4 year old girl who had fallen off her pony. She exhibited no pain and was dancing when I arrived. The radiographs did not reveal, in my opinion, an injury but when the GP viewed them she felt there was a fracture. When I pointed out that the line she indicated as a fracture was in fact a soft tissue line at the back of the chubby child's neck, pointing out that it extended well beyond the borders of the vertebrae she ignored my assessment. She then proceeded to tell the child's grandmother that the child had a broken neck and had her placed in a neck brace. An ambulance was called and the child referred to a city hospital for CT assessment. Subsequent radiologist reports from both x-ray and CT evaluation indicated there was no injury present however, there was a high level of stress placed upon the family. Fortunately this happens very rarely.'* [10]

Expectations of radiographers

Participant 6 raised the point that medical assessment and resultant failure to request radiology or excessive requesting places demands on radiographers. This results in further work either immediately or as recall. Now that patients are aware of the immediacy of digital image results they have greater expectations of radiographer capability. Due to the controlling nature of radiologists over the way radiographers are allowed to work this creates further pressures both on radiologists who are disturbed frequently, or through generating problems for younger radiographers. Participant 6 discusses this below:

> *'Most doctors will listen to our opinion if they come and ask us directly. We do hear though, of mixed results – things plastered that are normal, and fractured ankles that are not even x-rayed, let alone treated. This amazes me when we x-ray so much "normal" stuff – kids with good ranges of movement and little pain, but the doctor's order x-rays just to cover themselves. There sometimes seems no consistency and very little physical examination of the patient. Thus when they are properly examined later on, things have been missed initially and patients have to return to our department multiple times – very frustrating and time consuming. We are finding that the public assume we know results because they see us looking at their films, and GP's tell patients that we will tell them if we see anything, which puts a lot of pressure on the younger staff, and slows down our work throughput if we are chasing results for a lot of patients, and it forces us to interrupt the radiologists a lot. The introduction of the CR and DR consoles facing*

into the rooms has forced an increase of patients wanting results as they physically see us looking at the images rather than before when we would go out into the viewing room or darkrooms.'

[6]

Participant 9 made the point that radiographers have to frequently correct or amend/add further information to the histories obtained by ED medical staff. This was illustrated through the need to examine a colleague who experienced pain following a moving and handling incident prompting a request for imaging:

> *'A staff member who had experienced pain in the neck following a pat slide was requested for C-spine imaging (AP/LAT) with clinical notes indication a "previous cervical crush fracture". Upon discussion with the patient it was revealed that she had never had a fracture at all and had only been told of impingement of the nerves by her doctor. She was frustrated as her clinical information was completely incorrect and may have negatively affected the radiologist reporting. Because of this I went on to do further oblique imaging. The ED doctor was notified but upon follow up the clinical notes had still not been amended. I feel that due to time constraints in the emergency settings the referring doctors will often miss relevant information that the patient's provides. This is often revealed to the radiographer during the radiographic examination and I feel in conjunction could provide a much better service to the patient.'* [9]

The final comment received was from participant 18 who simply stated that due to the private provider nature of his/her working arrangements radiographers were not permitted to comment on the images obtained.

> *'As my work is with a private employer, we are not permitted to comment on images obtained. Only the Radiologists are to comment on radiographs.'* [18]

Clearly this practice goes against the professional expectations of radiographers detailed in the regulations of both their professional and registering bodies and further negates any moral or ethical perspective that may be involved in this situation.

Question 9

To round off the second questionnaire participants were asked to make any further comments about participating in the study. Three areas came to light:

- Viewing system *(1 comment)*
- Test length *(2 comments)*
- Clarification of practice areas *(1 comment)*

Viewing system

With respect to the viewing system participant 2 remarked that the software image viewing background was too bright and unlike the clinical setting whereby the unused area on the monitor is blackened. As a personal preference this participant felt that being able to view in this mode would have been preferable.

Test length

The comments received from participants 5 and 18 considered the length of the study was possibly too excessive to convince larger numbers to participate [5] and that feedback on the study day identifying what was happening would have been helpful [18]. Evidently the second participant failed to understand the reasoning for not looking at the images in the study session as this would mean the answers to the re-test were effectively given.

Clarification of practice areas

Participant 7 made the point that appendicular describing would be possible at the same level as the radiologists but that other examinations may have affected their relative performance when compared with the radiologists:

> *'Regarding question 5 – I believe that we would always be able to report at the same level as a radiologist on extremities. Including spines and facial bones may reduce our accuracy.' [7]*

Several of the participants acknowledged the value of the course making comments that expressed hope for the future of radiographers providing some kind of service through describing image content following trauma. Most importantly the final comment received was the wish to be kept informed about progress in the study to take the radiographer's cause forward.

7.3.1 Summary of the key points from the radiographer surveys

A large amount of detail has been collected through the surveys. At this point a summary of the key findings is appropriate and is presented in table 7.4 p165 and table 7.5 p166. The key points presented here are also further discussed in detail in chapter 8.

Question	Key findings
1. State why you wanted to participate in this study	Radiographers expressed they felt there would be improvements in: • Own interpretive ability; • Professional standing of radiography; • Improved service; • Better employment of an under utilised workforce; • Maintaining own knowledge base in the light of current undergraduate radiographer education.
2. State in the box below any anxieties/concerns you may have before participating in this study about performing an interpretation function	The main concerns for radiographers were: • Lack of ability to interpret; • Being wrong will impact on the patient and profession from multiple perspectives within the multidisciplinary team; • What will the relative responsibility and support from the wider team? • What is the legal standing?
3. Are you aware of any professional body input to furthering role development for radiographers?	Radiographers indicated they believed there was a general lack of support, however it was evident that there was an overall lack of knowledge about availability of support.
4. If radiographer describing for emergency musculo-skeletal image interpretation became part of your role, please state what on-going support would be required to enable you to perform this duty.	A wide range of ideas were suggested regarding initial and on-going educational support, which were computer, journal and tutorial based. Radiographers indicated that: • There is a need for support within and external to radiology • A feedback and governance system has to be created • This should be an expected role for all grades as it is service driven and does not necessarily require re-grading
5. As part of the study you are asked to participate in 2 tests completing 209 interpretations per test to compare against the radiologist. Please detail any challenges you feel about doing this.	The intensive nature of the testing regime required great focus from those participating; this might also be a cause for potential participant's decision not to join in. Overall there were concerns: • Regarding prior knowledge and how a lack of ability might be perceived by colleagues – especially difficult cases • Radiographers have very high expectations of their ability • There is an expectation that radiologists have a specific work system that makes them better at providing a reporting service
6. Do you believe radiographers can describe the content of an emergency musculo-skeletal radiograph at a level matching the radiologist?	Most radiographers said they felt they could describe to a level equal to the radiologists
7. By indicating YES or NO in the appropriate box, do you think commenting on the images while the patient is still present	Radiographers indicated that with the patient still in the department generally good outcomes would be likely. Patient presence supported the ability to describe and this would be helpful to E. As well describing is likely to enhance their acquisition skills.
8. Please indicate any other ways that interpretation of images by radiographers while patients are still present in the department may be affected.	Radiographers generally felt describing could impact on workflow but acknowledged this input should be better for the patient. It was also perceived describing would be beneficial to service users as it provides an answer quicker. Radiographer autonomy as describing and its knowledge base will give radiographers the potential to respond to patient needs and will ease the burden on the radiologist.

Table 7.4 Key findings from the radiographer pre image test 1 survey

Question	**Key findings**
1. State why you wanted to participate in this study	A slight change is focus was evident but there was still a drive towards performing a describing role. Key gains were: • Role enhancement/change • Improved knowledge base • An opportunity to test interpretation skills • Improve the standing of radiography within the MDT
2. State in the box below if any anxieties / concerns you had before participating in this study about <u>performing an interpretation function</u> have changed	Again the main focus was an anxiety about performing well and that there was a need for more education to aid confidence. The legal position was questioned again, however there was an expression of improved confidence despite these worries.
3. Since participating in this study, if radiographers were to participate in an image interpretation role, detail in the box below any changes of attitude you have had with respect to what on-going support would be required to enable you to perform this duty.	Radiographers indicated that: • On-going support was key • There is a need to be accepted by all colleagues to make the initiative work • Time to complete the extra role has to be built into the natural working expectation of the idea is likely to fail
4. As part of the study you have participated in 2 tests and completed 209 interpretations in each test to compare against the radiologist. Have the challenges you felt before completing test 1 changed?	As a generalisation radiographers expressed on-going confidence that they can describe at a level equivalent to the radiologist. There was a suggestion that it is more difficult than first appreciated because more information is now being extracted from the image as techniques of looking at the image have been enhanced. Radiographers believe their specificity ability is now greater.
5. Since participating in the study do you believe radiographers can always describe the content of an emergency musculo-skeletal radiograph at a level matching the radiologist?	Radiographers again stated that even though confidence is improved it's not as easy as they first thought. Apart from time pressures to perform describing within a normal workload the radiographers believe the initiative is worth pursuing. This may be particularly pertinent if the areas to be described are carefully controlled, initial and on-going education is in place and an appropriate audit system is developed to provide feedback.
6. Has participation in this study changed your thoughts about the obtaining and interpretation of emergency musculo-skeletal appendicular skeletal plain radiographs?	Radiographers are enthusiastic about interpreting as a way forward for Australian practice if careful planning is evident. Australian geography dictates there is a need for input due to doctor recruitment to rural areas. Educational support is a key factor to success. Describing/interpretation will improve image acquisition standards
7. Please could you recall an event of an episode where you believe your input through direct contact with the patient and your subsequent interpretation was not acted upon by the ED doctor?	A range of anecdotes/experiences of participants was gathered. These are discussed fully in chapter 8. Key points these experiences raised included: • A responsibility to inform • Teamwork and impact of failure to act on or recall due to radiographer input • Over treatment • Expectations of radiographer colleagues.

Table 7.5 Key findings from the radiographer post image test 2 survey

From tables 7.4 and 7.5 it became apparent that the radiographers after test 2 still appreciated the need for role change and development but for image interpretation there was a persistent anxiety to perform well but a legal and insurance prerogative rested heavily with them. Acceptance by the medical profession either radiologists or ED Drs is a key aspect of concern as radiographers feel without this they will not be able to safely perform an interpretive role. Managers also have to recognise there needs to be time allocation to provide interpretations, however there was no recognition of different ways of working raised by radiographers to negotiate time as an issue. Overall radiographers felt they could interpret MSK trauma as well as the radiologists but recognised the need for further and on-going education in multiple formats.

Several aspects of value that radiographers can contribute through participating in an interpretive role were expressed. This included a reduction in false positive and negative diagnosis, an improvement in team position within ED and recognition of how interpretation can improve image acquisition as well as aid the junior Dr through a requirement to inform them of abnormalities. Finally the radiographers perceived that to ensure fair access to reliable healthcare for all Australians, then radiographer interpretation can fill the geographical shortfall experienced outside cities and larger towns where services are more readily provided.

7.4 The medical student survey responses

Fourteen of the sixteen final year medical students that participated in the project completed a survey. The content was deliberately split up (as was the case with the radiographers questionnaires) so that theme generation did not automatically occur i.e. the students were asked about different facets at differing stages of the questionnaire to reduce the chances of them being led by the direction and focus of the questions. *Appendix 8* details the content of the medical students' questionnaire.

The survey was designed to establish the reasons why they wanted to participate, any anxieties before attempting the image test and the perceived level of difficulty expected in interpreting the range of examinations covered by the test. The medical students were also asked about their perceptions of the content of the undergraduate programme with respect to teaching of radiological interpretation. Other questions were directed at the students to establish their understanding of the role of the radiographer with respect to image commenting or abnormality highlighting in Australia and internationally. The medical students were also asked about aspects of whether they believed an input by radiographers through a descriptions role would aid patient management, and whether this input would have other impacts such as enhancing the operation of the multi disciplinary team. They were also asked if radiographer descriptions could improve imaging modality choices and the interpretation of images made by junior medical staff to result in an enhanced patient experience. As with the radiographers, sometimes students made comments that gave more than one answer that could be allocated to a developing theme that the question elicited.

Question 1

When asked why the students wished to participate in the study, three main thematic responses became evident. There was a perceived general educational need due to the content received in the undergraduate programme (5 responses). Several participants identified that they felt the study would help them prepare for their internship by enhancing their clinical skills for the post graduation internship period (5 responses).

> *"Formal radiology teaching is reasonably limited during medical training. Majority of teaching is taught informally and often without appropriate teaching by qualified radiologists. I thought it would be interesting to undertake the study and critically assess my ability to interpret images that will be common in my work as an intern next year."*

A further 5 responses in some way identified they wished to self evaluate as they wanted to demonstrate their ability to interpret images as they had been on a radiology elective and were interested in following this career pathway.

> *"I undertook a radiologist elective term under the guidance of a well respected senior radiologist. I enjoyed this term and am looking at potentially moving towards a career in radiology. As such keeping up my skills in image interpretation will be very useful."*

One participant also made the point that participating in research generally is *'a good thing to do.'*

Question 2

The medical students, like the radiographers, were also asked to express any anxieties or concerns that they have with respect to their performance in the test. Six students didn't have any concerns about their potential performance. The remaining eight students indicated they were concerned about their overall lack of knowledge (2), the potential difficult cases and not appreciating the detail that might be called for in terms of the report content (3). A subgroup had concerns about making an appropriate diagnosis (3). Evidently from this group of participants there were two clear groupings with respect to perceived performance.

Question 3

Question 3 asked the medical students, with respect to current roles that radiographers are expected to perform, what descriptions or advice radiographers provide to doctors either nationally or internationally. The responses are indicated in table 7.6:

Question	YES	NO
a. Radiographers are obliged to verbally indicate abnormalities to the referrer.	3	11
b. Radiographers can suggest alternative approaches to imaging for the request made.	14	0
c. Radiographers in other countries perform an interpretive role in multiple areas of radiology.	6	8
d. Some radiographers in Australia participate in an abnormality highlighting scheme.	11	3
e. You are aware that radiographers in Australia might contribute to the patient pathway by providing indicative descriptions for ED referrals.	9	5

Table 7.6 Medical student understanding of current radiographer roles with respect to describing image content

Students were also asked if they had any comments regarding the questions presented. Only one remark was received indicating that this participant had not undergone an ED placement yet so might not be fully familiar with the expectations of the role of the radiographer in trauma management.

Question 4

To break up the flow of the questions so students did not become blasé about their answering due to sequencing similarities, the survey asked medical students about which body areas they might experience most difficulty with in plain radiograph image interpretation. Students were asked to indicate in one of four levels of difficulty; this number of Likert type responses being chosen so that a middle response could not be selected. The replies are shown in table 7.7:

Area of radiography	Very hard	Hard	Easy	Very easy
Paediatric examinations (any from those listed below)	7	7	0	0
The hand and wrist	0	9	4	1
The foot and ankle	3	6	5	0
Skull and facial bones	6	8	0	0
Cervical spine	4	8	2	0
The elbow, humerus and shoulder	0	3	9	2
The tibia/fibula, knee and femur	0	2	11	1
The pelvis and hip	0	8	5	1
Thoracic, lumbar, sacral spines and coccyx	3	7	4	0

Table 7.7 Medical student difficulty perceptions of interpreting various images.

Further comments were again sought, with the student who had not yet participated in any ED experience flagging confidence concerns he/she had about the answers given, due to lack of exposure to the trauma setting to date.

Question 5

This question asked whether the medical students who participated in the study believed their education about radiological interpretation was sufficient. It further enquired about any details they wished to share regarding the content of the undergraduate medical programme. A range of responses were received, with the general perception there is insufficient teaching in the degree. It was indicated that further support for medical students was provided by those individuals that had an interest in image interpretation. This further input was received whilst in clinical placement and was dependent on the availability of the interested individuals. To summarise, it was rare to encounter defined sessions at regular intervals within clinical placements. Within the degree there was a perceived lack of structure with respect to image interpretation and a focus on the chest radiograph was noted within the course. Students believe they should consider more aspects such as other areas of plain radiograph interpretation, help recognise the value and abilities of other modalities and how to utilise them appropriately. Some students had taken a specific radiology elective during their studies but they also responded in an unfavourable way with respect to the undergraduate medical degree radiology content. Several noteworthy comments are worth including here to express student feelings about the degree content for radiology and image interpretation:

> *'Absolutely not. I think the amount of education we are given during pre-clinical and clinical is nowhere near sufficient considering how important it is.'*
>
> *'We could have been taught more systematically and for longer periods of time during our pre-clinical years. I feel we learnt how to interpret imaging more when we were in hospital (depending on if a doctor was free to teach).'*
>
> *'No. Most formal teaching was focused on CXR interpretation with some on brain CT. Majority has been informal teaching which has quite often been rushed.'*
>
> *'Not at all. The MBBS does not provide enough teaching in radiology. The most teaching was ad-hoc teaching at the hospital and the tutes we received were from either more senior students or doctors in our teams.'*
>
> *'No, I did a rotation in radiology this year so feel more comfortable than I did before this year, especially in the interpreting of plain films. Previous teaching did not seem particularly structured and involved many CXRs but little trauma XR teaching.'*
>
> *'No it was not. We were only taught to exclude certain red flag signs or recognise common signs on X-ray/CT images.'*
>
> *'Not really. Mostly learned through informal teaching with clinicians in the wards. Weekly radiological class with radiologist in Year 3 first semester was difficult to relate to due to our limited clinical experience at the time.'*

Some students expressed they were happy with the teaching received earlier in the degree, however the statements given by these participants also hinted at some criticism:

'The radiological education with regards to X-rays was sufficient. However I found there was insufficient education with regards to other modalities such as CT scans, MRI and ultrasound. Part of the education involved weekly tutorials on a systematic approach to interpreting radiological images during year 3. There was a strong focus on CXR interpretation. There were many opportunities to hone these skills during the time spent in wards.'

'Yes, however interpretation skills always become better with practice.'

Question 6

Medical students were asked whether they would be happy to accept the description provided by a radiographer to help make a decision about patient treatment/further imaging management. A 4-point scaled response was provided for answers plus a 'Don't know' option, with further comments requested. The replies (table 7.8) were as follows:

Always	Most of the time	Occasionally	Never	Don't know
3	4	7	0	0

Table 7.8 Are medical students happy to receive a description from radiographers?

Associated comments that were made seemed to indicate there is reticence about using other staff that do not hold a medical degree, even if this still delays the diagnostic outcome before treatment management is embarked upon:

'This vastly hinges on the perceived experience of the radiographer. However, from a medico-legal perspective, it is perhaps prudent to await the interpretation of a trained radiologist before making a clinical decision.'

'I've often seen consultant dispute the radiographers' findings, however as a junior doctor I will be following their recommendations' [It is unclear if the respondent think radiographers are radiologists?] Parentheses added.

One student made two comments:

'It depends on the imaging modality. For plain X-rays of the limbs and maybe CXRs I would, but for most others I would be reluctant.'

'Would most likely correlate their interpretation with my own, allowing me to be more confident in my interpretation if they were the same or similar. However, if a discrepancy existed, I would most likely seek a radiologists' opinion.'

Which perhaps sums up the thinking of medical students about to embark on their clinical careers.

Question 7

The final question sought opinions by medical students on radiographers providing comments on the images they produce. They were asked how this might impact on their ability to perform differently during their internship. The results are shown below in table 7.9:

Comment	YES	NO	Don't know
Will enable you to interpret the images more confidently.	9	1	4
Gives you an interpretive advantage over the radiologist.	1	8	5
Will improve the patient experience.	4	2	8
Will enable you to express to the radiographer what other imaging you might need.	12	0	3
Will improve the multidisciplinary team approach and enhance the relationship between the radiology department and you.	12	0	2

Table 7.9 Would a radiographer description aid your performance during your internship?

An option to add a comment if required was given. Only one student took this opportunity remarking:

> '*I think the quality of interpretation by a radiologist will always be superior, but as mentioned above, the availability of radiographers will enable them to improve the patient experience by providing rapid interpretation with suggestions regarding further imaging etc.'*

This would appear to suggest that this respondent is open to the idea but knows where to seek further help if uncertain.

This concludes the qualitative results section. The next part of the thesis discusses the findings and analyses whether there is a statistically significant or numerical difference between the radiologists, radiographers and medical students. The discussion then will consider the thoughts, impressions and attitudes expressed by the radiographers and medical students about radiographer describing to show any linkages that between the aspects mentioned. It will also analyse where there are limitations to the study so that final conclusions and recommendations can be drawn.

PART 4

DISCUSSION

'He said, in effect, that everything should be as simple as it can be but not simpler!'

Roger Sessions (composer) paraphrasing Albert Einstein
'How a difficult composer gets that way',
New York Times, January 8, 1950.

Chapter 8 Understanding the results

8.1 Methodological approach.

It was shown in the literature review by investigators such as Brealey et al [165 - 168] (sections 3.3 p44 and 3.4 p50) that when applied to material produced by Australian researchers [184-188] (section 4.2 p65), bias of varying causes has crept into studies of image interpretation comparison. Furthermore, critical discussion in section 3.5 p51 demonstrated the merits or otherwise of the choice of measurement value and how comparison statistics may be applicable [181-198]. Section 3.6 p61 explored the causes of bias in clinical decision making [190, 199] and highlights how a test creates results that are unexpected due to the constitution of the image library used [204 - 207]. This investigation was carefully constructed to attempt to avoid repeating those errors and table 8.1 p179 shows how the standards by Brealey et al [166] were met by this study. Table 8.2 p180 reviews the ways in which the forms of bias defined by Brealey et al [165] have been avoided in this investigation, which is defined as a diagnostic accuracy study. Chapter 8 continues by further discussing the results and show if and where numerical and qualitative findings align, to explain the performance differences observed between the participant groups and the radiologists.

8.1.1 Why was this method chosen?

When this study was devised, work on eye tracking and radiographer led ROC approaches were still relatively new in the measurement of radiologists, radiographers and other medical professionals [233, 234]. During the study, refinements to the ROC analysis approaches has resulted in significant changes to account for the clinical impact of they way variables are accounted for in image analysis. These have recently become evident using the refined ROC methodologies, as discussed by Chakraborty [235]. Lack of availability of this material as computer software or equipment meant that adopting Chakraborty's approaches for data collection was not feasible. The factors that influenced method choices are discussed below.

The large numbers of images that each participant was expected to complete took a long time to read/interpret. This number of images was devised to prevent criticism about the overall capability of the radiographer and medical student participants. Criticisms may include; insufficient examples of image types or lack of variation in difficulty to test the participants interpretive ability. This could not have been achieved using a smaller test. Further, this number of images allowed issues of prevalence to be addressed and to produce an image test batch that represented the typical workload experienced by healthcare personnel dealing with ED referrals. This was informed by the work of several authors [218 - 223] matching the population image profile suggested in the studies described in section 5.2.1 p84 with the range of trauma to the musculo-skeletal system. It also meant that all participants completed the same test with no need to construct a composite result as seen in a balanced incomplete block design method [236]. The balanced incomplete block design could be criticised by those who may wish to question the work on the basis that insufficient examples per participant were completed. In total for individual examination viewings there were 3344 separate events per group of 16 participants. As well, there could be a further variable control failure through the degree of difficulty not matching across the image test batches by splitting the composite group into smaller batches of images. This would then be introduced into each participant's test group to enable contribution to the final result to align with Brealey et al's spectrum bias definition. [165]

The eye tracking, image reading methods devised to perform the studies by researchers such as Krupinski, Kundel, Manning [237 - 239] amongst others, required access to specialised equipment and computer software that was usually based in a single research centre. These approaches could therefore only be achieved if the participants were able to travel to the research centre multiple times. Due to the nature of radiology service provision in the sample population of radiographers e.g. single handed departments, travel to individual centres was impossible to achieve amongst this participant group. Guaranteeing participant availability would also be impossible to achieve. This would therefore have prevented a population size being generated that would be acceptable for a level III study as defined by Obuchowski.[117] Had a single testing centre approach been adopted, the study would have been unable to investigate the performance of a range of radiographers and medical students who were arguably representative of the wider professional population in the State of Victoria. Furthermore, this work establishes performance by a group of volunteers who would have access to home based personal computing devices. These machines would normally operate to a standard that would ensure a minimum image quality that could be achieved to meet the basic PACS image quality guidelines stipulated by various bodies such as the RCR [225] and discussed by Spigos et al [224]. This ensured control of variables in terms of image quality without having to rely upon specialist equipment transfer. Furthermore, the method adopted avoided the need to use computing software that would require greater computing performance capability than the standard achievable by most domestic systems.

Even if equipment of a greater specification had been moved to the localities of participants then each individual would have to give or be given a set period of time in which to view the test bank. This would most probably have been difficult to achieve due to their working arrangements and result in excluding many radiographers and medical students from the study. Relocating equipment to the reader locality would also require the participant to work in exam type conditions, which may lead to mistakes and certainly would not allow time for the participant to consider the appearances fully before giving an answer; in other words inappropriate and excess pressure is placed upon the individual and this was not one of the variables being tested in this study. Using a peripatetic approach, unless performed using a research assistant, would also ruin the anonymity generated by the choice to send and receive material through a third party. Furthermore the timeframe for completing the study would be extended beyond an acceptable level. A further variable that meant radiographer participants would then access the research test material at widely varying timeframes to each other following the educational intervention is introduced due to the time required to move equipment. This would potentially allow some participants longer to work with the educational material than others before attempting the second test. This could have introduced another source of inaccuracy to the results obtained. Without performing the research in the way adopted, then for the reasons discussed the validity and reliability of the study could be jeopardised.

8.1.2 Meeting international best practice standards and navigating bias in this study.

Table 8.1 p179 lists the standards, as defined by Brealey et al [166] on pages 45 and 49 that should be addressed when constructing a diagnostic accuracy study. Table 8.2 p180 refers back to table 3.2 p50 to show how bias of the types detected by Brealey et al for the diagnostic accuracy studies they reviewed have been addressed by the approach in this investigation. According to table 3.1 p46, Brealey et al identified many more forms of bias that were not linked in their examination to the diagnostic accuracy study reported here. Table 8.3 p181 highlights those further points of bias that may be identified within image interpretation studies that could be applied to this work and shows how they have been met in this investigation. As discussed in sections 3.3 p44 and 3.4 p50 it is evident that multiple forms of bias may inveigle their way into image interpretation studies. By careful analysis of the work performed by Brealey et al [149, 150] this investigation accounts for all limiting factors except for the arbiter comparator bias. Any other bias not accounted for was not applicable to the approach adopted for this work however, had the initial planned initial investigation been able to take place then arbiter bias could also have been addressed. In comparison with earlier Australian studies [208 - 212] this means that the investigation reported here demonstrates greater strength by avoiding the identified sources of bias and by meeting the defined standards that should be achieved.

Standard	**Avoided Y/N**	**How avoided**
Was an appropriate sample size considered?	Y	Prevalence calculations made then test size calculated according to Naing [157]. Whole test taken by all participants to avoid accusation of group 1 type biases from table 3.1.
Was a normal/abnormal report adequately defined?	Y	All images used were reported originally then re-reported by three radiologists. Agreement of 3 / 4 radiologists required to confirm normal or abnormal.
Was the observer's performance placed in the context of the diagnostic sequence?	Y	Not a diagnostic accuracy study concern however, use of history for referral criteria delivers appropriate context for all reporters including re-reporting radiologists.
Was the contribution of individual groups determined if the combined performance of two (or more) different groups of observers were assessed?	Y	Groups were evaluated separately therefore combined performance was not a feature of this investigation.
Was an appropriate (valid) reference standard ("gold" or "criterion") used?	Y	A consensually agreed report was generated where 3 / 4 radiologists confirmed normal or abnormal and identified locus / type of abnormality.
Was an appropriate (valid) arbiter used to compare radiographers' reports with the reference standards?	Y	A fully trained reporter arbiter was used to review participant responses. Participants were anonymised from the arbiter through a third party numeric identification allocation for participants.
Was an appropriate control used?	Y	The first test performed by radiographers acts as a control in this instance as no education provided up to this point. Self selection into the study could be deemed a limitation on this front.
Were films appropriately analysed for pertinent sub groups?	Y	The images selected for the test were carefully controlled to meet the calculated prevalence values (Caesar et al) and randomly allocated from body areas to meet known proportions seen in trauma epidemiology studies.
Was the data presented in enough detail to allow for the re-calculation of performance statistics e.g. sensitivity, specificity and confidence interval?	Y	All participant basic data (TN, TP, FN, FP) values that would enable calculations are included in appendix 9 ROC fitted and empirical curves are also available in appendix 11.
Were indeterminate i.e. equivocal, missing data, non-diagnostic results appropriately presented?	Y	Due to the nature of defining the abnormality identified by each participant equivocal data were not generated. Fitted ROC values account for variation around the threshold. No missing data was presented by participants.

Table 8.1
Meeting the investigatory standards posed by Brealey et al[166]

Bias type	**Avoided Y/N**	**How avoided**
Image filtering	Y	All images read by all participants to make avoidance impossible and allow full comparison to be made.
Observer cohort	Y	Individual participant details not known by arbiter during evaluation of reports. Arbiter made aware afterwards for comparison between participant groups if necessary.
Inter-observer variability	Y	All images read by all participants independently – allows consistency between tests 1 and 2 for radiographers and enables variability between groups to be accurately measured.
Intra-observer variability	Y	Radiographers re-interpreted all images in tests 1 and 2 to enable intra observer variability to be identified. The test size and timescale between tests enabled a memory effect to be minimised
Inter-arbiter variability	Y	Only a single arbiter was used who constructed the expected test responses from 3 / 4 radiologist reports or excluded variant reports from the test. Confirmatory cross checks regarding radiologist report intent took place where doubt about report content existed. This enabled full familiarity with the test content to allow appropriate performance allocation to individual observers.
Intra-arbiter variability	Y	Only a single arbiter was used who constructed the expected test responses from 3/4 radiologist reports or excluded variant reports from the test. This enables full familiarity with the test content to demonstrate consistent application of criteria to observer responses.
Observer	Y	Observers were not aware of participant colleagues to check with each other and were reminded that this investigation relied upon own performance as this was a diagnostic accuracy study.
Arbiter review	Y	The arbiter was not being tested as part of the investigation nor was the arbiter used as part of the team used to generate consensual image content agreement.
Arbiter	Y	Anonymisation of participants ensured the arbiter was unaware of individual participants and this was maintained for the second radiographer test as a numeric identifier was employed for individuals. The wide catchment that participants were drawn from ensured that participant recognition was not possible.
Image access	Y	Images were not accessed by the arbiter during evaluation. The criteria generated by the consensual radiologist group were used as the interpretive indicator of report content.
Arbiter comparator	N	Due to the nature of the recruitment process radiographers were evaluated as a separate group from the medical students so arbiter comparator bias could occur, despite reliance on the report criteria generated by the consensual radiologist group to attempt to standardise measurement.

Table 8.2
Addressing the diagnostic accuracy study biases posed by Brealey et al [166]

Bias type	Avoided Y/N/NA	How avoided
Group 1		
Referral bias	Y	Although individual experiences cannot always be accounted for, all images used had any abnormality highlighting system annotation removed if present. As this was effectively a 'one off' study this type of bias should not impact.
Film/Image cohort bias	Y	Test bank adjusted through redundancy random image selection approach from all body areas to appropriate size acceptable for calculated prevalence. All images reported by participants. Images not grouped into body areas for interpretation as random approach recognised to meet standard clinical presentation.
Spectrum bias	Y	Test adjusted to meet range as indicated by Caesar and Court-Brown investigations. Prevents spectrum bias occurring.
Population bias	Y	Consensually agreed 3 / 4 radiologist reports agreed before test bank constructed to ensure single radiologist not used as the reference standard. Prevalence calculated to meet expected value and appropriate abnormal images included in the test.
Group 2		
Observer selection bias	Y	Participant demographic data aligned with numeric identifier to enable experience and department type radiographers operating in to account for observer selection bias when results completed. Test covers whole spectrum of attendances typical of the tertiary level hospital without major trauma to enable comparison across a range of images.
Observer cohort comparator bias	Y	Same group used for intervention comparisons. Medical students evaluated without further education as supposition is that they are able to interpret for internship. Same number of participants achieved for each non-radiologist group.
Group 3		
Verification bias	NA	Consensus radiologist reference standard applied across all participant responses to prevent verification bias. Less likely to be a problem in diagnostic accuracy studies of the nature of this investigation.
Work up bias	NA	Consensus radiologist reference standard applied. Not problematic for diagnostic accuracy studies as this investigation does not use long term collection of data without the same reference standard.
Incorporation bias	Y	This method of generating the reference standard did not occur
Loss to follow up	NA	As this was not an on-going study loss to follow up bias did not occur

Table 8.3
How further forms of bias posed by Brealey et al [166] were addressed

Bias type	Avoided Y/N/NA	How avoided
Group 4		
Disease progression bias	NA	No long term comparison images used for this type of test
Withdrawal bias	NA	All images as per those read by the radiologist to generate the consensual report were included in each set of images for each patient. Withdrawal bias therefore could not occur
Indeterminate results	Y	Participants all made a decision but informed if they would like more imaging and for what reason. As a decision was given the bias generated by equivocal report generation was avoided. Further imaging was taken as another aspect of the study and investigated separately to establish if there was variation on an inter and intra test basis.
Group 5		
Observer review bias	Y	All observers (including radiologists during re-reporting phase) were blinded to reference standard reports that were present
Reference standard review bias	Y	The consensus radiologist re-reporting team were blinded to any previous reports and therefore could not be influenced by any prior report content
Observer comparator bias	Y	All participants viewed the same images in isolation so observer comparator bias could not occur
Co-image bias	Y	No further images were available to any participants or re-reporting radiologists preventing co-image bias generation
Clinical review bias	Y	Clinical information presented enabled a question to be framed and aligned with other details such of mechanism of injury, age and gender only
Cohort comparator bias	Y	Participant groups were blinded to each other. Individuals were reminded of the need to ensure this was their own effort if they were aware of other participants
Co-image comparator bias	Y	No further images were available to any participants ensuring co-image comparator bias could not occur

Table 8.3 (cont)
How further forms of bias posed by Brealey et al [166] were addressed

8.1.3 Statistical components – why the large range of statistics used?

The types of statistics that may be used in tests such as the ones in this investigation vary across other Australian studies that have been reported [208 - 212]. Section 3.5 p52 describes and critiques the relative merits of using different ways to report performance of a test or the reader of a test. The simplest data generated are the values of true positive and negative as well as false positive and negative (displayed in *appendix 9* for all participants and test formats including radiologists). These values are particularly important when considering threshold values for signal detection theory application. Moving the threshold that defines when a test result is considered positive or negative causes a relative change in sensitivity and specificity, the values of which are used to calculate accuracy and a range of other statistical indicators as described in sections 3.5.1 and 3.5.2 p53. Early studies of radiographer interpretation performance [26, 208, 209] reported sensitivity and specificity values but failed to consider wider reaching aspects that contribute to the understanding of individual and group performance in tests, such as has been done in this thesis. As a result predictive values, likelihood ratios and pre and post test odds calculations should be considered so that overall performance can be fully appreciated.

Predictive values can be affected by the prevalence of abnormality seen within a test. It would appear that there is some disagreement between authors [204, 205] regarding this feature resulting in a change of mind by Obuchowski [206], who previously supported the idea that prevalence affects performance. Recently however, Pusic et al [207] showed with respect to radiological plain image interpretive ability from an educational perspective, varying prevalence in a test batch of images results in sensitivity and specificity change. High prevalence values increase student sensitivity and reduce specificity performance and vice versa. With this in mind, to address spectrum bias as well as meet the appropriate sample size standard for the calculated injury prevalence from the image archive used, employing abnormality prevalence in the image test bank to produce an image test of clinical equivalence is appropriate [165, 182, 183]. Thus, reporting predictive values between groups has validity if the prevalence of a constructed test is similar to that seen clinically [184]. The predictive values calculated from this work therefore demonstrate group and individual performance that is valid.

Likelihood ratios are again built on sensitivity and specificity values so will be subject to prevalence impact as indicated above. A high likelihood ratio does not always mean that an abnormality of the nature under investigation is necessarily present [184]. A high likelihood ratio can be used as a tool for expressing the capability of a test or its reader to spot or rule out abnormality.

The Kappa statistic and the strengths and weaknesses of its relative forms are discussed extensively in section 3.5.4p58. This section demonstrates the impact that bias (_yes_ agree selections) and prevalence (_yes and no_ agree selections) have. When these are considered alongside the initial test performance, the consensus radiologist test batch, the reader results that were generated are better understood. Essentially, Kappa was initially developed [193] to show the degree of agreement between readers or groups of readers when a ground truth is available for comparison. In this investigation the ground truth is consensus agreement of image content generated by the radiologists to create the test batch. Further forms of the Kappa statistic corrected for guessing and the bias/prevalence compromise [196] later became available. Through using the weighted Kappa (Wtd Kappa) and the bias and prevalence adjusted Kappa (BPK) guessing and consistency variation relative to the observed score is corrected. This allows recognition that the performance between groups and individuals to be reported to fall within an acceptable range [194-196]. As such this means the ability displayed in each group test relative to the consensually agreed image content is reliable and valid, as the variables that may enter Kappa calculations are accounted for.

Gwet's AC1 statistic [198] takes these ideas a step further. Gwet argues that the score achievable by groups or individuals cannot work based on a decimal score as a proportion of 1.0 for chance selection of the correct outcome. By considering that chance agreement can be no more than 0.5 due to responses being of a binary nature, the marginal agreements shown in a 2 x 2 square for the earlier problems identified with weighted Kappa and BPK are corrected so a reliable Kappa statistic is reported. The overall stability of Gwet's AC1 statistic compared against Kappa has also been confirmed in a study on personality disorder [241] in 2013, thus supporting the decision to apply this statistic in this study. Reporting the three forms of Kappa therefore allows full comparison of performance between groups so that an over arching evaluation can be expressed.

The ROC curve, as indicated in section 3.5.3 p55, has limitations that depend upon the correct binary response and location to match to, which ensures the answers represents the true response in the test. Chakraborty [235] has discussed the current state of FROC developments and the role of computer software to reveal how multiple lesions at several sites can now be analysed in the laboratory setting to achieve a near clinical representation. As the abnormalities within this study were essentially single in nature a simplified free text response with tick box and confidence indication was used by the arbiter to generate a reader positive or negative response. This was then entered into Eng's ROC calculator software [242] as a single ROC response that allows some clinical variation by employing confidence level selection to generate the empirical and fitted variations of ROCs. These are then displayed as two AUC values that can be compared. Although not in the laboratory setting where computer based target selection software with eye tracking can be employed, as in the situations described by Chakraborty [235], the measurement approach in this investigation took a simple confidence indicator plus location response to measure individual performance. By relating responses to the consensus agreed radiologist image interpretations, the fitted and empirical AUC values were generated to allow a simplified, pictorial comparison between groups.

Consequently all the values generated by the various calculations could be compared for statistical significance using the Mann Whitney U non parametric test. This test was chosen due to the non normal distribution of the responses by participants that could be grouped as two independent populations that are then analysed by comparing the distribution of ranked data i.e. the scores of each individual. This test can also be applied to comparison of different sample sizes as it relies upon the ranked data to generate any differences if they are present as a result of the relative positions of each score, for each group, within the ranks created [243]. Theoretically all three groups could be compared directly with each other using the Kruskal-Wallis statistical test. However this test is unreliable in groups of fewer than five participants. As only four radiologists contributed to the consensus report generation direct statistical comparison was not possible due to the test's unreliability.

8.2 Numerical results discussion

8.2.1 Participant sample demographics.

Reliance on volunteers necessarily tends to generate a study sample population that has an interest in the subject material being investigated and its outcomes. This could be levelled as a weakness in the investigation, however conversely to recruit outside a voluntary approach suggests there is potential for various ethical considerations to impact as well as potentially generating a non-compliant test sample [244]. A potential radiographer population of 434 registered practitioners that met the recruitment profile, based on hospital/radiology service delivery type the MRPBV, were approached. Although only 16 radiographers finally contributed to the whole study, this equated to 3.86% of the available radiographer population after losses due to incorrect contact information. The voluntary approach generated a radiographer profile that included representation of the various types of imaging service that may be delivered across Victoria. Volunteering also recruited across a range of experiential backgrounds of between 2 – 4 years and over 20 years. The recruitment approach adopted for the medical students that were interested has allowed them to be exposed to further education they felt was required compared with that delivered by the MBBS and is discussed later. The study has also provided a form of self directed performance measurement with feedback that demonstrates a higher degree of professional maturity and meets with some of the ideas expressed by Boutis et al [245]. This latter feature can only be achieved when a balanced or 'average' nature of images is included in the image interpretation test.

The radiologists who agreed to contribute to this investigation expressed an interest in MSK plain radiograph interpretation. Although the experiential level of the original reporting radiologists could not always be confirmed to be at consultant grade, the image report verification system ensured that senior level involvement occurred to validate report content before appending to the patient's notes. This meets the requirements of the RANZCR reporting standards document [246]. The three re-reporting radiologists were at consultant level, one with a UK RCR Fellowship, and a second with a previous background of having moved onto medicine from an earlier career as a radiographer. It is feasible that these backgrounds, along with the third radiologist believing that radiographers have a greater role to play, made it possible to construct the test library bearing in mind some of the non supportive commentary of radiologists towards radiographers described and discussed in chapter 2.

8.2.2 Radiologist performance.

It is evident from the results between p108 and p111, that there is the potential for interpretive variation amongst radiologists. If sensitivity, specificity and accuracy percentage scores are used as an indicator then the variation at 5% for sensitivity, 10% for specificity and 6% for accuracy for the full test is under the 10-11% suggested by the work of Robinson et al [177] . This indicates that experienced radiologists vary in their plain radiograph interpretation. For numerical comparisons, inter-reader values have been used to generate mean and medians for the radiologists as a whole. Variation in ability and interpretation is smoothed to create a gold standard of performance for comparison with the radiographers and medical students. Table 6.15 p126 also shows that the radiologist who had the greatest variance from the wider performance figures, featured more commonly with respect to requesting or advising on the use of more imaging. These characteristics combined with the general tendency of the report content to err on the side of caution, suggests a reason for the variation seen in this individual's responses.

For the statistical comparisons all participants whether radiologist, radiographer or medical student had their scores evaluated using the Mann Whitney U test statistic to show significance or not. This allows ranking to be performed across the respondents for that statistical test e.g. radiologists against all second test radiographers. The Mann Whitney U test allows this comparison despite there being sample size differences between participant groups [243].

8.2.3 Radiographer performance between tests.

The mean and median values for the second test by radiographers were used as the comparator data set to establish whether a difference could be seen between radiologists, radiographers and medical students. These values were used as it was expected that the educational input generated better scores for radiographers. This therefore made the second test most appropriate as the educational input was recognised. As such this demonstrates the presence of either numerical or statistically significant differences between radiographers and radiologists, and radiographers and medical students.

It is of note however that, taking the mean and median values into account, there was very little difference between the two scores achieved by each radiographer test. Often post educational input radiographers were found to have performed less well in the second test. This phenomenon was also seen in the work by McConnell and Webster [64] who looked at the impact of a short course of study for radiographers in the UK who were abnormality highlighting. In that study greater score reduction was identified in the second test. This prompted a third test, which was possible to administer as the image test bank was much smaller, to establish if the course had achieved its aims following a period of assimilation of the new educational material. McConnell and Webster's work [64] appears to have indicated that at the third test significant improvements were noted several weeks after the intervention. This finding helped drive the decision to build in a longer period between tests in this investigation to attempt to account for this impact. Evidently though, a poor result in test 2 is still apparent, suggesting a need to consider some other reasoning for this cohort of radiographers from across the State of Victoria. No evidence from the participants during attendance at the study sessions suggested a failure to engage with the learning materials. This reduced the potential for lack of engagement being a cause for the problem.

The new MRPBA professional capability requirements expect radiographers to be able to recognise a defined list of abnormalities revealed by plain radiography [32]. Prior to this radiographers' were expected to differentiate between normal and abnormal appearances on plain radiographs [106, 107 111]. This requirement necessarily drives the need to consider whether the image obtained is affected by disease or trauma, or whether the appearance or lack of it could be a result of sub optimal examination technical capability. In short the radiograph fails to show those anatomical areas that a clinical question may be asking about. These considerations are likely to encourage clinical decision making by radiographers towards evaluating the need for improved imaging from the technical perspective, or to provide further projections to aid the diagnostic process. These deliberations are more often associated with the 'how' process of obtaining and accepting the image. However, pattern recognition of normal from abnormal, or acceptability of image content to answer the clinical question or whether a further image would be required, is the expected radiographer knowledge base regarding image evaluation. This includes deliberations about correcting technical failures in the image or providing extra information as a diagnostic aid by giving extra projections. It is therefore suggested that the failure to improve between tests recognises the different expectation of the traditional role of radiographers compared with medical students. This reflects the teaching, learning and assessment content of previous /traditional radiographer education that has shaped attitudes towards new learning that is diagnosis and treatment orientated. This approach is familiar to the medical student but acts as a barrier to taking on new information amongst the radiographers. As such, educational requirements that were previously met fail to enable performance of a new role and way of working as the radiographer is unfamiliar with this approach.

In contrast, medical students' learning is directed towards diagnosis and treatment, so the information looked for in images by this group differs from the radiographers. Radiographers are taught about how to acquire radiographic images, correcting mistakes or adding further images to aid diagnosis, when a range of appearances are seen as part of a pattern or fit with an imaging referral protocol. To do this radiographers have to be able to determine when this is necessary and therefore are strong judges of normal appearances in an image. As such the educational intervention of this study will require a longer period of time to be incorporated into the knowledge base of radiographers. Knowledge about diagnosis from images, or having an ability to append a label to appearances, is likely to be applied in ways that differ from the learning approach currently predominantly adopted by radiographers in their current learning experience. It is only when they are asked to perform a different role i.e. describing the image content that is equivalent to the radiologist that the educational approach needs to change. As such radiographers need to apply a knowledge base that differs from that which they are used to and become more akin to that seen in medical education. This is evidenced in this investigation by the greater number of further examinations that radiographers request compared with the medical students. It is also clear however that some medical student experience/understanding is limited from an analysis of individual results as was also discovered by Zhou et al [8] to spur Goergen's comments [10].

In the UK there has been a move away from the RDS [247] due to its limitations, towards one of radiographer commenting where the radiographer's scope of practice now expects participation at a level different to that expected of Australian radiographers [69]. To achieve this in the UK, universities have been required to include image interpretation as part of their programmes of study since 2010. This has been reiterated in the 2013 Education and Career Framework document developed by the SCoR [112] and is producing a workforce expectation of contributing diagnostically to the patient pathway. However, performance audit and in house departmental education approaches have not yet been fully evaluated for their impact, which is mainly due to radiographer commenting not having been implemented in all radiology departments across the UK [247]. It can also be suggested that local resistance by radiologists has blocked development and use of skills possessed by radiographers. This is best supported by the sentiment expressed in the withdrawn 2010 RCR '*Medical image interpretation by radiographers*' document [132] where resentment towards radiographer reporting was expressed.

Radiographers are critical experts of the technical appearance of radiographs to include positioning, image quality from contrast and density perspectives. Their education tells them to rationalise the reasons given to justify why a patient may be exposed to a dose of ionising radiation to generate an image [103, 106, 111, 112]. Expert knowledge through the radiographic process of image critique is evident in this study in the comments made by radiographers; it is revealed as commentary on the image technical quality not meeting the standard that radiographers felt was required. This reasoning was given most frequently as a requirement for further radiographic projections being suggested. Occasionally, further projections were asked for by radiographers because of an inability to confirm an abnormality by them when they viewed the image test bank. Alternatively because radiographers stated they were aware of the role of other imaging in the confirmation or refutation of abnormality as part of a patient pathway further imaging was suggested. Thus radiographers follow protocols and make further imaging suggestions rather than considering what could be gleaned from the radiograph that may not necessarily meet normal technical acceptance criteria. As such this can be given as a cause for elevating the requests for further imaging by radiographers. A sub optimal but still diagnostically useful image when combined with other diagnostic pathway knowledge such as available to doctors might render a technically weaker image as being diagnostically acceptable to the referring doctor or radiologist.

Of note the radiographers who requested fewer repeat images were those with medium length periods of clinical experience. They had 5 – 14 yrs wholly in clinical practice rather than acting in a clinical area with managerial responsibilities. Those radiographers operating outside mere protocol based approaches also included those who interacted with other imaging modalities e.g. sonography. In this situation these participants would be familiar with the need to make decisions based on the images provided. Support for this association was also evidenced by the much lower overall requirement for further imaging suggested by the radiologists, as they are educated to make decisions based on image content and have medical knowledge that is in advance of the sonographer experience. This position is held by the RANZCR [45, 46]. They opine that inexperience along with a lack of a medical degree limits the possibility of radiographers contributing to an interpretive role. This reasoning supports the RANZCR's negative response to the initial scoping exercise for the development of the MRPBA capabilities document that eventually led to the new code of professional practice [45, 100]. This leads to the impression from this study that radiographers without a medical degree background should have extensive clinical experience of more than five years. Ideally radiographers should also possess the experience through working in a further imaging type, which gives an added perspective on the role of imaging and diagnosis achievable from complementary effects multi-modality capabilities. This extends to greater understanding of appearances and imaging capabilities that would support interpretation by the image reader. The radiologists position therefore is one of superiority achieved by studying for a medical degree plus specialist fellowship and that no matter what experience a radiographer may have, without further education it is believed by them that radiographers cannot make a contribution. In effect this reflects medical dominance and as such demonstrates that doctors, particularly the radiologists, hold a controlling influence.

Norman et al [248] discuss diagnostic expertise in medicine and surgery and consider its generation as being due to the combination and co-ordination of causal, analytical and experiential knowledge. They discuss causal knowledge from the perspective of knowledge structure and argue that basic scientific knowledge is rarely used by the expert. As well they suggest expert's reason in a forward direction i.e. top down rather than backwards or bottom up. The latter that adds features together to narrow down diagnoses, is slower than the top down method that arrives more directly to a likely and specific outcome. Effectively expert clinicians generate their knowledge base as case descriptions and extract likely diagnoses from the information generated by probe questions. In connection with this investigation, probe question answers are generated by considering the histories given linked to the images in the test. As such this shows the expert is making connections through known mechanisms of disease or trauma. Norman et al however indicate that experts occasionally revert to the use of basic science to build a new knowledge set to draw upon. This occurs when a further example that meets a matching clinical presentation is not linked to a known image appearance or is atypical in the expert's knowledge framework. Radiographers may do this when assessing images for technical appropriateness or making a decision about further images when they are unfamiliar with an appearance to fit their work protocols. This could be labelled as pattern recognition; however an ability to rapidly ascribe a reason without the need for further information is a hallmark of the expert and demonstrates forward or top down working.

The analytical component that Norman et al [248] describe suggests how experts employ prototype theories. Using this method, experts link specific diseases or injuries to a broader systems approach to allow more rapid and accurate connections to be made. The investigation reported in this thesis did not look at the time taken to make decisions; however prototype theories suggest that clinical problems are framed within a representation type, based on the work by Bordage et al [249]. These researchers suggest that knowledge is organised from low quality representations and therefore least expert, to high quality, or 'compiled', which demonstrates highly expert performance. The four levels are; *'reduced'* which demonstrates few features or links between features to enable diagnosis; the *'dispersed'* level has many features that are disorganised; the *'elaborated'* level demonstrates features with clear diagnostic associations and finally the *'compiled'* approach is reached where features and associations are connected rapidly to achieve correct diagnoses. Despite these ideas it has been impossible to say whether this represents increased expertise or merely the ability to acquire more extensive knowledge but Eva et al [250] suggest that there is a correlation between fast analytical approaches (compiled) and expertise. It would be sensible to suggest that participants who performed at a higher level in both radiographer tests demonstrate use of knowledge based tools such as this when describing image content. Based on concise comments made in addition to the tick box responses and the move towards decision making with greater confidence in test 2, there appears to be evidence for this phenomenon amongst radiographers. Further support for this hypothesis is provided by the reduced need to request further radiographic projections or other imaging modalities, and is seen in those participants who have greater experience in clinical time or other modality uses.

Finally experiential knowledge contributes to medical expertise. This is important to some extent in those with the middle range of clinical experience without the impact of managerial or other duties to influence practice performance. Norman et al quote Anderson *"One becomes an expert by making routine what to the novice requires creative problem-solving ability",* [248 p344] to discuss the idea of exemplar theory. This approach requires extensive experiential exposure to build a series of categories with multiple examples that allows the expert to retrieve a diagnosis through similarity rather than analysis or conscious thought. This approach would be in keeping with the radiographers with greater experience, however the mid range (5 – 14 years) participants and those with other modalities exposure were those who performed better. This suggests regular use of experiential knowledge combined with a wider associative potential led to better performance. It is suggested that this is due to these individuals having more and wider experience based information and examples they regularly draw upon, to represent a break away from habitual thinking to become more critical through reflection. Based on the expertise definition given by Anderson, it could therefore be argued that faster assimilation of the new information given in the education programme was possible amongst the mid range and multiple imaging modality experienced radiographers. So, although radiographer scores were lower in the second test, this section of the population performed better. This theory is also supported by recognition that the weaker scores were achieved by those with lower experience or that performing other responsibilities erodes the clinical focus. Consequently a greater amount of information has to be integrated into their knowledge base for use in image interpretation.

Krupinski [251] discusses the role of experience in building expertise amongst pathologists, pathology residents and medical students. She measures eye movements whilst looking at pathological sample slide images and draws image reading comparisons with radiology expertise development as a similar function. As with the development of radiology image reading skills she found there is a gradual increase in efficiency of eye movement with experience. Accordingly the individual begins to expect and recognise various appearances to reduce eye fixation times on important image aspects to reach a diagnosis. Had an eye tracking method been employed for this investigation, the impact of relative experience and the new information given could have been compared between tests to establish whether this was a feature. Eye tracking efficiency and accuracy has been shown to be related when comparing student radiographers with radiographer reporters in training or qualified and radiologists by Manning et al [233]. This idea is important when the radiographers qualitative comments are considered as some, mainly the under 5 years of experience participants, recognised that they now have more knowledge that makes decision making more difficult. In contrast one radiographer with over 15 years experience felt more confident that he/she would now be happier to describe a normal appearance and the course has helped another participant (32 years experience) see more in the image.

Co-ordination of the three knowledge types led Norman et al [248] to conclude that those with greater experience tended to favour exemplar based experiential methods to make a decision/diagnosis. Less experienced medical and surgical personnel tended to follow rules based approaches which favoured the analytical and causal knowledge frameworks. From the results obtained in this study, even though slightly lower in numerical value for test 2, it would appear that the performance of radiographers with greater experience is impacted less from taking on more knowledge. This may be due to the application of an experiential exemplar knowledge base. Support for this theory is provided by the lower requirement for repeat radiographs or use of other modalities in test 2 amongst radiographers with middle range of experience or regular interaction with other modalities.

8.2.4 Statistical comparisons between radiologists and radiographers

When the three groupings of full test, appendicular only images and adult only images are compared using the Mann Whitney U statistical test, it is seen that radiographers and radiologists show no statistically significant difference in their abilities to identify normal images. Radiographers have statistically significantly more false positives (FP) but fewer false negatives (FN) when considering appendicular only images compared with radiologists. Excessive FP calling questions the radiographer's ability to recognise true positive images; alternatively they may be erring on the side of caution. A cautious approach inevitably causes a statistically significant difference across all three sub sections of the image test for measurement of this type i.e. TP, TN, FP, FN. When considering the earlier discussion of the type of education typically received by radiographers it becomes evident that an expectation of the radiographer would be to recognise normality. This is supported by the above results as no statistically significant difference is identified. It also meets with Swinburne's initial suggestions that radiographers could be used to identify images that appear to have an abnormality and therefore act in a triage role to flag more urgent cases to the radiologist, even if this is purely by exclusion of normal images [70].

As a result of the scores obtained as negative and positive, figures generated and statistically compared in the other measurement criteria that rely on those base figures for calculation, are inextricably linked. Accordingly there is no statistically significant difference in the sensitivity percentage scores but highly statistically significant difference in the specificity scores. This appears at odds with the definitions and the performance numerically when TN, TP, FN and FP values are reviewed. Radiographers have a raised FP rate to reduce the number of correct responses that could be counted towards the specificity total. This therefore generates a statistically significant difference. As a result the accuracy percentage statistical comparison also shows a highly significant difference between radiographers and radiologists as the TN plus TP scores add together and form a proportion of the accuracy total. If excessive FP and FN in the case of the full and adult only image test groupings scores are generated these will make for large numerical differences and ranking for the Mann Whitney U test. This again generates a statistically significant difference between radiologists and radiographers. Even where, in the case of the FN score in appendicular only images is not statistically significantly different, the proportion it contributes to the overall test score means that the accuracy total could show a significant statistical difference, as is the case in the comparison results.

The base results of TN, TP, FN and FP are constituent calculation components to the predictive values and likelihood ratios. As a result it would be expected that where the TN value contributes then the associated NPV and LR-ve would not show a statistically significant difference and this is the case. Conversely where the TP value contributes to PPV and LR+ve the statistical comparison should be significant and, as expected, this is demonstrated. The TN and TP selection choices by radiographers have an impact on the Ppos and Pneg values. It is apparent that the radiographers and radiologists selections are very similar in the appendicular only images when TN, NPV and LR-ve statistical comparisons are made relative to the Pneg value. In this criterion too it can be seen that there was also no statistically significant difference in the Ppos selections made, however this could be caused by the single radiologist score that leaves only two radiographers in the rankings below the lowest radiologist value. As such this has an impact on the statistical significance value that is generated.

When comparing the kappa values (*appendix 10*) it becomes evident from the bias and prevalence adjusted calculations of Kappa that radiographer's scores are not statistically significantly different to the radiologists. As the individual radiologists are being compared against a merged value of their total performance it would be expected that the bias index would be low and this appears to be the case with mean bias index values of -0.03 for the full and appendicular test results, and -0.04 for the adult only images. Equally the radiographers mean values for the bias index are relatively low -0.10 for the full test, -0.11 for appendicular only images and -0.12 for the adult only images respectively. Prevalence index mean values demonstrated by the radiologists were -0.31, -0.36 and -0.45 for the full, appendicular only and adult only test groupings respectively. The radiographers showed better mean performance values for the prevalence index of -0.31, -0.28 and -0.37 respectively. The combination of these figures and review of individual performance values of BPK in each test grouping shows that radiographers were able to demonstrate similar performance to radiologists. So even though numerically radiographers may not have performed as well as the radiologists the statistical calculations employed and recognised by Byrt et al [179] suggest radiographers were not statistically significantly different.

It is clear however that radiographers do not perform as well in either the weighted Kappa [193] or AC1 Statistic [198]. This is also seen with the individual scores (*appendix 10*). As the Wtd Kappa and AC1 Statistic are related it would be expected that the two outcomes would be similar even though Gwet's assertions suggest that the original ideas of Cohen were flawed [193, 198]. Wongkaparan et al [241] support this position and have shown that the AC1 Statistic is more stable than Wtd Kappa. As such the AC1 values should be considered a truer representation of comparative performance between readers or groups of readers. However, due to the method used to calculate the Wtd Kappa and AC1 statistic, similar substantial or almost perfect agreement values [197] as individual scores are generated for each sub group of analysis. This is seen within the results for both the radiographers and radiologists. So even though radiographers tended to perform less well individually the breadth of agreement in their Wtd Kappa and AC1 scores were roughly the same in each image analysis group as were the radiologists.

When considering the ROC values, only the appendicular image sub grouping of the tests displays significant statistical difference between radiologists and radiographers. The radiographers performed very closely to the radiologists when individual ROC emp and ROC fit scores are compared in the full test and adult sub groups (*appendix 10*). The radiologists had scores in excess of the radiographers in the appendicular sub group to make their rankings higher which explains why there was statistical significance in that results set even though the mean and median values suggest otherwise. In the full test and adult only image groups the radiographers are seen to perform better than the radiologists in some cases. This impacts on rankings and effectively explains the lack of statistically significant difference between the viewer groupings. So even though the mean and median values may not be as supportive (tables 6.2 p109, 6.3 p110, 6.4 p110 and 6.8 p117, 6.11 p121 and 6.14 p125) some individual performance values suggest otherwise and have influenced the statistical testing approach that was used.

When the ROC plots are viewed in *appendix 11,* even though hooks (which indicate a drop in performance at the curve extremities) are demonstrated in the fitted scores, they are for the lower scoring confidence rating and they occur at relatively far to the right and upper ends of the plot. This indicates the AUC is of an appropriately high value. Reliance on mean and median values can result in misrepresentation of the performance of a group especially where the comparator is smaller than the main group. In this case this has resulted in an impression of lower performance by one group when using simple descriptive approaches, therefore non parametric statistical comparison, despite the potential for weaknesses in their use, has given valid performance indications from the scores that have been obtained. This is despite the group size variation between radiologists and radiographers [243, 244]. The comparative close scoring of radiographers compared with radiologists for ROC measurements is also of interest. As discussed in section 3.5.3 there are potential problems with the ROC curve, particularly reader confidence level contributions, that may result in higher scores being generated than would be by simple binary responses. The calculator created by Eng and his recommendation to look for plot variations between empirical and fitted ROC outputs allows for some balance in interpretation of the results. Arbiter recognition of correct localisation of an abnormality from earlier education and experience, in combination with the suggestions of Eng, has contributed to a reduction of a false high score. This means that, in consideration with the close numerical performances, the lack of statistical significance between radiologists and radiographers, except for when the appendicular image results are considered as a sub set of the test, must be appropriate. Even though some scores clearly show there is statistically significant difference in performance due to the ranking effect, appropriate comparator measures show the differences are not always evident. Demonstration of these depends very much on the ROC measurement type, empirical against fitted, that is used.

The impression of the performance of radiographers relative to the radiologist can be swayed significantly by the type of statistic used to describe performance and clearly group size also has an effect. It should be remembered that these tests were measured using a small group of radiologists all of fellowship level and significant years of experience compared against a group of radiographers with mixed experience and specific educational knowledge regarding what constitutes normal.

8.2.5 Statistical comparison between radiographers and final year medical students.

It was suggested previously that the educational approaches experienced by medical students or qualified medical practitioners is driven by a diagnostic perspective. In contrast radiographers were initially educated through a technical approach that is concerned with meeting outcomes to enable diagnosis by others, from images acquired. Although the medical students have had less experience than the radiographers, score comparison is important to establish whether radiographers can perform to a level within the diagnostic paradigm. In this way radiographers are shown to provide a useful adjunct to the patient pathway that is safe and helpful to the newly qualified doctor who is less experienced. As such a recently qualified doctor will be able to react to information held in the plain radiograph and treat the patient accordingly based on a correct diagnosis aided by descriptions formulated by the further educated radiographer.

When looking at the base figures (TN, TP, FN, FP) against the statistical significance values it is evident that through the ranking process of the Mann Whitney U test there is a collapsing of the rank order and separations between viewer groups. This means that at times worse numerical scores by the medical students (FN, FP), similar values (TP) and better scores (TN) has caused unexpected results in terms of statistical significance. The FN scores responded as would be expected showing statistical significance between radiographers and medical students. The medical student scores were frequently worse than the radiographers for FP but the spread (*appendix 12*) caused a no statistical difference to be evident. The similarity and spread of the TP values created a non statistical effect as would be expected, however the TN values demonstrated statistical significance in favour of better numerical scores by the medical students except for the adult only images grouping. This has however translated into statistically significant differences for the sensitivity percentage values but not the specificity or accuracy.

The influence of FN and FP values and how they contribute to sensitivity, specificity and accuracy calculations aligns with the discussion above. Because radiographers have lower FN scores overall then the TP values are elevated. As a result the ranking procedure in the Mann Whitney test gives a statistically significant outcome in favour of radiographers compared against the medical students. Furthermore, because the FP scores are lower by the radiographers, though by no means close to the radiologists as individuals, a smoothing effect occurs with the TN contribution to specificity calculations. This makes the results less statistically significant. A combined effect is therefore seen to occur with the accuracy result that relies on adding TN and TP scores out of the total so a slightly better FN and FP by the radiographers contributes to generating results that are ranked so that no statistical significance is created. Clearly the relationship between component parts for calculation contribute to the impression of high or no statistical significant difference in performance at the final summation between radiographers and medical students and the sub sets of images viewed.

As noted previously between the radiographers and radiologist performances, where TP and FN contribute to the calculation of PPV and LR+ve, no statistical significance is observed. Likewise with TN and FP being the calculating contributors statistical significance is generated as the numerical results can be cleanly ranked to show better performance to a level beyond p=0.05 significance. Even though these results generate interest in their own right, what could have caused them? From a perspective of understanding why any differences do not always favour the radiographers, which may be expected due to the perspective that they have greater experience in working with images than the medical students, the diagnostic education paradigm seems to be contributing to the way each group is trained to think and work. As indicated earlier the radiographer is educated to recognise normal, which has contributed to both stronger TP scores where a variation in ages of subjects occurs i.e. full test and appendicular only images, and lower FN values. This suggests that where the juvenile skeleton is concerned the radiographer is able to recognise normality or variation from it better then the medical student and thus assess images correctly. Conversely, radiographers may be disadvantaged due to a lack of in-depth clinical information linked to a diagnostic template approach as taught to medical students. Consequently radiographers tend to err on the side of caution to generate a higher FP value that impacts negatively on the TN score. This would seem to be the case for the less experienced radiographers and those without wider experience in other imaging modalities. This is clarified when individual test scores are linked to information known about the individual radiographer participant available from the initial recruitment questionnaire and the qualitative surveys. As such this either brings scores closer together to reduce statistical significance, or shows the medical student to perform better both numerically and statistically significantly. This connection is borne out when the proportions positive and negative values are observed for statistical significance where none is revealed and that of the post odds probability scores clearly demonstrate stronger performance by the medical students.

In consideration of the Kappa and ROC values that are generated it is noted that the statistical significance results between the radiographers and medical students is reversed when compared with the radiographers and radiologists (Tables 6.15 and 6.16 p126). The Wtd Kappa and AC1 statistic show no statistically significant difference when the radiographers and medical students are compared but the BPK value is significant (p=0.05). Evidently the BPK comparison accounts for variation in the marginal totals produced in the 2 x 2 square that a Kappa calculation is constructed from. This suggests the influence of bias and prevalence in terms of correct choices matching the radiologists as discussed by Byrt et al [196], have an impact that favours the radiographers performance compared with the medical students.

Both of the ROC calculations favour better performance by the radiographers compared with the medical students. This supports the observation that no statistically significant difference was produced between the radiographers and radiologists for the full and adult image tests and only a small difference in the appendicular only scores that favours the radiographers when individual scores are scrutinised, even though radiologist participants are fewer. So from a perspective of using the currently favoured and perceived to be clinically more closely aligned measurement approach [235], the ROC measurement indicates better capability by the radiographers both numerically and statistically, when compared with medical students. When the individual ROC plots are reviewed (*appendix 11*) it becomes evident that fewer and smaller hooks are generated by the radiographers on the fitted ROC plots than either the radiologists or medical students. As well the curves of the radiographers tended to climb more rapidly on the left of the graph and plateau sooner creating a better AUC value pictorially than the medical students to generate the outcomes discussed. This suggests that the confidence level of radiographers is more certain than the medical students and is on a par with the radiologists and therefore harks back to a reliance on recognising normal appearances or a variation from it.

Coupled with the need to localise and identify the abnormality due to trauma to gain a mark for correct results to plot the ROC, radiographers must be making appropriate suggestions with greater confidence than medical student. Results further suggest performance at least approaching equivalence to the radiologists. Again individual backgrounds showed best performance amongst those radiographers with mid range years of experience and/or use of a further imaging modality in their professional background. Experience it would seem has given insight or extra knowledge as has regular use of a further imaging modality. This in its own right enables further consideration of who may be best suited to taking on an advanced role such as image describing amongst radiographers as it would appear improved performance may be linked to experience and other imaging knowledge. An ability to assimilate knowledge that is delivered within a different working paradigm as discussed in section 8.2.3 p187, that is the standard approach for medical education, is a likely further advantage for the individual mid range experience radiographers. Conversely, a lack of experience by medical students and therefore an inability to recognise image appearances, despite having a different educational background, has contributed to their performance.

8.3 Qualitative responses discussion

8.3.1 Radiographer pre test 1 and post test 2 survey comparison

Radiographers were asked for their opinions at two points in the study to establish if their attitudes had changed as a result of participation. Before beginning the first test radiographers gave several reasons why they wanted to join the investigation.

8.3.1.1 Question 1

State why you wanted to participate in this study

Radiographers indicated that they often had to work without radiologist support on site in a rural environment so had to proffer opinions to the referring doctor without a radiologist's input. The experience and impact of working internationally to see overseas radiographers contribute to patient pathways through reporting was offered as appropriate reasoning for joining in. Radiographers were interested in seeing themselves potentially advancing their profession in Australia and being of greater use in the working environment. This would enhance the radiographer workforce beyond currently being perceived as a technician responsible only for image acquisition [253]. This idea married well with the perception that newly qualified radiographers or students, visiting the departments of more experienced radiographers, often had contemporaneous and more advanced knowledge than they possibly possessed with respect to image interpretation. This encouraged some radiographers to use the study as a way of updating themselves and enabling them to provide answers to the inquisitive students they had on placement with them.

In the second survey after test two the same question was asked. Although the responses appeared to fall into slightly different groupings similar lines of thought became apparent for this group of radiographers. Role change was cited as a main reason for participating. It became evident that increasing one's knowledge base formed a significant driver that operated alongside the need to enhance knowledge to maintain professional currency. Interestingly, further knowledge from an interpretive context suggested to some radiographers that their radiographic technique would improve. Evidently a position of 'why' was growing in the radiographer participants minds rather than merely 'how' or 'what', which contributes to the patient pathway participation and team working suggested in the pre test one survey. Although not explicitly stating radiographers were asking 'why' the responses suggest that recognition a connection has been made between interpretation knowledge and an improvement in acquisition quality in their everyday work. This was however clearly expressed by participant 17, who recognised that an improvement in interpretive capability has a positive effect on image quality and decision making regarding the appropriateness of further projections. Furthermore, radiographers identified that the team contribution to those staff with responsibility for diagnosis and treatment would be aided by input from appropriately educated radiographers.

Of particular interest was a comment by one participant who said in the post test two survey, that he/she was prepared to give up time to participate in the study. This was an interesting stance and suggested that, if this was a common sentiment for other radiographers, continuing professional development or advancing practice in this way should be supported by the workplace allocating time to do it. Although in the context of participating in a research study, this possibly represents a mindset that radiographers expect employers to donate more resources to individuals prepared to extend themselves; a failure of employers to do this, results in unwillingness by radiographers to participate in initiatives to establish their interpretation abilities. This suggests that radiographers may be reticent about any potential to develop their professional standing by demanding recognition and support by their managers. This stance is likely to be viewed negatively by the workplace. It is also a continuation of sentiments expressed within the findings of the AIR 'Future Directions' working party of 2004 [125].

8.3.1.2 Question 2

> ***Pre test 1:*** *State in the box below any anxieties/concerns you may have before participating in this study about* *<u>performing an interpretation function</u>*
>
> ***Post test 2:*** *State in the box below if any anxieties / concerns you had before participating in this study about* *<u>performing an interpretation function</u>* *have changed*

Resistance to participate in research designed to establish the radiographers' position connects with some of the perspectives described in response to question two by the participants in both surveys. Although some radiographers had no concerns, two key findings were expressed in the first survey. Radiographers were concerned about their ability to provide an appropriately accurate description and how this could impact on the patient or others involved in the patient pathway. The second key finding seems more pragmatic, rather than being emotionally driven. Here radiographers asked what would the legal perspectives be with respect to taking on this role and what level of responsibility would the radiographer have with respect to final diagnosis? Would they receive acceptance by the medical staff, particularly radiologists that they are able to perform appropriately; alternatively would radiologists provide support with difficult cases. Clearly the position of the medical interpretation always being correct is deep-seated in the minds of radiographers. Examples illustrating that the doctor was not always right diagnostically were gathered at the end of the second survey (discussed later) and could be drawn upon by radiographers to recognise an interpretive role for them is appropriate.

Performance level anxiety still forms a significant concern amongst responses in the second survey. In recognising that their initial knowledge level was insufficient and moving on to appreciate that there is still much to learn beyond that provided in this short course, there is a perception amongst radiographers that it is unacceptable to be incorrect. This was strongly demonstrated where a false negative description was concerned. However, this perspective forms a foundation on which to build as over confidence can cause problems; radiographers have recognised their position with respect to describing appearances but also understand that this can be improved upon.

The financial perspective of report generation by radiologists was raised by one participant as a barrier to radiographers progressing in an interpretive role. This participant indicates that radiographers will not progress due to Australian funding arrangements, particularly in private practices,. However, it was suggested by other radiographer participants that where there is limited radiologist availability or excess workload for more demanding or urgent reporting, there may be a role for radiographers to contribute. This gives the impression that a two tier system may operate, where to complete the workload coming through a radiology department it would be ‘acceptable’ to allow radiographers to contribute. What should be borne in mind is that this does not mean a sub standard service is provided. Much discussion has taken place in the UK about performance levels, with initial limitation to a controlled range of examinations or referral sources that has since expanded. However, performance levels have to be the same as that seen amongst radiologists. This stipulation is seen despite the arguments about lack of measurement of the radiologist as the ‘gold standard’ or the performance of other diagnosticians interpreting radiographs. Without equivalent performance with the current provider of interpretations there is no place for allowing image interpretation by professional groups like radiographers [214, 252].

Finally question two raised concerns about the legal position. It is evident that radiographers fail to grasp their current legal responsibility within the imaging process. Although a diagnosis is seen as the final stage in imaging, legal recourse is possible for aspects of the acquisition component as well as the interpretive. The final interpretation is seen as the ultimate goal, however poor acquisition also contributes to the whole reporting process. Where this is the case it is feasible that the radiographer could be held accountable for a failed diagnosis. Some radiographers recognised that when interpretive knowledge is increased this may improve radiographic technique. To reduce mistakes every radiographer should work with this principle in mind. Essentially the radiologist is limited by the quality of imaging provided from which a diagnosis is generated. The same care applied to final clinical decision by the radiologist is heavily influenced by the attention to detail delivered in the image acquisition phase. As such, the radiographer has already made clinical decisions about the effective provision of the image to contribute significantly to the overall success of the imaging event; this fits closely with the arguments proffered by Smith and Lewis [128, 129]. When seen in this light it becomes evident that legal responsibility could be shouldered by the radiographer during acquisition of the image in the first instance, as the radiologist may argue the interpretation was swayed by the quality of the images provided.

Radiographers are educated to identify appearances within images [106] it may be opined that, although a diagnosis has not been provided, recognition of variation from normal by the radiographer suggests an interpretive process has already taken place. This fits with the capability framework and ultimate code of practice adopted by the MRPBA [106, 113]. A new professional freedom away from stringent protocol working may encourage the radiographer to perform more projections to add information or correct a sub optimal examination so that it meets the basic expectations. This is in contradiction to the commonly perceived belief that radiographers are taught purely from within a technical paradigm. However, continuation of this position, via responses such as those by the RANZCR to the MRPBA during development of its capabilities framework [45], serves to maintain a wide separation in abilities between the radiologist and radiographer. Currently, many clinical decision making events are protocol driven suggesting medical practice is to some extent also delivered within a technically directed methodology. There has long been a view that medicine and radiography are both a science and an art due to the need to interact with individual patients and tend to their associated needs. Legally therefore the level of responsibility is unchanged and there should be no reason for radiographers to feel that one profession's preconceptions necessarily controls another's to create a barrier. However if political patronage continues to respond only to the position and advice of the profession traditionally believed to hold power as discussed in section 2.3 p21, then the position will be perpetuated.

8.3.1.3 Question 3 survey pre test 1

> *Are you aware of any professional body input to furthering role development for radiographers?*

At the time of the first survey responses to question three, it was suggested that radiographer participants were unaware of the professional body's contribution to furthering radiographer role development. As indicated in the literature review, despite formation of the IPAT in 2012 [135], comparison of the Australian position with the UK by participants suggests this radiographic sample did not feel they were prepared for role development by the professional body. This compares with the Australian Sonographers Association (ASA) that seems to have a direction that supports the position of the sonographer [254] by *'…positioning the profession as the experts in Medical Sonography'*. This may stem from the nature of the work performed in the ultrasound department that requires the sonographer to generate, collate and interpret dynamic and still image appearances in order for the radiologist to provide a report. Alternatively the sonographer provides an interim interpretation that is then verified by the radiologist with the aid of captured images. Often however, due to the practitioner based nature of sonography, the report is generated by the person who acquired the images, as such making the sonographer responsible for diagnosis in their area of expertise. The findings of the AIR 2004 future directions working party have led to a slow formation of IPAT. Perhaps the multidisciplinary nature of IPAT has contributed to this. Alternatively long standing rules that bound ways of working with ionising medical radiation has caused slow progress, though a proposed advanced pathway for radiographers has now been generated by the AIR [255]. Most probably however, the financial implications of changing practices are the greater control feature and, as such, the radiologist representation on the IPAT has contributed to slowed progress. As indicated earlier, since the surveys were performed the deliberations of the MRPBA capability discussions for future registration needs occurred. During this period of consultation the RANZCR resisted inclusion of any competencies or standards that suggested radiographers should be taught any interpretive skills, despite this need being required to perform an acquisition role. The explicit commentary made in the capabilities consultation documentation [106] has been toned down by the MRPBA so that the code of conduct [113] and accreditation document for education institutes [103] suggests alignment with the RANZCR [45]. However, there is still room to translate the wording of the MRPBA capability expectations for the educational content of radiography degrees. This approach could also be applied to other medical radiation practitioner courses to allow programmes to be delivered that align with the principles espoused by the UK CoR through radiographer commenting [69].

8.3.1.4 Question 4 survey pre test 1 and question 3 survey post test 2

> ***Pre test 1:*** *If radiographer interpretation for emergency musculo-skeletal image interpretation became part of your role, please state what on-going support would be required to enable you to perform this duty.*
> ***Post test 2:*** *Since participating in this study, if radiographers were to participate in an image interpretation role, detail in the box below any changes of attitude you have had with respect to what on-going support would be required to enable you to perform this duty.*

Radiographers expressed clearly in the pre test 1 survey that there was a need to provide education in multiple formats and at regular intervals during development to support maintenance of knowledge levels. It was interesting to see that some radiographers felt that the education for describing should be provided as either a bachelor or diploma level qualification suggesting that there may be a lack of educational level recognition amongst them. Within the educational needs analysis question it was evident that radiographers believed that they should have verification and acceptance of taking on a decision making role by doctors such as the ED consultant or radiologist. This position is one that has become ingrained within the mindset of radiographers due to many years of being subjected to medical dominance and links back to Rouse's suggestion that radiographers have an inferiority complex [125]. Radiographers did however express that they could learn and maintain their skills through the multiple methods seen in pages 150 – 152 of chapter 7 of the thesis. This is in keeping with the recently published work of Neep et al who state that amongst Queensland metropolitan radiographers there are essentially two approaches to on-going education [258]. Each approach has benefits and limitations that are based on either length of time and multiple short presentation sessions or an intensive approach as adopted by this study. No ultimate preference was expressed by the respondents in the work of Neep et al [258].

Finally several radiographers did not feel there was necessarily a need for further monetary reward for performing the descriptive role, as informing the referrer of concerns over image content should be seen as a responsibility and role of the radiographer. This is in keeping with the expectations of the AIR [103] and echoes the ideas expressed in the capability documentation of the MRPBA that was produced after this survey data was gathered [103 – 108, 113]. One radiographer rounded off the responses by stating that the final decision about treatment, and so inferring that the interpretation of appearances, sat with the referring doctor. As such it therefore makes monetary reward difficult to claim for a description role if radiographers reject taking on an extra responsibility through abrogating final accountability.

In the survey after the second image test a shift in self understanding about the radiographers' knowledge base became clear. Several respondents identified that although knowledge had increased the course had flagged that much more needed to be known. There was clear recognition that on-going education is required and that this should be individually tailored.

The topic of quality assurance for measuring radiographer interpretation to maintain high level performance was raised. No comment was received recognising that no individual practitioner quality assurance measurement system was in place for Australian radiologists, despite their standards document [246]. As such no true gold standard is available to compare readers against, whatever their professional background, if radiologists are perceived as the best performers. It was clear from the radiologist figures that there could be a significant variation in report content (almost 7% accuracy difference [mean = 94.25% median 95.68%] - table 6.2 p109) between radiologists. Therefore the agreed target of 95% match between radiographers and radiologists adopted by most researchers, which is based on notional statistical principles around acceptable precision, has to be questioned [177, 178, 182] and an agreed measurement generated.

One radiographer inferred that the course length could be greater to ensure appropriate outcomes and fits with some of the replies in the work by Neep et al [257]. All reporting programmes seen within the UK follow a pattern that requires a whole year of input into a postgraduate certificate as the basic educational requirement. This requires employer acceptance of the need for in depth education with staff release and replacement. Even if staff replacement with study time is given by the employer, individuals are often required to find funding to pay for the course, which can be expensive and therefore a disincentive as discussed in chapter 2 p24. This was also noted as a barrier to progress by Neep et al [257].

Radiographers again reiterated the need to gain acceptance from medical colleagues with respect to performing an interpretive role for ED patients. In particular, this group of radiographers appeared to perceive that radiographer describing would not happen without radiologist input. Furthermore there is a perceived 'us and them' attitude predominant between the radiographers, radiologists and ED doctors; without acceptance into this team radiographers perceive the initiative would not work. Should this silo mentality continue then as detailed in the Health Workforce Australia document 'Leadership for the Sustainability of the Health System' literature review [159], the major challenges with respect to health service leadership and service provision (discussed chapter 2 pp 36 - 37) as paraphrased below cannot be met:

Address divisions to enable workforce flexibility and deployment for multidisciplinary teams;

Build organisational capacity and innovation;
Lead health professionals who focus on professional autonomy and patient/population rather than organisational outcomes;
Provide incentives to health professionals who innovate for the good of community and patients.

8.3.1.5 Question 5 survey pre test 1 and question 4 survey post test 2

> ***Pre test 1:*** *As part of the study you are asked to participate in 2 tests completing 209 interpretations per test to compare against the radiologist. Please detail any challenges you feel about doing this.*
> ***Post test 2:*** *As part of the study you have participated in 2 tests and completed 209 interpretations in each test to compare against the radiologist. Have the challenges you felt before completing test 1 changed?*

Radiographers were asked about the intensive nature of the testing regime, that is the large number images to interpret and relatively limited timeframe within a busy work or family life, or no-one to refer to. Confidence in performance ability was the key feature from responses and feeling responsible for performing badly, especially if colleagues asked them how they had performed. A lack of basic image knowledge was also a concern as well as pre conceptions about how to report with the assumption that radiologists follow a prescriptive technique.

In the survey after the second image describing time allowed to complete the test was flagged again, more specifically that a defined limit per examination was not set. Time limits are generated only in the clinical setting where perceived work load building causes pressure to deliver the service as quickly as possible and was also reported by Neep et al [257]. This perception is inappropriate as in the clinical setting no real time limit is set by either the RANZCR [246] or RCR [1] though nominal expectations have been suggested. In looking at the potential for radiographer reporting in Scotland a suggested plain image rate of reporting for a radiologist was 60-120 per four hour session. An accepted average of 80 per session and therefore 3 minutes per examination as a minimum was the final figure adopted for use in calculations [256]. However, should the clinical presentation be difficult then consultation between colleagues would occur, effectively meaning more time is devoted to a particular case. As such a false pressure is being placed upon the individual by the workload, when in reality a correct diagnosis is more important.

This perception probably emanates from the belief that radiologists complete large lists of reports in the reporting room, which by the calculations by Cannon et al [256] is not the case.

The latter perception also impacts on confidence levels about individual capabilities. Radiographers increased their confidence levels in recognition and description of appearances in test 2, opting for stronger responses within the tick box component than in test 1. This supports the ideas expressed by Neep et al [258] who recently looked at perceived confidence levels amongst Queensland radiographers. Furthermore, in this investigation, the descriptive content improved and became more succinct. Although having a large taxonomy to describe the range of appearances in the tests, radiographers believed they became better at recognising and stating normality. Further the image was evaluated differently according to the clinical question being asked within the referral history, thus streamlining the radiographers response. In reality there was little difference in the recognition of true and false positive or negatives as seen in table 6.5 p111. However, lower false positives and negatives effectively elevated the median sensitivity, specificity and accuracy scores by a small amount. To summarise the radiographers' confidence improved with better and improved search routines and vocabulary for the descriptions. Overall there was no significant improvement in the group as a whole, which contradicts the ideas of Krupinski [251] but supported the phenomenon reported by McConnell and Webster in 2000 [64].

8.3.1.6 Question 6 survey pre test 1 and question 5 survey post test 2

> **Pre test 1:** Do you believe radiographers can describe the content of an emergency musculo-skeletal radiograph at a level matching the radiologist?
> ***Post test 2:*** *Since participating in the study do you believe radiographers can always describe the content of an emergency musculo-skeletal radiograph at a level matching the radiologist?*

In the survey before test 1 it was evident that radiographers were strongly of the opinion they could interpret the content of the image from ED as well as the radiologist on a yes/no ratio of 13:4. The second test revealed a change in opinion suggesting 9 radiographers felt they could report as well as the radiologist in ED on most occasions with 5 saying they would occasionally match radiologist performance. This was despite the findings of the tick box component. In the survey linked to test 2 the question was phrased slightly differently giving radiographers a range of responses that ideally should have been offered in the first survey. However, it was felt during survey development this would not be inappropriate as offering a range of responses in the second survey would still elicit the radiographers' perceptions. The responses appear to be in keeping with the ability perceptions discussed above, and reflect a change in attitude following how much they recognised their knowledge base was lacking and required on-going support.

8.3.1.7 Question 7 survey pre test 1 and question 6 survey post test 2

> *By indicating YES or NO in the appropriate box, do you think commenting on the images while the patient is still present...*

These questions, between surveys, were asked to elicit slightly different but in depth information. Radiographers generally believed in their first survey that describing the image content in the clinical setting with the patient present would improve confidence in recognition of image diagnostic constituents and quality. This results in an advantage over the radiologist who is remote from the patient and in a radiology reporting room; it also acts as a service enhancement for the ED doctors and was unanimously accepted as a gain. Radiographers who were describing believed their status would improve within radiology and ED as well as enhancing the patient experience. All these factors were effectively seen as positives and gained in support when asked as questions in the survey linked to image test 2. Neep et al have also recognised that the team aspect is likely to be a major gain from adopting interpretation by radiographers [257].

Several further questions were asked as a result of the responses from the pre image test 1 survey. The need for on-going education and recurrent audit was recognised and strongly reiterated by participants. However, fewer concerns were expressed regarding liability insurance outside of that already provided by the work place. Radiographers also felt performing the role would be difficult due to time pressures and believed there would be a need to limit the areas of work radiographers performed in. These aspects link back to earlier discussions around radiographer confidence, acceptance that their knowledge base is sufficient, hospital and team working and a focus on the patient rather than the organisational needs [159].

8.3.1.8 Question 8 survey pre test 1 and question 7 survey post test 2

> ***Pre test 1:*** *Please indicate any other ways that interpretation of images by radiographers while patients are still present in the department may be affected.*
> ***Post test 2:*** *Has participation in this study changed your thoughts about the obtaining and interpretation of emergency musculo-skeletal appendicular skeletal plain radiographs?*

These questions were asked in both surveys to establish if radiographers believed, or changed their impressions, that describing by radiographers would be affected if the patient was present in the department. To date however no-one has investigated whether this phenomenon is real, although as pilot work to this study a group of Brisbane radiographers have indicated that they believed interpretation was easier with the patient still in the radiology department.[5] In the survey before the first image test it is clear that radiographers believed they were to provide an immediate service by interpreting image content, as the images were completed by them with the patient still present. However, to achieve this they also perceived that time was important in a busy image acquisition situation and that when this occurred the radiographer would not be able to provide an interpretation unless patients had fixed appointment times. Alternatively it was suggested that the ED would be too busy to enable this to happen as insufficient time would be available. None of the participants suggested that if the radiographer was able to work outside image acquisition then an interpretation service that is immediate for the areas for which they were educated could be offered. Clearly this would be more difficult in single handed departments/situations and suggests that the radiographers believed their function was to be linked only to images they produced. This is in contrast to that seen in the UK where cold reporting - radiographers replacing radiologists in reporting sessions – occurs, or a more senior role where a radiographer immediately interprets another’s images as part of the service provided. Time as a barrier has been reported by Neep et al, however this group did not make the suggestion that a different working approach could be adopted to navigate this issue [257].

Despite the concerns about available time to perform an interpretation role, patient service provision is uppermost in the radiographers' minds. They suggested that workflow could improve, waiting times in ED would be reduced and radiographer autonomy enhanced. At the time of the survey the prescriptive requirement from various professional and registration bodies that did not allow discussion of appearances with the patient needed to change to enable this potential. If practice expectations expressed in this study by radiographers occurs then the expected gains identified above will happen. Apart from an improved patient event, it was suggested other staff may enjoy a positive experience through radiographer interpretation. This was tempered by the potential for incorrect interpretations that could cause patient dissatisfaction or the belief that a doctor should provide the service, particularly if being paid for at a private radiology provider. A positive perception as suggested has particular importance in smaller centres where a radiologist may not always be available, even with telemedicine. Descriptions by radiographers could replace the delay experienced through a lack of radiologists to report electronically transmitted images and potentially navigate local governance issues from report quality perspectives [259]. Radiographer interpretations would enable faster response times, provide support to inexperienced medical staff working beyond normal office hours without senior support, improve relations between ED and radiology or not require the radiologist input for all cases if the further educated radiographer was available [126].

Radiographer autonomy may also be enhanced with interpretive education. This would include functions such as improving imaging quality, making decisions about performing further projections or suggesting alternative modality use. When patients are still present in radiology, further physical assessment by the radiographer to aid diagnosis and improve treatment could be possible [42]. An approach such as this has been suggested as a practice enhancement in the UK [260]. Clinical assessment enables clarification of previous events that impact on image appearances or if co-morbidities were detected on the image then further views would aid diagnosis. With this autonomy available to the radiographer then closure of this service loop is assured. This component has been discussed in the framework of the undergraduate radiographer skills base as long ago as 2004 [42] and now is recognised via the AIR Proposed Pathway to Advanced Practice document [255]. Participants also suggested that inappropriate imaging could be addressed and reduced if radiographers had increased autonomy and education. In conjunction with further imaging suggestions increased radiographer autonomy has an associated positive effect on the work of the radiologist, enabling focus on more difficult imaging without being over loaded by plain radiograph reporting. A particularly helpful impact is possible for the rural and remote populations often served by single handed imaging providers. This also meets with proposals made by the RANZCR in the National Health and Hospitals Reform Commission investigation of 2008 [259].

In a contrary position, some city or radiographers at regional base hospitals recognised that, even though sonographers have adopted these principles already, care should be taken in further clinical assessment. They expressed that it is difficult not to be swayed by patient description of their problem, or to allow the clinical impression to drive a position whereby the image interpretation is moulded to fit the established signs and symptoms. Clearly, the type of service that is provided in centres outside city or regional base hospitals requires a broader consideration. Although this service may generate problems such as a public expectation that a decision be made outside the radiographers' scope of practice, other commentary suggested that radiographers should be afforded more respect for what they do and interpreting could achieve this. An example of over interpretation through a clinical impression being made to fit image appearances by some medical staff leads to other problems as was given on p163. The patient would have been better served had the radiographer's input been acknowledged.

When table 6.16 p126 is compared against the above impressions received from radiographers in the survey before the first imaging test, it is clear that radiographers favoured the production of more plain radiographs compared with the medical students. This trend was evident in the second survey as well and CT was the favoured choice modality of medical students despite the radiation protection connotations. Both groups appeared to employ non-ionising radiation imaging modalities for further information to a similar extent however radiographers and medical students requested many more extra examinations than the radiologists. Expertise and satisfaction about image content for the radiologists to diagnose from is possibly coming into play with this difference [190, 197, 237 – 240, 251].

As indicated in section 8.2.3 p187 an explanation is given for why radiographers may want further imaging due to the technical educational and protocol based routines of image acquisition. A lack of knowledge about the potential that differing types of imaging may achieve in terms of answering a clinical question has also potentially driven further imaging choice selections. Alternatively, treatment options dictate the need for further imaging rather than diagnosis and so drive further imaging requests through a protocols approach. However, it is clear that the medical students prefer sectional imaging to enable them to make a diagnosis. Perhaps this harks back to Morton's reminiscences [98] to suggest a continued expectation by the medical student that imaging is the answer to a diagnosis. This idea today however sits in a situation of greater expectation of the medical student having to know about more disease processes than was perhaps necessary in the early part of the 20th century [98] and therefore promotes a reliance on further testing to aid diagnosis.

8.3.1.9 Question 8 survey post test 2

> *Please could you recall an event of an episode where you believe your input through direct contact with the patient and your subsequent interpretation was not acted upon by the emergency department medical practitioner? For example you may have verbally interacted with the ED doctor and you later checked to see if the radiologist agreed with you and you found the patient had to be recalled for further management. How did you feel about this? Does it happen often?*

To conclude the second survey radiographers were asked to give examples of where they believed their input was ignored and the consequences of this, or if there was regular use of their interpretations. From the responses between pages 181 and 186 of this study, it is evident radiographers recognised there was a responsibility to inform their clinical colleagues in the ED department or the referrer, which meets current registration and professional body requirements [107, 113]. In many instances the offer of advice was received well and consequently acted upon. However participants stated there were occasions when this was not so resulting in poor consequences for the patient or inappropriate worry and expense incurred when an over inference into the interpretation was made by non-radiologists. An example of recognition of the radiographer input resulting from the further education received during this investigation (p160 participant 11) supports the finding of variation amongst radiologists seen within the gold standard development for this study. If ability is not acknowledged by the radiologists, it would appear that radiographers have standing within the ED team. It seems however that this may come from trust built over many years of working within the same group rather than recognition that radiographers have an ability to interpret the images they produce. Occasionally, as one radiographer pointed out, there is frustration that trust in the radiographers is not complete and treatments occur that are unnecessary.

Recognition by radiographers that there is a culture of over imaging to either meet patient wishes or to cover against litigation is noted. Radiographers have stated in this study they are seen by GP referrers to be able to pass on results to patients. As this is not legally correct, problems are created for inexperienced staff members, which slow down workflow if radiologist reporting sessions have to be interrupted to obtain a report for the GP, which is out of sequence in the reporting list. This suggests that if the working approach was changed to recognise the radiographer with further education within the team from an interpretive perspective, then workflow would be improved [132 – 134, 159, 160, 256].

A recent pair of coroner's inquest findings in Victoria serves to illustrate that those external to radiology see the case for team change. In the first case the adequacy of the clinical management over the period of a week was questioned (2007) [261] and for a second (2013) [262] that interaction with imaging technology caused problems. In both cases it is clear that had radiographers been allowed and expected to contribute to the situation then it is likely the deaths at the time could have been avoided. In the first case [261] summarising comments by the coroner suggest that improved communication between referring doctor and radiologist, to express the concerns for the patient, would be a way to improve the service. The appearances seen within the abdominal radiograph are likely to have been such, in light of the evidence given in the inquest, that a radiographer could have alerted the referrer at an earlier stage and therefore have changed management. In the second case [240] communication breakdown, technological faults and the lack of expectation that a radiographer ought or can provide a diagnostic input contributed. In the second case the expert witness flags similar issues to the first coronial report regarding radiographer, radiologist/doctor silo based working and the inhibitory culture that prevents radiographers indicating an abnormality when they see one. The coroner believed that this issue was so serious that the recommendation that;

> *'…skilled radiographers be permitted to alert medical staff to an issue of clear and significant nature relating to patient safety. I do so in accepting that interpreting diagnostic images is strictly outside the scope of practice of a radiographer. I note that care will have to be taken to avoid development of an expectation that radiographers will routinely alert medical staff to an issue with images.'*
>
> *Gray p11 Inquest of Verna Therese Hamilton 26th July 2013* [262]

It would seem that there is high regard for the value and potential of radiographer capabilities including interpretation perceived by observers external to the radiology environment. It was also significant within the inquest of Verna Hamilton that the coroner noted the expert witness, Prof Donald Campbell, has been working on ways to break down the silo based culture of medicine and service delivery. His position recognises the merits of inter/multidisciplinary working, however, there is still reluctance on the part of radiologists to allow radiographers to contribute to the interpretive process. The coroner quoted discussions between the healthcare provider's lawyer and Prof Stuckey the Director of Diagnostic Imaging at Monash Medical Centre where the death of Verna Hamilton occurred stating that:

> *'…this is a controversial and "industrially sensitive" issue. …Professor Stuckey has advised that interpreting diagnostic images is outside the scope of the practice of the radiographer…he supports a voluntary system where experienced, skilled radiographers are permitted to alert medical staff to a clear and significant issue relating to patient safety. …there may be a problem arising for medical staff having an expectation that a radiographer would always do that and he also noted that a significant proportion of radiographers at Southern Health are relatively junior and could not be expected to shoulder the responsibility of reporting on images to referring doctors.'*
>
> *Stuckey to Snowdon p8 Inquest of Verna Therese Hamilton 26th July 2013* [262]

The position taken by Stuckey perpetuates the official RANZCR position discussed earlier [48, 156] that fails to recognise the team based approach suggested by Rodger in Scotland [157] and the now disbanded HWA more recently [159,160]. This was most recently illustrated by the RANZCR's [45] attempts to influence the content of the capabilities document for radiographers devised as appropriate practice by the MRPBA and supported by the AIR [106 - 108]. Through this statement there continues to be resistance expressed by radiologists to radiographer involvement with the interpretive process, that was also seen in 2006 [46]. Even though Stuckey [262] and Fabiny [48] express limited acknowledgement and suggest a veiled RDS approach, other radiologists continue to attempt to undermine any input by radiographers [263] by trying to weaken the RDS position in Australia. Through using a deliberate focus on aspects of practice that suggests performance is insufficient when applying a warning flag as seen in RDS approaches, Brown and Leschke continue by reiterating the limited role perspective suggested by Donovan and Manning [158]. A strong rebuke that indicates how the radiologists approach was flawed and the suggestion that radiographer commenting would be a way forward in Australia was subsequently made by Neep [264]. Interestingly in a commenting trial non further educated radiographers followed in Queensland [265] showed accuracy of 76% in the comments produced, which is in line with the test 1 findings of this study.

When the recent report [5] of 48,000 radiographs not being 'properly reviewed' by radiologists on the Gold Coast region of Queensland with probable resultant effects on the population is considered, then questions about the ability of radiologists to meet their targets needs to be asked. This is especially pertinent in the light of comments in the same report by Greg Slater of the RANZCR who indicated there had been problems for 'several years' [5]. Of note similar stances were taken when questions were asked of the New South Wales image reporting system in 2012. Through the Labor opposition spokesman, Dr Andrew McDonald, political patronage position was continued by supporting the need to employ more radiologists rather than adopting an alternative radiographer based approach to meeting demand [6]. The AMA perpetuated this position in the same document by stating *'…it was important that radiologists reported on X-rays to prevent serious problems being missed.'*

Clearly the continued belief that only radiologists can perform the role to the best level is supported by their union but no-one recognised the potential for discrepancies between doctors even though Brian McCaughan, a medical professor, accepts mistakes are made [6]. As this study shows performance variation resulting in discrepancies occurs amongst radiologists as well as other specialists.

Since the original flagging of reporting back logs, NSW has published the findings of the Clinical Excellence Commission report [7]. Although a suggestion that radiographers may contribute by interpreting a range of images no real impetus to make this happen has filtered through into the recommendations. This is likely to originate from reluctance by radiographers and radiologists to follow the path of multidisciplinary working at the time of the commission investigation, despite international evidence to the contrary [29, 65, 66, 144].

8.3.2 Medical student survey responses.

Moving on from radiographer interpretation and professional silo based working, it is pertinent to note that medical students were keen to express the view that they did not believe they had received sufficient education in image interpretation at this stage of their careers. They also identified that the medical degree should change to reflect the role of imaging in healthcare practice. This observation was in keeping with various findings locally and internationally and is a feature raised widely by junior medical staff during education [8 - 10, 21, 22, 75]. The medical students suggested they felt this study would give them an opportunity to establish how well they were doing with respect to interpretive ability and that participation would help them recognise their preparedness for internship. Although some students felt reasonably confident in their abilities, probably because they had participated in a radiology or ED rotation, there was a belief that they had an overall lack of knowledge for the test and that they would have difficulties in formulating a report or making an appropriate diagnosis.

To establish whether the soon to be medical interns knew what radiographers could do for them, whether in Australia or internationally should they eventually work in different countries, questions about the radiographer role were asked. It became clear that the role of the radiographer was understood in some ways but not others, and that there was a possibility that radiographers might eventually provide interpretations prior to the radiologist report. Of concern was the lack of knowledge that at least a verbal indication should be given when abnormalities the referring doctor might not see were detected by the radiographer and contradicts the interpretive potential indicated above. This suggests a continued silo type approach to working, although the medical students realised that the radiographer could suggest alternatives to the request if a better examination or modality would be appropriate. There was less appreciation of the way radiographers operated internationally in terms of providing a report.

The medical students were asked if certain plain radiographic examinations would be more difficult to interpret than others. It became evident that paediatric examinations, radiography of the skull and face, and the various spinal examinations held most concern for the participants as they graded these more difficult. Of interest the elbow/humerus/shoulder and tibia and fibula/knee and femur examinations were scored lowest for difficulty. This is most likely explained by the fact that skull and face radiography is less frequently performed due to the utility of the imaging type and the three dimensional capability of CT that enables other clinical questions to be answered. This would evidently mean that experience with skull and facial radiography would be lower and make the gaining of expertise more difficult.

Although imaged more frequently with plain radiography, particular difficulties encountered with the paediatric skeleton at its various stages of development, coupled with potential concerns about patient outcomes should the interpretation be incorrect, the response of the medical students was aligned with images being more difficult to diagnose. To some extent this also appears to be the case for those referred for spinal images. It would seem that there is strong likelihood for heuristics and utility function [190, 199] to impact in the decision making in these examinations as discussed in section 3.6 p61.

A strong message was received from medical students when asked directly whether their image interpretation education was sufficient. Early years pre-clinical teaching is limited and does not cover the areas of radiology that the medical students believed should be included. Furthermore, unless an ED or radiology elective occurs there was a perception of insufficient education clinically as any education in hospitals was driven mainly by interested staff when they had time while students were on rotation. Much image interpretation teaching, it would appear, was based on self directed learning that called for a realisation by the student that there was an educational gap. One medical student stated that he/she felt interpretation skills improve with practice, however without sufficient guidance this could prove dangerous. Statements made here clearly support the concerns of Goergen, Zhou and Subramaniam [8 - 10]. This lack of a knowledge base appears to contribute to the poorer performance when reviewed across the quantitative results, whether they are statistically significant or merely numerically worse.

The next question went on to ask if the medical students would be prepared to receive help from radiographers educated to provide interpretations. There seems to be a 2-way split in that some medical students are prepared to accept an input a significant proportion of the time but the other half of respondents were more reticent. It seems to be, amongst comments received, that this would be acceptable if a senior radiographer gave the description. However there is a caveat that when the radiologist report is available then they would act upon this. One student felt that plain radiographs would be an acceptable modality to receive comments about and if radiographers disagreed with the medical student then a radiologist opinion would be sought. What is apparent though is that there is, despite the comments made earlier, a continued reliance between doctors on each other, as developed during the 1920's [33, 84, 90], rather than considering different ways of working even when the educational approach is strong. Rather than being a concern for Goergen who wishes to be involved in more teaching [10], retention of the status quo is potentially more useful to the radiologist to maintain reliance by other medical staff on the radiologists position and role.

The final question to the medical students was one that asked if their access to patients gave them an advantage over the radiologist to make a correct diagnosis when also receiving a radiographer interpretation. It was clear that the multidisciplinary team and ability to express to radiographers any other imaging that may be required would be enhanced. Although there was some indecision, more medical students thought they would improve their chances of a correct interpretation with radiographer input than not, which was in keeping with limited work performed in the areas of the wrist radiograph and CT of the brain [43]. The value and ability of radiographer advice in head CT in Australia was also remarked upon positively by Heng et al in 2001, when studying the impact of a registrar being available for interpretation of these images [272]. However, there was a definite medical student rejection of the notion that patient access with radiographer input would give an advantage over the radiologist. Presumably this is because there is respect for the radiologist and that they are seen as being the expert standard without the patient being present. However, no study to establish whether this is correct or not has been performed although investigations have shown the ED doctor still has a low but not unexpected level of mis-interpretation [173, 174]. There was less certainty regarding whether the patient experience would improve with radiographer descriptions. Much would depend on how patient experience is measured to state that improvement is the case. However, in the UK, various approaches to this question have been used to attempt to show how improved patient experience might be measured [67, 266]. Evidently a way to establish this would be to introduce radiographer interpreting and use measures such as report turnaround times to demonstrate whether an improvement is possible. Despite this position however, the strong answers given that state multidisciplinary team working will improve is a positive outcome for the radiographers cause. Better instruction to the radiographer regarding the imaging required seems to infer that these are areas of patient experience improvement that would be acceptable and match those impressions gained by Brealey and colleagues [267]. It appears that the medical students are being somewhat contradictory in their thinking and become defensive when the questions are more overtly phrased to encroach on traditional medical ground.

8.4 Final discussion reflections

It is clear that medical dominance, political patronage and radiographer perceptions of their abilities have impacted on how this study was developed and performed as well as influencing the findings that have been obtained. Woznitza [268] comments that with advanced education radiographer interpretation of MSK, chest and abdominal plain radiographs is of a standard equivalent to radiologists. The SCoR indicates that in 2012, 41% of UK departments of radiology used radiographers to provide definitive reports on skeletal radiographs [269]. Yielder has worked over several years to try to explain why radiographers have not progressed in Australia and New Zealand and firmly states in an editorial piece '… *there is a culture of subservience and apathy in the profession*…' and blames this on the hierarchical system developed in the early 20th century [252]. She also states workplace culture contributes and that behaviours of conformity and compliance favour perpetuation of the subservient position [126 - 128]. This could however have been influenced significantly by the privatisation of radiology in Australia and harks back to the 1949 refusal by radiologists to have anything but a direct employment relationship with the patient. Yielder argues however that if the profession is to have a future it should insist on being respected. Support for this view is seen amongst some radiographer comments in this study. The profession, Yielder suggests, should also move away from the terms that imply technician status and in her editorial indicated favouring the term radiographer over such titles as Medical Imaging or Medical Radiation Technologist; she argues that the technologist title perpetuates a lower professional level [253, 271] and fits with the latest direction that the ISRRT and EFRS is travelling with respect to enhancing the professional status of radiography [23]. Finally Yielder implores the professional bodies of the AIR and NZIMRT to '…*create change in the professional culture and to progress an advanced practitioner framework*.' It would seem that there are still many hurdles that the AIR faces within Australia and that it should become more forthright in its position. Otherwise, it may be suggested, the issues discussed in 2004 [125] and the work done since will have minimal effect in achieving advanced status and enabling radiographers to provide an interpretation role from graduation onwards.

PART 5

STUDY LIMITATIONS, CONCLUSIONS, RECOMMENDATIONS AND FURTHER WORK

'Health care employers will be looking for skilled practitioners trained in critical thinking and problem-solving skills'

Steven Dowd, Elwin Tilson
Re-engineering via patient-centred care,
Radiologic Technology, 1996, Vol 67/ No 5 p 424.

CHAPTER 9 Limitations of the study approach and conclusions.

9.1 Strengths and limitations

Rather than divide this section into particular strengths and weaknesses, the limitations will be raised and analysed with respect to establishing whether the feature influenced the investigation positively or negatively.

It is acknowledged by the researcher that use of final year medical students as not being a qualified comparator leaves the study open to criticism. However as discussed on page 4, the final year medical student, who at the timing of the study participation was in his/her final clinical placement period is required to possess the appropriate foundational knowledge to ensure their image interpretation skills can be extended during the internship. Until recently with the publication of the MRPBA Capabilities Framework, Australian radiographers were expected to only comment on the technical content of the images they produced. Thus the choice to compare radiographers with experience plus further education and final year medical students in the study ensures equivalent ability levels between participant groups is assured in light of the medical students having previously received a minimum of 85 hours of specific radiology training [9]. This alignment of capabilities will have also accounted for variation in time since qualification of radiographers who may have gained insufficient or inappropriate knowledge since qualification. As a result, even if the expectation would be through experiential exposure by radiographers to a wider range of image appearances and subsequently interpretations that radiographers would perform better, this approach attempts to standardise the starting ability of participants in the study. Clearly evaluation of interpretation performance of those doctors after a year's experience relative to the further educated radiographers would have been of value however, recruitment issues prevented this approach from being adopted.

This investigation was constructed to account for the potential sources of bias within image interpretation studies [127, 165 – 168] that have been discovered by a range of researchers. Previous Australian attempts to follow the UK in developing radiographer interpretation have been shown to be flawed in the research approaches adopted. Methodologically, despite the strides towards radiographer interpretation in the UK, investigators have raised issues with some of the methods used by UK researchers that could be questioned with respect to a given study’s validity and reliability [145, 166]. By correcting for these it is opined that this investigation is the strongest yet performed within an Australian context. However, there are still aspects of the study that may be open to criticism. These should be discussed first in the context of whether they actually represent strengths rather than limitations, based on earlier discussion and findings in the thesis.

The number of participants at 16 radiographers and medical students, and that they all came from the State of Victoria may be perceived to be insufficient for wider generalisation across the Australian radiographer population for interpretive performance [228]. Equal participant cohorts of 16 radiographers and final year medical students’, results in the ability to comparatively analyse participant scores equally, to act as a point of strength. Arguments have been put forward by Obuchowski [217] that indicates the sample size for this investigation is appropriate.

Medical student participants came from a single medical school in Victoria. When considered further this is a study strength as sample standardisation is achieved [228] to account for variations that may arise amongst medical students due to different teaching or educational delivery timings. These variables have the potential impact on a wider medical student body taken from across Australia and as such may affect validity and reliability.

To aid participation uptake and randomisation, a self selection approach was adopted through contacts made using the MRPBV for radiographers and a recruitment exercise via the medical school internet virtual learning environment. Clearly recruitment of this nature suggests that this group of radiographer volunteers wished to further the development of their profession, especially when the content of their survey returns were considered. Medical students were also able to identify personal learning; this study clarified for these students what those needs were. As with the radiographers, this indicates a potential bias in that only those who had a self belief in strong interpretive ability from both participant groups would step forward. In actuality a range of radiographers from differing clinical backgrounds and post qualified experience volunteered giving a wider perspective across the typical radiographer population. As well, there were several medical students who had taken a specialist radiology placement, thus potentially enhancing their performance ability, to add to the overall medical student final measurement statistics. With both groups of the population sample displaying this variation then it can be argued the study has, admittedly through serendipitous self selection, been able to demonstrate a population sample with features that makes the results more generalisable.

By using a third party to ensure participant anonymity through a numerical coding system, the arbiter/researcher could not establish details about individuals during the scoring process. This met consent requirements for ethical purposes and ensured that sources of arbiter related bias were not introduced into the study [166, 167] (see section 3.3 p44 and tables 3.1 p46, 3.2 p50). Due to the timing of the image tests however, it was clear that the participants being marked for their ability came from either the radiographer or medical student group. It is therefore possible for arbiter bias to feature from the perspective of favouring one group over another. However the marking tool content produced through the consensus radiology reports made it difficult for the arbiter to vary the scoring awarded to individual participants.

The image test was balanced in such a way as to account for the wide range of bias types, defined by Brealey et al [165 - 168], that may surreptitiously affect this kind of investigation. Only images with strong agreement about their content were included so that a clear yes or no position could be adopted. This ensured the measurement process is not based on a single radiologist report that could only be labelled a reference standard, which meant a weaker investigation process would have been employed. The measurement calculation process used a range of checks, balances and cross referencing techniques to prevent bias in result reporting. Approaches included a tick box initial impression request of the participants, their confidence levels, free text expansion of image content and questions about further imaging needs (Figures 5.2 p88 and 5.3 p91). A wide range of statistics was employed to flag how reliance on a single measurement approach can lead to incorrect impressions of performance of one group over another [192, 233 - 235]. This also enabled the investigation to cross reference performance figures that may be impacted upon due to the need to ask participants to use home based computing equipment rather than in a standardised laboratory approach. This approach does have limitations especially in regards to the quality of the computer monitor that was used by the participants. Although an in depth argument was given for the approach on p89 and 90, this could still be perceived as a limitation to the study because control over monitor resolution could not be assured. Collusion between participants could also not be controlled although participants were asked to respect a professional stance and not do this. The spread of the individual scores generated and shown in appendices 9 – 12 demonstrated that collusion was highly unlikely.

The literature review into methodological approaches showed how the use of differing *Kappa* type statistics can cause incorrect comparison in performance to be made. Furthermore the selection of positive and negative compared with the radiologist standard significantly affects final outcomes across groups and individuals. This is due to the proportions of agreement with the radiologist consensus test images and results contributing to sensitivity and specificity scoring [193 - 198]. Therefore the range of statistics provided acts positively to give a full understanding of the different performance by each participant group. In short any study of this nature should consider how it expresses performance. The ROC methodology has advanced during the period of this study and is labelled as the most clinically appropriate [235], however this has to be tempered with how the sample population used for measurement can be accessed. Reliance on specialised software may not enable an appropriately wide population inclusion. Alternatively an exam type false viewing situation, as overall interpretation time may have to be controlled, might be generated due to the need to use specialised computer software, thus reducing potential for wider applicability of the results. Even if these problems can be overcome such as by using an internet based approach, there is still a potential for image viewing condition variation to impact on individual performance. This is despite commentary that states standard viewing conditions available on an entry level computer monitor is acceptable [224, 225].

The decision to ask all participants to view a large test bank was driven by the potential for criticism that may arise with the content of a smaller image trial [236]. This weakness could be levelled at any study; however care was taken to avoid this though it was pointed out by participants that the testing approach demanded significant input from each individual. The fact that a wide ranging test was created, correcting for issues identified in other studies, gives this investigation one of its greatest strengths.

The findings from the study suggest that radiographers have a strong reference level of ability achieved through experience or, as in the more recently qualified, via components in their degree based education. Although the second test results showed little improvement in most values of radiographer performance, the study has flagged that the UK model of postgraduate study for longer time periods is the correct method to employ for advanced practice education. The results also serve as an indicator that due to the changing nature of imaging and diagnosis, more clinical decision making based education in the diagnostic paradigm for radiographers as discussed in chapter 8 p175 would be appropriate. Therefore, results that suggest a short course is less effective, indicates that a potential change to how radiographers should be operating in their everyday practice is identified. This requires amendment to the under and postgraduate radiography educational didactic paradigm that is often favoured from a desire to pass on large volumes of knowledge, to use of a deductive analytical approach as suggested in section 8.2.3 p187. Education institutes would argue they are inculcating students with the tools to achieve this. However, because Australia has followed two models of undergraduate radiography education, teaching focuses on outcomes about how and what radiography to perform rather than why. The contradictory position is supported by evidence in this study, and questions of the role of radiography may be enhanced through interpretation of the clinical results. This means the needs of healthcare delivery are adjusted and, more importantly, changing patient requirements can be met.

This investigation was constructed to explore whether, after a short course of education, experienced radiographers from the State of Victoria could identify and interpret abnormalities on plain images of musculo-skeletal (MSK) trauma to support the junior doctor. Despite the potential limitations of the study this aim has been met. Five further objectives were the focus of the investigation. These were an evaluation of:

1. literature to identify the factors that have hindered radiographers from participating in musculo-skeletal trauma image interpretation;
2. the ability of further educated experienced radiographers and final year medical students capacity to interpret appearances seen in musculo-skeletal trauma radiographs in order to establish if each group has accuracies close to that seen amongst radiologists;
3. the ability of further educated experienced radiographers and final year medical students to describe incidental findings on an examination and express whether further investigation(s) is/are warranted ;
4. the number of requests for further imaging between further educated experienced radiographers and final year medical students in comparison with radiologists;
5. whether final year medical students are aware of and open to input by radiographers via image interpretations to the emergency department (ED) to aid their own performance and if radiographers believe they are able to do this.

From the results and discussion presented it is clear that these objectives have been explored to show as strengths through the literature demonstrating where radiographer progression has been hindered, be it through another profession or via its own approaches to practice development in the past. Radiographers have also been shown to perform at a level not statistically significantly different to the radiologists in some measurement values although, as expected, the radiologists overall perform better. Again, although expected, the radiographers performed better than the medical students. Radiographers also demonstrate that they comment more on further findings than the medical students who seem to be interested in confirming diagnoses. Further requesting of imaging by radiographers is often technical acceptability driven although there is recognition that image content/appearances also contributes to the use of further imaging or projections. Medical students favour high radiation dose techniques to achieve the same outcomes as radiographers however, their diagnostic educational paradigm favours a request for fewer further examinations than the radiographers. Finally, there is some understanding by medical students that radiographers can make a contribution via image interpretation although favouring the medical input id predominant in the student mind set of achieving a diagnostic answer.

These associations with the aim and objectives will now be summarised within the conclusions.

9.2 Conclusions

Healthcare in Australia is funded from the public purse via Medicare, often in association with private health insurance. In both cases payment to the imaging service provider is only received when the report is issued by the doctor, in this case the radiologist. This is an example of political patronage levied through medical dominance, which has been developed and maintained in radiology for around a century [80, 81, 84, 91 - 94, 96 - 100]. The medical profession ensures it maintains a commanding position with either other healthcare workers or through appropriate political manipulation, by changing allegiances to meet the requirements of the profession at a given point in time. Duckett [161, 162] and de Voe and Short [163] outline this process in sections 2.6.1 p36 and 2.6.2 p37. Unless this position is refashioned the potential for radiographers to be involved with the interpretive process through initial image content description is unlikely to occur, as financial drivers will ultimately control any changes to the current healthcare delivery perspective. This position seems to be perpetuated amongst this study's participant group of medical students who demonstrated contradictory responses within their survey but firmly aligned with other medical colleagues.

For the medical students in this study, radiologists are seen as the only professional group with the requisite skill to provide a definitive interpretation of images. This is an interesting position, as the international experience of educating a reporting radiographer is through mentorship by radiologists. Radiographers are thus taught to use an approach similar in descriptive style to radiologists. Therefore inculcation with a radiologist's education and experience must occur, as the same approach to reporting is closely matched. Authors have indicated that radiographers must perform any interpretive or RDS role at a level equivalent to radiologists [69, 137, 141, 147, 214]. Any lesser ability in performance of the same task than that provided by the practitioner normally providing the service is not acceptable. Therefore arguments that suggest radiographer interpretation does not have parity with a medical opinion can be called into question; any lesser abilities in skill or knowledge whilst performing the same task are not acceptable. If radiographers do not interpret at an equivalent level, the new approach cannot be adopted from the perspectives of safety and governance. [166, 175] This study has shown there to be over 5% variation amongst the radiologists (accuracy min 89.5% - max 96.2%) who took part in the study to generate the image test bank [177]. This must raise questions about acceptable practice levels within the image interpretation community when a 95% agreement with the reference standard is the accepted norm for practice seen in the UK. This performance recommendation has also been suggested by research within Australia [211, 212]. Reliance on the ability and performance of "specialists" is accepted practice within the medical model of healthcare delivery. Evidently this level of performance cannot be achieved by all as was demonstrated in this study. Based on the results obtained during development of the image test bank, acceptance that the specialist doctor is always right is open for reconsideration. If radiographers can be shown to meet a 95% agreement then there may be a safe, reliable and better use of personnel who have been further educated in the health service.

The aim of the study was to show that experienced radiographers from the State of Victoria can, after a short course of education, identify and interpret abnormalities on plain images of musculo-skeletal (MSK) trauma to support the junior doctor. The radiographers in this study have shown that they have the ability to perform better numerically than the medical students in most measurements, though not always with statistical significance. This was also seen in some of the scoring comparisons with the radiologists where there was no statistically significant difference, indicating similar performance. As such it can be stated that the aim of the study has been met in terms of supporting the junior doctor although, as indicated below, the course length is important in terms of consolidating new information. Investigations from several years ago [26, 27, 64], and amongst radiographers in this study, show that experience accounts for stronger baseline performance. When further education was provided to enable enhanced decision making skills, then ability did not improve as much as was expected or was even reduced. This was also the case in previous international studies [24, 25, 212], where until further experiential application had occurred, the level of interpretive performance amongst radiographers did not significantly improve. However in this investigation, the range of scores was narrowed in the second test suggesting knowledge consolidation had taken place to account for the better scores being achieved by radiographers in comparison with the medical students. In order to put new knowledge into individual frameworks of understanding that is accessible to radiographers and applicable to the decision making situation, it appears a longer timeframe in which to add experience is necessary; that is course length is paramount.

Experiential ability change has also been noted internationally in studies looking at image interpretation in pathology as a medical specialism [251]. In analysing why knowledge framework building varies between individuals, it becomes clear that the educational paradigm adopted during initial learning also contributes to new knowledge building. This feature impacts on the final outcome of knowledge application by radiographers and is revealed through a reduction in further image requesting by them. It has been suggested by radiographer participants that new knowledge consolidation influences their regular work activity. This allows them to apply recently acquired information differently in their daily practice to expand their capabilities. Features derived from this phenomenon have the potential to improve patient outcomes in terms of image acquisition quality. This was recognised by some of the radiographers in their survey responses. Patient outcome improvement was also identified by the medical students who acknowledged that they would be able to communicate differently with the radiographers. Accordingly a potential enhancement of interaction between the newly qualified intern in the ED setting and the radiology department, through more appropriate image procedural requesting, is recognised by the medical students. Significantly this could be a helpful support in response to Goergen's concerns [10] about junior doctor referral practices.

When considering how a radiology department operates two positions could therefore be taken; firstly the status quo is maintained where the radiologists continue to be the sole providers of an interpretation before initiating patient management. This would allow the medical position to persist by continued recognition of the radiologist as the only expert providing an interpretation. Secondly, and alternatively, the radiographer with appropriate advanced education would be available to immediately provide the knowledge for diagnosis by interns and junior doctors, and maintain image requesting standards by providing appropriate advice. This supports the need to alter the current educational paradigm employed by universities teaching radiography in Australia. As a result, developed understanding of imaging and its interpretation is achievable by radiographers at an under graduate and graduate level. With an interpretive ability in place, what is now considered an advanced role with greater autonomy than that seen currently, eventually becomes the norm for the radiographer and demonstrates role development.

Radiographers indicated within the study that they believed the public would expect the doctor to provide the report but that a faster response would also be well received. The latter perspective is supported by the perception of the patient that the radiographer interprets the image before sending them for further medical management and is mentioned by radiographers in their second survey responses. Moves by nursing colleagues in Victoria, following the lead from the UK, suggests that nurses have the belief that with appropriate education they could perform the interpretive role and initiate treatment. This contradicts the perception of radiographers who believe that the public expect a doctors input to interpretation and treatment. If radiographers could, despite the expressed concern that the task of providing an interpretation was harder than expected, overcome the inferiority complex as outlined in the 2004 AIR Future Directions study [125], then they could contribute to the patient pathway through an interpretive role. Consequently a stronger radiological and wider multidisciplinary team and professional role would be possible, if radiographers were also seen as image interpretation experts. Indeed the significant over reaching by emergency nursing colleagues highlighted in section 2.5.1 p32 in terms of understanding how to measure performance formed the basis of one of the publications linked to the thesis. Many of the same problems identified in Australian radiographer interpretation research that were discussed in chapter 4 were also made in this study by the ENPs. Interestingly support for the ENP investigation [148] was provided by a radiologist, which appears to perpetuate the position discussed in section 2.5.1 and meets with the responses made by medical students in their survey regarding radiographer input.

Radiographers as a professional group therefore should be more confident as has been noted on p33 as a finding of the AIR Future Directions report or other professions will step into a role that will speed the patient pathway. Internationally the radiographer has been shown to perform an interpretive role in designated areas of imaging. Radiologists, from an Australian service delivery perspective may construe this as representing erosion of earnings capacity. From the literature review, and in conjunction with previous work of the now defunct HWA, seeking potential new ways of working, a lack of support by radiologists may be considered an attempt to prevent service development. Radiographer interpretation would be a service where radiographers provide a financially efficient one stop shop delivering plain radiography image acquisition and interpretation of given body areas, last seen in the 1920's.

Changes that make a one stop service of radiographer interpretation possible are seen within the expectations of the MRPBA through its code of conduct and capability framework, the AIR and HWA proposals. Consequently this places the medical profession and the RANZCR in particular under pressure to consider changing their position. Interpretation of the MRPBA, AIR and HWA literature [103, 106 - 108, 113, 159, 160] and inferred expectations suggests that universities and healthcare providers will be able to operate in ways that require innovative approaches and fit well with the arguments expressed by Duckett [81 – 83, 161]. These differ from the current medical lead that is followed due to political expedience. The public expects politicians to deliver a health service that is safe and accessible to all. This is likely to drive political alliances as discussed by deVoe and Short [163] and as such may result in a change in approach to healthcare delivery beyond that described by HWA [159, 160] as the heroic tradition. As a result the political landscape will change and make it possible for the foundations to be laid that could bring about radiographer role development within MSK image content interpreting.

Examples of radiographer input being helpful are also provided in this research. From the radiographer survey responses it seems that a close working environment results in trust of experienced radiographers by doctors in the ED. When this trust is ignored the impact on the patient, their family or carers and the health service is significant and detrimental. Of particular note was the recognition during the coronial investigations discussed in chapter eight that radiographers could play a more integral role and that this should be encouraged. Clearly the 'industry concerns' that prevent radiographers from participating in an interpretive role should be addressed. This could occur at least within the context of improving safety via a systems approach that allows radiographers to contribute to the patient pathway via interpretation.

The statistics that have been generated make it clear that this group of radiographers performed better than the final year medical students who participated. This result as discussed in section 9.1 is no great surprise. Concerns however are expressed by the medical students with respect to image interpretation and the amount of diagnostic imaging education at the undergraduate level is not deemed acceptable for today's expectations of the medical workforce. Interestingly though, Australia does not stand out significantly in terms of time allocated to radiology education in the medical undergraduate programme, when compared to equivalent European countries. Some medical students performed very well and the reasons for this have been suggested. However from a position of patient safety, inclusion of radiographers more formally in the interpretive pathway is a sensible approach. The pilot work undertaken in Brisbane connected with this thesis clarifies that the team approach is appropriate as it improves overall outcomes for the patient. It would appear that until a maturity in the level of radiographer interpretation performance research has been reached within Australia, then any published figures may be more for identification of a position for one group rather than showing better or equivalent performance than the current service provider. Currently there have been no published benchmarking type studies of radiologist performance to set the level that others can be reliably measured against, though an accepted value (95% sensitivity, specificity and accuracy) is unquestionably taken as the standard to achieve, despite variation in radiologist performance having been shown in this study and in other work [177].

This study has tried to remediate mistakes that have been made in Australian radiographer interpretation research. The investigation also takes a supporting position for radiographer development. However, in returning to medical student education it is clear that there is a lack of instruction for certain aspects of image interpretation for them. The medical students expressed their concerns focussing particularly on paediatric interpretation and areas less often imaged within radiography such as the skull and facial regions. Performance by medical students fell below that of the radiographers in these areas.

Radiographers also expressed concerns over expectation of levels of performance in some areas, which resulted in the finer analysis of scores through generating comparison sub groups in this study. The population sample was specifically selected to include radiographers who were familiar with paediatric patients referred from the ED. This excluded trauma centre radiographers who might only deal with adults or children alone. Scores revealed that medical students and radiographers were not evenly matched in a statistically significant sense when looking at base values of TN, TP, FN and FP across the three sub sets of the image test bank. Radiographers were able to recognise normality better than the medical students and missed fewer positive images. This was discussed in terms of the current education received by radiographers in their initial and subsequent educational and clinical exposure. However, it is evident from this investigation that the radiographer can add to the interpretive process. If radiographers become an accepted source of interpretation through description provision, mistakes through misdiagnosis can be prevented[5]. This will allow medical educational approaches to change, or for radiography instruction to incorporate recognition of the role of imaging into its delivery approach. This would then create a framework to deliver within a paradigm that would favour advanced clinical decision making at an earlier time in the career of a radiographer. This track has been developed through initial image commenting in the UK. For radiographers who are already clinically active, postgraduate education and experience of an interpretive and subsequent image acquisition quality nature has to be cemented into radiographer practice, to further enhance their performance. Achievement of this is possible through appropriate professional development, but will require support of radiologists, that may be achieved if the political landscape changes as suggested on p234.

The radiographer participants were keen to ensure any initiative of an interpretive nature requires careful governance to include on-going practice audit and educational refreshers using a range of approaches. They recognised that governance audit was an opportunity to share with other members of the multidisciplinary team for the good of the patient. Good governance approaches also serve as a learning exercise where mistakes are discovered rather than adopting a blame culture approach. In considering this it is evident that an appropriate methodology for practice audit should be adopted to avoid the issues identified from the literature and ensure the best measurement statistics are used. This requires employment of a range of figures, as seen in this thesis, to be applied longitudinally, to identify issues of further professional development or revision, and to demonstrate where a future radiographer descriptive role may be extended. The approach further allows Australian radiographers educated to perform an interpretive role to follow their UK counterparts and provide interpretation services where provision gaps are identified. Consequently as the radiographers skill range develops, individuals gain more experience and begin to provide interpretations for a wider range of referral types.

However, a fundamental change in the way Medicare is allocated to make radiographer interpretation financially attractive to public or private radiology providers is necessary. A further consideration that makes this possible is that the current state control over healthcare delivery means that variation in expectations of personnel according to the jurisdiction they operate under is the approach to take. As such, local needs would lead and political patronage would shift according to the requirement the public expects of its health service. This would therefore require appropriate national leadership, possibly through the AIR, as the registration body does not currently have a mandate to recognise advanced practice roles through endorsement. In this way postgraduate education becomes one tool that acts through the MRPBA as a safety net for the public against bad clinical practice. Although suggestions have been made within the deliberations of the AIR regarding the expectations for accrediting an advanced practice radiographer this has to still be accepted by the wider medical, nursing and allied health professional community. To enable advanced practice enactment as a way to enhance healthcare delivery, radiographer interpretation should be part of a wider understanding of professional practice. It should also be an expectation of radiographer practice recognised at the state/territory and federal government levels.

To summarise the key conclusions to the investigation are listed below. They revealed that:

1. *Political patronage throughout history favours the medical model and will not be challenged until politicians shift the balance of power from medicine;*
2. *Current pressures on radiologists requires a defensive stance to be taken to prevent radiographer interpretation;*
3. *Radiographers retain an inferiority belief compared against radiologist performance and the perceptions of nurses;*
4. *Radiologists used to develop the test tool in this study showed variation in performance without any evidence of on-going audit;*
5. *A radiographer initial description does not differ in form and content to that of a radiologist;*
6. *Radiographers showed better numerical performance than medical students and equal to radiologists in some aspects. This is thought to be a consequence of the educational approach, the technological didactic paradigm, that should be changed to a deductive diagnostic approach;*
7. *Knowledge addition and consolidation by radiographers is affected by experience and multimodality working;*
8. *A multidisciplinary team approach to include radiographer interpretation via initial descriptions should be followed to enable Australia to deliver appropriate healthcare;*
9. *For advanced practice beyond initial image descriptions, radiographers should study at postgraduate award level as seen in the case of the UK.*

This thesis questioned whether radiographer interpretation of MSK trauma radiographs could re-position the profession within Australian healthcare. Notwithstanding the limitations of the study especially in respect of access constraints to recruiting qualified medical staff as a comparison group, arguments have been developed and supported to suggest this could be the case. However, many variables outside the sphere of the investigation are still being debated in the context of arguing for a change in healthcare practice approaches in an always changing socio-political environment that favours the medical profession. The most that can be suggested by this research is that there are limitations in the education of doctors and radiographers which provide opportunities to develop new approaches to the improvement of services to the end users i.e. patients and those requesting radiology services. The research suggests methods by which to achieve change and how to continually evaluate performance in the field of medical image interpretation. At the same time radiographers themselves also need to perceive their abilities more positively to ensure professional repositioning can be achieved as recent examples and evidence suggests this is appropriate and necessary.

'…an improved better streamlined multidisciplinary team is possible, preferable and should be supported to improve healthcare delivery.'

W.W. Gibbon, Radiology Professor
Workforce models for a healthier Australia: a productivity commission submission, 2006.

CHAPTER 10 Future work and recommendations from the study.

10.1 Key points

Future work that needs to be performed includes:

1. *Wider population sampling across Australia of all groups participating;*
2. *Inclusion of interns with ED experience and at least 1 year of post qualification experience for comparison with international studies;*
3. *Develop an internet based system to enable benchmarking across all staff involved with this type of work, at undergraduate and post qualified levels;*

This leads to the following recommendations:

1. *Gain funding to enable a larger study to proceed using internet based approaches;*
2. *Ensure professional stakeholders work together to provide the best healthcare delivery whilst considering how the workforce should be developed to enable this;*
3. *Encourage postgraduate education development and provide support for graduate radiographers to enable affordable stud in image interpretation;*
4. *Federal and State/Territory governments should work together to enable Medicare numbers to be held by radiographers with interpretation skills;*
5. *Medical schools should consider the radiology content of their undergraduate programmes and develop the multidisciplinary agenda to enable staff without a medical degree to contribute.*

10.2 Future work

Population sample size is often levelled as a cause of weakness in an investigation. Although this has been discussed and, for the sample size finally used, there is published evidence to support the approach adopted, a larger representation of Australian radiographers and medical students would give greater strength to a study of this nature. Furthermore, recruitment across the whole of Australia ensures representation of the investigated groups has greater study result validity, reliability and ultimately generalisability. Ideally, re-reporting the image test bank with more radiologists across Australia would also add to the picture of what is an acceptable level of performance amongst the whole community involved in plain radiograph interpretation of musculo-skeletal trauma. Therefore support to enable application of this test across a wider population would be an appropriate move forward, both for this research and in a governance perspective for radiologists.

Initially when the investigation was devised the intent was to also look at medical interns who had spent time in the ED, to establish if they believed their preparatory education was sufficient, and to measure whether their image interpretive performance was acceptable. Recruitment difficulties led to the study focusing on final year medical students who have not been studied previously. The literature review and subsequent participant responses has identified a gap in the educational support for what is perceived by the medical students as a key aspect of their work. As such inclusion of a group of interns with ED experience would be an appropriate extension of this work. Further, comparison with an international group of junior doctors and final year students would add to the understanding of medical education in the area of MSK trauma plain film interpretation. As imaging becomes an ever increasing component of the junior doctor's work and skill base requirement, the establishment of educational needs and identifying how international experience compares with Australian practice is a comparison imperative that should be made. Through further study of this arm of the investigation, greater appreciation of medical education programme content and skills base that contributes to the operation of the global workforce that medicine and those allied with medicine has become is feasible. Furthermore, learning from the experience of others is the hallmark of a mature profession be it medicine or allied health/nursing. As has been stated earlier, team working is more productive than having a single lead profession, which has been recognised in documentation from the now disbanded HWA.

To achieve the above and make the testing simpler and available more widely, the development of an internet based testing tool would be appropriate. Ideally this system would be able to provide scores immediately for personnel to benchmark themselves against, though to achieve this, a simpler binary approach ignoring the richness of the data received via FROC type studies would have to be adopted. Tick box type responses as applied in this study could be employed so that ROC curves, simple sensitivity and specificity values and calculation of such figures as likelihood ratios and the most appropriate Kappa style of comparative statistic could be achieved relatively simply, with software developed to perform these functions.

The participants who took part in this study were self selecting. To add a final piece of correction to the population that was tested in this investigation, a feedback system within a testing tool, such as the one proposed above could, contribute to an appropriate educational approach for all students within an undergraduate medical programme. Application of the capability and code of practice documents issued by the MRPBA and AIR would ensure that undergraduate radiography programmes have wider ranging radiographer interpretation outcomes. As a result the testing approach described above could also be used by about to qualify radiographers. Those already qualified could participate by way of a professional development opportunity to help them identify the education they would need to perform an interpretive role. This would bring Australia to a level equal to that seen in the UK where the CoR expects to provide an initial interpretation through a comment. Without this the question 'why educate a radiographer to have a limited role if that individual could be developed to enhance the provision of healthcare in a cost effective way?' has to be asked. Furthermore, an interpretation testing regime would build the evidence to support the role development of radiographers or at least identify who would be an appropriate candidate to perform an advanced role. As a generalisation the test tool could be used to identify how much post qualified experience would be required before competency of providing an interpretation is agreed for individuals in clinical practice. Further it could also act as a way to identify if the full postgraduate educational model as seen in the UK reporting radiographer pathway is the only way forward, especially if radiographer interpretation is seen as a method to change the face of Australian undergraduate radiography by effectively contributing to the patient assessment process.

With evidence that may be generated by the testing regime described above available to the radiography profession, a strong argument for support to be provided by government to enable funding of post qualified education is possible. In the light of the Victorian coronial suggestions [261, 262] and the recent issues identified on the Gold Coast and in Sydney with respect to the enormity of unchecked radiographs [5 - 7], then the state and federal governments must seek ways to address these issues. Providing education to do this would be a positive step and does not necessarily mean that health care providers have to re-grade staff. This was identified by some radiographers who suggested that they could and should be providing a better service as a standard approach, which would include radiographer interpretation. However, having to bear all the costs of education themselves is probably an insurmountable disincentive to the individual if no further financial reward is forthcoming.

A further investigation that would be warranted across Australia is to establish whether experienced radiographers are accepted by the medical profession as a source of help to interpret the image. A survey across the country would establish whether the impressions gained from this study are repeated elsewhere, as there are limitations with the sample size and controlled population sources from which participants self selected. Further, information from this investigation allows radiographers to show whether prevention of the proposed radiographer interpretation service emanates purely from radiologists, or if there are concerns in the wider medical workforce that resists input by a radiographer into image interpretation. The experience level of the doctor may also influence self stated confidence in interpretation ability. These features contribute to the medical students impressions of interpretive ability in this study, as well as influencing the medical students knowledge of how radiographers fit into the radiology team to deliver the imaging service.

10.3 Recommendations

The following recommendations from the study are made:

i) Seek funding and support to perform a wider study across Australia to establish capability amongst radiographers, medical students or other healthcare professions wishing to participate. With appropriate support an internet based system could be developed and used as a test across the suggested groups. This approach would assure longevity, be updated as required and act as a bench marking tool nationally if not internationally;

ii) Discussion between the professional and registration body about how the capability documentation should be interpreted. This will inform the appropriateness of radiographer education development and how it might be achieved at various higher education institutes. Due to the remit and operation regulations for the MRPBA, there is a need for the AIR to work together with universities and wider government. This should ensure the development of the role of the radiographer continues positively and that the degree approach is employed to its maximum benefit for patients and the public purse. Newly qualified radiographers should be prepared educationally to perform an interpretive role such as that seen in the UK radiographer commenting approach. This may include enhancing the content of anatomy, physiology and pathology to a level where recognition by all professions of radiographer capability is such that interpretation becomes an expected next step for the profession. Recognition by radiographer managers also needs to occur so that demands on the imaging service require development of the radiographer workforce to possess interpretation skills. As such this will necessitate a change in initial qualification and graduate capabilities to deliver the service. Further, there should be eventual development of the post qualified radiographer into an advanced practice reporting role, which extends beyond the proposed interpretation practice level discussed in this thesis. These ideas will eventually be seen to translate back to the MRPBA capabilities framework so that the registration board's remit of protecting the title of radiographer to protect the patient is aligned with graduate practice;

iii) The results of this investigation suggest that a short course has an effect on radiographer interpretive ability, but postgraduate education for radiographers appears to be the way forward for full reporting status. Postgraduate courses should be developed by Universities, preferably those with experience delivering undergraduate diagnostic radiography or possibly medical degrees. The short course as developed for this study could be used for the professional development of post qualified general radiographers to provide interpretations. Alternatively a short course may be used as an educational module insertion into undergraduate degrees, to prepare newly qualified radiographers for an interpreting role or possibly to enhance the education of the medical student prior to internship;

iv) Government (state and federal) should consider how the radiographers’ role could change from that currently seen. To do this the government has to look at the way Medicare operates and make changes to ensure funding would come to any changed service delivery model, such as seen in other allied health professionals like physiotherapy. Further, political and healthcare leaders should encourage development of the medical imaging team so it can respond flexibly to future demands from demographic and workforce issues; there should be investment in post qualified education to enable an initiative such as radiographer interpretation to grow. Clearly evidence discussed from the Victorian coronial investigations, comments made by radiographers in this study regarding current use of their skills and the recently identified problems of failure to provide radiology reports on the Gold Coast and in Sydney, suggest that radiographer interpretation is a way forward;

v) Schools of medicine should consider the performance results from this selected group of final year medical students in conjunction with the findings of the literature review and comments by participants. Changes to the undergraduate medical degree to enhance image interpretation and further image requesting should be made. Furthermore, there should be greater team working cohesion developed within the undergraduate programme or the clinical experiential setting (teachers, clinical practitioners including radiographers and medical students) so that potentials from each group of staff may be explored and developed into the future.

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APPENDIX 1 Instructions for using Microsoft © picture manager and completing a worksheet.

Front line musculo - skeletal trauma image interpretation: who does it better?
Radiographers or final year medical students?

Image viewing
and worksheet completion
instructions

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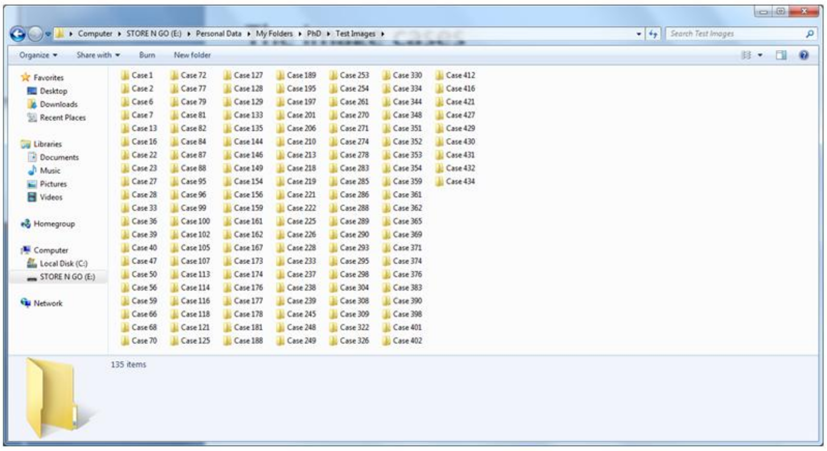
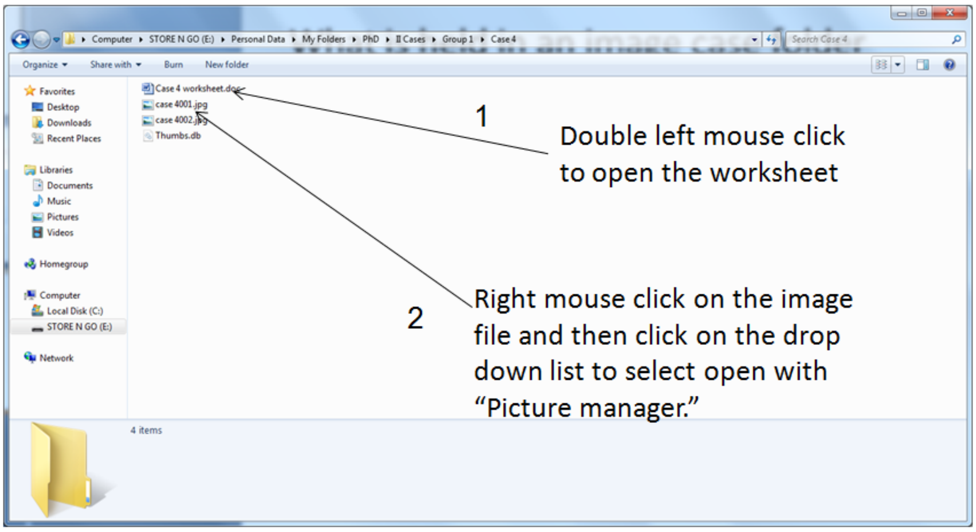
The image cases



When you open the test bank folder on the USB memory stick this is what you will see. Next, double left mouse click on the image case folder so you can see the images and worksheet.

What is held in an image case folder

Left mouse click to advance instructions in the slide

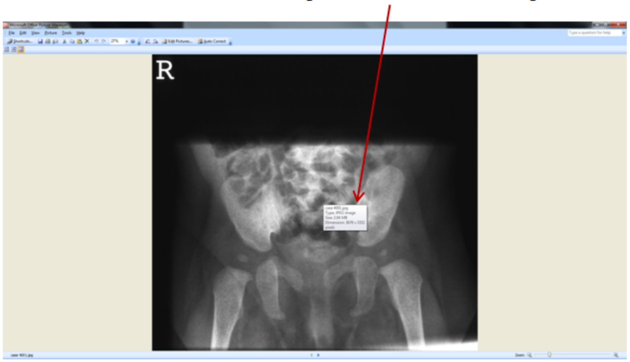


Picture manager 1

Left mouse click to advance slide instructions

2 Image information – appears when you click on the image or rest the cursor on the image

1 The Picture Manager front page



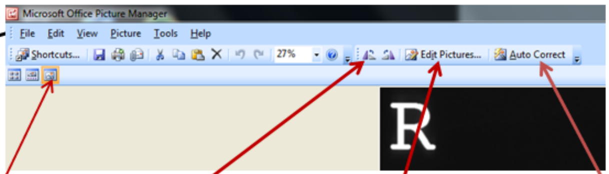
4 Image scrolling bar – click to move between images when there is more than 1 in the case folder

3 Sliding scale for magnification. Due to the image format when you magnify very large you may begin to see the original laser pattern in the image. Do not try to view when this happens – reduce magnification to stop seeing the artefact.

Picture manager 2

Left mouse click to advance slide instructions

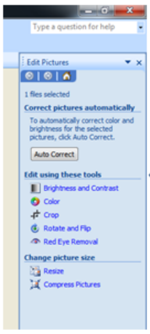
1 Tool bar for picture manager



3
Image rotation – you shouldn't have to use this

4
Clicking this button automatically selects pre set values of brightness and contrast to enhance the image

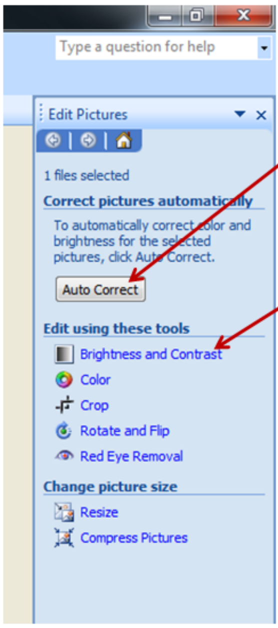
2
Different image viewing options – use the one highlighted on the right to give maximum size



5
When you click edit picture option on tool bar this drop down list appears alongside the image pane – see next slide for its functions

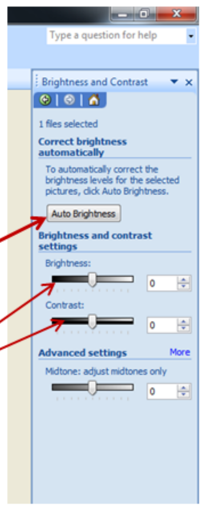
Using edit picture

Left mouse click to advance slide instructions



1 Only use the arrowed functions from Edit Pictures

Double left click to open Brightness and Contrast

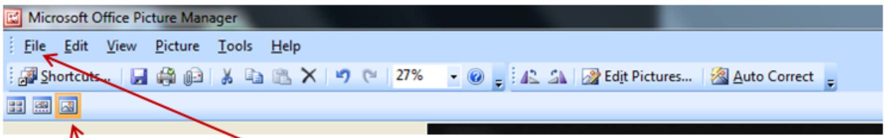


2
You may click on auto brightness or use the slider scales by dragging with the mouse to change the image appearances

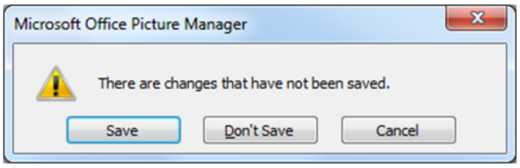
Exiting Picture Manager

Left mouse click to advance slide instructions

1



To exit picture manager left click on file and select EXIT from the drop down list.



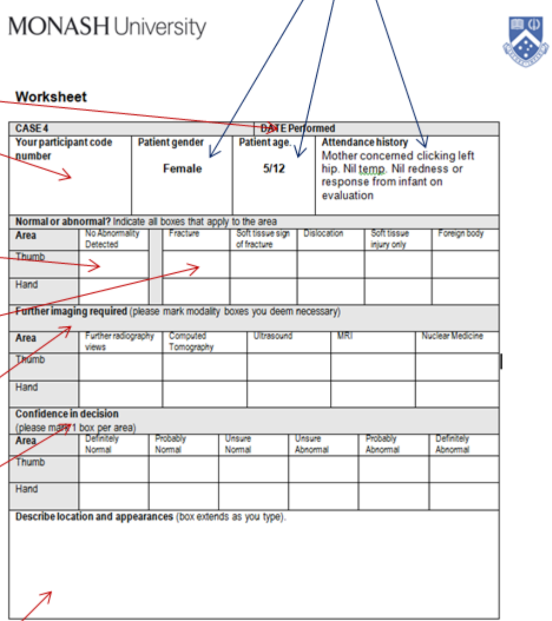
3
If you cancel the dialogue box before closing after having made changes, re - select the right hand image viewing icon to allow you to see the full image before going on to close again.

2
If you had to change any settings to view the image (e.g. Brightness/Contrast/Magnification) the image viewing panel will turn white and show the dialogue box. Click "Don't Save" as "Save" will change the image quality from the standard setting you began with should you wish to view again. The image file will then close and you can exit the folder.

The worksheet

Click left mouse to advance information

1 History prior to attendance patient age and gender



2 Ensure you add your participant number and date performed.

3 If you think there is no abnormality to report place a cross matching the examination in the No Abnormality Detected box. This response may be different for examinations in the same case folder.

4 If you think there is an abnormality place a cross in the box (boxes) best matching the appearances you can see for each examination in the case folder.

5 If you believe more imaging is required place a cross in the best box for further imaging for that examination. No further imaging requires no cross.

6 Place a cross to indicate your decision confidence based on the images you see for each examination area.

7 When you think there is an abnormality type a description into the last box to include localisation and descriptive comments about the appearances – the box will extend as you type information into it.

Saving the worksheet

- This is the most important part of your work.
  - When you have added the information to the worksheet click the save icon as you would with any word document.
  - You can check it has been saved by looking at the worksheet file in the image case folder to see if your additions have been retained.
  - When you are happy all is saved close the image case folder and move on to the next case. Remember all this is run from the USB memory stick provided.
  - Return your completed worksheets on the USB memory stick in the pre paid envelope. Remember to wrap with the protective material as Australia post may damage the USB and all your work will have been lost.

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RESEARCH TEAM
Jonathan McConnell
A/Prof Marilyn Baird
Department of Medical Imaging and Radiation Sciences, Monash University

Image test worksheet instructions

Look at the images on the USB stick labelled with the corresponding case number. To enable magnification and contrast/density changes use Microsoft "Picture manager" but DO NOT save any image changes when you close the case as this will change the image.

Use the patient information and history provided to come to a decision of normality or otherwise. Please add in your participant code and complete the worksheet by placing a cross (x) in the normal or abnormality type section and any boxes you believe are appropriate should further imaging be necessary. Then give your confidence in your decision by placing a cross (x) in the appropriate box. Add descriptive comments in the final box to describe the appearances you see. This box will extend as you type. Save the worksheet to the USB and continue through the remaining image cases.

CASE 1		**DATE Performed**	
Your participant code number	**Patient gender** **Male**	**Patient age.** **28yrs**	**Attendance history** Hyperextension injury to thumb following fall onto outstretched hand. No ASB tenderness

Normal or abnormal? Indicate all boxes that apply to the area

Area	No Abnormality Detected		Fracture	Soft tissue sign of fracture	Dislocation	Soft tissue injury only	Foreign body
Thumb							
Hand							

Further imaging required (please mark modality boxes you deem necessary)

Area	Further radiography views	Computed Tomography	Ultrasound	MRI	Nuclear Medicine
Thumb					
Hand					

Confidence in decision
(please mark 1 box per area)

Area	Definitely Normal	Probably Normal	Unsure Normal	Unsure Abnormal	Probably Abnormal	Definitely Abnormal
Thumb						
Hand						

Describe location and appearances (box extends as you type).

Alternatively follow the power point slides on the USB or as print copy enclosed.

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Worksheet instructions

Look at the images on the USB stick labelled as the corresponding case number on the worksheet e.g. Case 1. To enable magnification and contrast/density changes use Microsoft “Picture manager” to open the images – you can then scroll through all the images in the case folder. If you change the contrast, density or image size, when closing the image for the case DO NOT SAVE as this changes the appearances that may be required for future viewing.

AS YOU VIEW THE IMAGES:

- Please add in your participant code in the space labelled on the sheet.
- Use the patient information and history provided to come to a decision of normality or otherwise. Complete this part of the worksheet by placing a cross (x) in the abnormality type.
- Add a cross (x) to any boxes where you believe further imaging of that type is necessary e.g. if you think CT is needed to confirm or add to the diagnosis place a cross in that box.
- Add a cross (x) to the confidence category that best fits your decision
- Add descriptive comments in the final box to describe the appearances you see. This box will extend as you type.

WHEN YOU ARE HAPPY YOU HAVE COMPLETED THE BOXES

- Save to the USB (remember not to save any changes you might have made to the images).
- Continue through the remaining image cases performing the same routine.

FEEL FREE TO RETURN TO ANY IMAGE CASES or to view out of order if you find those images more challenging. Please DO NOT leave any cases without an answer / response.

Bring your USB stick with you to the teaching session.

If you have any problems please contact Jonathan McConnell on:

[redacted]

to discuss further. Only identify yourself as a participant in the study using your participant number that you should have received earlier.

THANK YOU.

APPENDIX 2 Radiographer recruitment poster

WANTED:

RADIOGRAPHERS FOR

AN EMERGENCY DEPARTMENT IMAGE READING PROJECT.

Radiographer interpretation is an aspect of advanced practice that is currently being discussed in Australia. Until recently no controlled study about radiographer interpretation and image description ability has been performed in Victoria to provide the evidence for or against taking on this role.

WOULD YOU LIKE TO TAKE THE CHALLENGE AND BE ONE OF THE FIRST TO DEMONSTRATE YOUR ABILITY WHILE EARNING CPD POINTS?

We are looking for 20 radiographers across Victoria with over 2 years experience, who work regularly in the Emergency Department (ED) that treat adults and children.

WHAT DOES IT ENTAIL?

Following completion of a questionnaire, you will be asked to interpret up to 190 musculo-skeletal trauma images from a dataset that has patient age, gender and history to describe what you see on the images and, where you believe necessary, suggest if other imaging is required. Then you are invited to attend a weekend course of study at Monash University (date to be decided by consensus). Finally you are requested to re-interpret the images and complete a final questionnaire about your experience 8 weeks after the teaching session.

DO YOU FIT THE PROFILE AND ARE YOU INTERESTED?

If so please contact Eugenia Sequeira-Leo on:
[redacted] for more details.

Selection is on a first come first served basis, so get in touch quickly.

RESEARCH TEAM
Jonathan McConnell PhD Candidate
SUPERVISED BY:
A/Prof Marilyn Baird
Department of Medical Imaging and Radiation Sciences, Monash University

MONASH University

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APPENDIX 3 Radiographer recruitment survey

RESEARCH TEAM
Jonathan McConnell
A/Prof Marilyn Baird

Department of Medical Imaging and Radiation Sciences, Monash University

Can radiographers provide musculo-skeletal emergency image interpretations after further education?

RADIOGRAPHER PARTICIPANTS

Questions to establish suitability for inclusion in the study

The following questions will be asked by the third party assistant to establish suitability of applicant to participate in the above study.

1. Please ask for participant name.

2. How long have you been qualified as a radiographer? **Y / N**

3. Do you have an Emergency Department that treats adults and children as part of its usual workload?
   Y / N

4. Have you completed any level of study in image interpretation in Australia or overseas?
   Y / N

5. Are you able to attend a 2 day weekend study session to be held at Monash University?
   Y / N

6. Please provide contact information:

   Mail E-mail

   Telephone

Please state to the respondent, that they will receive full details of the project and a consent form to return to us. Only when completed and returned will the participant be eligible for selection into the study.

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APPENDIX 4 Radiographer consent form and explanatory statement

CONSENT FORM

Title: Can radiographers provide musculo-skeletal emergency image interpretations after further education?

NOTE: *This consent form will remain with the Monash University researcher for their records*

I agree to take part in the Monash University research project specified above. I have had the project explained to me, and I have read the Explanatory Statement, which I keep for my records. I understand that agreeing to take part means that:

I agree to complete questionnaires asking me about radiographer interpretation and role development

☐ Yes ☐ No

I agree to formulate interpretations for images in the test bank on two occasions to enable comparisons of my performance before and after education input.

☐ Yes ☐ No

and

I understand that my participation is voluntary, that I can choose not to participate in part or all of the project, and that I can withdraw at any stage of the project without being penalised or disadvantaged in any way.

I understand that any data that the researcher extracts from the questionnaire / description worksheets for use in reports or published findings will not, under any circumstances, contain names or identifying characteristics.

I understand that I will be given a summary of results concerning me for my approval before it is included in the write up of the research.

I understand that any information I provide is confidential, and that no information that could lead to the identification of any individual will be disclosed in any reports on the project, or to any other party.

I understand that data from the questionnaire and description collection tool will be kept in a secure storage accessible only to the research team. I also understand that the data will be destroyed after a 5 year period unless I consent to it being used in future research.

Participant's name (Print)

Signature **Date**

MONASH University

APPENDIX 4 Radiographer consent form and explanatory statement

Explanatory Statement

Radiographer Participants

28/2/11 - This information sheet is for you to keep.

Title: Can radiographers provide musculo-skeletal emergency image interpretations after further education?

Group 1 - radiographers

Student research project

My name is Jonathan McConnell and I am conducting a research project towards a PhD with Associate Profession Marilyn Baird and Dr Michal Schneider-Kolsky a senior lecturer in the Department of Medical Imaging and Radiation Sciences at Monash University. This means that I will be writing a thesis which is the equivalent of a 300 page book and several magazine articles and possibly reporting findings to conferences.

Using information from the MRPB public register we wish to invite radiographers in Victoria:

1. with two years or more experience
2. where their work involves imaging of children and adults for musculo – skeletal trauma

to participate in this study, as we believe radiographers with some experience are the best people to participate in this study.

The aim/purpose of the research

The aim of this study is to establish whether radiographers are able to interpret abnormalities on trauma images to a level matching the radiologist. The research will be carried out to see if there is a difference in capability before and after a short course of study.

What are the possible benefits in participating?

You are probably aware of the arguments for radiographer role change. To date a carefully controlled trial has not taken place in Australia to prove radiographer capability. Results may then be used for service change in your workplace. It is envisaged that you will gain an increased knowledge base that will support your practice in multiple ways; in other words when you know why you do something the performance becomes better for you, your patient, the radiologist and referring practitioner.

What does the research involve?

After being randomly selected from all respondents wishing to participate, you will be measured against a test bank of images that has had the image content agreed upon through multiple reporting by several radiologists.

Should you decide to go ahead in participating in this study there will be an expectation that you will contribute in a few ways;

1. complete a consent form;
2. complete a survey (and return anonymously in the post paid envelope) establishing your thoughts and concerns in participating in what is seen as an advanced role;
3. you will review and describe the appearances in two image tests, one taken before attendance at the education session and at eight weeks post completion of the teaching session;
4. complete a second questionnaire to see if any of your perspectives in questionnaire
   1 have changed after participation in this project;
5. attend a two day education session that can be used for professional development points;

How much time will the research take?
In total we believe that you will spend about 12 days of your time on the project:

1. two days will be receiving the education session,
2. up to five days to complete each of the image bank tests (i.e. ten days in total)
3. about an hour at most answering your questionnaires.

Will there be any inconvenience or discomfort
We do not envisage any discomfort to you in participating other than an imposition on your time.
Being that this study is voluntary you are under no obligation to consent to participation however, if you do consent to participate, you may withdraw at any time. If however, you have submitted the anonymous survey questionnaire it will be impossible to remove from the data set and will be included in the summary.

Confidentiality

As you have received this information, your contact point with the University (not connected with the research process), will have allocated you a code number which you will retain throughout the study. All material received from you will then be treated with this code applied and at no time will we be able to identify you or your department.

Storage of data

Data will be stored in this format on a password protected computer in a locked room with any paperwork securely stored in a locked cupboard in the same office. Storage of the data collected will adhere to the University regulations and kept on University premises in a locked cupboard/filing cabinet for 5 years.

Use of data for other purposes

It is possible that data from this study may be used in other research. Participant data used in this way will be retained in an anonymised form.

Results

Participants will be informed of the aggregate research finding and their individual results to allow you to evaluate your performance within the group for yourself. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report. Once the report is completed and feedback supplied to each participant the codes applied to individuals will be destroyed, thus rendering results anonymous. For any other information regarding results please contact Jonathan McConnell [redacted]

Payment
No payment is made for your contribution however the course will gain professional development recognition and is provided free of charge.

If you would like to contact the researchers about any aspect of this study, please contact the Chief Investigator:	If you have a complaint concerning the manner in which this research is being conducted, please contact:
A/Prof Marilyn Baird Department of Medical Imaging and Radiation Sciences Building 13C Room C129 Monash University Wellington Road Clayton VIC 3800 [redacted]	Executive Officer Monash University Human Research Ethics Committee (MUHREC) Building 3e Room 111 Research Office Monash University VIC 3800 [redacted]

Thank you.

Jonathan McConnell

MONASH University

APPENDIX 5 Pre test 1 and post test 2 radiographer questionnaires

RESEARCH TEAM
Jonathan McConnell
A/Prof Marilyn Baird

Department of Medical Imaging and Radiation Sciences, Monash University

Can radiographers provide musculo-skeletal emergency image interpretations after further education?

RADIOGRAPHER PRE TEST QUESTIONNAIRE

The consent form and information sheet about this study indicated that you are requested to complete an anonymous survey as the first part of the investigation. Please answer the questions below BEFORE you attempt the interpretation test. Save the questionnaire to your USB memory stick then e-mail your reply to [redacted] ALL boxes will extend as you type.

1. Please state in the box below why you wanted to participate in this study.

2. Please state in the box below any anxieties / concerns you may have **before participating** in this study about performing an interpretation function.

3. Are you aware of any professional body input to furthering role development for radiographers?

(Tick 1 box)

YES	NO

If yes please state what input you are aware of.

4. If radiographer interpretation for emergency musculo-skeletal image interpretation became part of your role, please state in the box below what on-going support would be required to enable you to perform this duty?

5. As part of the study you are asked to participate in 2 tests completing 135 interpretations cases per test to compare against the radiologist. Please detail any challenges you feel about doing this in the box below.

6. Do you believe radiographers can describe the content of an emergency musculo-skeletal radiograph at a level matching the radiologist?

(Tick 1 box)

YES	NO

7. By indicating YES or NO in the appropriate box, do you think commenting on the images while the patient is still present:

Comment	YES	NO
Will enable you to interpret the images more confidently?		
Gives you an interpretive advantage over the radiologist?		
Will be helpful for the emergency department doctors?		
Will encourage better quality radiographic technique?		
Will enhance your status amongst radiology and emergency department colleagues?		
Will improve the patient experience?		

8. Please indicate in the box below any other ways that interpretation of images by radiographers while patients are still present in the department may be affected.

Thank you for taking the time to complete the questionnaire along with the image test. We look forward to meeting you at the education session.

Jonathan McConnell
A/Prof Marilyn Baird

MONASH University

RESEARCH TEAM
Jonathan McConnell
A/Prof Marilyn Baird

Department of Medical Imaging and Radiation Sciences, Monash University

Can radiographers provide musculo-skeletal emergency image interpretations after further education?

RADIOGRAPHERS POST 2nd TEST QUESTIONNAIRE

The consent form and information sheet about this study indicated that you are requested to complete a second anonymous survey as the final part of the investigation. Please answer the questions below, save to your USB memory stick with your interpretations and return in the pre-paid addressed envelope.

All single boxes will extend as you type in them.

1. Please state in the box below why you wanted to participate in this study.

2. Please state in the box below if any anxieties / concerns you had **before participating** in this study about performing an interpretation function have changed.

3. Since participating in this study, if radiographers were to participate in an image interpretation role, detail in the box below any changes of attitude you have had with respect to what on-going support would be required to enable you to perform this duty?

4. As part of the study you have participated in 2 tests and completed 135 interpretation cases in each test to compare against the radiologist. Have the challenges you felt before completing test 1 changed? Please detail any changes in the box below.

5. Since participating in the study do you believe radiographers can always describe the content of an emergency musculo-skeletal radiograph at a level matching the radiologist?

(Tick 1 box)

Always	Mostly	Occasion ally	Rarely	Never

6 By indicating YES or NO in the appropriate box, do you think commenting on the images while the patient is still present:

Comment	YES	NO
Will enable you to interpret the images more confidently?		
Gives you an interpretive advantage over the radiologist?		
Will be helpful for the emergency department doctors?		
Will encourage better quality radiographic technique?		
Will enhance your status amongst radiology and emergency department colleagues?		
Will improve the patient experience?		
Will be difficult to achieve due to pressures on your time.		
Will require support in forms of liability insurance beyond that provided by your place of work?		
Can only be provided in fixed areas of the body.		
Requires significant further education and on-going performance audit.		

7. Has participation in this study changed your thoughts about the obtaining and interpretation of emergency musculo-skeletal appendicular skeletal plain radiographs? Please add comments in the box below.

8. Please could you recall (in the box below) an event of an episode where you believe your input through direct contact with the patient and your subsequent interpretation was not acted upon by the emergency department medical practitioner? For example you may have verbally interacted with the ED doctor and you later checked to see if the radiologist agreed with you and you found the patient had to be recalled for further management. How did you feel about this? Does it happen often?

9. Are there any further comments you wish to add about participating in this study?

Thank you for participating in this study. We are very appreciative of your time and efforts, which have been significant in your busy working lives. A summary of results and your scores as a participant will be sent to you in the near future.

Jonathan McConnell
A/Prof Marilyn Baird

APPENDIX 6 Medical Student recruitment poster

How good are your skills in reading trauma x rays?

Normally X rays are taken by radiographers and interpreted predominately by medical specialists called radiologists**.** Internationally there is great interest in exploring the potential for radiographers to assist emergency departments in providing written findings on some trauma x rays. This study aims to compare the ability in providing an opinion on trauma x rays between final year medical students and radiographers. The results of the study will be useful in evaluating the current knowledge and confidence in x ray interpretation among medical students and recent medical graduates of Monash University.

All final year medical students are invited to take part in the study.

WHAT DO YOU NEED TO DO?

1. Please contact Eugenia Sequeira-Leo via email [redacted] no later than XXXX (dates for intake in 2012 and 2013)
2. Interpret a series of trauma x ray cases through a worksheet via a USB stick without assistance (texts or colleagues)
3. Email completed questionnaire to Eugenia
4. Complete the cases in your own time but before XXXX (dates according to intake)
5. There are 135 cases which we suggest you complete at the rate of approximately 2 a day
6. Return USB in self-addressed envelope to Eugenia

WHAT ARE THE BENEFITS TO YOU?

1. Expert reports for each case will be provided to you after the due date
2. Participation will greatly enhance your knowledge in the interpretation of trauma x rays

RESEARCH TEAM
Jonathan McConnell PhD Candidate
SUPERVISED BY:
A/Prof Marilyn Baird
Department of Medical Imaging and Radiation Sciences, Monash University

MONASH University

www.monash.edu

MONASH University

APPENDIX 7 Medical Students Consent Form and Explanatory Statement

CONSENT FORM

Title: Front line musculo - skeletal trauma image interpretation: who does it better: Radiographers or final year medical students?

***NOTE:** This consent form will remain with the Monash University researcher for their records*

I agree to take part in the Monash University research project specified above. I have had the project explained to me, and I have read the Explanatory Statement, which I keep for my records. I understand that agreeing to take part means that:

I agree to complete a questionnaire asking me about participation in this study and radiograph interpretation for musculo-skeletal trauma

☐ Yes ☐ No

I agree to formulate interpretations for images in the test bank to enable comparisons of my performance with radiographers who have received a short course of further study, other final year medical students and/or medical interns.

☐ Yes ☐ No

and

I understand that my participation is voluntary, that I can choose not to participate in part or all of the project, and that I can withdraw at any stage of the project without being penalised or disadvantaged in any way.

I understand that any data that the researcher extracts from the questionnaire / description worksheets for use in reports or published findings will not, under any circumstances, contain names or identifying characteristics.

I understand that I will be given a summary of results concerning me for my approval before it is included in the write up of the research.

I understand that any information I provide is confidential, and that no information that could lead to the identification of any individual will be disclosed in any reports on the project, or to any other party.

I understand that data from the questionnaire and description collection tool will be kept in a secure storage accessible only to the research team. I also understand that the data will be destroyed after a 5 year period unless I consent to it being used in future research.

Participant's name (Print)

Signature **Date**

MONASH University

APPENDIX 7 Medical Students Consent Form and Explanatory Statement

Explanatory Statement

Title: Front line musculo - skeletal trauma image interpretation: who does it better: Radiographers or final year medical students?

This information sheet is for you to keep.

Introduction

My name is Jonathan McConnell and I am conducting a research project towards a PhD. My supervisors are Associate Professor Marilyn Baird Head of the Department of Medical Imaging and Radiation Sciences at Monash University.

The aim/purpose of the research

We wish to invite final year medical students to participate in this study. We have already evaluated the performance level of radiographers and we would now like to establish what your knowledge base is in relation to image interpretation. This will help us inform current clinical practice and the MBBS curriculum at Monash University.

The results of this research will be used to see if there is a difference in performance between radiographers, interns and final year medical students.

What are the possible benefits in participating?

1. Expert reports for each case will be provided to you after the due date
2. Participation will greatly enhance your knowledge in the interpretation of trauma x rays

What does the research involve?

Participants will be asked to provided findings of a series of trauma musculo skeletal x-rays. The expert report for each case has been provided by a consensus of three radiologists. You will be able to work through the cases in your own time. Please remember we need you to make your decisions and complete the interpretation test on your own and NOT COLLABORATE with colleagues about what they felt was evident in the images.

Should you decide to go ahead in participating in this study there will be an expectation that you will contribute in the following way;

3. complete a consent form;
4. complete a survey establishing your thoughts and concerns in participating in this study and your perceptions of the knowledge base that you have; and
5. review and describe the appearances in the image case series.

How much time will the research take?

In total we believe that you will spend about 5 – 6 hours (maximum) of your time on the project over approximately two months (or less if you prefer) to attempt the image descriptions:

Will there be any inconvenience or discomfort

We do not envisage any discomfort to you in participating other than an imposition on your time. As this study is voluntary you are under no obligation to consent to participate however, if you do consent to participate, you may withdraw at any time. If however, you have submitted the anonymous survey it will be impossible to remove from your input from the data set.

Confidentiality

You will be allocated a code number by an independent research assistant which you will retain throughout the study. The research team will not be able to identify you.

Storage of data

Data will be stored on a password protected computer in a locked room with any paperwork securely stored in a locked cupboard in the same office. Storage of the data will be kept for 5 years and then permanently deleted and hard copies shredded.

Use of data for other purposes

It is possible that data from this study may be used in other research. Participant data used in this way will be retained in an anonymised form.

Results

A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report. Once the report is completed and feedback supplied to each participant the codes applied to individuals will be destroyed, thus rendering results anonymous. For any other information regarding results please contact on [redacted]

Payment

No payment is made for your contribution however we believe participation in the project will benefit your future medical career.

If you would like to contact the researchers about any aspect of this study, please contact the Chief Investigator:	**If you have a complaint concerning the manner in which this research CFf11/0213 - 2011000077 is being conducted, please contact:**
A/Prof Marilyn Baird Department of Medical Imaging and Radiation Sciences Building 13C Room C129 Monash University Wellington Road Clayton VIC 3800 [redacted]	Executive Officer Monash University Human Research Ethics Committee (MUHREC) Building 3e Room 111 Research Office Monash University VIC 3800 [redacted]

Thank you.

Jonathan McConnell

APPENDIX 8 Medical students pre test questionnaire

RESEARCH TEAM
Jonathan McConnell
A/Prof Marilyn Baird

Department of Medical Imaging and Radiation Sciences, Monash University

Front line musculo - skeletal trauma image interpretation: who does it better? Radiographers or final year medical students?

FINAL YEAR MEDICAL STUDENT PRE TEST QUESTIONNAIRE

The consent form and information sheet about this study indicated that you are requested to complete an anonymous survey as the first part of the investigation. Please answer the questions below BEFORE you attempt the interpretation test. Save the questionnaire to your USB memory stick then e-mail your reply to [redacted]. **ALL boxes will extend as you type.**

1. Please type in the box below why you wanted to participate in this study.

2. Please type in the box below any anxieties / concerns you may have **before participating** in this study about writing your interpretations

3. Regarding the role of the radiographer – answer yes or no for each statement:

Question	YES	NO
a. You know that radiographers are obliged to verbally indicate abnormalities to the referrer?		
b. You know that radiographers might suggest alternative approaches to imaging for the request made?		
c. You are aware that radiographers in other countries perform an interpretive role in multiple areas of radiology?		
d. You know that some radiographers in Australia participate in an abnormality highlighting scheme?		
e. You are aware that radiographers in Australia might contribute to the patient pathway by providing indicative descriptions for ED referrals		

4. Which image area(s) did you finds hardest to interpret in this test e.g. paediatric studies, shoulder, wrist, ankle, spine etc

5. Do you think that the radiological education received in your MBBS was sufficient? Please give details about what you learnt about interpretation of images whatever your response

6. (Tick 1 box)

	Always	Most of the time	Occasionally	Never	Don't know
Do you believe YOU can describe the content of an emergency musculo-skeletal radiograph at a level matching the radiologist?					
Do you believe radiographers can describe the content of an emergency musculo-skeletal radiograph at a level matching the radiologist?					
Would you be happy to accept the description provided by a radiographer to help you make a decision about patient treatment/further imaging management?					

7. By indicating YES / NO or don't know in the appropriate box, do you think commenting on the images when the patient is present in the department:

Comment	YES	NO	Don't know
Will enable you to interpret the images more confidently?			
Gives you an interpretive advantage over the radiologist?			
Will improve the patient experience?			
Will enable you to express to the radiographer what other imaging you might need?			
Will improve the multidisciplinary team approach and enhance the relationship between the radiology department and you.			

Thank you for taking the time to complete the questionnaire along with the image test. Depending on how quickly your co-participants return their responses we will return some feedback to you in the near future.
Jonathan McConnell
A/Prof Marilyn Baird

APPENDIX 9 TN, TP, FN and FP scores for all participants

Radiographers

Full test - 209 Examinations

TEST 1

Part No	TN	TP	FN	FP
1	108	55	6	40
2	131	57	4	17
3	140	56	5	8
4	140	54	7	8
5	116	56	5	32
6	100	60	1	48
7	130	54	7	18
9	123	58	3	25
10	134	53	8	14
11	122	60	1	26
16	129	58	3	19
17	110	56	5	38
18	125	50	11	23
19	80	60	1	68
23	141	55	6	7
27	119	53	8	29

TEST 2

Part No	TN	TP	FN	FP
1	107	56	5	41
2	112	60	1	36
3	130	57	4	18
4	133	56	5	15
5	127	58	3	21
6	114	60	1	34
7	126	57	4	22
9	113	59	2	35
10	126	60	1	22
11	125	60	1	23
16	130	59	2	18
17	100	56	5	48
18	125	56	5	23
19	111	57	4	37
23	128	57	4	20
27	120	52	9	28

Medical Students

Full test - 209 Examinations

Part No	TN	TP	FN	FP
A	134	54	7	14
B	115	57	4	33
C	135	50	11	13
D	132	55	6	16
E	109	51	10	39
F	111	52	9	37
G	115	52	9	33
H	132	51	10	16
I	128	60	1	20
J	137	53	8	11
K	137	53	8	11
L	111	52	9	37
M	110	51	10	38
N	113	54	7	35
O	107	52	9	41
P	111	57	4	37

Radiographers

Appendicular only - 186 examinations

1	96	53	4	33
2	115	53	4	14
3	123	53	4	6
4	123	51	6	6
5	102	54	3	27
6	90	56	1	39
7	118	51	6	11
9	108	55	2	21
10	118	50	7	11
11	110	57	0	19
16	115	55	2	14
17	94	53	4	35
18	109	47	10	20
19	71	56	1	58
23	123	52	5	6
27	104	51	6	25

1	96	53	4	33
2	97	56	1	32
3	114	54	3	15
4	117	53	4	12
5	114	55	2	15
6	100	57	0	29
7	113	54	3	16
9	102	55	2	27
10	109	56	1	20
11	109	57	0	20
16	116	56	1	13
17	87	52	5	42
18	110	54	3	19
19	100	54	3	29
23	112	54	3	17
27	104	50	7	25

Medical Students

Appendicular only - 186 examinations

A	118	52	5	11
B	103	54	3	26
C	117	47	10	12
D	113	52	5	16
E	97	50	7	32
F	95	48	9	34
G	98	48	9	31
H	117	48	9	12
I	112	57	0	17
J	121	50	7	8
K	120	49	8	9
L	96	49	8	33
M	95	48	9	34
N	97	51	6	32
O	91	49	8	38
P	94	54	3	35

Radiographers

Adult only - 151 examinations

Part No	TN	TP	FN	FP
1	80	34	5	32
2	102	38	1	10
3	106	36	3	6
4	107	35	4	5
5	93	35	4	19
6	76	39	0	36
7	99	34	5	13
9	95	37	2	17
10	103	35	4	9
11	93	38	1	19
16	103	37	2	9
17	79	37	2	33
18	95	32	7	17
19	65	38	1	47
23	107	34	5	5
27	92	33	6	20

Part No	TN	TP	FN	FP
1	80	35	4	32
2	89	39	0	23
3	99	37	2	13
4	102	36	3	10
5	98	37	2	14
6	88	38	1	24
7	98	37	2	16
9	86	38	1	26
10	97	39	0	15
11	98	38	1	14
16	101	37	2	11
17	75	37	2	37
18	101	36	3	11
19	84	36	3	28
23	97	37	2	15
27	90	33	6	22

Medical Students

Adult only - 151 examinations

Part No	TN	TP	FN	FP
A	102	36	3	10
B	90	37	2	22
C	102	32	7	10
D	103	36	3	9
E	84	34	5	28
F	84	33	6	28
G	90	35	4	22
H	100	34	5	12
I	97	38	1	15
J	106	34	5	6
K	103	33	6	9
L	82	33	6	30
M	81	32	7	31
N	91	35	4	21
O	84	33	6	28
P	89	37	2	23

Radiologists

Full test - 209 Examinations

Radiol	TN	TP	FN	FP
Orig	142	58	3	6
Radiol 1	143	57	4	5
Radiol 2	127	60	1	21
Radiol 3	142	59	2	6

Appendicular only - 186 examinations

Radiol	TN	TP	FN	FP
Orig	126	55	2	3
Radiol 1	127	54	3	2
Radiol 2	111	56	1	18
Radiol 3	124	56	1	5

Adult only - 151 examinations

Radiol	TN	TP	FN	FP
Orig	106	37	2	6
Radiol 1	107	36	3	5
Radiol 2	98	39	0	14
Radiol 3	109	37	2	3

Appendix 10 – Individual Kappa and ROC scores for all participants (radiographers test 2 only).

Radiographers

Full test - 209 Examinations						Appendicular only - 186 examinations						Adult only - 151 examinations					
Part	Wtd Kappa	BPK	AC-1	ROC emp	ROC fit	**Part**	Wtd Kappa	BPK	AC-1	ROC emp	ROC fit	**Part**	Wtd Kappa	BPK	AC-1	ROC emp	ROC fit
1	0.536	0.785	0.576	0.864	0.893	**1**	0.536	0.848	0.622	0.882	0.913	**1**	0.496	0.766	0.562	0.853	0.903
2	0.633	0.964	0.667	0.929	0.972	**2**	0.638	0.463	0.662	0.932	0.972	**2**	0.666	1.000	0.725	0.971	0.945
3	0.761	0.724	0.812	0.928	0.955	**3**	0.785	0.739	0.825	0.939	0.963	**3**	0.762	0.719	0.830	0.948	0.966
4	0.780	0.810	0.831	0.965	0.973	**4**	0.805	0.840	0.846	0.968	0.976	**4**	0.788	0.809	0.855	0.972	0.980
5	0.744	0.679	0.793	0.945	0.966	**5**	0.798	0.74	0.834	0.967	0.982	**5**	0.749	0.699	0.818	0.946	0.962
6	0.650	0.904	0.686	0.954	0.978	**6**	0.679	1.000	0.704	0.962	0.986	**6**	0.638	0.941	0.702	0.950	0.972
7	0.723	0.852	0.776	0.939	0.958	**7**	0.774	0.882	0.814	0.953	0.969	**7**	0.749	0.877	0.816	0.932	0.954
9	0.630	0.928	0.668	0.948	0.967	**9**	0.673	0.924	0.707	0.948	0.971	**9**	0.614	0.941	0.675	0.950	0.967
10	0.758	0.667	0.800	0.963	0.977	**10**	0.757	0.659	0.790	0.961	0.978	**10**	0.769	0.682	0.827	0.979	0.989
11	0.748	0.963	0.791	0.964	0.979	**11**	0.770	1.000	0.801	0.963	0.979	**11**	0.766	0.939	0.828	0.978	0.987
16	0.785	0.726	0.828	0.976	0.986	**16**	0.833	0.774	0.864	0.981	0.992	**16**	0.791	0.760	0.854	0.974	0.983
17	0.491	0.854	0.514	0.854	0.909	**17**	0.497	0.810	0.512	0.859	0.914	**17**	0.478	0.884	0.514	0.860	0.895
18	0.701	0.815	0.758	0.916	0.953	**18**	0.742	0.883	0.783	0.934	0.972	**18**	0.773	0.811	0.844	0.934	0.955
19	0.590	0.857	0.632	0.894	0.943	**19**	0.641	0.885	0.676	0.908	0.951	**19**	0.557	0.832	0.627	0.881	0.929
23	0.742	0.852	0.794	0.953	0.962	**23**	0.763	0.883	0.804	0.958	0.970	**23**	0.729	0.877	0.806	0.956	0.966
27	0.607	0.668	0.680	0.859	0.908	**27**	0.607	0.729	0.683	0.865	0.917	**27**	0.573	0.636	0.675	0.865	0.915

Medical Students

A	0.764	0.731	0.825	0.930	0.942	**A**	0.803	0.799	0.847	0.941	0.953	**A**	0.787	0.809	0.855	0.942	0.956
B	0.624	0.855	0.671	0.939	0.948	**B**	0.670	0.885	0.708	0.954	0.963	**B**	0.645	0.881	0.717	0.944	0.954
C	0.724	0.568	0.803	0.896	0.897	**C**	0.724	0.591	0.793	0.899	0.898	**C**	0.713	0.543	0.815	0.904	0.914
D	0.757	0.772	0.815	0.941	0.959	**D**	0.748	0.803	0.796	0.940	0.961	**D**	0.802	0.808	0.867	0.965	0.976
E	0.502	0.637	0.565	0.846	0.861	**E**	0.561	0.732	0.606	0.868	0.883	**E**	0.522	0.704	0.606	0.866	0.877
F	0.530	0.673	0.592	0.822	0.836	**F**	0.515	0.656	0.565	0.814	0.831	**F**	0.504	0.644	0.596	0.839	0.850
G	0.564	0.671	0.632	0.847	0.858	**G**	0.543	0.650	0.599	0.841	0.855	**G**	0.609	0.760	0.696	0.872	0.871
H	0.708	0.614	0.784	0.898	0.910	**H**	0.738	0.634	0.802	0.905	0.916	**H**	0.708	0.682	0.811	0.899	0.908
I	0.777	0.963	0.818	0.972	0.984	**I**	0.802	1.000	0.832	0.979	0.984	**I**	0.777	0.681	0.816	0.977	0.987
J	0.783	0.687	0.843	0.934	0.945	**J**	0.811	0.712	0.859	0.951	0.958	**J**	0.783	0.668	0.881	0.921	0.936
K	0.783	0.687	0.843	0.947	0.962	**K**	0.786	0.671	0.840	0.947	0.962	**K**	0.783	0.608	0.836	0.935	0.946
L	0.531	0.673	0.529	0.816	0.847	**L**	0.538	0.694	0.586	0.816	0.846	**L**	0.482	0.646	0.569	0.800	0.845
M	0.510	0.637	0.575	0.863	0.881	**M**	0.515	0.656	0.565	0.872	0.890	**M**	0.510	0.587	0.545	0.841	0.860
N	0.572	0.746	0.628	0.907	0.936	**N**	0.574	0.771	0.615	0.911	0.941	**N**	0.572	0.759	0.709	0.920	0.945
O	0.499	0.675	0.553	0.873	0.898	**O**	0.493	0.696	0.529	0.879	0.902	**O**	0.499	0.664	0.596	0.878	0.903
P	0.591	0.856	0.632	0.897	0.924	**P**	0.584	0.886	0.609	0.902	0.929	**P**	0.591	0.881	0.704	0.914	0.934

Radiologists

Full test - 209 Examinations

Radiol	Wtd Kappa	BPK	AC-1	ROC emp	ROC fit
Orig	0.897	0.883	0.926	0.948	0.980
1	0.896	0.842	0.926	0.947	0.969
2	0.768	0.963	0.809	0.935	0.945
3	0.909	0.923	0.934	0.964	0.986

Appendicular only - 186 examinations

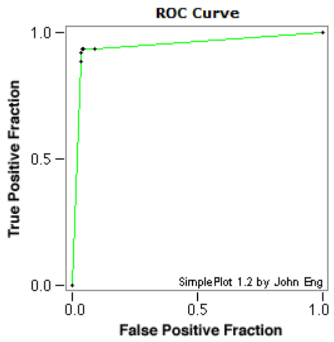
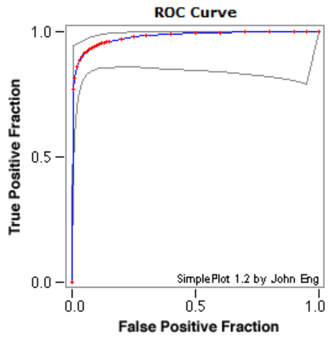
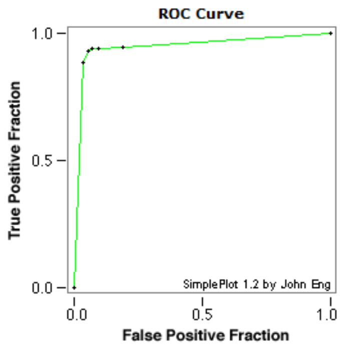
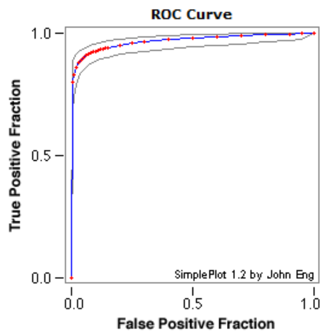
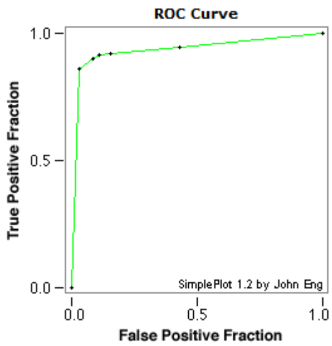
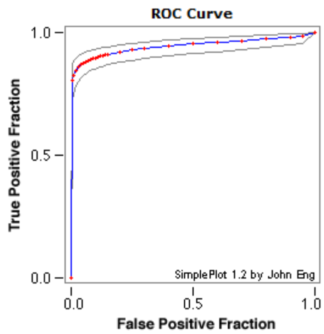
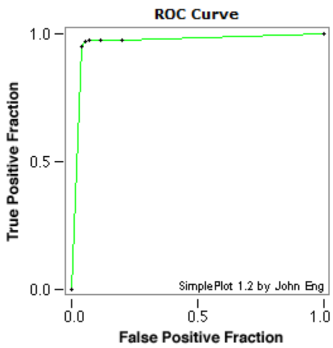
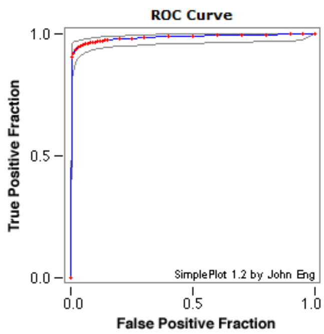
Radiol	Wtd Kappa	BPK	AC-1	ROC emp	ROC fit
Orig	0.937	0.918	0.953	0.964	0.983
1	0.936	0.876	0.953	0.964	0.983
2	0.778	0.961	0.812	0.964	0.982
3	0.926	0.959	0.943	0.981	0.993

Adult only - 151 examinations

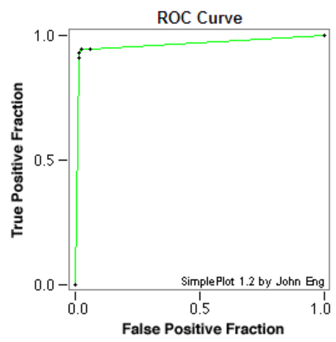
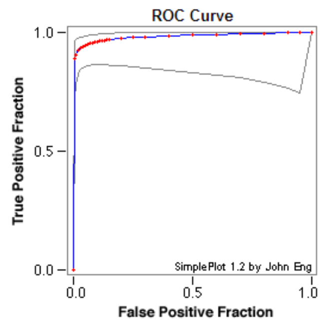
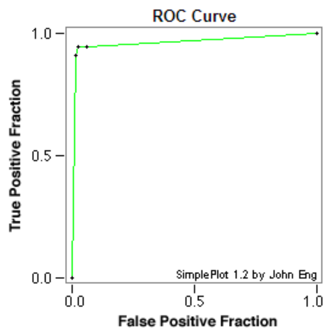
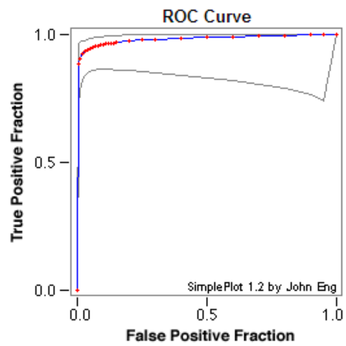
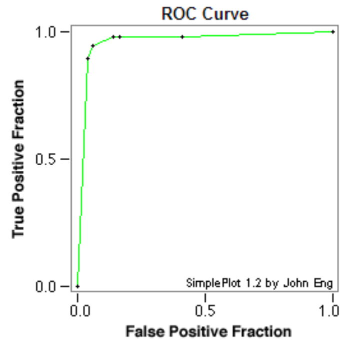
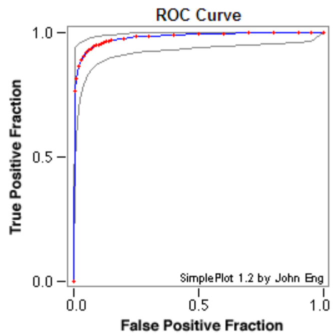
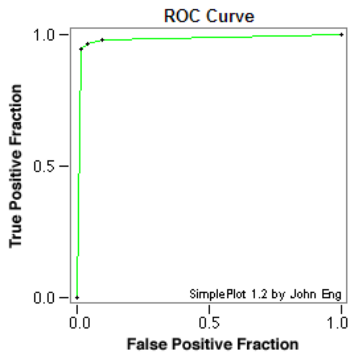
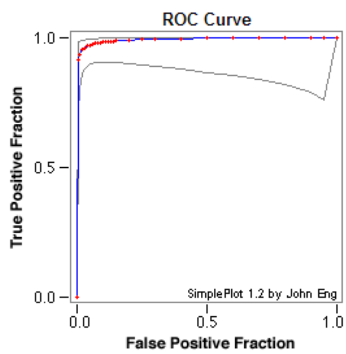
Radiol	Wtd Kappa	BPK	AC-1	ROC emp	ROC fit
Orig	0.866	0.870	0.912	0.936	0.972
1	0.926	0.802	0.913	0.936	0.972
2	0.783	1.000	0.839	0.975	Degenerate Sens 100%
3	0.914	0.867	0.946	0.975	0.990

Appendix 11 ROC plots from the Eng calculator for all participants

ROC curve plots – Radiologists

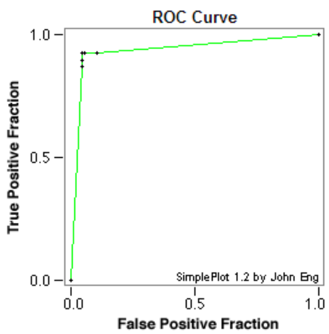
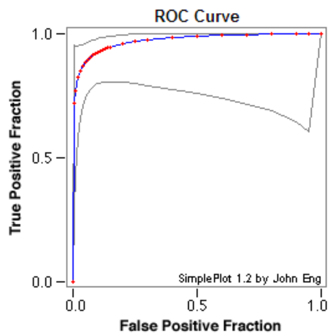
Full test	Empirical plot	Fitted plot
Original radiologists AUC ROC emp = 0.948 ROC fit = 0.980		
Radiologist 1 AUC ROC emp = 0.947 ROC fit = 0.969		
Radiologist 2 AUC ROC emp = 0.935 ROC fit = 0.945		
Radiologist 3 ROC emp = 0.964 ROC fit = 0.986		

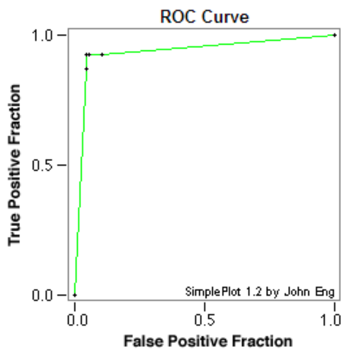
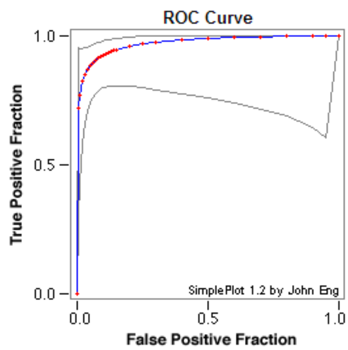
ROC curve plots – Radiologists

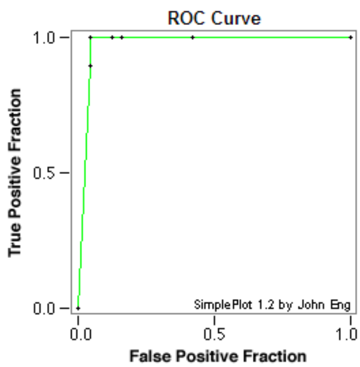
Appendicular test	Empirical plot	Fitted plot
Original radiologists AUC ROC emp = 0.964 ROC fit = 0.983		
Radiologist 1 AUC ROC emp = 0.964 ROC fit = 0.983		
Radiologist 2 AUC ROC emp = 0.964 ROC fit = 0.982		
Radiologist 3 AUC ROC emp = 0.981 ROC fit = 0.993		

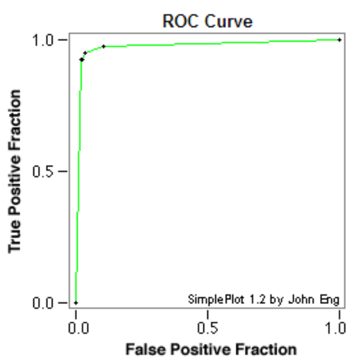
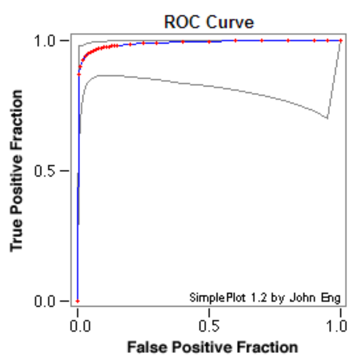
ROC curve plots – Radiologists

<table>
<tr><th>Adult only test</th><th>Empirical plot</th><th>Fitted plot</th></tr>
<tr><td>Original radiologists

AUC
ROC emp = 0.936
ROC fit = 0.972</td><td>
</td><td>
</td></tr>
<tr><td>Radiologist 1

AUC
ROC emp = 0.936
ROC fit = 0.972</td><td>
</td><td>
</td></tr>
<tr><td>Radiologist 2

AUC
ROC emp = 0.975
ROC fit = degenerate</td><td>
</td><td>No fitted image can be generated as the ROC is degenerate. A high or zero sensitivity or specificity value can impact on final values due to the unlikely event that this would normally occur clinically.</td></tr>
<tr><td>Radiologist 3

AUC
ROC emp = 0.975
ROC fit = 0.990</td><td>
</td><td>
</td></tr>
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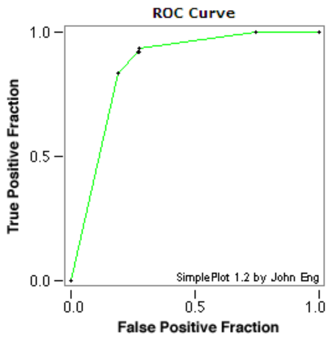
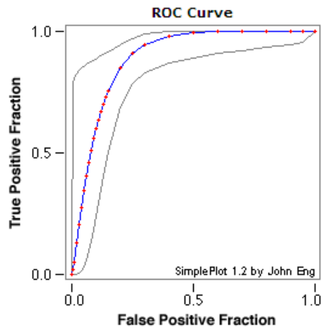
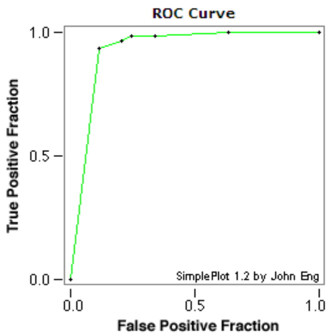
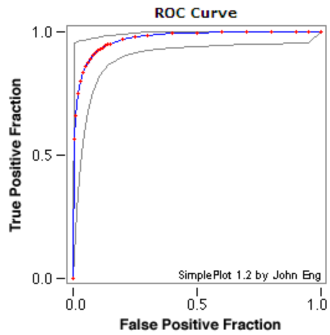
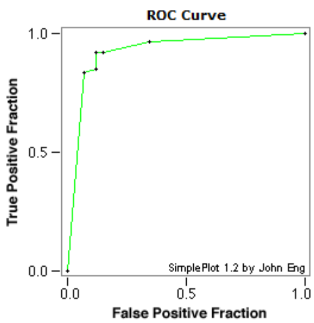
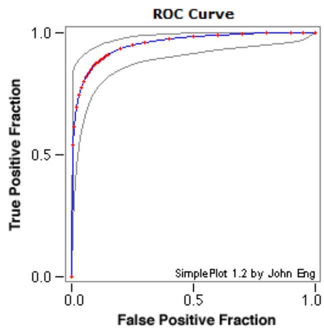
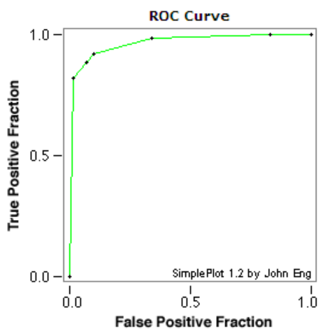
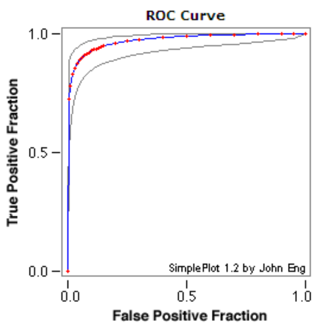
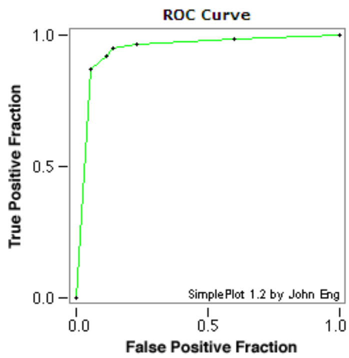
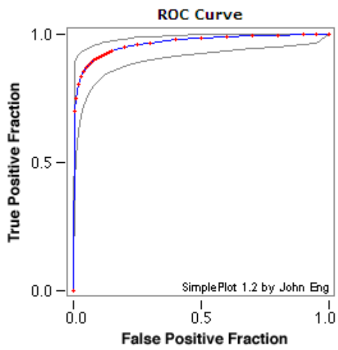
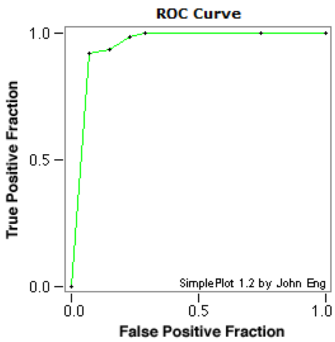
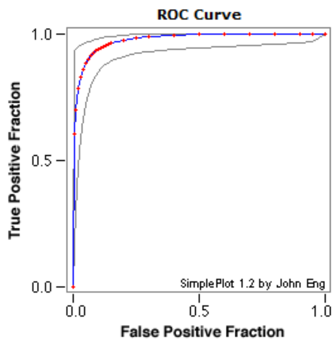
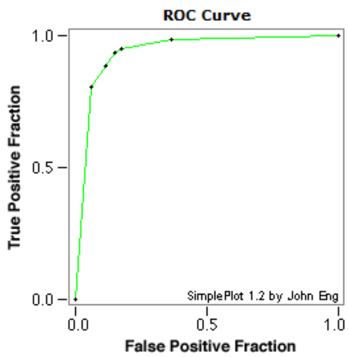
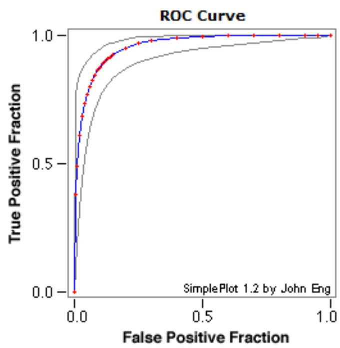
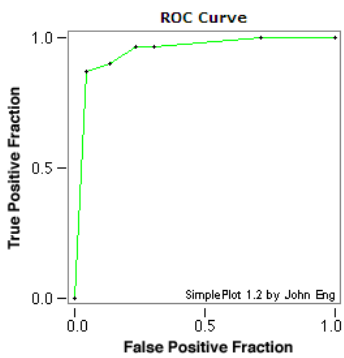
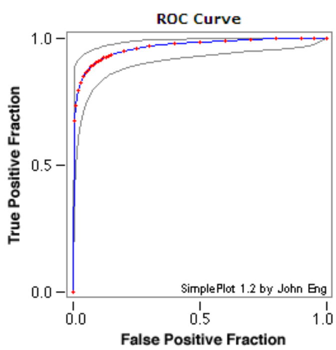
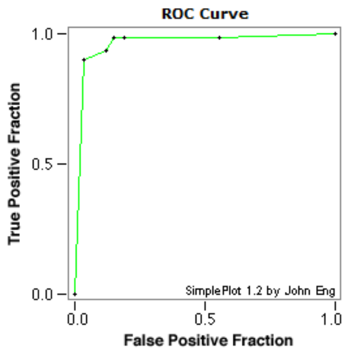
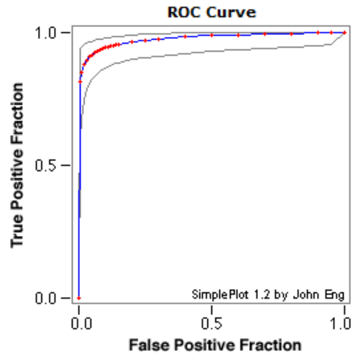
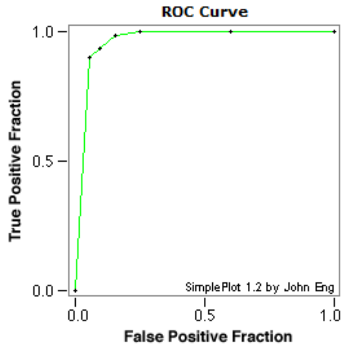
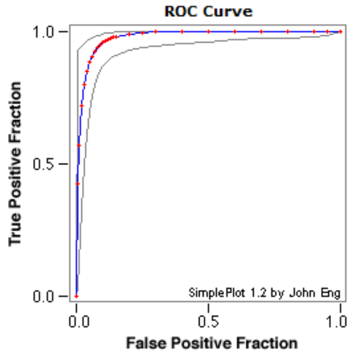
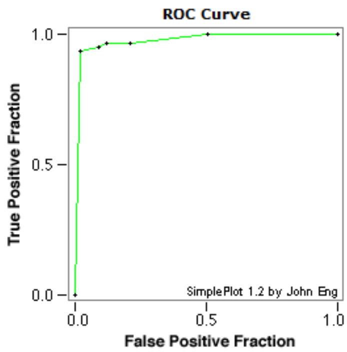
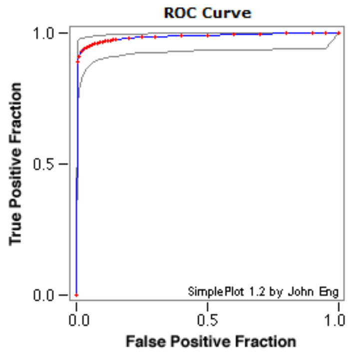
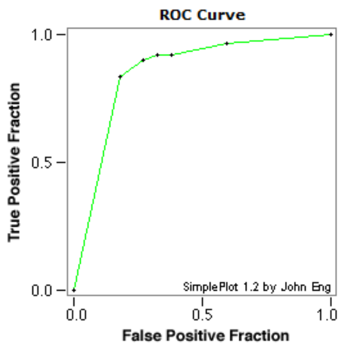
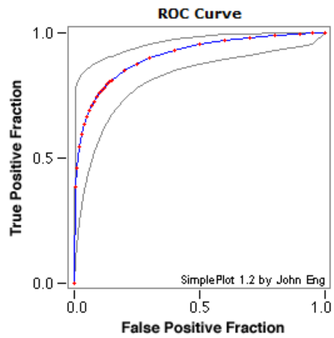
ROC curve plots – Radiographers

Full test	Empirical plot	Fitted plot
Participant 1 AUC ROC emp = 0.864 ROC fit = 0.893		
Participant 2 AUC ROC emp = 0.929 ROC fit = 0.972		
Participant 3 AUC ROC emp = 0.928 ROC fit = 0.955		
Participant 4 AUC ROC emp = 0.965 ROC fit = 0.973		

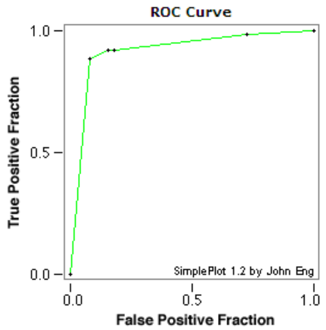
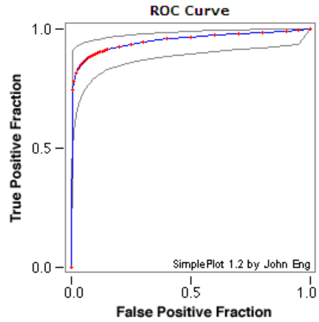
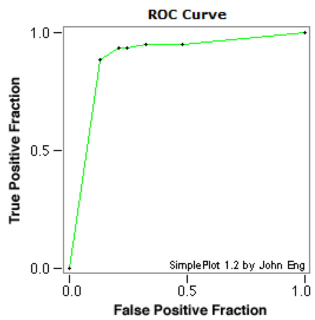
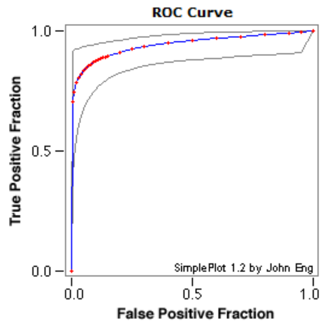
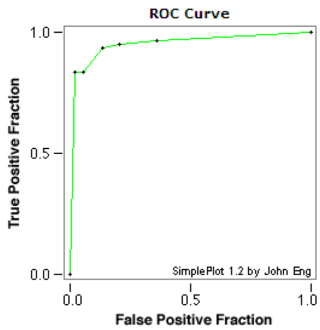
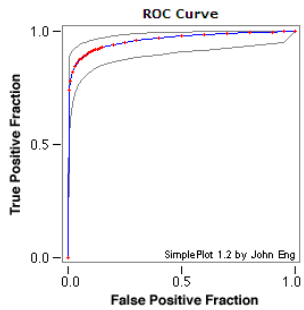
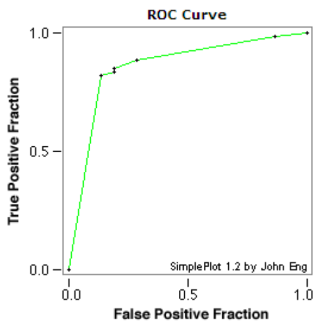
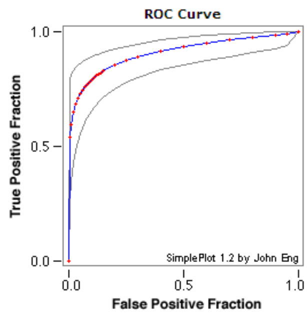
ROC curve plots – Radiographers

Full test	Empirical plot	Fitted plot
Participant 5 AUC ROC emp = 0.945 ROC fit = 0.966		
Participant 6 AUC ROC emp = 0.954 ROC fit = 0.978		
Participant 7 AUC ROC emp = 0.939 ROC fit = 0.958		
Participant 9 AUC ROC emp = 0.948 ROC fit = 0.967		

ROC curve plots – Radiographers

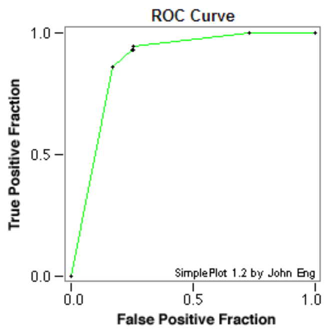
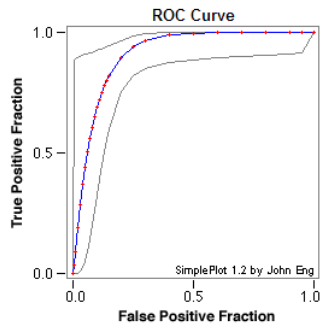
Full test	Empirical plot	Fitted plot
Participant 10 AUC ROC emp = 0.963 ROC fit = 0.977		
Participant 11 AUC ROC emp = 0.964 ROC fit = 0.979		
Participant 16 AUC ROC emp = 0.976 ROC fit = 0.986		
Participant 17 AUC ROC emp = 0.854 ROC fit = 0.909		

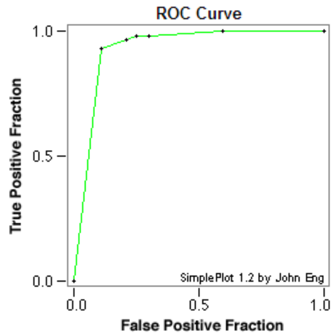
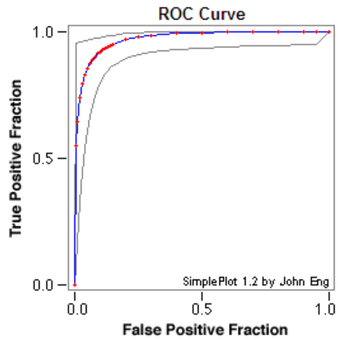
ROC curve plots – Radiographers

Full test	Empirical plot	Fitted plot
Participant 18 AUC ROC emp = 0.916 ROC fit = 0.953		
Participant 19 AUC ROC emp = 0.894 ROC fit = 0.943		
Participant 23 AUC ROC emp = 0.953 ROC fit = 0.962		
Participant 27 AUC ROC emp = 0.859 ROC fit = 0.908		

ROC curve plots – Radiographers

<table>
<tr><th>Appendicular test</th><th>Empirical plot</th><th>Fitted plot</th></tr>
<tr><td>Participant 1

AUC
ROC emp = 0.882
ROC fit = 0.913</td><td>
</td><td>
</td></tr>
<tr><td>Participant 2

AUC
ROC emp = 0.932
ROC fit = 0.972</td><td>
</td><td>
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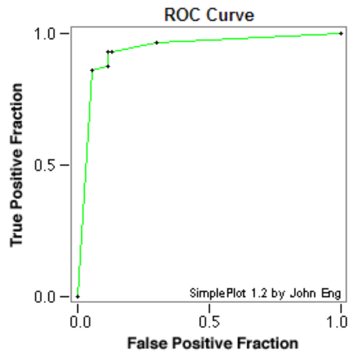
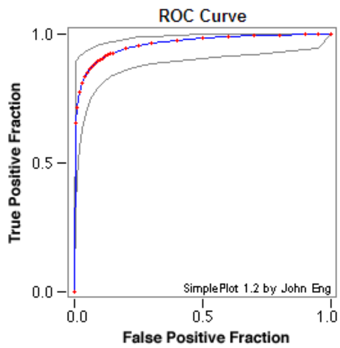
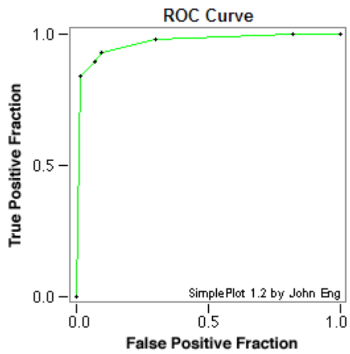
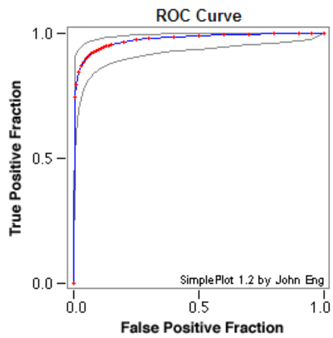
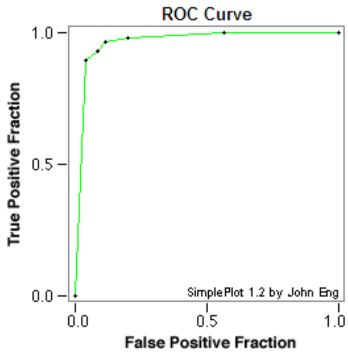
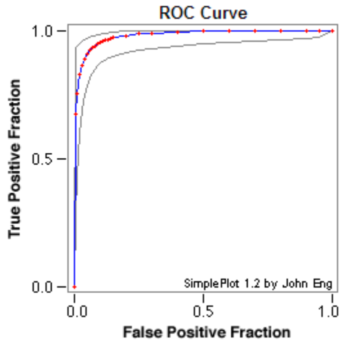
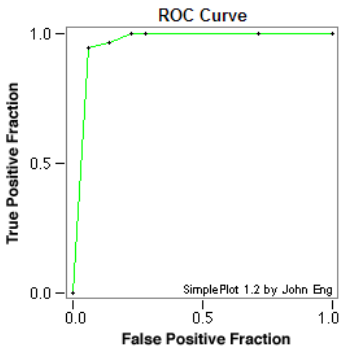
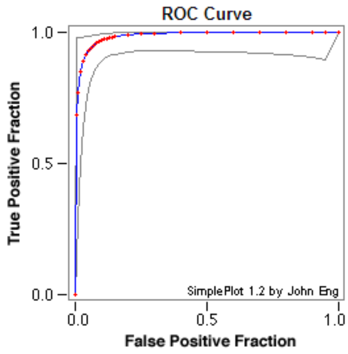
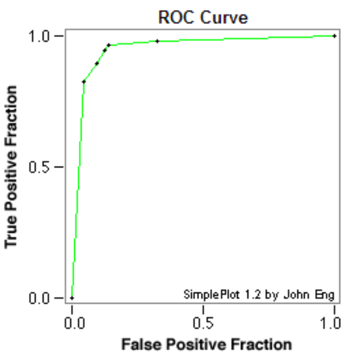
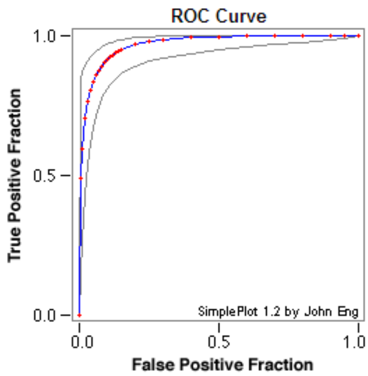
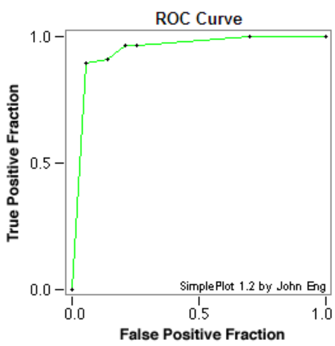
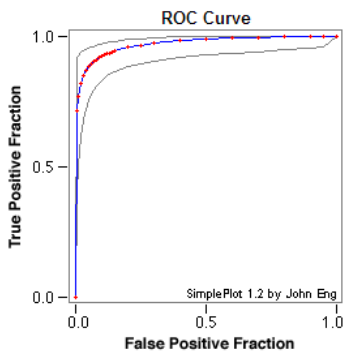
<tr><td>Participant 3

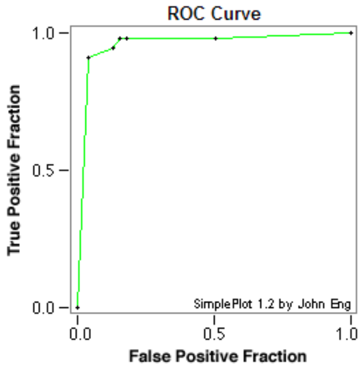
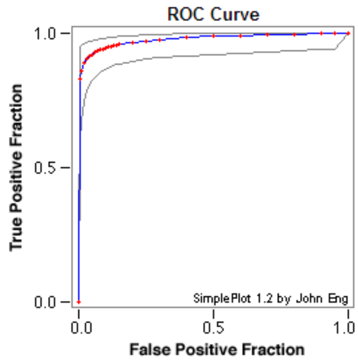
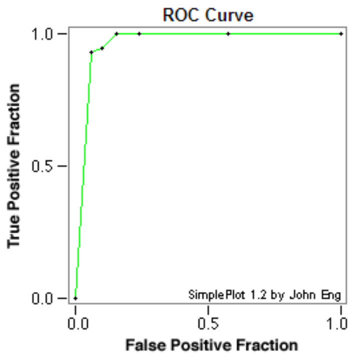
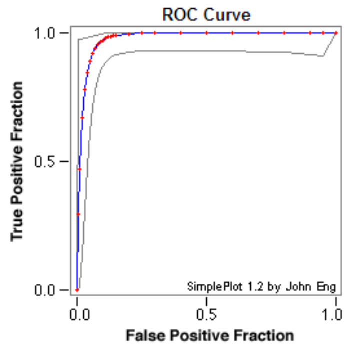
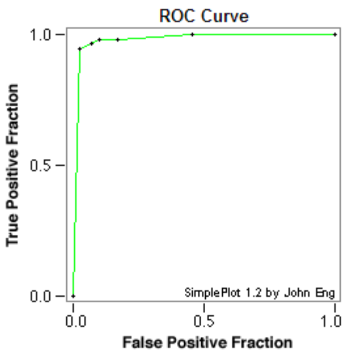
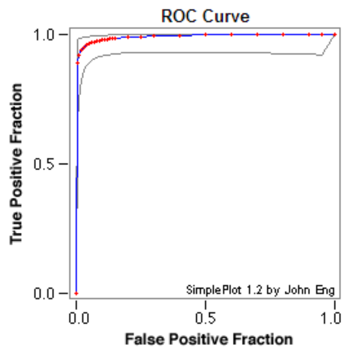
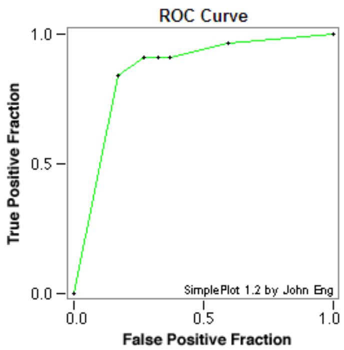
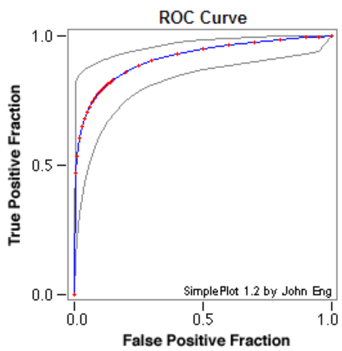
AUC
ROC emp = 0.939
ROC fit = 0.963</td><td>
</td><td>
</td></tr>
<tr><td>Participant 4

AUC
ROC emp = 0.968
ROC fit = 0.976</td><td>
</td><td>
</td></tr>
</table>

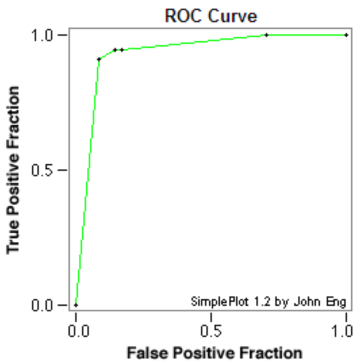
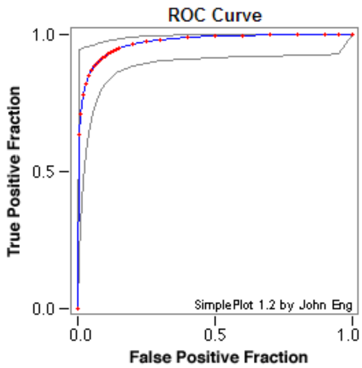
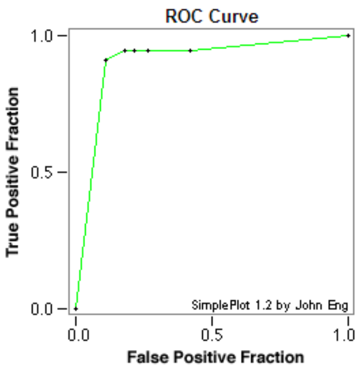
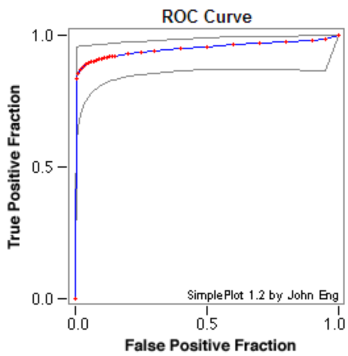
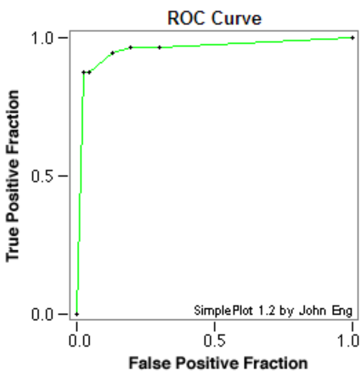
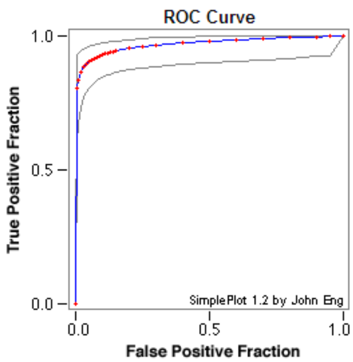
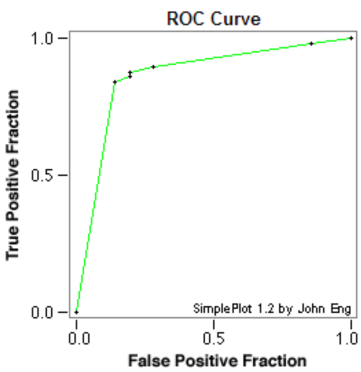
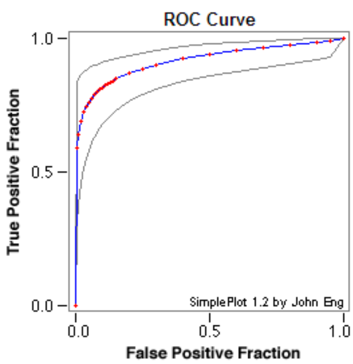
ROC curve plots – Radiographers

Appendicular test	Empirical plot	Fitted plot
Participant 5 AUC ROC emp = 0.967 ROC fit = 0.982		
Participant 6 AUC ROC emp = 0.962 ROC fit = 0.986		
Participant 7 AUC ROC emp = 0.953 ROC fit = 0.969		
Participant 9 AUC ROC emp = 0.948 ROC fit = 0.971		

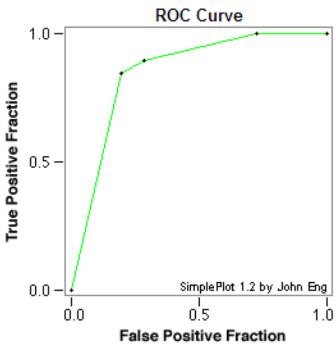
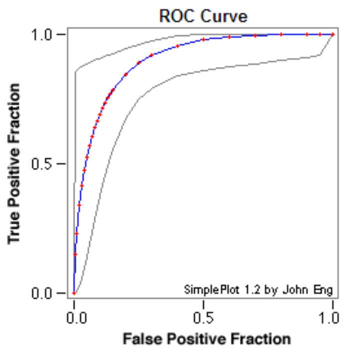
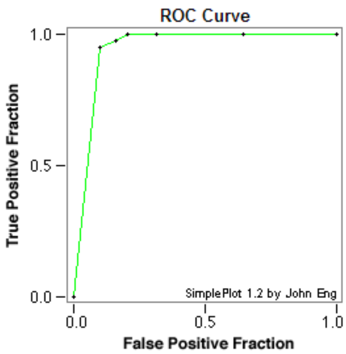
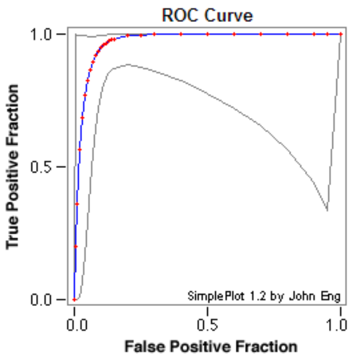
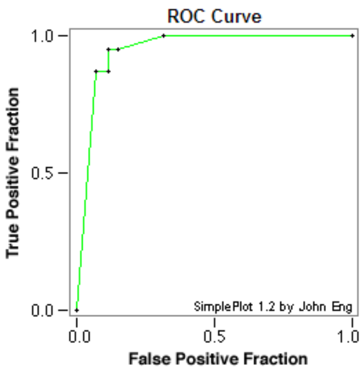
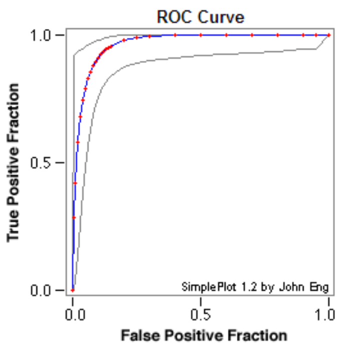
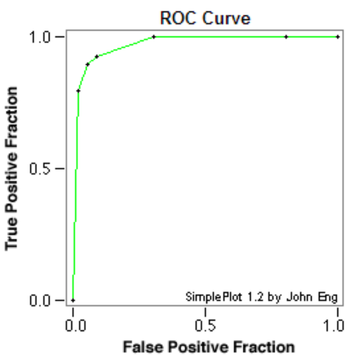
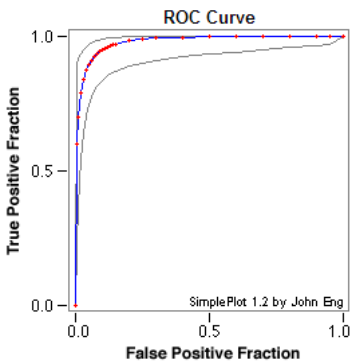
ROC curve plots – Radiographers

Appendicular test	Empirical plot	Fitted plot
Participant 10 AUC ROC emp = 0.961 ROC fit = 0.978		
Participant 11 AUC ROC emp = 0.963 ROC fit = 0.979		
Participant 16 AUC ROC emp = 0.981 ROC fit = 0.992		
Participant 17 AUC ROC emp = 0.859 ROC fit = 0.914		

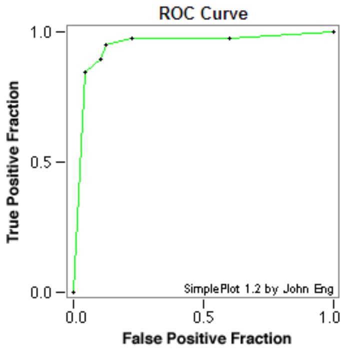
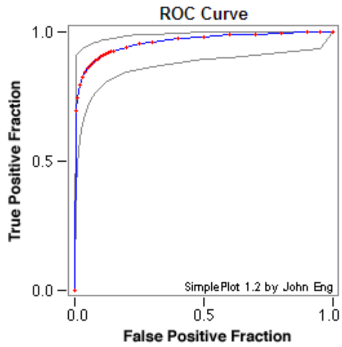
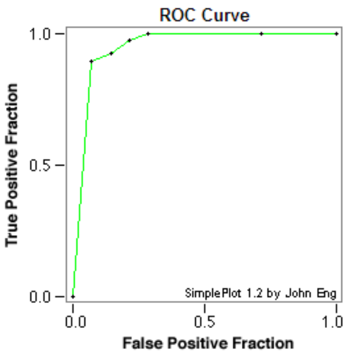
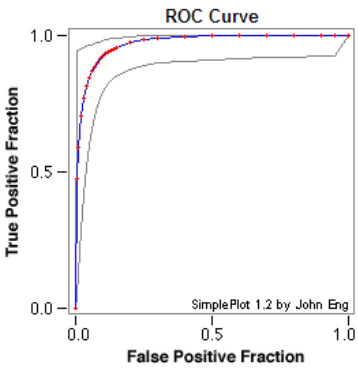
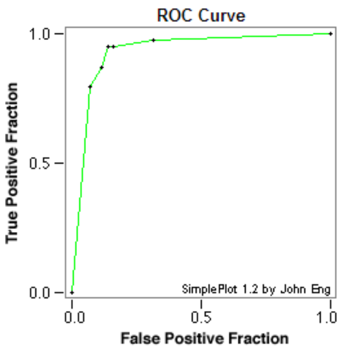
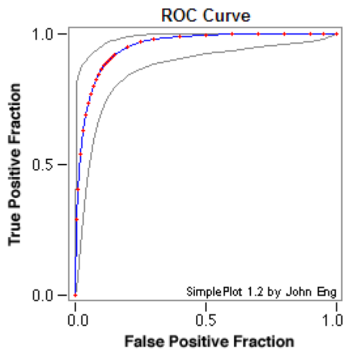
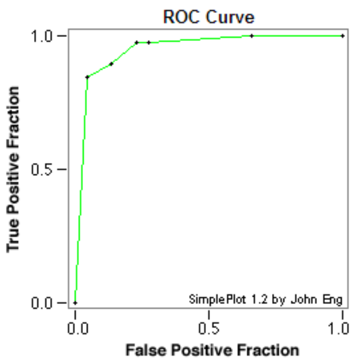
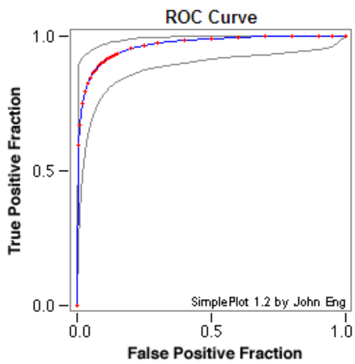
ROC curve plots – Radiographers

Appendicular test	Empirical plot	Fitted plot
Participant 18 AUC ROC emp = 0.934 ROC fit = 0.972		
Participant 19 AUC ROC emp = 0.908 ROC fit = 0.951		
Participant 23 AUC ROC emp = 0.958 ROC fit = 0.970		
Participant 27 AUC ROC emp = 0.865 ROC fit = 0.917		

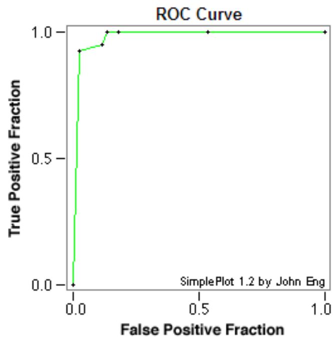
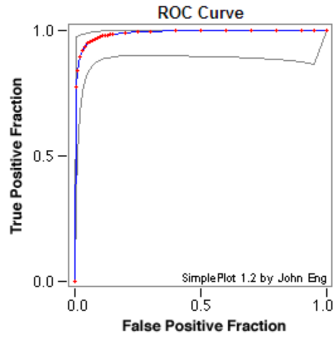
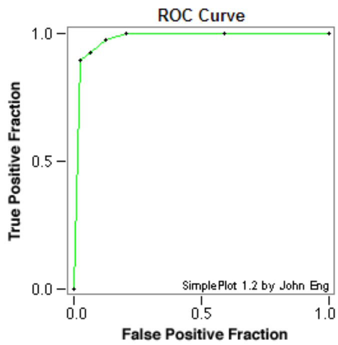
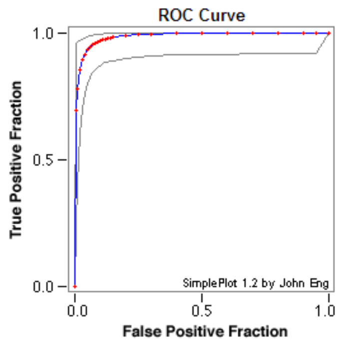
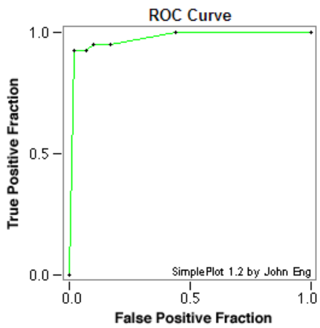
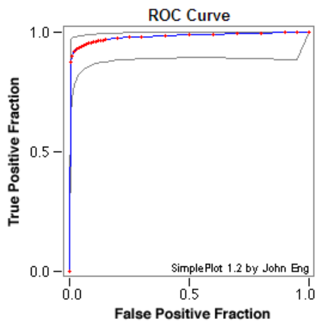
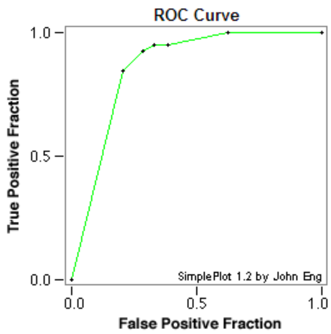
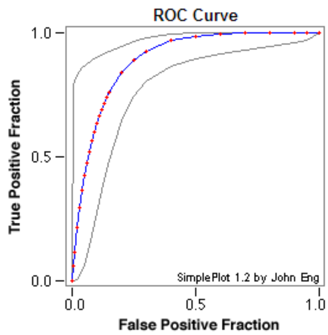
ROC curve plots – Radiographers

Adult only test	Empirical plot	Fitted plot
Participant 1 AUC ROC emp = 0.853 ROC fit = 0.903		
Participant 2 AUC ROC emp = 0.971 ROC fit = 0.945		
Participant 3 AUC ROC emp = 0.948 ROC fit = 0.966		
Participant 4 AUC ROC emp = 0.972 ROC fit = 0.980		

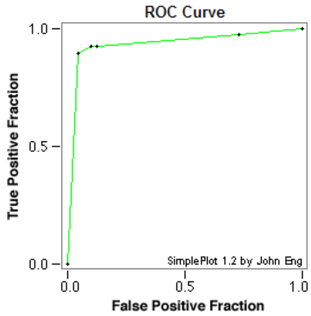
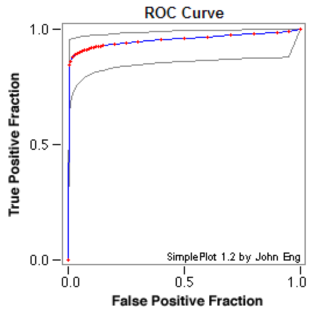
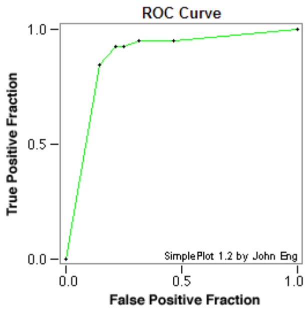
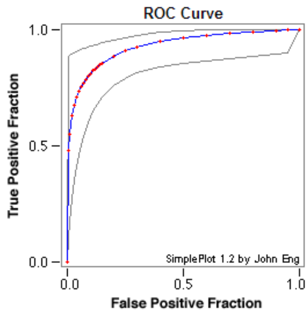
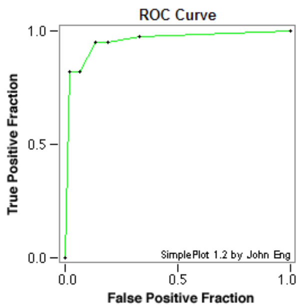
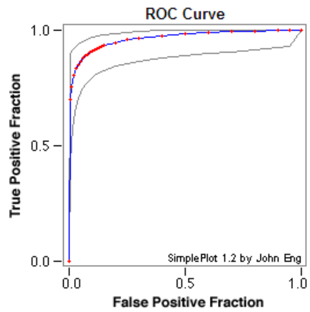
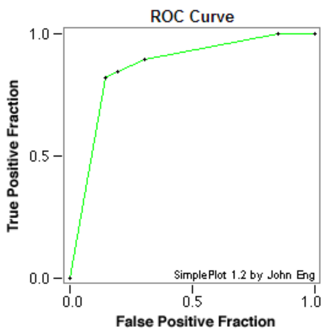
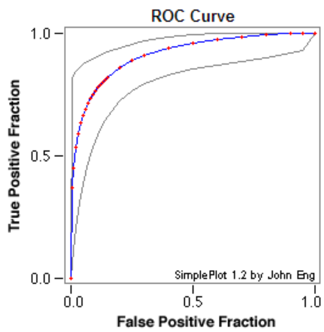
ROC curve plots – Radiographers

Adult only test	Empirical plot	Fitted plot
Participant 5 AUC ROC emp = 0.946 ROC fit = 0.962		
Participant 6 AUC ROC emp = 0.950 ROC fit = 0.972		
Participant 7 AUC ROC emp = 0.932 ROC fit = 0.954		
Participant 9 AUC ROC emp = 0.950 ROC fit = 0.967		

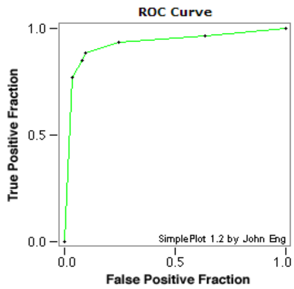
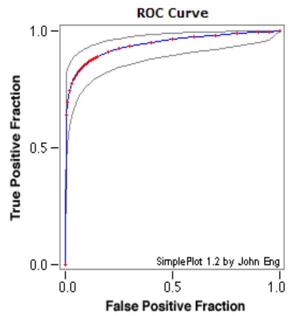
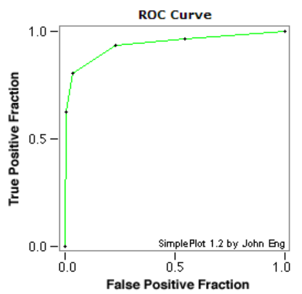
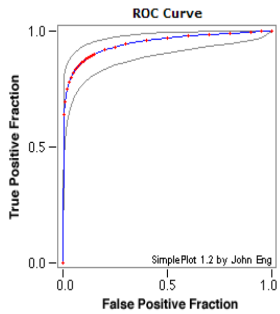
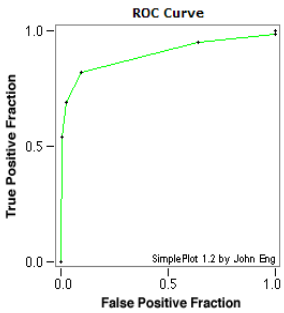
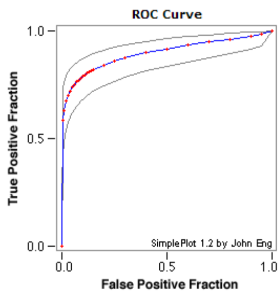
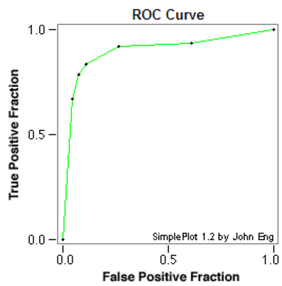
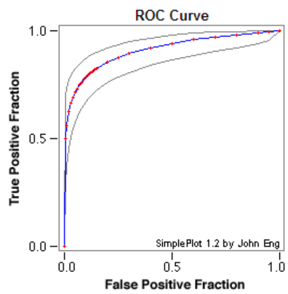
ROC curve plots – Radiographers

Adult only test	Empirical plot	Fitted plot
Participant 10 AUC ROC emp = 0.979 ROC fit = 0.989		
Participant 11 AUC ROC emp = 0.978 ROC fit = 0.987		
Participant 16 AUC ROC emp = 0.974 ROC fit = 0.983		
Participant 17 AUC ROC emp = 0.860 ROC fit = 0.895		

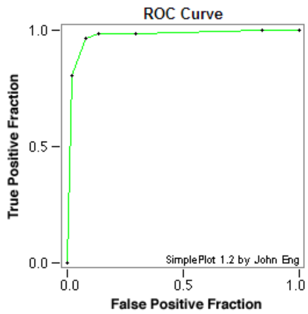
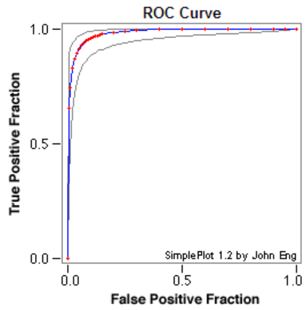
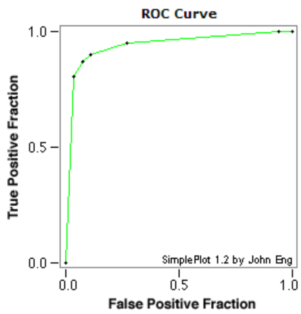
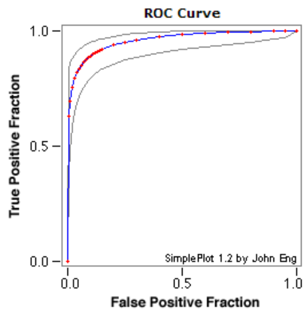
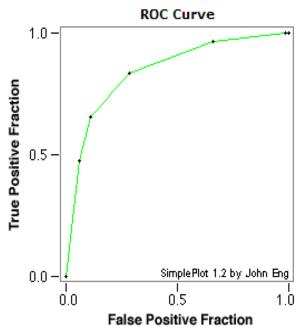
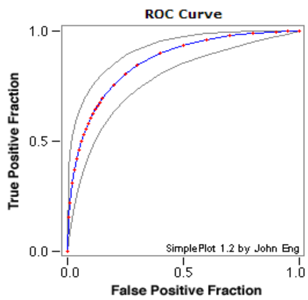
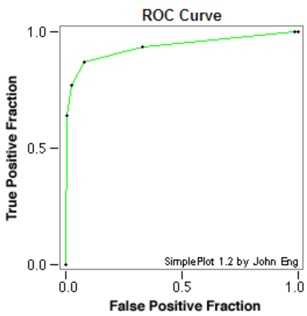
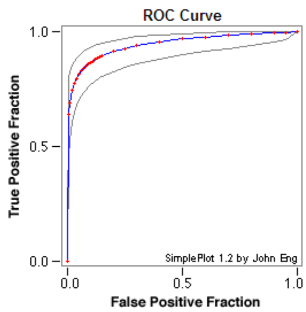
ROC curve plots – Radiographers

Adult only test	Empirical plot	Fitted plot
Participant 18 AUC ROC emp = 0.934 ROC fit = 0.955		
Participant 19 AUC ROC emp = 0.881 ROC fit = 0.929		
Participant 23 AUC ROC emp = 0.956 ROC fit = 0.966		
Participant 27 AUC ROC emp = 0.865 ROC fit = 0.915		

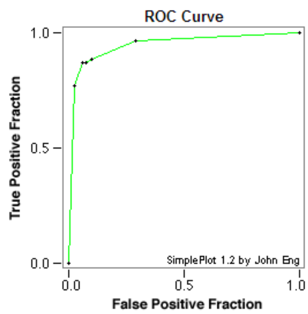
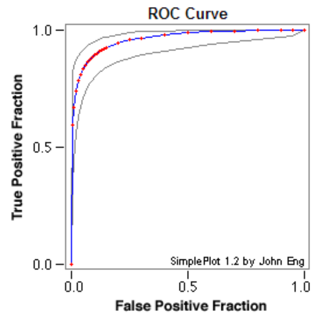
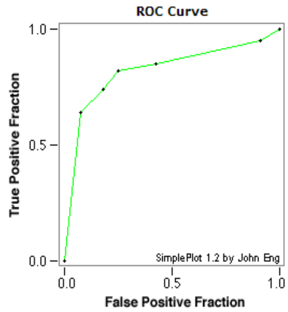
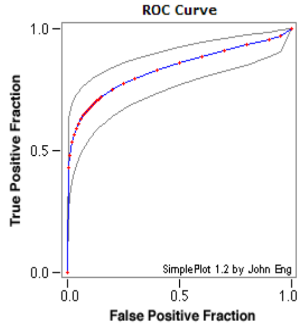
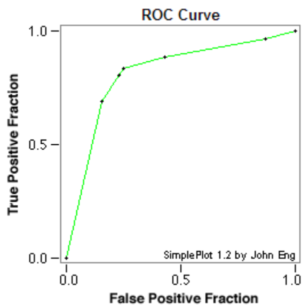
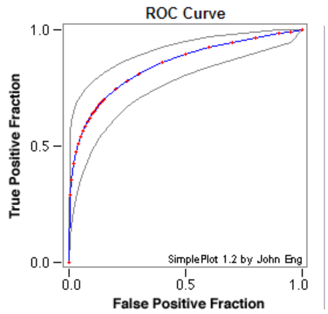
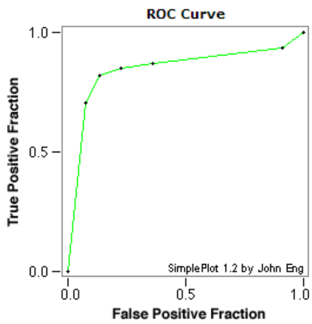
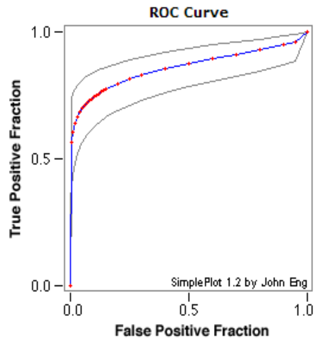
ROC curve plots – Medical Students

Full test	Empirical plot	Fitted plot
Participant A AUC ROC emp = 0.930 ROC fit = 0.942		
Participant B AUC ROC emp = 0.939 ROC fit = 0.948		
Participant C AUC ROC emp = 0.896 ROC fit = 0.897		
Participant D AUC ROC emp = 0.941 ROC fit = 0.959		

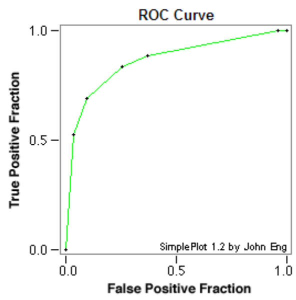
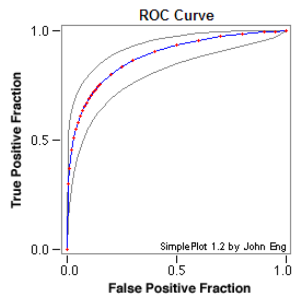
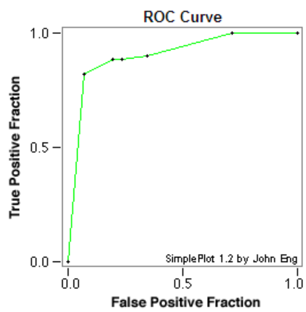
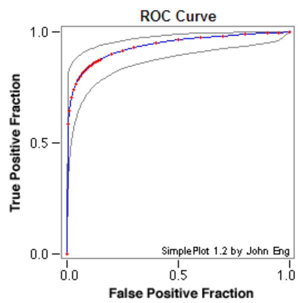
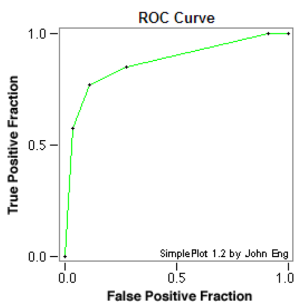
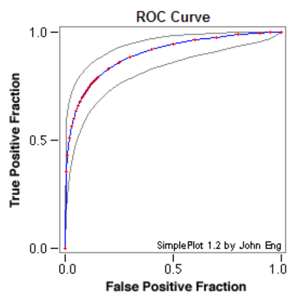
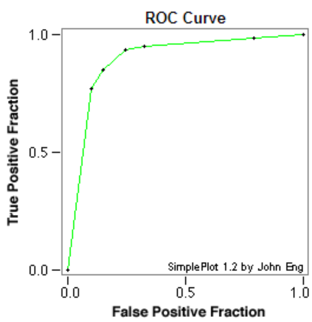
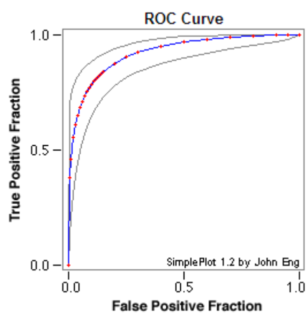
ROC curve plots – Medical Students

Full test	Empirical plot	Fitted plot
Participant E AUC ROC emp = 0.846 ROC fit = 0.861		
Participant F AUC ROC emp = 0.822 ROC fit = 0.836		
Participant G AUC ROC emp = 0.847 ROC fit = 0.858		
Participant H AUC ROC emp = 0.898 ROC fit = 0.910		

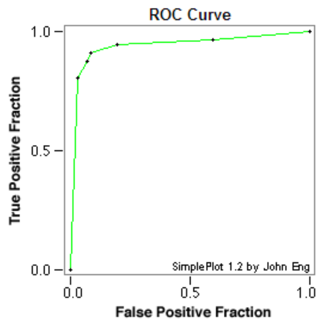
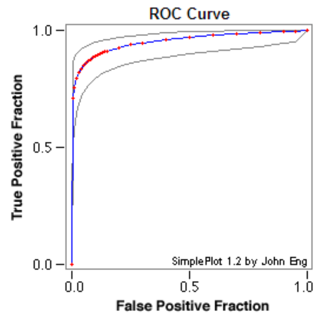
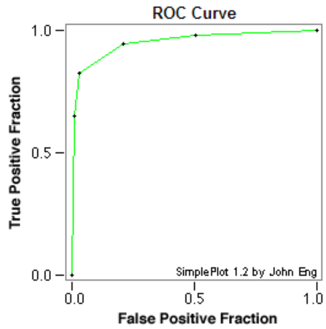
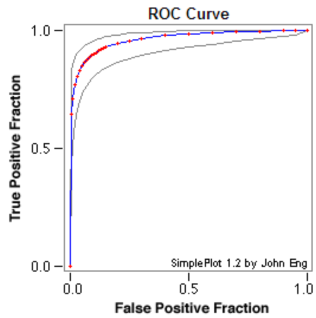
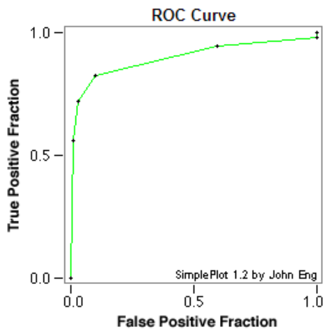
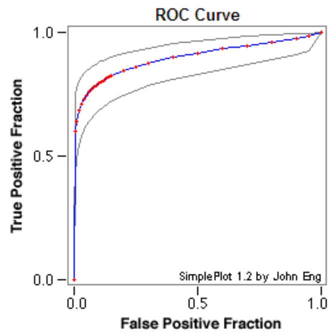
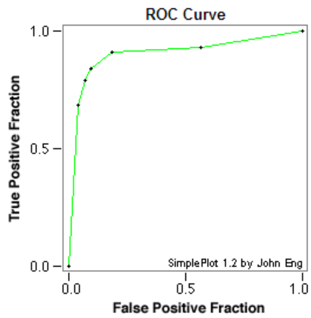
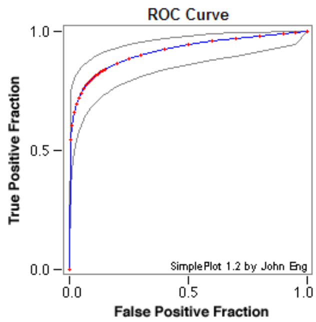
ROC curve plots – Medical Students

Full test	Empirical plot	Fitted plot
Participant I AUC ROC emp = 0.972 ROC fit = 0.984		
Participant J AUC ROC emp = 0.934 ROC fit = 0.945		
Participant K AUC ROC emp = 0.947 ROC fit = 0.962		
Participant L AUC ROC emp = 0.816 ROC fit = 0.847		

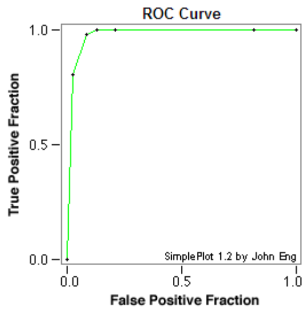
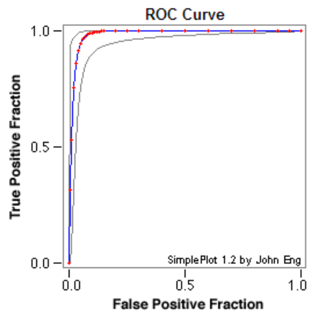
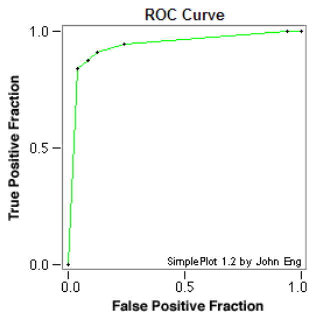
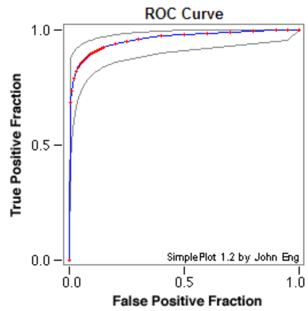
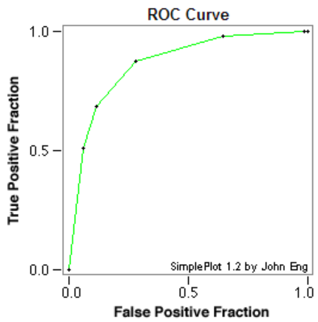
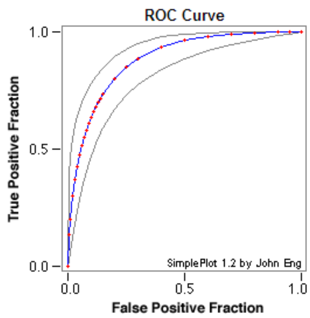
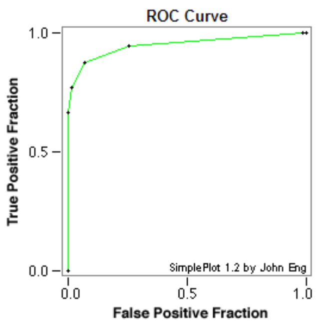
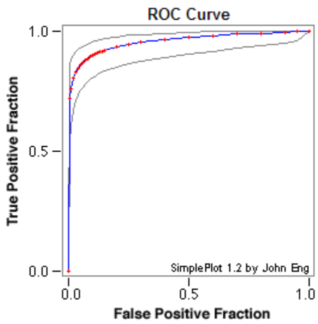
ROC curve plots – Medical Students

Full test	Empirical plot	Fitted plot
Participant M AUC ROC emp = 0.863 ROC fit = 0.881		
Participant N AUC ROC emp = 0.907 ROC fit = 0.936		
Participant O AUC ROC emp = 0.873 ROC fit = 0.898		
Participant P AUC ROC emp = 0.897 ROC fit = 0.924		

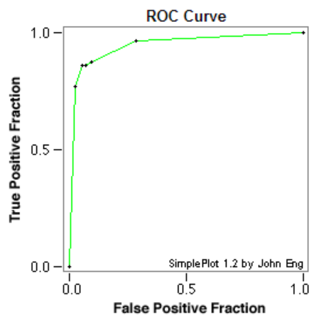
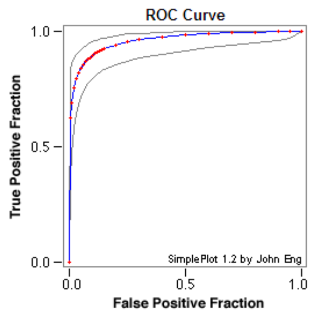
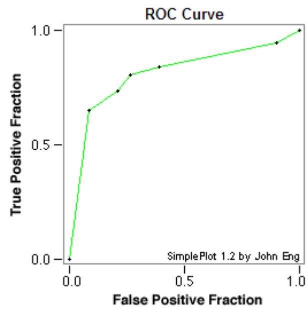
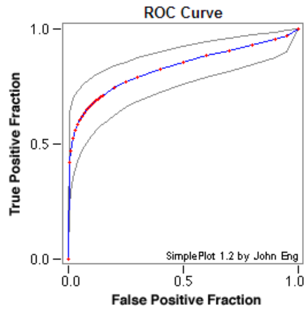
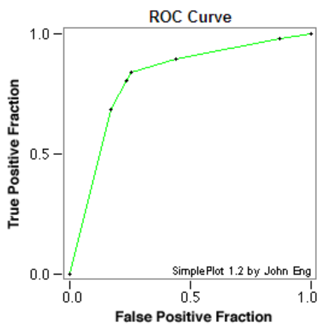
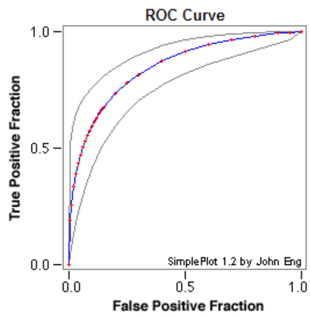
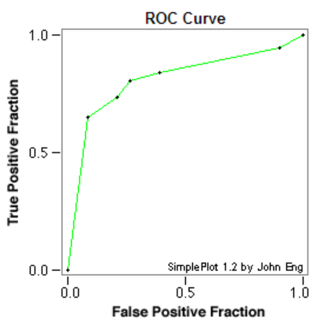
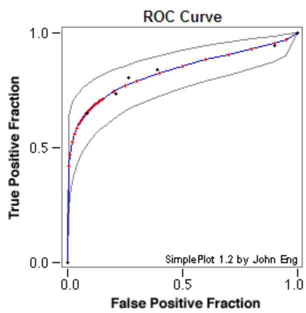
ROC curve plots – Medical Students

Appendicular test	Empirical plot	Fitted plot
Participant A AUC ROC emp = 0.941 ROC fit = 0.953		
Participant B AUC ROC emp = 0.954 ROC fit = 0.963		
Participant C AUC ROC emp = 0.899 ROC fit = 0.898		
Participant D AUC ROC emp = 0.940 ROC fit = 0.961		

ROC curve plots – Medical Students

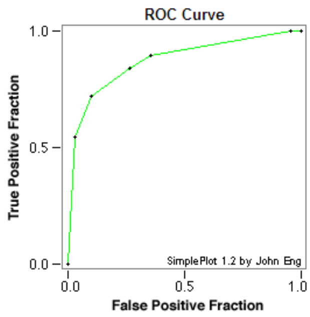
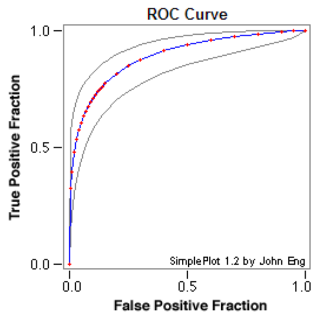
Appendicular test	Empirical plot	Fitted plot
Participant E AUC ROC emp = 0.868 ROC fit = 0.883		
Participant F AUC ROC emp = 0.814 ROC fit = 0.831		
Participant G AUC ROC emp = 0.841 ROC fit = 0.855		
Participant H AUC ROC emp = 0.905 ROC fit = 0.916		

ROC curve plots – Medical Students

Appendicular test	Empirical plot	Fitted plot
Participant I AUC ROC emp = 0.979 ROC fit = 0.984		
Participant J AUC ROC emp = 0.951 ROC fit = 0.958		
Participant K AUC ROC emp = 0.947 ROC fit = 0.962		
Participant L AUC ROC emp = 0.816 ROC fit = 0.846		

ROC curve plots – Medical Students

<table>
<tr><th>Appendicular test</th><th>Empirical plot</th><th>Fitted plot</th></tr>
<tr><td>Participant M

AUC
ROC emp = 0.872
ROC fit = 0.890</td><td>
</td><td>
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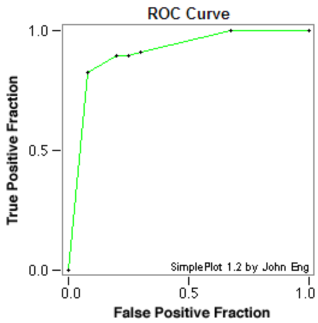
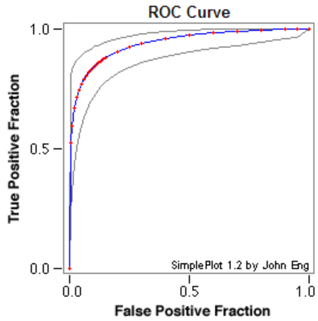
<tr><td>Participant N

AUC
ROC emp = 0.911
ROC fit = 0.941</td><td>
</td><td>
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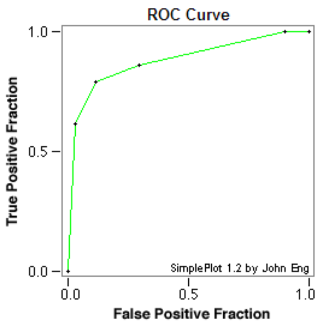
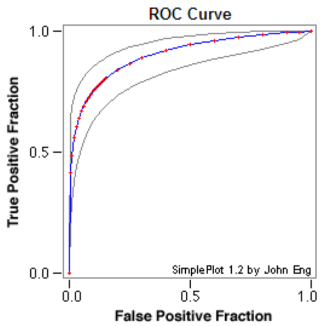
<tr><td>Participant O

AUC
ROC emp = 0.879
ROC fit = 0.902</td><td>
</td><td>
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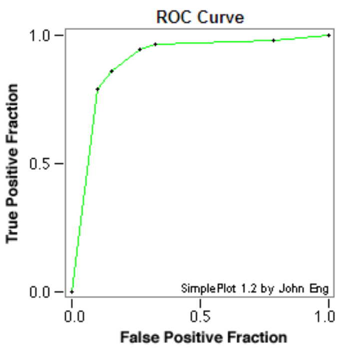
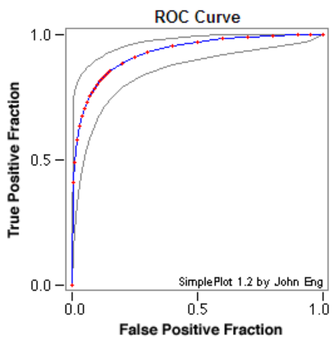
<tr><td>Participant P

AUC
ROC emp = 0.902
ROC fit = 0.929</td><td>
</td><td>
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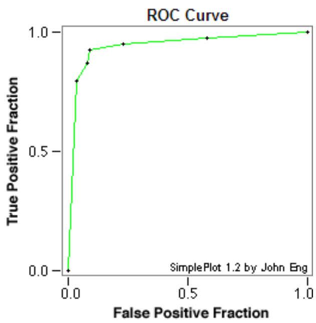
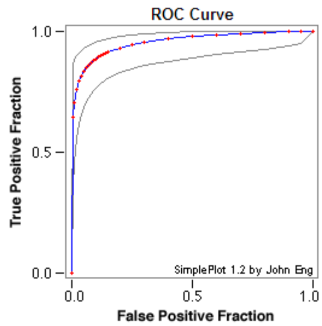
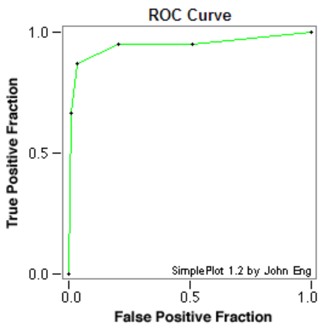
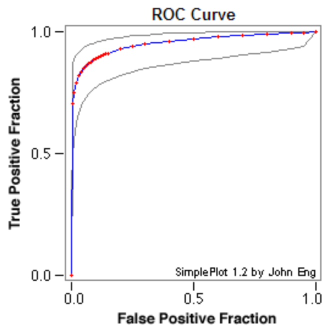
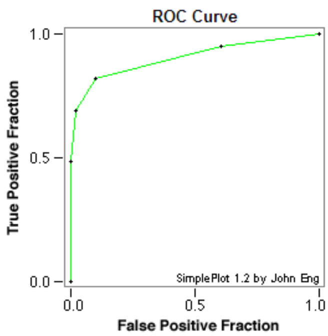
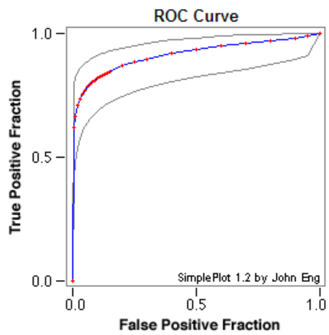
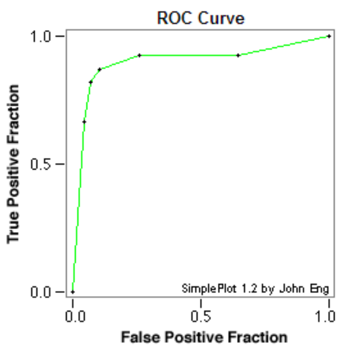
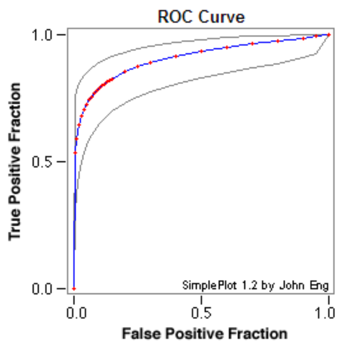
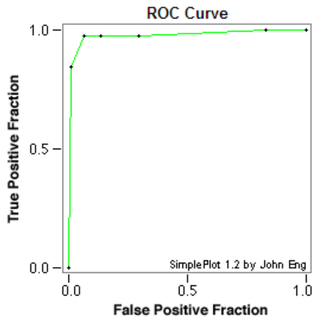
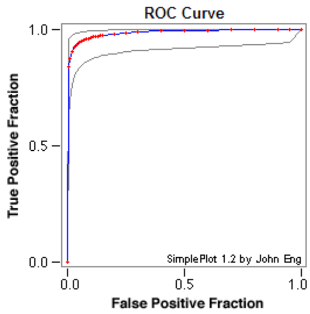
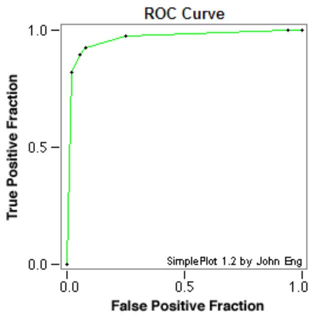
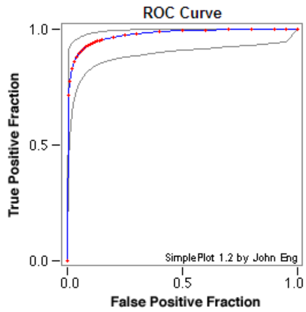
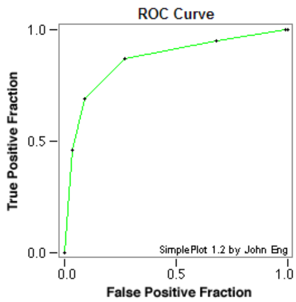
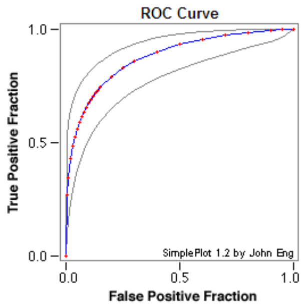
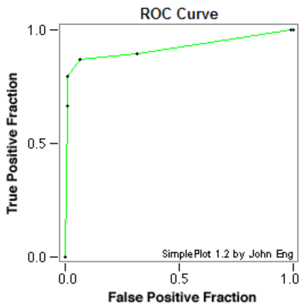
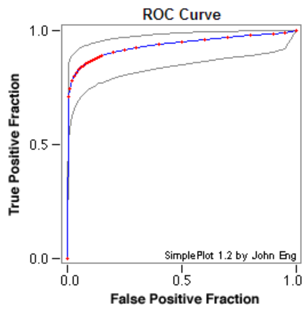
ROC curve plots – Medical Students

Adult only test	Empirical plot	Fitted plot
Participant A AUC ROC emp = 0.942 ROC fit = 0.956		
Participant B AUC ROC emp = 0.944 ROC fit = 0.954		
Participant C AUC ROC emp = 0.904 ROC fit = 0.914		
Participant D AUC ROC emp = 0.965 ROC fit = 0.976		

ROC curve plots – Medical Students

Adult only test	Empirical plot	Fitted plot
Participant E AUC ROC emp = 0.866 ROC fit = 0.877		
Participant F AUC ROC emp = 0.839 ROC fit = 0.850		
Participant G AUC ROC emp = 0.872 ROC fit = 0.871		
Participant H AUC ROC emp = 0.899 ROC fit = 0.908		

ROC curve plots – Medical Students

<table>
<tr><th>Adult only test</th><th>Empirical plot</th><th>Fitted plot</th></tr>
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AUC
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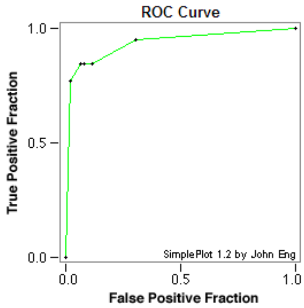
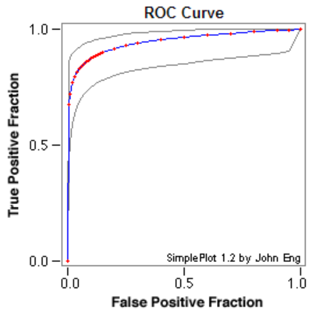
ROC fit = 0.987</td><td>
</td><td>
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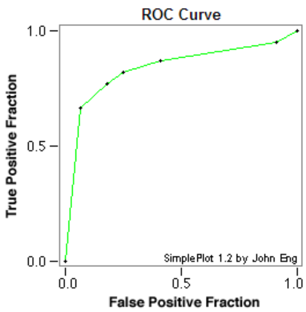
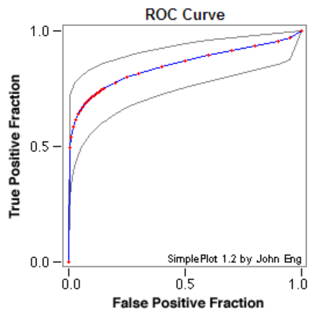
ROC fit = 0.936</td><td>
</td><td>
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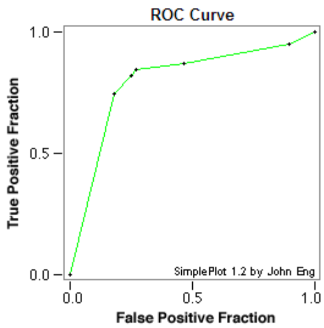
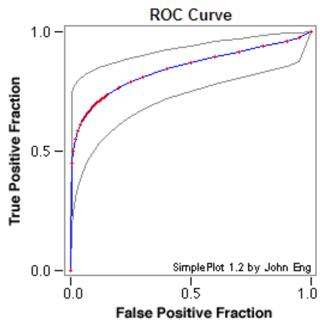
ROC fit = 0.946</td><td>
</td><td>
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AUC
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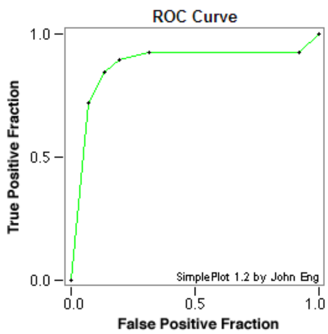
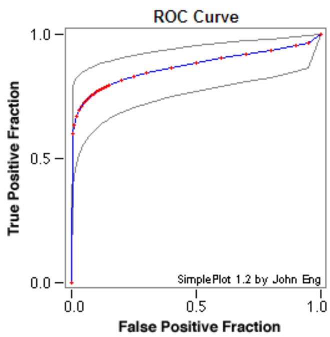
ROC fit = 0.846</td><td>
</td><td>
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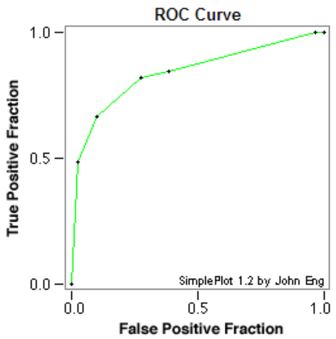
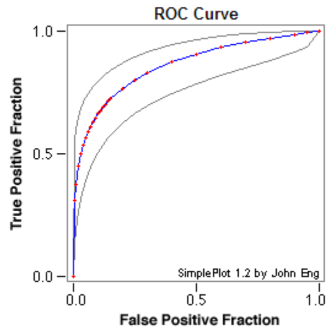
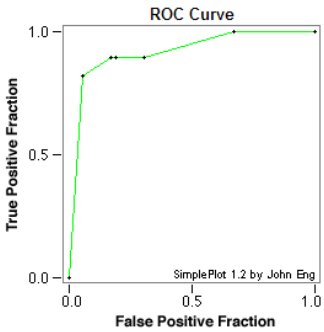
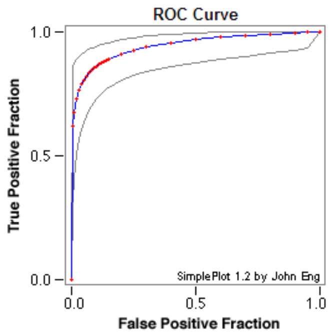
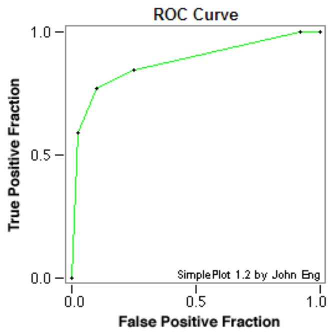
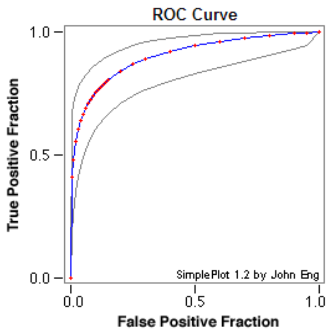
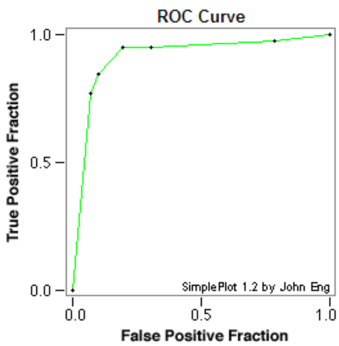
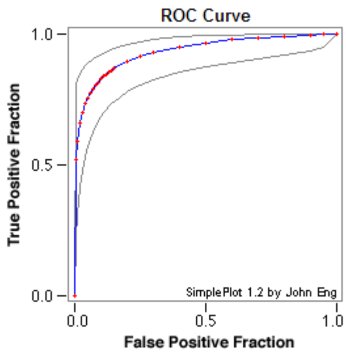
ROC curve plots – Medical Students

Adult only test	Empirical plot	Fitted plot
Participant M AUC ROC emp = 0.841 ROC fit = 0.860		
Participant N AUC ROC emp = 0.920 ROC fit = 0.945		
Participant O AUC ROC emp = 0.878 ROC fit = 0.903		
Participant P AUC ROC emp = 0.914 ROC fit = 0.934		

Appendix 12 Individual medical students and radiographers 2nd Test scores – predictive values and likelihood ratios

Radiographers Test 2

Full test

Part No	% Sens	% Spec	% Acc	PPV	NPV	LR+ve	LR -ve	Ppos	Pneg	Post Odds	Post odds probs
1	91.80	72.30	77.99	0.57	0.96	3.25	0.14	0.701	0.820	0.625	0.325
2	98.36	75.68	82.30	0.63	0.99	4.04	0.02	0.764	0.858	0.776	0.437
3	93.44	87.84	89.47	0.76	0.97	7.68	0.07	0.838	0.922	1.475	0.595
4	91.80	89.86	90.43	0.79	0.96	9.06	0.09	0.848	0.930	1.739	0.635
5	95.08	85.81	88.52	0.73	0.98	6.70	0.06	0.829	0.914	1.286	0.563
6	98.36	77.03	83.25	0.64	0.99	4.28	0.02	0.774	0.867	0.822	0.451
7	93.44	85.14	87.56	0.72	0.97	6.29	0.08	0.814	0.906	1.207	0.549
9	96.72	76.35	82.30	0.63	0.98	4.09	0.04	0.761	0.859	0.785	0.440
10	98.36	85.14	89.00	0.73	0.99	6.62	0.02	0.839	0.916	1.270	0.560
11	98.36	84.46	88.52	0.72	0.99	6.33	0.02	0.835	0.912	1.215	0.549
16	96.72	87.84	90.43	0.77	0.98	7.95	0.04	0.855	0.929	1.527	0.604
17	93.33	67.11	74.64	0.54	0.95	2.84	0.10	0.679	0.791	0.545	0.353
18	91.80	84.46	86.60	0.71	0.96	5.91	0.10	0.800	0.899	1.134	0.531
19	93.44	75.00	80.38	0.61	0.97	3.74	0.09	0.735	0.844	0.718	0.417
23	93.44	86.49	88.52	0.74	0.97	6.91	0.08	0.826	0.914	1.327	0.570
27	85.25	81.08	82.30	0.65	0.93	4.51	0.18	0.738	0.866	0.447	0.464

Appendicular Part No	% Sens	% Spec	% Acc	PPV	NPV	LR+ve	LR -ve	Ppos	Pneg	Post Odds	Post odds probs
1	92.98	74.42	80.11	0.62	0.96	3.63	0.09	0.741	0.838	0.698	0.411
2	98.28	75.19	82.26	0.64	0.99	3.96	0.02	0.772	0.855	0.760	0.432
3	94.74	88.37	90.32	0.78	0.97	8.15	0.06	0.857	0.927	1.564	0.610
4	92.98	90.70	91.40	0.82	0.97	10.00	0.08	0.869	0.936	1.920	0.657
5	96.49	88.37	90.86	0.79	0.98	8.30	0.04	0.866	0.931	1.593	0.614
6	100.00	77.52	84.41	0.66	1.00	4.45	0.00	0.797	0.873	0.854	0.461
7	94.74	87.60	89.78	0.77	0.97	7.64	0.06	0.850	0.922	1.466	0.594
9	96.49	79.07	84.41	0.67	0.98	4.61	0.04	0.791	0.876	0.885	0.469
10	98.25	84.50	88.71	0.74	0.99	6.34	0.02	0.842	0.912	1.217	0.549
11	100.00	84.50	89.25	0.74	1.00	6.45	0.00	0.857	0.916	1.238	0.553
16	98.25	89.92	92.47	0.81	0.99	9.75	0.02	0.889	0.943	1.872	0.652
17	91.23	67.44	74.73	0.55	0.95	2.80	0.13	0.689	0.787	0.538	0.349
18	94.74	85.27	88.17	0.74	0.97	6.43	0.06	0.831	0.909	1.235	0.553
19	94.74	77.52	82.80	0.65	0.97	4.21	0.07	0.771	0.862	0.809	0.447
23	94.74	86.82	89.25	0.76	0.97	7.19	0.06	0.844	0.918	1.380	0.580
27	87.72	80.62	82.80	0.67	0.94	4.53	0.15	0.758	0.867	0.869	0.465

Adult Part No	% Sens	% Spec	% Acc	PPV	NPV	LR+ve	LR -ve	Ppos	Pneg	Post Odds	Post odds probs
1	89.74	71.43	76.16	0.52	0.95	3.14	0.14	0.660	0.816	0.603	0.376
2	100.00	79.46	84.77	0.63	1.00	4.87	0.00	0.772	0.886	0.935	0.483
3	94.87	88.39	90.07	0.74	0.98	8.17	0.06	0.831	0.930	1.570	0.611
4	92.31	91.07	91.39	0.78	0.97	10.34	0.08	0.847	0.940	1.985	0.665
5	94.87	87.5	89.40	0.73	0.98	7.59	0.06	0.822	0.925	1.457	0.593
6	97.44	78.57	83.44	0.61	0.99	4.55	0.03	0.752	0.876	0.873	0.466
7	94.87	87.50	89.40	0.70	0.98	7.59	0.06	0.804	0.925	1.457	0.593
9	97.44	76.79	82.12	0.59	0.99	4.20	0.03	0.738	0.864	0.806	0.446
10	100.00	86.61	90.07	0.72	1.00	7.47	0.00	0.839	0.928	1.434	0.590
11	97.44	87.50	90.07	0.73	0.99	7.79	0.03	0.835	0.929	1.497	0.599
16	94.87	90.18	91.39	0.77	0.98	9.66	0.06	0.851	0.940	1.855	0.650
17	94.87	66.96	74.17	0.50	0.97	2.87	0.08	0.655	0.794	0.551	0.355
18	92.31	90.18	90.73	0.77	0.97	9.40	0.09	0.837	0.935	1.804	0.643
19	92.31	75.00	79.47	0.56	0.97	3.69	0.10	0.699	0.844	0.709	0.415
23	94.87	86.61	88.74	0.71	0.98	7.08	0.06	0.813	0.919	1.360	0.576
27	84.62	80.36	81.46	0.60	0.94	4.31	0.19	0.702	0.865	0.827	0.453

Medical Students

Full test

Part No	% Sens	% Spec	% Acc	PPV	NPV	LR+ve	LR -ve	Ppos	Pneg	Post Odds	Post odds probs
A	88.52	90.54	89.95	0.79	0.95	9.36	0.13	0.837	0.927	1.796	0.642
B	93.44	77.70	82.30	0.63	0.97	4.19	0.08	0.755	0.861	0.804	0.446
C	81.97	91.22	88.52	0.79	0.92	9.33	0.20	0.806	0.918	1.791	0.641
D	90.16	89.19	89.47	0.77	0.96	8.34	0.11	0.833	0.923	1.601	0.615
E	83.61	73.65	76.56	0.57	0.92	3.17	0.22	0.675	0.816	0.609	0.378
F	85.25	75.00	77.99	0.58	0.93	3.41	0.20	0.693	0.828	0.654	0.396
G	85.20	77.70	79.90	0.61	0.93	3.82	0.19	0.712	0.846	0.734	0.423
H	83.61	89.19	87.56	0.76	0.93	7.73	0.18	0.797	0.910	1.485	0.598
I	98.36	86.49	89.95	0.75	0.99	7.28	0.02	0.851	0.924	1.398	0.583
J	86.89	92.57	90.91	0.83	0.94	11.69	0.14	0.848	0.935	2.244	0.692
K	86.89	92.57	90.91	0.83	0.94	11.69	0.14	0.848	0.935	2.244	0.692
L	85.25	75.00	77.99	0.58	0.93	3.41	0.20	0.693	0.828	0.655	0.396
M	83.61	74.32	77.03	0.57	0.92	3.26	0.22	0.680	0.821	0.625	0.385
N	88.52	76.35	79.90	0.61	0.94	3.74	0.15	0.720	0.843	0.719	0.418
O	85.25	72.30	76.08	0.56	0.92	3.08	0.20	0.675	0.811	0.591	0.371
P	93.44	75.00	80.38	0.61	0.97	3.74	0.09	0.735	0.844	0.718	0.418

Appendicular

Part No	% Sens	% Spec	% Acc	PPV	NPV	LR+ve	LR -ve	Ppos	Pneg	Post Odds	Post odds probs
A	92.31	91.07	91.37	0.78	0.97	10.34	0.08	0.847	0.940	1.985	0.665
B	94.87	80.36	84.11	0.63	0.98	4.83	0.06	0.755	0.882	0.927	0.481
C	82.05	91.07	88.74	0.76	0.94	9.19	0.20	0.790	0.923	1.764	0.638
D	92.31	91.96	92.05	0.80	0.97	11.49	0.08	0.857	0.945	2.206	0.688
E	87.18	75.00	78.15	0.55	0.94	3.49	0.17	0.673	0.836	0.669	0.401
F	84.62	75.00	77.48	0.54	0.93	3.38	0.21	0.660	0.836	0.650	0.393
G	89.74	80.36	82.78	0.61	0.96	4.57	0.13	0.729	0.874	0.877	0.467
H	84.21	90.70	88.71	0.80	0.93	9.05	0.17	0.821	0.918	1.738	0.635
I	100.00	86.82	90.86	0.77	1.00	7.59	0.00	0.870	0.929	1.457	0.593
J	87.72	93.80	91.94	0.86	0.95	14.14	0.13	0.870	0.942	2.716	0.731
K	85.96	93.02	90.86	0.84	0.94	12.32	0.15	0.852	0.934	2.366	0.703
L	85.96	74.42	77.96	0.60	0.92	3.36	0.19	0.705	0.824	0.645	0.392
M	84.21	73.64	76.88	0.59	0.91	3.20	0.21	0.690	0.815	0.613	0.380
N	89.47	75.19	79.57	0.61	0.94	3.61	0.14	0.729	0.836	0.693	0.469
O	85.96	70.54	75.27	0.56	0.92	2.92	0.20	0.681	0.798	0.560	0.359
P	94.74	72.87	79.57	0.61	0.97	3.49	0.07	0.740	0.832	0.670	0.401

Adult

Part No	% Sens	% Spec	% Acc	PPV	NPV	LR+ve	LR -ve	Ppos	Pneg	Post Odds	Post odds probs
A	91.23	91.47	91.40	0.83	0.96	10.70	0.10	0.867	0.937	2.054	0.673
B	94.74	79.84	84.41	0.68	0.97	4.70	0.07	0.788	0.877	0.902	0.474
C	82.46	90.70	88.17	0.80	0.92	8.86	0.19	0.810	0.914	1.702	0.630
D	91.23	87.60	88.71	0.76	0.96	7.36	0.10	0.832	0.915	1.412	0.585
E	87.72	75.19	79.03	0.61	0.93	3.54	0.16	0.719	0.833	0.679	0.404
F	84.21	73.64	76.88	0.59	0.91	3.20	0.21	0.691	0.815	0.613	0.380
G	84.21	75.97	78.49	0.61	0.92	3.50	0.21	0.706	0.831	0.673	0.402
H	87.01	89.29	88.74	0.74	0.95	8.14	0.14	0.800	0.922	1.562	0.610
I	97.44	86.61	89.40	0.72	0.99	7.28	0.03	0.826	0.924	1.400	0.583
J	87.18	94.64	92.72	0.85	0.95	16.27	0.14	0.861	0.951	3.124	0.760
K	84.62	91.96	90.70	0.79	0.94	10.53	0.17	0.815	0.932	2.022	0.670
L	84.62	73.21	76.16	0.52	0.93	3.16	0.21	0.647	0.820	0.606	0.377
M	82.05	72.32	74.83	0.51	0.92	2.96	0.25	0.627	0.810	0.569	0.363
N	89.74	81.25	83.44	0.63	0.96	4.79	0.13	0.737	0.879	0.919	0.479
O	84.62	75.00	77.48	0.54	0.93	3.38	0.21	0.660	0.832	0.650	0.394
P	94.87	79.49	83.44	0.62	0.98	4.62	0.06	0.747	0.872	0.887	0.470

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The impact of a pilot education programme on Queensland radiographer abnormality description of adult appendicular musculo-skeletal trauma

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ABSTRACT

Introduction: Interpretation of trauma images by radiographers is a task substitution that has been debated for many years in Australia and enacted in various forms internationally since the 1980s. This paper describes the standardised test portion of a pilot project (which also had a clinical component) that investigated the potential for radiographers to describe abnormalities as a change to models of healthcare delivery being adopted in Queensland.

Method: Randomly selected appendicular musculo-skeletal trauma images were reported by four radiologists to confirm image content. 102 images, matched for population injury incidence and body area proportionality served as a standardised image test. Ten radiographers described images before, immediately after and 8–10 weeks following an education programme. Receiver operator characteristic curves and kappa statistics were calculated to evaluate radiographer descriptive performance relative to the radiologist reports.

Results: Using the Friedman and Wilcoxon signed ranks tests there was statistically significant improvement of sensitivity and accuracy of radiographer performance by the third standardised test with values: sensitivity ($p = 0.023/0.012$), accuracy ($p = 0.012/0.021$) specificity demonstrated no or very close statistically significant change (0.118/0.058). Kappa values (Cohen $p = 0.019/0.011$, Gwet 0.025/0.007 and Byrt et al. 0.021/0.047) demonstrated statistically significant change across the test sequence. Positive and negative predictive values with positive likelihood ratios were also calculated.

Discussion: Most (9/10) radiographers demonstrated a high level of agreement of description accuracy with the radiologists used to create the standardised test.

Conclusion: With appropriate education radiographers can match radiologist descriptions of appendicular musculo-skeletal trauma.

Introduction

Debate about task substitution of medical roles to the non-medically educated within Australia continues. Several authors[1–3] have expressed the potential for radiographers to safely relieve pressure on the emergency healthcare system through preliminary abnormality description of radiograph content. They assert this would enhance radiographer job satisfaction whilst enhancing the effectiveness of the multi-professional team. A submission by the Australian Institute of Radiography[4] to the Garling inquiry[5] suggested that radiology reporting turnaround times are not meeting expected targets, and abnormalities seen by radiographers have been missed or dismissed by the emergency department resulting in management delays. As far back as 1999[6] it was indicated at Alice Springs hospital up to 1.5% of examinations received no report. Despite efforts to provide services through 'nighthawk' providers (radiologists reporting in a time zone different to the country requiring the service), there are still issues in radiological servicing of emergency department in some areas of Australia as suggested by Garling.[5]

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Duckett,[3] Gibbon[2] and McConnell and Smith[7] have indicated where the bottlenecks occur in the prevention of radiographer input into the interpretation process (detailed below), while enhancing the diagnostic pathway between radiology and the emergency department. Despite international evidence that radiographer interpretation with appropriate radiologist report verification safety nets is possible, the movement towards this process has not been forthcoming in Australia. In fact there has been open rejection by radiologists often with minimal evidence to support this position.[8,9] The current Medicare rebate system, that only allows certified medical practitioners to provide services in radiology, acts as a barrier to improving the efficiency of public healthcare delivery through the use of radiographers.[1,7] Although postgraduate study in image interpretation for radiographers is available in several Australian universities, the benefit to emergency departments has failed to be realised. The existence of a professional silo mind set and political nervousness by the federal government has delayed evaluation of the potential to change current working practices. Currently, radiographers are expected by their professional body to verbally indicate to the referrer of the radiographic examination when they believe an abnormality is present on the images they produce[10] and takes the form of tracking the referrer and discussing image appearances with them. This position is also endorsed by state and territory registration boards. The initial developments in the U.K. supported the same premise,[11] leading to the eventual removal of the 'infamous conduct' statement from registration documentation,[12] thus enabling radiographer interpretation. Change of practice through wider radiographer use in U.K. radiology departments was raised by the NHS Audit Commission report of 1995.[13] This was supported by University courses to masters' level with significant radiologist input. Through developments by the colleges of radiologists and radiographers, U.K. practice has now moved toward an expectation that all radiographers will provide descriptions of abnormality location and characterisation on radiographs. As such interpretation by radiographers in emergency settings has become a core skill[14] even though some barriers exist. U.K. research has also demonstrated that radiographers are the best alternative professional group to perform a trauma image description function despite the thrust to encourage the use of the emergency nurse practitioner[15,16] as a replacement doctor for minor injuries.

There is a relative scarcity of research into radiographer interpretation/description in Australia with only five related papers identified between 1997 and 2009.[6,17–20] This paper will describe a pilot project performed in Queensland to develop an education programme (EP) delivered in two stages, create a worksheet response system similar to one initially suggested by Smith and Younger[18] and measure the descriptive performance impact that the EP has had on radiographer ability.

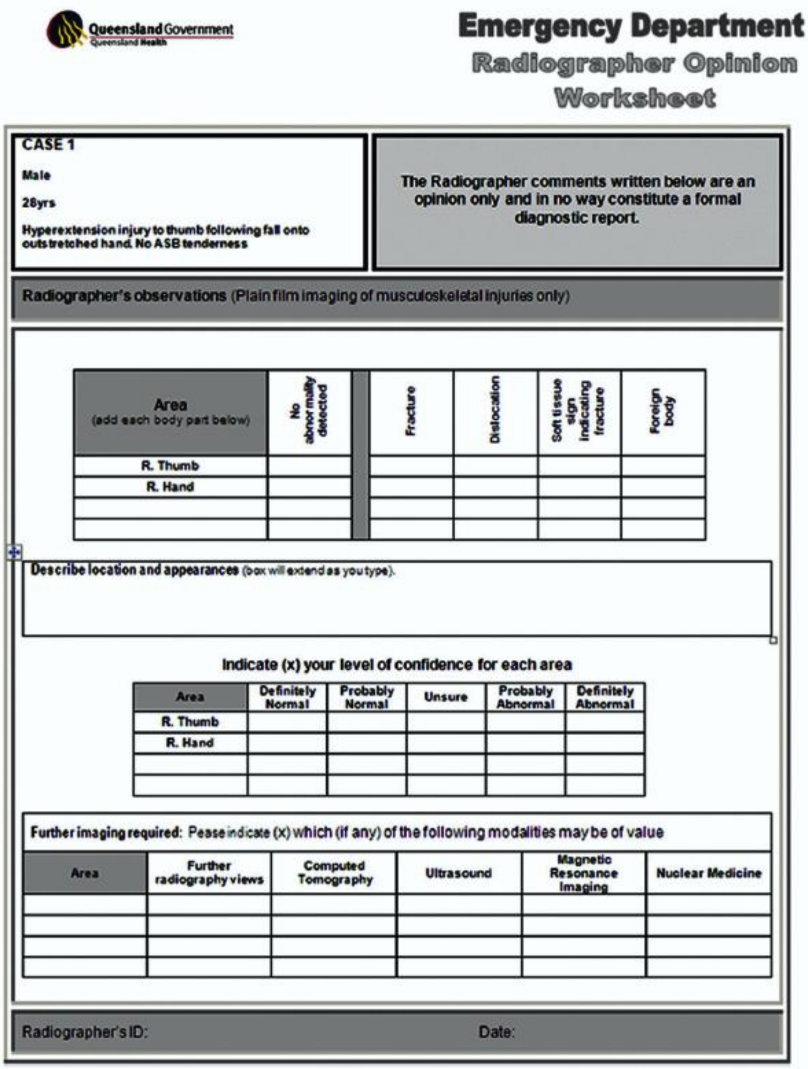
Method

An image test library was created from emergency department images of the appendicular skeleton selected at random from a five year old radiographic film based archive that had been previously radiologist reported. These images were scanned at high resolution (600 dpi) to enable computer based viewing with no image degradation and full image manipulation capable with the software available within a standard Microsoft© Office package. The patient age, gender and history were provided to three radiologists to re-report the radiographs and add to the initial report so that agreement about image content could be assured. From 435 cases generating 650 examinations as the image library, 102 examinations investigating trauma to the adult appendicular skeleton, including the hip and shoulder joint, were chosen to form an image test. Body areas were created in the image test library to include images of normal and abnormal appearance defined by consensus of report content of at least three of the four radiologists. Radiographic images at body area rates evident from the initial selection of cases from the archive, were randomly selected and added to the radiographer's test. From this selection process a 30.3% injury rate was revealed resulting in 35 abnormal examinations being included in the test, constructed to reflect the range and proportions of examinations noted within the image library.

All 102 images were viewed by each participant covering the areas described above each time the test was performed. A worksheet was developed that used a tick box approach and freehand descriptions for the participants to give responses about their impressions of image content (see Fig. 1). The patient age, gender and a short history was provided on each worksheet, which was associated with a 'jpeg' image file for each radiographic study. Microsoft© 'Picture Manager' was used to view the images so that magnification and image brightness/contrast could be adjusted as would be possible in the clinical setting. This software was chosen as future testing using this image library was to be performed on a standard 1 megapixel monitor, which is ubiquitously available to home computers or radiographer workstations. Earlier research has shown that resolution is acceptable to emergency images.[21] Tick boxes on the worksheet included indications of no abnormality, fracture, dislocation, soft tissue sign for fracture and foreign body presence. Additional tick boxes asked whether the radiographer believed further imaging was necessary in the form of more radiographic projections, Computed Tomography, Ultrasound, Magnetic Resonance Imaging, and Nuclear Medicine. A free comment response section was also available for participants to add details about the appearances seen in the images. This allowed confirmation of appropriate tick box selection by the marker. Finally a confidence level tick box section was also included to establish the level of certainty the radiographer had in his/her description so that a receiver Operator Characteristic (ROC) curve could be calculated using Eng's[22,23] internet calculator. Empirical or raw ROC and fitted ROC curves were constructed by inputting the confidence information into the tool. Participants knew that normal and abnormal images would be present but were not aware of the relative proportions. No time limit was placed on the participants for completion of the test and all were asked not to discuss the content of the test between sittings. Repeat tests were performed in the same departments, using the same conditions and monitors.

Ten radiographers of mixed clinical experience in two groups of five from two Brisbane tertiary hospitals, volunteered to participate in the research. Ethics approval from the Human Research Ethics Committee at The Royal Brisbane and Women's Hospital was received in February 2010. Participants, who received identifiers to maintain anonymity from the test marker, were requested to describe image content before the first of the two education sessions in the EP. This test was administered by two research coordinators who were radiographers based in one of the two Brisbane hospitals who also had a responsibility to regularly report progress to the funding bodies. The standardised test images were re-read within two weeks of the first education session then for a third time within three weeks of a second weekend study period. No feedback was given between readings and image numbers were sufficient to reduce memorising of case presentations. The Kappa statistic was used to compare inter rater variability with the types proposed by Cohen, Gwet and Byrt et al.,[24–26] being performed to address issues linked with this statistic and provide the potential range of performance that was evident.

The EP was developed and delivered by a senior lecturer in medical imaging with U.K. radiographer reporting training and


Queensland Government
Queensland Health

Emergency Department
Radiographer Opinion Worksheet

CASE 1 **Male** **28yrs** **Hyperextension injury to thumb following fall onto outstretched hand. No ASB tenderness**	**The Radiographer comments written below are an opinion only and in no way constitute a formal diagnostic report.**

Radiographer's observations (Plain film imaging of musculoskeletal injuries only)

Area (add each body part below)	No abnormality detected	Fracture	Dislocation	Soft tissue sign indicating fracture	Foreign body
R. Thumb					
R. Hand					

Describe location and appearances (box will extend as you type).

Indicate (x) your level of confidence for each area

Area	Definitely Normal	Probably Normal	Unsure	Probably Abnormal	Definitely Abnormal
R. Thumb					
R. Hand					

Further imaging required: Pease indicate (x) which (if any) of the following modalities may be of value

Area	Further radiography views	Computed Tomography	Ultrasound	Magnetic Resonance Imaging	Nuclear Medicine

Radiographer's ID: Date:

Figure 1. Radiographer Description Worksheet.

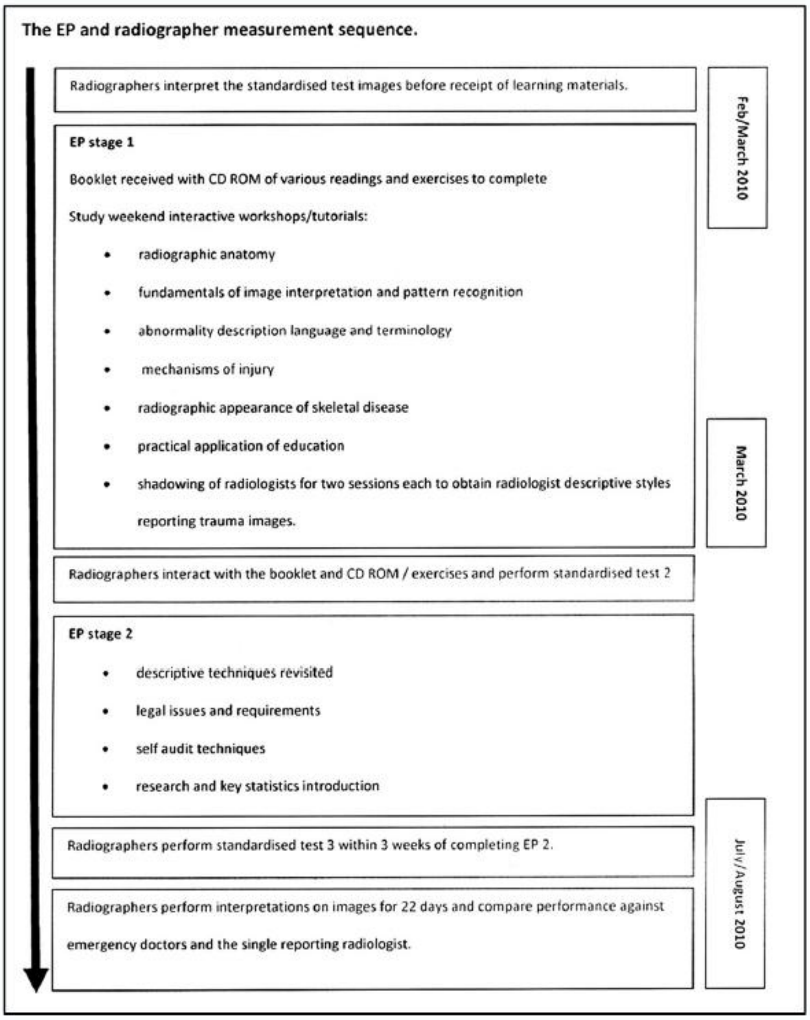
a clinical research/publication background in the field. Box 1 details the curriculum and timeframe of the EP and radiographer performance measurement sequencing.

Results

Apart from one participant, all radiographers demonstrated significant improvements in their performances across the three standardised image tests, with mean values for sensitivity, specificity, accuracy, positive and negative predictive values, and positive likelihood ratio. These are presented in Table 1 as mean, median, maximum and minimum values. The empirical and fitted ROC and three Kappa statistic variables in the same detail are shown in 2. The Kappa statistic variables were used to show relative performance between the individual radiographers and the radiologist's group response. Statistical inference for the, sensitivity, specificity, accuracy and Kappa results was performed and are demonstrated in Table 1 and Table 2 respectively. The Friedman test shows if the distribution of results across all three image tests was the same and the Wilcoxon signed ranks test was employed to show whether the median of the differences between first and last tests varied. This acted as a confirmation of the validity of the Friedman test calculations.

It is apparent from the results that radiographer mean sensitivity increased significantly across the three tests with statistical evidence from the Friedman test indicating that the distribution

Box 1. The Education Programme.



between participants is not the same. This is supported by the Wilcoxon signed ranks test that indicates the median of the differences of participant performances between the first and last tests is not the same. As accuracy is a function of sensitivity and specificity it would be expected that this would also improve. This analysis shows the variation between standardised image tests with no patient contact is statistically significant. Gradual increases are evident across the predictive values and the likelihood ratio of the radiographers. Kappa scores were calculated to show performance relative to the consensus radiologist reports. A consistently low Kappa value of 0.484 indicated that a relatively cautious approach taken by one individual persisted resulting in high false positive responses, which contrasted with the remaining participants. According to the definitions of Kappa values by Landis and Koch[27] (who applied their definitions to Cohen's Kappa see Fig. 2) there is a general shift from moderate to substantial agreement with the radiologists, with some participants achieving almost perfect agreement as their values exceed 0.81. The spread of Kappa variant results demonstrated 6/9 substantially agreeing and 3/9 reaching almost perfect agreement by test 3. Statistically significant change in performance across the Kappa statistics variations is also evident, when calculated with Friedman and Wilcoxon signed ranks of first and third tests using SPSS 17.0©.

Table 1
Standardised image test results $n = 10$.

Test	Sensitivity %			Specificity %			Accuracy %			PPV			NPV			LR +ve		
	Mean	Median	Min/Max	Mean	Median	Min/Max	Mean	Median	Min/Max	Mean	Median	Min/Max	Mean	Median	Min/Max	Mean	Median	Min/Max
1	87.3	90.6	73.0/97.3	78.9	80.8	64.6/90.8	82.0	82.4	73.5/89.2	0.71	0.72	0.59/0.84	0.92	0.93	0.84/0.98	4.73	4.45	2.52/9.40
2	90.8	89.2	83.8/100.0	76.0	70.8	64.6/93.8	81.4	78.9	73.5/91.2	0.70	0.64	0.59/0.89	0.94	0.93	0.88/1.00	5.23	3.21	2.52/13.95
3	93.5	94.6	89.2/ 100.0	82.9	86.2	58.5/96.9	86.8	88.7	72.5/95.1	0.77	0.80	0.57/0.94	0.96	0.96	0.92/1.00	8.57	6.80	2.34/29.65
Friedman test $p =$	0.023			0.118			0.030											
Wilcoxon signed ranks test $p =$	0.012			0.058			0.021											

ROC values demonstrate a strong performance as both the empirical (raw calculation), or fitted versions. Radiographer performance measured as the area under the curve increases as raw calculations demonstrated mean values between 87% and 90.4% and median values of 88.4%–92.1%. Fitted ROCs again show an approximate 3% increase with means rising from 89.4% to 92.6% and median values increasing from 91.1% to 94.3%. This is supported by generally increased results of sensitivity, specificity and accuracy across the three tests with gradually greater numbers of radiographers performing above 85% accuracy at test 3 (6/10) compared with test 1 (3/10).

Discussion

Improving sensitivity and specificity (Table 1) shows that even though false positive scores were higher to begin with this decreased over the period of testing. A pattern of areas where participants were incorrect with this range of images is not shown as this changed across the testing sequence. Overall the results obtained around the delivery of the EP are encouraging. Employing a worksheet with defined criteria and at the same time giving the radiographer the opportunity to express opinion by freehand comment, has the potential to provide helpful information to the referring emergency doctor. Often management of patients is begun in a protective sense, driven by concerns over litigation. Excessive treatment before radiological reporting can be obtained may result in recall to hospital with associated concerns and costs for the patient. Timely information that is available and reliable may help reduce costs caused by excessive treatment or prevent an occasional missed injury. Furthermore, last but not least, descriptions provided by radiographers would be less expensive to the healthcare system.

The use of the various measurement approaches acts in a 'belt and braces' way to demonstrate how reporting of just one method can be misleading. Although Cohen's Kappa is meant to correct for chance in the decision making between raters/readers of a test, use of the multiple Kappa methods accounts for the failure to account for bias and prevalence in the choices made in a binary measuring system such as seen in Cohen's testing method. Byrt et al.[26] created an adjustment for bias (the proportion of yes choices by a reader compared to the original) and prevalence (probability of a 'Yes and No' choice compared with the original). They state if bias increases then the chance agreement expectation falls to cause Kappa to be artificially raised. Likewise, if prevalence rises so too does the chance agreement expectation, as a result this artificially reduces the Kappa value. Gwet[24] also argues that the assumptions used to calculate the level of chance assumed within Cohen's Kappa are flawed. He asserts that the probability for chance agreement should not exceed 0.5 in value if both observers have randomly come to a decision that they both agree on. Following this argument enables the Kappa statistic to be calculated taking into account variation in marginal values that are necessarily generated in a 2×2 square.

The descriptive ability of this group of radiographers for this range of radiographs shows gradual improvement that starts at a high level. There is a trend towards matching radiologist performance and there appears to be statistical significance overall. Specificity however shows least improvement with responses tending towards excessive false positive reporting. The ROC curves give the highest values of performance but as Eng[22] points out these values should not just be taken at face value. When reviewing ROC curves plotted from the figures generated by each individual,

Table 2
Standardised image test – Kappa variations and ROC scores $n = 10$.

Kappa variations	Descriptive statistic		
	Mean	Median	Min/Max
Cohen 1	0.589	0.594	0.468/0.756
Gwet 1	0.594	0.628	0.452/0.698
Byrt et al 1	0.728	0.775	0.202/0.999
Cohen 2	0.545	0.539	0.427/0.768
Gwet 2	0.542	0.548	0.295/0.798
Byrt et al 2	0.724	0.715	0.390/0.943
Cohen 3	0.674	0.710	0.452/0.795
Gwet 3	0.683	0.724	0.412/0.813
Byrt et al 3	0.847	0.860	0.657/0.999
	Friedman test $p =$		
Cohen	0.019		
Gwet	0.025		
Byrt et al	0.021		
	Wilcoxon signed ranks test $p =$		
Cohen	0.011		
Gwet	0.007		
Byrt et al	0.047		

Test number	Descriptive statistic					
	ROC – empirical (raw)			ROC – fitted		
	Mean	Median	Min/Max	Mean	Median	Min/Max
1	0.870	0.884	0.704/0.925	0.894	0.911	0.731/0.940
2	0.880	0.886	0.814/0.934	0.912	0.919	0.829/0.965
3	0.904	0.921	0.704/0.974	0.926	0.943	0.731/0.980

Kappa statistic value	Strength of agreement
<0.00	Poor
0.00-0.20	Slight
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Substantial
0.81-1.00	Almost perfect

Figure 2. Landis and Koch's agreement definitions for Cohen's Kappa.

fitted variations smooth out the performance and tend to increase reported ability. However 'hooks' may be present in the empirically plotted graphs which are a more truthful representation and as such the empirical value is more representative of true performance. Acknowledging this, these radiographers demonstrated mean upper performance accuracy values ranging approximately between 90 and 92% and medians of 91–94%.

There are some weaknesses in this study that should be considered. The size of the study and using only adult appendicular trauma images limits it to the status of pilot. Those participants that volunteered were clearly interested in enhancing their work thus leading to the potential for selection bias amongst radiographers. The experience of radiographers was not differentiated or controlled; length of time since qualification varied, prior education in image interpretation from Australian or U.K. universities and the impact of other imaging modality experience was not accounted for. Multiple use of the same test with a short time between them using one examination type that aimed to detect the presence of limited appearances to measure change is open to criticism.[28] The size of this study and mix of appearances influences with no feedback given until the end of the investigation could account for this limitation; closer analysis of individual performance showed variation in descriptions between tests suggesting that memorising by individuals was minimised. The safety of this approach has been discussed.[29] A lack of feedback can cause uncertainty and an investigation of intra observer variation would be helpful to analyse this.

Despite some limitations, this study attempted to account for several weaknesses in the Australian work performed between 1997 and 2009.[6,17–20] A clinical radiographer description pilot (performed after this component and to be reported elsewhere) may reinforce the perception that patient presence influences decision making and descriptive content. This could be a notable context to consider when the non-medically educated are compared against medical staff in the emergency department. This may mean there is a greater degree of safety in radiographer abnormality descriptions when radiographers assess images for signs of injury with the advantage of the patient being present.

The assertion that same day reporting is not required in well supervised emergency departments[30] may hold concerns for the accreditation of radiology departments in Australia, especially when the work of Hallas and Ellingsen[31] on an international basis is also considered. They suggest up to 3.1% of fractures are missed, thus supporting this research that identifies immediate radiographer input could be valuable. This study that follows the outcomes of a condensed education programme, has shown radiographers are capable of closely matching the radiologist in their descriptions of image appearances in adult musculo skeletal trauma. Where delays in emergency trauma reporting by radiologists are noted,[4,5] then radiographer contributions could ensure radiology department input in a timely fashion is guaranteed. This could also satisfy performance indicators for Australian departmental accreditation processes, whereby the departmental performance is measured for accreditation to provide services within Medicare, one of which is speediness of radiologist report turnaround time.

Conclusion

It would appear that there is potential, with the right educational support and on-going audit of performance, for Australian radiographers to make a useful contribution to an aspect of practice that may be understaffed or relies on relatively junior medical personnel. In the regional and rural setting where attracting staff is problematic then radiographer contributions could be more valuable both in terms of service provision and attracting staff to non metropolitan working. A larger study with wider coverage of radiographic examinations should be performed to fully establish where radiographers can be appropriately employed, and in what ways they make mistakes that could impact on overall imaging management. By this it is meant that the scope of practice within radiographer descriptions can be defined clearly, so that an acceptable self regulating framework can be developed and applied and recognised across Australian radiology practice. Emergency medical staff should be invited to perform the standardised test to establish their relative performance compared with radiographers; it may also be possible to establish whether clinical contact impacts on emergency department doctor's performance. Radiologist colleagues should welcome the opportunity to confirm or refute any findings, as improved radiological teamwork to meet demand is the key outcome of this research as suggested by Gibbon.[2] Enhancement of the multi-professional team rather than pressurising a smaller number of non-medically/specialist educated groups to take on other roles for which they are inappropriately prepared is the correct way to move forward. Radiographers have received a degree based education across the whole of Australia for more than 20 years and are not being utilised to their highest potential. This is a waste of resources when the healthcare system faces challenges that could be addressed by use of the right person at the right time in the right place.

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Competing interests

Jonathan McConnell received financial support from Queensland Health to enable travel to facilitate the project.

Carron Devaney – Competing interests: none identified.

Matthew Gordon – Competing interests: none identified.

Mark Goodwin – Competing interests: none identified.

Rodney Strahan – Competing interests: none identified.

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Queensland radiographer clinical descriptions of adult appendicular musculo-skeletal trauma following a condensed education programme

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ABSTRACT

Introduction: A previous paper discussed the standardised test preparation and performance of a group of 10 Brisbane based radiographers. This report describes the follow up clinical component whereby radiographers were compared against emergency department doctors and radiologists.

Method: Adult appendicular musculo-skeletal trauma images were immediately described in the emergency department (ED) by 10 radiographers previously exposed to a condensed education programme. Twenty two days (10 day then 12 day collection periods) with a 346 and 307 examinations, were respectively completed by the participants. Radiographer image description content was compared against emergency department doctors and radiologists reports using a previously defined content tool by two research co-ordinator radiographers not participating in the clinical testing sequence to avoid arbiter bias. Sensitivity, specificity, accuracy, positive and negative predictive values were calculated. Kappa statistics (Cohen, Gwet and Byrt et al. variations) were used to establish variability between radiographers and emergency doctors with radiologists.

Results: Mean radiographer performance after the collection periods matched those reported about radiographer interpretation outside Australia. Results showed no statistically significant differences between the radiographers and emergency department doctors as groups, within Cohen Kappa and Gwet's AC-1 statistic ($p = 0.975$ and $p = 0.972$ respectively) and marginally statistically significant in the Byrt et al. measurement ($p = 0.047$). Radiographers showed strong agreement with emergency doctors and conjointly found more abnormalities before referral for report to the radiologist.

Conclusion: With appropriate education and clinical contact no significant difference between these Australian radiographers and emergency doctors was noted.

Introduction

Several authors[1–3] have outlined the financial, team working and service delivery gains that can be made from Australian radiographers participating in an emergency department preliminary abnormality description role. Failings in the current approach have been listed by the Australian Institute of Radiography,[4] the Garling enquiry[5] and through submissions to the recent health and hospitals reform commission investigation.[6,7] These same authors have expressed the potential for radiographers to safely relieve pressure on the emergency healthcare system through preliminary abnormality description of radiograph content. They opine this would enhance radiographer job satisfaction and enhance multi-professional team effectiveness. Brisbane emergency department radiology report turnaround times are a significant issue. Report turnaround times were identified in a preliminary study[8] to the pilot being described here and, respective to the two participating hospitals, demonstrated that 4 or 9% of plain radiographs are reported in less than an hour, 26 or 41% within 24 h and 36 or 67% in 72 h. This left a large number of plain radiographs taking over three days to receive a radiologist report. Furthermore, as noted in the initial U.K. situation,[9] abnormalities seen by radiographers have not been recognised by emergency department doctors thus impacting on patient management.[4] A study in Alice Springs in 1999[10] indicated that up to 15% of examinations received no report at all. Despite efforts to provide services through 'nighthawk' providers (where emergency referrals for reports are electronically sent offshore outside normal office hours), there are still issues in radiological servicing of the emergency department in some areas

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of the country[5] and concerns about the quality of the service where Australian input is not received[11(p26)] quoting the International Radiology Quality Network (IRQN). Concerns include the point that teleradiology should retain the best interests of the patient and the contact between them and the radiologist should not be compromised; the standard of care should be uniform without loss of image quality; radiologists and technologists should be appropriately trained, licensed, registered and insured for image production; language should not be a barrier to providing a specialist opinion and, whilst maintaining data security, the imaging and reporting process should occur following appropriate ethical guidelines and quality control procedures. It would appear that external providers are now being scrutinised by 'home' radiologists with these concerns recently gaining traction in the U.K. This was noted in the results of a recent poll taken at the 2011 UKRC conference[12] where 81% of 350 radiologists, radiographers and radiology managers felt it important that radiologists participating in teleradiology in the NHS should have also worked within the NHS. Key points similar to the IRQN have been voiced including previous medical history access and an ability to consult quickly with the referring clinician.

The current approach to healthcare funding through Medicare is argued as a major bottleneck to change[3,7] and contributes to inefficiencies in the system as a whole.[2,3] The semantics of role change nomenclature preys heavily on the minds of Australian radiologists, resulting in the acceptance that radiographers can describe and not report or interpret the image. As such this effectively takes away the advisory and advocacy potential for the advanced practice radiographer while maintaining the control of the medically qualified whatever experiential level that doctor is operating at. Even though the potential role is acknowledged, in the same discussion paper, the Royal Australian and New Zealand College of Radiologists (RANZCR) argue that insufficient research evidence is available to allow role delegation.[13] Evidently the plethora of international evidence[14–16] that radiographer interpretation with appropriate radiologist report verification safety nets is possible carries insufficient weight in Australia. Furthermore, there has been open rejection by radiologists often with minimal evidence to support their perspective.[17,18] This is compounded by the recognition by radiologists that many undergraduate medical degrees in Australia contain insufficient radiology education. A lack of knowledge about imaging investigations and their interpretation fuels misuse and potential patient mismanagement[19] but strengthens the radiologists' role.

Postgraduate study for radiographers in image interpretation is available within several Australian universities, but the benefit to emergency departments has failed to be realised. The Medicare rebate system prevents radiographer input through limiting service delivery to medical practitioners. Coupled with professional silo mindsets and the minority federal government nervousness to act, improving the efficiency of public healthcare delivery through the use of radiographers remains unlikely.[1,7] Australian radiographers are expected by their professional body to verbally indicate to the referrer of the radiographic examination when they believe an image abnormality is present. This is supported by the state and territory registration boards[20] and the new national registration schema becoming operational in July 2012.

Historically, role development by U.K. radiographers has progressed through the working together of various bodies that are clinically, educationally and regulatory in nature. U.K. practice has now moved forward to the extent where radiographer image interpretation forms a significant portion of undergraduate courses (though not replacing advanced postgraduate education) and has gained such momentum that the College of Radiographers expects all radiographers will provide descriptions of abnormality location and characterisation on radiographs.[21] In support of this, U.K. research has also demonstrated that radiographers are the best alternative professional group to perform this function despite the drive towards the use of the emergency nurse practitioner[22,23] in minor injuries presentations. Recent reports in 'The Age' newspaper in Melbourne, suggests that nurses are taking on an unregulated role whereby they are performing radiographic examinations to a sub standard level.[24] Nurses, through state government patronage through a workforce innovation programme, are happy to support the workforce change argument, but without meeting any standards themselves.[25] This is within a minor injuries context where it is claimed radiographer availability is limited and would require significant travel to receive an imaging service for 'simple' limb, chest and in some instances spinal examinations. It would therefore appear that, as other authors have suggested, when government support is present then role change is possible.[26–28] This argument though has not been fully extended into Australian radiographer's contribution to trauma or other image interpretation, as the disagreement about what forms professional autonomy in radiography still stands.[29,30]

There is a scarcity of research into radiographer interpretation/description in Australia with only five papers identified between 1997 and 2009.[10,31–34] This paper is the second part of two papers developed to describe a pilot project performed in Queensland following an education programme (EP). Radiographers' descriptive performance of adult musculo-skeletal trauma was evaluated with a standardised test and no patient contact using a worksheet response system based on one initially suggested by Smith and Younger.[32] This paper reports the clinical performance and measurement of the same radiographers who had access to the patient in their clinical environment. It measures the descriptive ability of radiographers reading adult musculo-skeletal trauma radiographs against emergency department doctors' performance and radiologists. The study was performed in the light of Australian Council on Healthcare Standards (ACHS) expectation that a non-urgent diagnostic report should be provided within 24 h of examination completion.

Method

Participant radiographers had previously completed a study programme to prepare them for providing initial radiographer descriptions for the scope of practice identified in this model of care. The timeline for the project and education programme content is shown in Box 1. Detailed feedback from the first part of the project had not been received by the participants although an indication of their level of performance i.e. sensitivity, specificity accuracy scores and common areas where mistakes were made had been provided so that participants felt they were in a position to continue with the second, clinically oriented phase.

A worksheet was developed that used a tick box approach and freehand descriptions for the participants to give responses about their impressions of image content (Fig. 1) in adult appendicular trauma referrals and matching the current 'red dot' areas of inclusion. The patient age, gender and a short history were provided with the referral as per standard practice. Images were viewed on the PACS system using the radiographer workstation, which matched the performance capabilities of the emergency department viewing system.

Tick boxes on the worksheet included indications of no abnormality, fracture, dislocation, soft tissue sign for fracture and foreign body presence. A free comment response section was also available for participants to add details about the appearances seen in the images or to make any further pertinent comments and allow confirmation of appropriate tick box selection by the marker.

Box 1. The EP and radiographer measurement sequence.

Radiographers interpret the standardised test images before receipt of learning materials.

Feb/March 2010

EP stage 1

Booklet received with CD ROM of various readings and exercises to complete

Study weekend interactive workshops/tutorials:

- radiographic anatomy
- fundamentals of image interpretation and pattern recognition
- abnormality description language and terminology
- mechanisms of injury
- radiographic appearance of skeletal disease
- practical application of education
- shadowing of radiologists for two sessions each to obtain radiologist descriptive styles reporting trauma images.

March 2010

Radiographers interact with the booklet and CD ROM / exercises and perform standardised test 2

EP stage 2

- descriptive techniques revisited
- legal issues and requirements
- self audit techniques
- research and key statistics introduction

Radiographers perform standardised test 3 within 3 weeks of completing EP 2.

Radiographers perform interpretations on images for 22 days and compare performance against emergency doctors and the single reporting radiologist.

July/August 2010

Ten radiographers of mixed clinical experience in two groups of five from two Brisbane tertiary hospitals participated in this second phase of the research. Two participants had received previous postgraduate education in image interpretation whilst the remainder ranged in experience from two years post qualified to 20+ years. Ethics approval from the Human Research Ethics Committee at The Royal Brisbane and Women's Hospital was received in February 2010. Participants received identifiers to maintain anonymity from the test marker, and described image content on all images that fell into the adult appendicular trauma scope of activity. Participants commented on their own images as well as those produced by colleagues when on duty in the emergency radiology department. Radiographers were rotated into their respective emergency departments to cover service delivery between 08:00 and 22:00 for each day. Two sessions of radiographer descriptions were provided spanning a period lasting 10 days and 12 days over a month i.e. each period was back to back. The first period of activity was to be blind to the emergency department with the follow up session intended to provide the radiographer descriptions to the emergency department before radiologist reporting.

The radiographer's worksheet contents were compared against the emergency doctors' entries to the patient notes and radiologist report by the research co-ordinators. The emergency doctors' did not use worksheets due to the initial wish to blind them to the procedure as a whole. Their interpretations were measured from information gathered through patient notes with marking criteria for them and the radiographers generated by using the radiologist report as the comparator standard. The intended second period of radiographer descriptions involving revelation of the radiographer opinions to the emergency department prior (and hence worksheet


Queensland Government

Emergency Department
Radiographer Abnormality Description Worksheet Trial

This worksheet must be used in conjunction with the Radiographer Abnormality Description Worksheet Guidelines

Place Patient ID Sticker here Or Accession No. Label for Exam	The Radiographer comments below are an opinion only and in no way replace a formal diagnostic report by a Radiologist

Radiographer's observations

☐ No Abnormality Detected

☐ Abnormal

- ☐ Fracture
- ☐ Dislocation
- ☐ Soft Tissue Sign
- ☐ Foreign Body

Please give description:________________

☐ No opinion given

Additional Information:________________

Radiographer's Identifier________ Date________ Time________

Any difference in opinion with the above Radiographer description must be referred to a Senior Emergency Clinician or Radiologist

If you require further information regarding this description, please contact the Radiographer on ext

Figure 1. Clinical description response worksheet.

Table 1
Breakdown of images described across both clinical periods.

Area	Phase 1		Phase 2		Total	
	$n = 348$	%	$n = 307$	%	$n = 655$	%
Hand, wrist, forearm	115	33.0	98	31.9	213	32.52
Elbow, humerus, shoulder	64	18.4	62	20.2	126	19.24
Foot, ankle, tib/fib	90	25.9	66	21.5	156	23.82
Knee, femur, hip, pelvis	79	22.7	81	26.4	160	24.42
Totals	**348**	**100**	**307**	**100**	**655**	**100**

Proportions described per participant – percent (number)

Participant number	1	2	3	4	5	6	7	8	9	10	Total
Hand, wrist, forearm ($n = 213$)	14.1 (30)	13.6 (29)	13.6 (29)	11.3 (24)	12.2 (26)	1.9 (4)	6.1 (13)	15.0 (32)	9.9 (21)	2.3 (5)	**100 (213)**
Elbow, humerus, shoulder ($n = 126$)	19.8 (25)	15.1 (19)	16.7 (21)	11.1 (14)	12.7 (16)	0.8 (1)	6.3 (8)	6.3 (8)	9.5 (12)	1.6 (2)	**100 (126)**
Foot, ankle, tib/fib ($n = 156$)	17.9 (28)	12.8 (20)	7.7 (12)	12.2 (19)	16.0 (25)	3.2 (5)	9.0 (14)	9.0 (14)	10.3 (16)	1.9 (3)	**100 (156)**
Knee, femur, hip, pelvis ($n = 160$)	16.9 (27)	11.3 (18)	13.8 (22)	11.3 (18)	15.0 (24)	1.9 (3)	8.8 (14)	7.5 (12)	12.5 (20)	1.3 (2)	**100 (160)**
Number described by participant	110	86	84	75	91	13	49	66	69	12	**655**

Table 2
Range of scores and kappa statistics (mean and median) of radiographers and emergency doctors compared against the radiologist ($n = 10$).

		Sens	Spec	Acc	PPV	NPV	Cohen Kappa	Byrt Kappa	Gwet AC-1
Mean	Rad	0.948	0.948	0.886	0.970	0.948	0.877	0.871	0.896
	ED	0.908	0.968	0.895	0.975	0.948	0.871	0.772	0.896
Median	Rad	1.000	0.97	0.920	0.990	0.967	0.911	1.000	0.933
	ED	0.933	0.971	0.965	0.970	0.958	0.903	0.849	0.917
Range	Rad	0.200	0.206	0.370	0.090	0.187	0.411	0.549	0.375
	ED	0.250	0.125	0.390	0.160	0.167	0.375	0.741	0.333
SD	Rad	0.066	0.062	0.125	0.030	0.052	0.122	0.171	0.105
	ED	0.090	0.039	0.011	0.045	0.047	0.119	0.229	0.095
SE	Rad	0.016	0.015	0.045	0.010	0.013	0.030	0.041	0.026
	ED	0.022	0.010	0.035	0.015	0.011	0.029	0.056	0.023

Sens = Sensitivity.
Spec = Specificity.
Acc = Accuracy.
SD = Standard Deviation of the mean.
SE = Standard Error of the mean.
Rad = Radiographer.
ED = Emergency Dr.
PPV = Positive predictive value.
NPV = Negative predictive value.

content) to radiologist input was prevented from taking place at one centre. In its place a further period of gathering comparative worksheets blinded to the emergency department was generated to provide more evidence of radiographer description performance and immediately followed an initial 10 day period of data collection. Information was gathered about report return times but its discussion is beyond the remit of this paper other than to suggest a time for description provision with radiographer input.

Sensitivity, specificity, accuracy, positive and negative predictive values were calculated. Comparison between observers was performed using three types of Kappa statistic. Cohen's Kappa,[35] Byrt et al.'s bias and prevalence adjusted Kappa[36] and Gwet's AC-1 statistic[37] (Kappa variant). Use of these three statistics enables full discussion of inter-rater variability allowing for the different weaknesses exposed within Cohen's Kappa.[36,37] The Wilcoxon signed ranks test was used to evaluate for the presence of statistical significance between the various calculations and groups of observers.

Results

Results were generated for the participants in the clinical portion of the investigation when descriptions were created while the patient was present. Twenty two days (10 day then 12 day collection periods) of radiographer description pilots took place, with 346 and 307 examinations respectively completed by the participants. Table 1 shows the breakdown of the range of examinations described and their proportions across the whole of the two measurement periods for radiographers and emergency doctors. If the radiologist report is assumed to be correct then during the test periods there was a prevalence of 28.45%. A total of 10 radiographers and 10 emergency doctors participated across the two periods with nine in each group in period one and eight in period two. Comparisons between the emergency department doctor performance and the radiographers are presented (Table 2), using the reporting radiologist as the reference standard comparator with mean and median values for all kappa scores and predictive values being high. Table 3 shows the performance of the radiographers and emergency doctors as groups and individuals. Across the 22 days worth of radiographer descriptions only a narrow statistically significant difference was shown in the Byrt et al. bias and prevalence adjusted Kappa statistic using the Wilcoxon signed ranks test ($p = 0.047$). The Cohen's Kappa and Gwet's AC-1 statistic showed no such outcome ($p = 0.975$ and $p = 0.972$ respectively). As a check the same test was performed between the two periods of the radiographers and emergency doctors (i.e. radiographer week one versus radiographer week two) to see if any difference was noted there. These showed no statistical significance other than the first period of Byrt et al.'s bias and prevalence adjusted results (Table 4). When the raw results were examined it was noted that two of the emergency doctors performed less well (sensitivity lower) and helps to explain why Byrt's calculation showed statistical significance. If the impact of the bias and prevalence contribution to the Byrt et al. calculation is considered with respect to the sample size of the readers being compared ($n = 9$ emergency doctors), then the statistical significance of the Wilcoxon signed ranks test for this value becomes apparent i.e. these doctors scored at levels that were statistically significantly different.

Table 3
2 × 2 squares showing group performances from the group and individual scores.

Radiographers scores ($n = 10$)				Emergency doctors scores ($n = 10$)			
	T	n			T	n	
T	427 (TP) 97.3%	12 (FN) 2.7%	427/439 (sens) 97.3%	T	438 (TP) 96.3%	17 (FN) 3.7%	438/448 (sens) 97.8%
n	21 (FP) 9.7%	195 (TN) 90.3%	195/216 (spec) 90.3%	n	10 (FP) 8.2%	190 (TN) 91.8%	190/207 (spec) 91.8%
	448	207	622/655 (acc) 95.0%		448	207	628/655 (acc) 95.9%

True negative and positive, and false negative and positive by each participant and to show numbers of examinations described by each participant.

Participant number	1	2	3	4	5	6	7	8	9	10	Total
TN Rad	82	53	51	51	60	11	34	31	47	7	427
TP Rad	23	32	22	24	27	2	10	32	19	4	195
FN Rad	4	1	2	0	1	0	1	2	1	0	12
FP Rad	1	0	9	0	3	0	4	1	2	1	21
TN ED	83	51	59	51	62	10	35	32	48	7	438
TP ED	25	32	21	23	26	2	9	30	19	3	190
FN ED	2	1	3	1	2	0	2	4	1	1	17
FP ED	0	2	1	0	1	1	3	0	1	1	10
Total	**110**	**86**	**84**	**75**	**91**	**13**	**49**	**66**	**69**	**12**	**655**

Rad = Radiographer.
ED = Emergency doctor.

Table 4
Radiographer versus emergency doctor (individual scores) Wilcoxon signed ranks p values for each kappa test and each period of measurement.

Test period	Kappa statistic type	p value
Period 1(10 days)	Cohen's Kappa	0.499
	Byrt et al. Kappa	0.018
	Gwet AC-1 statistic	0.612
Period 2 (12 days)	Cohen's Kappa	0.612
	Byrt et al. Kappa	0.484
	Gwet AC-1 statistic	0.463

Table 5 shows the mean scores across the values given in Table 1 and reveals the 95% confidence intervals (95% CI) for those same values. The emergency doctors showed a narrower range of results than the radiographers, i.e. the spread around the mean tended to be lower whether doctors or radiographers scored higher.

No difference in the mean accuracy score is noted between the doctors and the radiographers, though doctors tended to score better individually with respect to specificity values while radiographers generally had higher sensitivity results. The Cohen and Byrt et al.'s Kappa calculations favoured the radiographers and no difference was seen in the figures produced by the Gwet AC-1 statistic method of establishing performance variation between these two groups of readers overall.

It became apparent through review of the results on an individual basis that six radiographers demonstrated a mean accuracy of above 95% agreement with the reference radiologist standard, three between 90 and 95% and one performing at 88.5%. By comparison eight of the ten emergency doctors demonstrated accuracy at 95% agreement or above with the reporting radiologist and two below 90% ranging between 89.8% and 83.3%. The numbers of times the radiographers and emergency doctors completely agreed with the radiologist in terms of sensitivity, specificity and accuracy during each reading period are shown in Table 6. No statistical significance was shown between the scores for these components of the project, nor for the predictive values gained by both groups of participants. Overall however, the emergency doctors performed slightly better in their mean values for the positive and negative predictive values.

Assuming that the definitions of Kappa values by Landis and Koch[38] (reviewed in Fig. 2) can be applied to the different Kappa statistic calculation there is only one occasion where the performance falls below the almost perfect grading (between 0.81 and 1.00). This occurs amongst the emergency doctors, which if considered within the 95% CI then all doctors would fit in the substantial to almost perfect agreement brackets. Analysis of individual scores showed that one emergency doctor consistently performed at a lower level across the two reading periods.

The impact of patient contact in the second part of the investigation is evident when compared against the nonpatient contact standardised test performed before the clinical component. Increased sensitivity, specificity and accuracy scores of radiographers are noted throughout however, some radiographers clearly do not perform as strongly as their colleagues.

Table 6
Showing when participants agreed completely with the radiologist. Total different participants for both professions $n = 10$.

Clinical period details	Radiographers			Emergency doctors		
	Sens	Spec	Acc	Sens	Spec	Acc
Period 18 10 days 348 exams $n = 9$	5	3	3	2	3	1
Period 2 12 days 307 exams $n = 8$	4	3	1	3	5	2
Total 22 days 655 exams	9	6	4	5	8	3

There were ten participants in total for each group across the two clinical assessment periods. Differing participants may have performed to higher standards in each session resulting in a total number of maximum scores shown in the lower row.

Finally, it was noted that when scores were combined, the overall accuracy performance from radiographers and emergency doctors improved. This occurred when one group spotted what the other missed. When this was closely analysed it became evident that this phenomenon was due to greater sensitivity scores of the radiographers. As a result, eight more positive for abnormality radiographs were identified, which was equivalent to the recognition of a further 1.2% of injuries in this series of images.

Discussion

Employing a worksheet with defined criteria and at the same time giving the radiographer the opportunity to express opinion by freehand comment, can provide helpful information to the referring emergency doctor.[32] On average, though not covered in the results section, the description was prepared within 16 min from completion of the radiograph. This was well inside the expectations of the ACHS clinical indicator and the 2010 Queensland Health Policy for the Provision of Diagnostic Imaging Reports as well as the timelines reported in the introduction of this paper. Often management of patients is begun in a protective sense, driven by concerns over litigation. Excessive treatment before radiological reporting can be achieved may result in recall with associated concerns and costs for the patient. Timely information that is available and reliable may help reduce costs caused by excessive treatment or prevent an occasional missed injury, which is evidenced by the rise in overall performance from combined results in the radiographer description clinical pilot. Analysis of the actual

Table 5
95% confidence intervals of the mean scores.

Statistic	Mean scores		95% CI value		95% CI range	
	Radiographers	Emergency Drs	Radiographers	Emergency Drs	Radiographers	Emergency Drs
Raw sensitivity score	0.948	0.908	0.032	0.043	0.916/0.980	0.865/0.951
Raw specificity score	0.948	0.968	0.029	0.019	0.919/0.977	0.949/0.987
Raw accuracy score	0.948	0.948	0.025	0.023	0.923/0.973	0.925/0.971
Cohen Kappa	0.877	0.871	0.058	0.056	0.819/0.935	0.815/0.927
Byrt et al. Kappa	0.871	0.772	0.081	0.109	0.790/0.952	0.663/0.881
Gwet AC-1 statistic	0.896	0.896	0.050	0.045	0.846/0.946	0.851/0.941
PPV[a]	0.886	0.895	0.088	0.069	0.798/0.974	0.826/0.964
NPV[b]	0.970	0.975	0.020	0.029	0.950/0.990	0.946/≥1.000

[a] Positive predictive value.
[b] Negative predictive value.

Kappa statistic value	Strength of agreement
<0.00	Poor
0.00-0.20	Slight
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Substantial
0.81-1.00	Almost perfect

Figure 2. Landis and Koch's agreement definitions for Cohen's Kappa.

responses between radiographers and medical staff showed several differences of interpretation that were then corrected through the radiologist's report.

It is evident that these radiographers tend to err on the side of caution, which is revealed from the sensitivity scores (mean radiographers score 0.948 [94.8%] and mean emergency doctor score 0.908 [90.8%]) being elevated compared with the emergency doctors. This is where a lack of knowledge and specialist skills application is most evident. Christensen[39] discussed the heuristics and choice preferences that may be favoured by the human decision making process and Snaith and Lancaster[40] have cogently argued for the initial impression to be supported by development of clinical assessment skills to aid and improve clinical decision making. Even so, had radiographers not contributed to early descriptions then a further eight examinations would have gone undetected for abnormality. If the same level of attendances is assumed between these two hospitals and the performance level is extrapolated over the year, then a potential 133 abnormalities significant to the referral will be identified before a radiologist report is generated.

The above inference should also be considered in the light of false positive scoring by the radiographers. The mean outcome from this investigation showed radiographers to be performing at a level that is two percent less specific than the emergency doctors. This has the potential to cause excessive early treatment of patients, although it is expected that the further assessment skills possessed by the medical staff should enable decision making that would prevent this. Notwithstanding this position however, the ideas expressed by Snaith and Lancaster[40] so that to effectively perform an immediate radiographic description service then radiographers should receive history and physical assessment skills in their education.

When comparing radiographer performance between the earlier standardised test and the clinical pilot, it is evident that patient presence has a large positive impact. The standardised test study showed a mean/median accuracy of 86.8/88.7% respectively compared with the clinical pilot results of 88.6/92.0% respectively. Even so, the radiographer overall accuracy performance (mean/median scores) is slightly less than the emergency doctors at 89.5/96.5% respectively in this study. Lower specificity recognition capabilities by radiographers are likely to be reflective of a lack of clinical assessment education that has been inculcated into medical staff from their earliest days of training.

Notwithstanding the last comment, the various Kappa statistics that have been calculated demonstrate an 'almost perfect' level of performance[38] by both professional groups with an apparently better performance by the radiographers across the mean and median scores of each type of inter-rater variability calculation. This serves to highlight the subtleties of statistical calculations and how the variation in choices between true positive and negative across a range of results may impact on the performance level that is reported. The use of the various measurement approaches acts in a 'belt and braces' way to demonstrate how reporting variability using of just one method can be misleading. Although Cohen's Kappa is meant to correct for chance in the decision making between raters/readers of a test, use of the multiple Kappa methods accounts for the failure to account for bias and prevalence in the choices made in a binary measuring system such as seen in Cohen's testing method.[35] Byrt et al.[36] created an adjustment for bias (the proportion of yes choices by a reader compared to the original) and prevalence (probability of a 'Yes and No' choice compared with the original). They state if bias increases then the chance agreement expectation falls to cause Kappa to be artificially raised. Likewise, if prevalence rises so too does the chance agreement expectation, as a result this artificially reduces the Kappa value. Gwet[37] also argues that the assumptions used to calculate the level of chance assumed within Cohen's Kappa are flawed. He asserts that the probability for chance agreement should not exceed 0.5 in value if both observers have randomly come to a decision that they both agree on. Following this argument enables the Kappa statistic to be calculated taking into account variation in marginal values that are necessarily generated in a 2×2 square.

There are some limitations to this study that should be considered. The size of the study and use of only adult appendicular trauma images limits its generalisability. Those participants that volunteered were clearly interested in enhancing their work thus potentiating selection bias amongst radiographers. The doctors were not separated into levels of experience for comparison, though it was assumed registrars of varying experience and consultants were measured during the clinical component of this study. Similarly the experience of radiographers was not differentiated; length of time since qualification varied, prior education in image interpretation from Australian or U.K. universities and the impact of other imaging modality experience was not accounted for. Finally, the radiographer clinical description pilot can only be compared in the light of being a reference standard due to single radiologist reporting.

Despite some limitations, this study attempted to account for limitations in reported Australian work performed between 1997 and 2009.[10,22,31,33,34] The clinical radiographer description pilot reinforced the perception that patient presence may influence decision making. This could be a notable context to consider when the non-medically educated are compared against medical staff in the emergency department. A greater degree of safety in radiographer abnormality descriptions when they assess images for signs of injury is apparent with the advantage of the patient being present.

The assertion that same day reporting is not required in well supervised emergency departments[41] may hold concerns for the accreditation of radiology departments in Australia, especially when the work of Hallas and Ellingsen[42] on a Norwegian basis is also considered. They suggest up to 3.1% of fractures are missed, thus supporting this research that identifies immediate radiographer input would be valuable. This study has shown radiographers working with emergency department doctors can minimise the potential for missed injury detection due to the double reading nature of the image review process shown by an overall reduction of missed abnormalities from 2.4% to 1.2%. By involving radiographers in the pre-radiologist phase of interpretation through description of image content, a very high accuracy rate is possible (98.8% when individual group missed interpretations are combined to generate a total accuracy). This would ensure radiology department input in a timely fashion is guaranteed, which could also satisfy performance indicators for departmental accreditation processes. The initial survey to identify timeliness of radiologist reports showed that 33% and 64% (at each centre involved in this study) of plain radiographs remained unreported for longer than three days. This lowers the clinical usefulness and questions the need for radiology in the first instance. Furthermore, radiographer input may result in patients being treated appropriately in an acceptable timeframe. As a result the potential for future recall from missed abnormality detection with possible concomitant litigation and the risk of long term morbidity issues is reduced.

Conclusion

Despite the limitations the results of this study support the positive impact of immediate describing by radiographers in the emergency department. The Australian government should consider how the emergency team at least can be made more responsive and less open to litigation as well as showing improvement in the radiology department service delivery overall. When coupled with the concerns about input by radiologists outside Australia, the question has to be asked why is further support for radiographers not forthcoming? Finally, as Gibbon[3] identified, an improved better streamlined multi-disciplinary team is possible, preferable and should be supported to improve healthcare delivery.

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Competing interests

Jonathan McConnell received financial support from Queensland Health to enable travel to facilitate the project.

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Commentary

The accuracy of adult limb radiograph interpretation by emergency nurse practitioners: A prospective comparative study

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We would like to congratulate the authors on the production of a paper (Lee et al., 2013) that goes some way to generating data in the Australian setting for emergency treatment of limb injuries based on the referral and interpretation of the plain radiographic image.

However, upon closer analysis the study raises methodological issues that we believe are worthy of discussion and which should be addressed in future studies of this nature. Firstly, there has been an over reliance on nursing oriented papers as reference sources that has resulted in aspects of the method not being fully appreciated. Brealey and co workers within a U.K. context have spelt out the perils of various forms of bias in their analysis of radiographer image reporting that may inadvertently creep into studies of this nature if a range of aspects are not checked (Brealey and Scally, 2001; Brealey et al., 2002a,b). For example, *spectrum bias* that is influenced by disease (trauma) type, severity and patient demographic; *population bias* that is affected by the use of a single radiologist for comparison purposes and may therefore be influenced by prevalence of the abnormality – furthermore without the input from more than one radiologist the reference standard could be wrong and if this is not identified it could impact on results.

Secondly, whilst the paper is clear about the number of participants and their professional backgrounds, the decision to combine the results into either emergency nurse practitioners (ENPs) or emergency physicians (EP) has led to some spurious numbers being presented. Furthermore the study was carried out over a six months timeframe for data collection, so questions about the prospective nature of the data generation must be questioned. This is based upon 200 cases from over 56,000 attendances per year that could be generated in a shorter timeframe suggesting that there is potential for *image selection bias* (Brealey et al., 2002a) to have occurred. As well, even though a power calculation has been generated for completeness sake (and to achieve participant anonymity) the relative amounts of contribution made by each individual could be presented. This was requested during the creation of a paper for a recent radiographer driven project in Queensland as the reviewers wanted to be certain that a balanced representation across all participants could be seen (McConnell et al., 2013).

The definitions given to calculate sensitivity, specificity etc. are correct, however a failure to show the actual performance within these categories raises a concern with respect to the actual values obtained by each group. Sensitivity is calculated by establishing how many positive results by the reader are obtained relative to the total number that are positive i.e. true positive (TP) of the reader plus their false negatives (FN). Likewise specificity demonstrates the ability to say an image is negative for abnormality and is represented by those deemed negative by the viewer divided by the reader's true negatives (TN)

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Table A
Suggested raw scores for ENPs and EPs.

	TP	TN	FP	FN	Total
ENPs	73	111	12	4	200
EPs	73	121	2	4	200

plus their false positives (FP). When the percentage performance values given in Table 4 are compared with the figures offered in Table 3 it would appear an error has been made. If there is 91% sensitivity agreement with the radiologists by ENPs then this means they spotted (assuming that 77 positive examinations are accepted) 70 positive images and at 85% sensitivity agreement this was 105 when decimal corrections are made. These figures do not match those given in Table 3. The same is true with the EPs who would spot 68 positive for fracture and 112 that are negative.

Failure to provide the actual values for TP, TN, FP, FN makes it difficult for the reader to double check the values presented and to confirm their veracity. It also makes it impossible to confirm the Weighted Kappa values and without these raw details application of alternative statistical comparison techniques is not possible. Through working back into the values given it is possible to make a suggested score for each group assuming all 5 extra 'possible fractures' are detected and are shown in Table A.

This would produce a range of results that are actually different from those seen in the tables (given by Lee et al) but a true representation of the scores achieved. This would also generate the Kappa value given (one assumes) for the ENPs ($k = 0.83$) as the EPs using the above values would be 0.936 (not stated in the article) which is significantly greater than the ENP score. Both results do however provide favourable outcomes when measured against Landis and Koch (1977) performance definitions. We have also included some further statistics of Kappa that take account of bias (the amount of positives agreed between reader and reference standard) and prevalence (positives and negatives agreed between reader and reference standard) (Feinstein and Cichetti, 1990a,b) which are responsible for having effects on the scores achieved that could be detrimental (Bias/Prevalence adjusted Kappa – BPK (Byrt et al., 1993)). We also provide the Gwet AC-1 (Gwet, 2002) statistic that is a correction for Kappa. The original Cohen's or subsequent weighted approach which has been used in this study, makes an assumption in a simple binary test that the maximum value that readers can obtain is 1. However according to Gwet's arguments this can only be 0.5. Both these values, using the proposed figures above, are useful performance indicators (and in the case of this study more favourable) if an ROC cannot be plotted. They are shown in Table B.

Thirdly, considering the timeframes involved did the images that were generated for the study receive a report from the radiologist at the time the patients attended the Emergency Department (ED)? Information provided within the paper suggests that it was possible for the radiologist to report the images in a single batch (or at very least more closely together) as controlling the trial to ensure only the single radiologist received the images would be difficult to achieve. Either way the radiologist would at least need basic demographic information as this is an important factor in this 'Diagnostic Outcome Study' as defined by Brealey et al. (2002a). If the images were reported as a batch at a later time then it would be possible for the radiologist to see either the original report or possibly electronically access more clinical information. Most electronic archival systems now make further images available or as an index of studies performed alongside the examination being evaluated or reported and therefore could bias the outcome via '*Co-image bias*' (Brealey et al., 2002a).

Finally, in considering the workforce issues and task substitution within Australia it is disappointing to see that the authors intend to replicate the study with physiotherapists as the image requesters and readers. Radiographers in the clinical setting have shown that they can describe image content to a high level with no statistically significant difference between emergency department medical staff and the radiologists involved in the reporting of images. Key values are shown below for the whole group of 10 radiographers at two Brisbane hospitals in the previously identified study (McConnell et al., 2013) are seen in Table C.

If this outcome is coupled with the overall patient pathway it would be advantageous to consider the input of radiographers as they could provide an immediate reporting service. A team based approach involving EPs or ENPs could result in an overall improvement for the patient and, as revealed in the Brisbane study, provide a

Table B
Calculations and new Kappa statistic values using suggested raw scores.

	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	BPK (over 0.81 = high agreed)	AC-1 (over 0.81 = high agreed)
ENPs	94.81	90.24	86.00	97.00	0.892	0.846
EPs	94.81	98.37	97.00	97.00	0.890	0.943

Table C
Brisbane hospitals clinical results of radiographers against EPs.

	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	BPK (over 0.81 = high agreed)	AC-1 (over 0.81 = high agreed)
Radiogs	94.8	94.8	97.00	94.80	0.871	0.896
EPs	90.8	96.8	97.50	94.80	0.772	0.896

'safety-net' approach for identifying missed abnormalities. This approach could address the large number of possible fractures seen by ENPs or EPs as the abnormality might be seen as the patient returns from radiology or a combined/cross over effect of one group spotting another's error would limit mistakes. The overt support provided by radiologists to other professions (Fabiny, 2011) rather than seeing the value of their radiographers continues to confound and perplex ENPs and radiographers in the U.K. Indeed this was a feature also seen in aspects of the Brisbane study (McConnell et al., 2013). We would urge the researchers to consider the inclusion of radiographers in any future investigations into improving the delivery of timely and cost effective emergency health care through the interpretation of radiographic images by non-radiologists.

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