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STRESS FRACTURE INJURY IN FEMALE ENDURANCE ATHLETES IN THE UNITED KINGDOM: A TWELVE MONTH PROSPECTIVE STUDY

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Abstract

Studies of stress fracture (SF) incidence are limited in number and geographical location; this study determined the incidence of SF injury in female endurance athletes based in the United Kingdom. A total of 70 athletes aged between 18-45 years were recruited and prospectively monitored for 12-months. Questionnaires at baseline and 12-months assessed: SF, menstrual and training history, eating psychopathology and compulsive exercise. Peak lower leg muscle strength was assessed in both legs using an isometric muscle rig. Bone mineral density (BMD) of total body, spine, hip and radius was assessed using dual x-ray absorptiometry (DXA). Among the 61 athletes who completed the 12-months monitoring, two sustained a stress fracture diagnosed by MRI, giving an incidence rate (95% confidence intervals) of 3.3 (0.8, 13.1) % of the study population sustaining a SF over 12 months. The SF cases were 800m runners aged 19 and 22 years, training on average 14.2 hours a week, eumenorrhoeic with no history of menstrual dysfunction. Case 1 had a higher than average energy intake and low eating psychopathology and compulsive exercise scores, whilst the reverse was true in case 2. BMD in both cases was similar to mean values in the non-SF group. The incidence of stress fracture in our female endurance athlete population based in the United Kingdom was 3.3%, which is lower than previously reported. Further work is needed to confirm the current incidence of SF and evaluate the associated risk factors.

Introduction

Stress fractures (SF) are the most common over use injury in athletes (Bennell & Brukner 2005) but only a limited number of studies have prospectively monitored incidence and risk of SF in young adult females, almost all conducted in North America or Australia (Bennell et al. 1996; Kelsey et al. 2007; Nattiv et al. 2013; Nattiv et al. 2000). Annual incidence of stress fracture ranged between 8.7 and 20.7% in track and field athletes (Bennell, Malcolm 1996; Kelsey, Bachrach 2007; Nattiv, Kennedy 2013; Nattiv, Puffer 2000), being greatest in female endurance athletes (30.7%) (Bennell, Malcolm 1996).

Previously identified risk factors of SF in adult female athletes have included: menstrual irregularity, low BMD, disordered eating, low energy availability, decreased strength, and decreased calf girth (Bennell et al. 1999; Kelsey, Bachrach 2007; Nattiv 2000; Snyder et al. 2006). Some of these risk factors for stress fracture overlap with the features of the Female Athlete Triad: a sex specific set of risk factors for impaired bone health and fracture including low energy intake with or without disordered eating, menstrual dysfunction and low bone density (De Souza et al. 2014; Nattiv et al. 2007). More recently it has been shown that compulsive exercise and amenorrhoea are independently related to stress fracture (Duckham et al. 2012). Although these factors have been comprehensively assessed in athletes, most studies have been cross sectional with measurements obtained following the SF injury. Findings are often contradictory: for instance later age at menarche was inconsistently associated with stress fracture (Bennell, Malcolm 1996; Kelsey, Bachrach 2007). An increase in the

awareness of the Female Athlete Triad, stress fractures and their associated risk factors has potentially lowered incidence of SF in female athletes over the last decade. Thus there is a need for a contemporary study of stress fracture incidence in athletes. The purpose of this study was thus to prospectively determine the annual incidence of SF in female endurance athletes based in the United Kingdom.

Methods

A twelve-month prospective study design monitored SF injury and training in 70 female endurance athletes aged 18-45 years. Athletes were recruited through the English Institute of Sport, UK Athletics, British Triathlon and UK-registered running and triathlon clubs, via letters, posters, group meetings and word-of-mouth. Inclusion criteria included healthy, un-injured athletes, competing at international or national level or training at least 8-10 hours per week for endurance athletes or 15-20 hours per week for triathletes. Athletes were excluded from the study if they had not trained in the past 6-months and if they were currently pregnant or lactating or had been in the last 12 months. The National Research Ethics Service (NRES) and Loughborough University Ethics Committee approved this study. All athletes gave written informed consent.

Questionnaires were completed at baseline to assess SF history, menstrual dysfunction, age at menarche, contraceptive use, training history, compulsive exercise, eating psychopathology, and dietary intakes. History of SF was defined as a fracture/reaction clinically diagnosed by a sports physician and confirmed with a positive diagnosis on X-ray, CT, or MRI. For each SF, athletes recorded the age when the SF occurred, the anatomical location, time of year and method of diagnosis. Menstrual function in the preceding 12-months was classified as secondary amenorrhoeic (less than 4 menses per year), oligomenorrhoeic (4-9 periods per year, periods occurring at intervals greater than 35 days after onset of menstruation) or eumenorrhoeic (10 or more periods per year) (Snow-Harter 1994). Athletes' eating behaviour, psychopathology and compulsive exercise traits were assessed using questionnaires: the European Prospective Investigation into Cancer (EPIC) food frequency questionnaire (FFQ) (Welsh 2005) coded using CompEat version 5.8 (Nutrition Systems, UK), the Eating Disorder Examination Questionnaire (EDE-Q) (Fairburn & Beglin 1994) and the Compulsive Exercise Test (CET) (Taranis et al. 2009). The EPIC FFQ provides general information of the number of portions consumed of a wide range of foods over the past 12-months. The EDE-Q is a self-reported version of the EDE, the current gold standard for measuring eating disordered psychopathology (Fairburn & Beglin 1994). The EDE-Q is a 36-item questionnaire scored from 0 to 6 with the high scores representing concerns with eating behaviours and attitudes. The EDE-Q comprises four subscales (restraint, eating concern, shape concern and weight concern), a global score and a specific section of diagnostic questions related to bingeing/purging. The CET is a 24-item self-reported questionnaire scored from 0 to 5 with the high scores representative of compulsive exercise

traits. It is designed to assess four domains of compulsive exercise (compulsivity, affect regulation, weight and shape driven exercise and behavioural rigidity (Taranis, Touyz 2009).

Dual energy x-ray absorptiometry (DXA) was used to measure Bone Mineral Density (BMD) and Content (BMC) of the total body, lumbar spine, femoral neck, and radius (Lunar Prodigy, GE Healthcare, Madison, WI, U.S.A using Encore software version 12.2). For all anatomical locations BMD Z-scores were calculated using the manufacturer UK adult female reference database according to age sex and ethnicity, except that for athletes aged 18-19 years, Z-scores were calculated relative to age 20 norms. Bone geometry at the femoral neck was estimated using Lunar Advanced Hip Structural Analysis (AHA) algorithms to determine the cross-sectional area (CSA), minimal femoral neck width and section modulus (Z). All scans were conducted on the dominant limb, the most prevalent side for injury (Bennell, Malcolm 1996), by the same operator same scanner. The short-term precision error (coefficient of variation, CV_{rms}) for the reported bone outcomes in our lab ranged from 0.7-4.6%

Height and body mass were measured prior to the DXA measurements using standard protocols, via a stadiometer (Holtain Ltd, Pembrokeshire) and beam balance scale (Herbert and Sons Ltd, London) respectively. Body composition (mass of fat, lean and bone) was assessed from a total body DXA scan. Athletes were blinded to the body composition results until the end of the study to prevent any possible bias when completing the questionnaires related to eating psychopathology. Calf circumference was measured at the midpoint between the proximal tibia border and the medial malleolus for the calf (Callaway et al. 1988).

Maximal isometric knee extensor force was determined using a custom-built muscle rig. Following three submaximal warm-up trials, athletes were instructed to produce a maximal effort, which increased smoothly to maximal tension within 4-5 seconds. The peak force was recorded.

Training, menstrual function and signs and symptoms of a stress fracture/reaction were prospectively monitored using monthly diaries (Bennell, Malcolm 1996; Matheson et al. 1987). For each diary, athletes recorded the training frequency, mode and duration each day, the start date of their menses, and any signs and symptoms (localized bone tenderness, swelling of surrounding soft tissue and increased pain during loading) of a stress fracture/reaction injury. At each 6-month assessment, athletes confirmed clinically diagnosed (X-Ray, MRI, or CT) stress fracture injuries.

Statistical analyses were performed using SPSS 16 (SPSS Chicago Illinois, USA). One-way analysis of variance (ANOVA) was used to compare means between the athletes who withdrew and those who completed the 12-month assessment to detect any dropout bias (Table 1). Categorical comparisons were evaluated using chi-squared tests. Incidence rates and their 95% confidence intervals (95%CI)

were calculated from number of stress fractures (d) and the person years of observation (T) according to formulae below (Kirkwood & Stern 2000):

$$\text{Incidence rate} = \frac{\text{number of stress fractures (d)}}{\text{person years of observation (T)}}$$

$$95\%CI(\text{rate}) = \text{rate} \div \exp\left(\frac{1.96}{\sqrt{d}}\right), \text{rate} \times \exp\left(\frac{1.96}{\sqrt{d}}\right)$$

Results

Participants were 58 runners (events 800m to marathon) and 12 triathletes (Table 1). Nine (6 runners and 3 triathletes) of the 70 female endurance athletes withdrew from the study, representing an overall attrition rate of 12.8% (Figure 1). Women that withdrew tended to be older, with a lower prevalence of past stress fracture and significantly lower prevalence of menstrual dysfunction (Table 1).

Two (3.3%) of the 61 remaining athletes sustained a clinically diagnosed SF over the 12-month period. Both stress fracture cases were confirmed by a sports physician and with a positive MRI within the first month of diagnosis. Case one was diagnosed with a SF on the dominant (right) side of the sacrum, and had no previous history of SF. Case two had an SF of the 2nd metatarsal of the right (dominant) foot. She had had one previous SF three years previously in the same location.

Baseline characteristics of the SF cases are shown in Table 2. Both cases were 800m runners competing at a national level for their age, and were younger than the group mean. Both were eumenorrhoeic with no history of menstrual dysfunction and were not currently taking hormonal contraception. Neither had low hip or spine BMD Z-scores (Z-scores at femoral neck and spine were +2.0 and +0.3 respectively for case 1 and +0.3 and +0.2 for case 2). Total percent body fat was lower than the group mean for each case. Otherwise, risk factors differed between cases: Case one was smaller and lighter than controls, with a higher energy intake and low eating psychopathology score. Case two had a late age at menarche (16 years), a higher BMI and a low energy intake. She had a particularly high duration of training, with a high EDE-Q and compulsive exercise score compared to controls. She had a high dominant leg extensor force and calf girth, but a high degree of strength asymmetry.

None of the control participants reported baseline eating psychopathology scores consistent with clinical diagnosis of eating disorder (global score: mean (CI) 1.4 (1.1, 1.7) , although two participants (neither of whom sustained stress fracture) in a follow-up questionnaire reported elevated global EDE-Q scores (3.9 and 4.1 respectively) and responses to diagnostic items indicating episodes of bulimic and weight control episodes between 16 and 30 days over the past 4 weeks, a level that may

be indicative of a positive diagnosis of an eating disorder with further clinical assessment (Fairburn & Beglin 2008; Fairburn et al. 2008).

Discussion

We conducted one of the larger prospective studies to monitor SF in young adult female endurance athletes, and the only study outside North America or Australia. The annual incidence of SF in our sample of UK female endurance athletes was 3.3 (0.8, 13.1) %. This is substantially lower compared to the incidence rate reported in 1996 in middle and long distance runners (Bennell, Malcolm 1996): which we estimated from the published data as 30.7 (17.3, 54.8)%. Our findings are more consistent with the 7.7 (4.8, 12.1) % reported more recently by Kelsey et al in cross-country runners (Kelsey, Bachrach 2007). Whilst the differing incidences may simply reflect the different samples studied, they may demonstrate a trend to a consistent reduction in stress fracture incidence over time (Bennell et al. 1996; Kelsey, Bachrach 2007; Nattiv, Puffer 2000).

One factor that may contribute to the lower SF incidence is the greater range of age of participants in this study (18-45 years) compared to previous studies (18-26 years) (Milgrom et al. 1994). Younger athletes may have increasing or higher training intensity and volume and hence be more vulnerable to over use injury. However, even if we restricted our analysis to athletes aged 18-26, the annual incidence of SF (5.3(1.4, 22.3) %) is still markedly lower than previously reported, so age can not entirely explain the low incidence seen in this study. Endurance athletes often continue training beyond the age of 26 years, making our study more representative of the endurance athlete population as a whole.

Later biological maturation (Malina & Bouchard 1991) was evident in the sample, with menarcheal age of 14.0 years compared to the general European population of 12.3 years (Morris et al. 2011). There was, if anything, a greater prevalence of menstrual dysfunction in this study (47.5%) compared to only 30 to 33% in previous reports (Bennell, Malcolm 1996; Kelsey, Bachrach 2007). Despite this, mean femoral neck BMD in this study (1.080 g/cm^2), was towards the higher end of that reported in previous studies (0.986 g/cm^2 to 1.181 g/cm^2) (Bennell, Malcolm 1996; Kelsey, Bachrach 2007), with none of the athletes having low femoral neck BMD, whether defined as Z-score less than -1 (Nattiv, Loucks 2007) or -2 (Lewiecki et al. 2008). This is consistent with the finding that amenorrhoeic endurance athletes had BMD that was lower than their regularly menstruating peers, but not lower than healthy non-athletic women (Duckham et al. 2013). Given that amenorrhoea is associated with increased risk of stress fracture it is perhaps surprising that we saw a low incidence of stress fracture in this sample with a high prevalence of amenorrhoea. It is possible that the absence of low BMD in this sample contributes to the low stress fracture incidence.

Interestingly, the two cases of stress fracture in the present study did not exhibit the previously identified risk factors for SF such as menstrual irregularities, or low hip or spine BMD (Bennell,

Malcolm 1996; Kelsey, Bachrach 2007). Delayed age at menarche, a potential risk factor for SF, was evident in case two (age at menarche 16.0 years), but not case one (13.0 years). One case reported a past SF, but with such a small incidence rate it cannot be concluded whether this is a significant risk factor.

It seems evident that the causes of SF in the present study were not related to the potential risk factors of SF such as menstrual dysfunction but could have been a result of changes in training. Cases of SF in the current study were both diagnosed at the start of the track season. This could have corresponded with an abrupt change from endurance winter training to the increased intensity of summer track sessions in these two athletes. Previous studies (Goldberg & Pecora 1994; Shaffer et al. 1999) have reported SF diagnosis to increase following a sudden change in training regimen, such as after a competitive track season (Goldberg & Pecora 1994). Findings in military recruits with low prior physical activity and poor physical fitness were reported to develop three times as many SF compared to those who were physically fit (Shaffer, Brodine 1999).

The risk for SF in case one may have been increased due to age. At age 18 the sacrum may not have been fully fused therefore increasing the risk for micro damage to occur resulting in a SF. The fusion of the sacral vertebra often begin at puberty, with complete fusion reported to occur between 25 and 33 years of age and is often related to the load bearing aspects of the region (Esses & Botsford 1997). Furthermore, although sacral stress fractures are rare in athletes, accounting for approximately 1.3-5.6% of stress fractures diagnosed (Matheson, Clement 1987; Wentz et al. 2011), they have predominately been described in distance runners (Fredericson et al. 2003; Johnson et al. 2001; Major & Helms 2000). Differences in SF location in the present study and previous work (Duckham, Peirce 2012; Snyder, Koester 2006), may explain the conflicting findings in the literature of risk factors for SF. Participants with SF at predominantly trabecular sites such as the sacrum were reported to have greater prevalence of disordered eating, menstrual dysfunction (Nattiv, Kennedy 2013), and lower BMD (Marx et al. 2001) compared to those who fractured at predominantly cortical sites, such that sacral SF was highlighted as being potentially indicative of high risk in Female Athlete Triad (De Souza, Nattiv 2014). However, our case with a sacral stress fracture did not exhibit features of Female Athlete Triad. It may therefore be pertinent to determine incidence and risk factor of SF at different anatomical fracture sites to fully understand SF aetiology.

The main strength of this study is its prospective design, with regular monitoring for, and clinical confirmation of stress fracture. The major limitation is that the sample size was modest and the low incidence of stress fractures meant that the study did not have statistical power to evaluate risk factors for stress fracture. The modest sample size also means our sample represents the population less well. We had access to athletes training at a high competitive level, and findings may be less generalizable to recreational runners and those from different geographical regions. Calculating Z-scores for those

aged 18-19 years relative to age 20 may slightly lower the BMD Z-scores in the small proportion of younger participants, thus Z-scores may, if anything, underestimate bone health in this sample of elite female endurance runners. A further limitation is that stress fractures were passively monitored so it is possible that an athlete may have failed to report potential symptoms, hence lowering observed incidence. However, given the regular assessments during the study and the study's focus on stress fractures we think this is unlikely. Menstrual function, dietary intakes and training histories were assessed using self-report and it was not possible to assess energy availability. Given these limitations and the inconsistent findings on incidence rates, further prospective studies are needed to clarify SF incidence and risk factors.

In conclusion, this study demonstrates that the annual incidence rate of SF in UK female endurance athletes was 3.3%: substantially lower than earlier prospective studies from North America and Australia. This lower incidence could not be explained by the higher mean age of our sample, or by awareness of Female Athlete Triad as there was a high prevalence of menstrual dysfunction. The lower incidence could thus reflect changes in athlete behaviour or training practices over the last two decades. Further studies are needed to confirm the incidence of SF in contemporary athlete groups and to evaluate risk factors for SF.

Perspectives

SF are the most common over use injury in athletes (Bennell & Brukner 2005), with previous reports of annual incidence ranging between 7.7 and 20.7% in track-and-field athletes (Bennell, Malcolm 1996; Kelsey, Bachrach 2007; Nattiv, Kennedy 2013; Nattiv, Puffer 2000). Studies of SF incidence however are limited in number and geographical location. This contemporary study prospectively monitored the annual incidence of SF in female endurance athletes based in the United Kingdom. This is one of the largest prospective studies to monitor SF in female endurance athletes, and the only study outside North America or Australia. The annual incidence of SF observed in our study was 3.3%, substantially lower than previous prospective studies (Bennell, Malcolm 1996; Kelsey, Bachrach 2007; Nattiv, Puffer 2000). These findings could not be explained by the higher mean age of our sample, or by awareness of Female Athlete Triad as there was a high prevalence of menstrual dysfunction, but could reflect changes in athlete behaviour or training practices. Further studies focused on predictors of SF are needed, especially given that this study highlights risk of SF among athletes who did not display the commonly identified risk factors for SF. Research must look beyond traditional risk factors for SF to aid prevention of this common injury.

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Table 1: Characteristics of analyzed athletes compared to the nine athletes who withdrew from the 12-month prospective study

	Analysed athlete group (N=61)	Athletes who withdrew (N=9)
Age (years)	25.3 (7.3)	30.2 (7.1)
Body Mass (kg)	54.8 (5.1)	58.6 (6.0)
Height (m)	1.67 (0.05)	1.69 (0.06)
BMI (Kg/m ²)	19.8 (1.5)	20.4 (2.3)
Body Fat (%)	17.0 (5.1)	18.5 (8.7)
Calf Girth (cm)	31.4 (2.4)	32.7 (2.0)
Competitive Level #		
Junior Elite (<23 years)	15 (25)	1 (11)
Elite (23-35 years)	20 (33)	3 (33)
Veteran Elite (>35 years)	4 (6)	1 (11)
County Level	22 (36)	4 (44)
Training		
Competitive training years (yrs)	7.6 (5.5)	7.8 (8.1)
Weekly training duration (hrs)	12.6 (4.5)	13.2 (5.5)
History of Stress Fracture #	18 (29.5)	0 (0)
Menstrual Function		
Age at Menarche (yrs)	14.0 (0.2)	14.2 (0.4)
Current A/oligomenorrhoea ##	47.5*	11.1
History of Amenorrhoea ##	60.7	44.4
Current Hormonal contraception use ##	31.1	22.2
Bone mineral density (BMD) (z-scores)		
Femoral neck	1.0 (0.1)	1.3 (0.3)
Lumbar spine (L1-L4)	-0.2 (0.1)	0.2 (0.3)
Total body	0.8 (0.1)	0.6 (0.3)
Distal Radius	-0.7 (0.1)	-0.9 (0.3)

All results reported as mean (SE) than otherwise stated. # Reported as number of athletes with a history of stress fracture (percentage), ## reported as the percentage of athletes

* Significant difference between the analysis and withdrawal group: p< 0.05

Table 2: Baseline descriptive characteristics of stress fracture cases and non-stress fracture group

	Stress Fractures		Non-Stress Fracture Group
	<i>Case One</i>	<i>Case Two</i>	(n=59) <i>Mean (95%CI)</i>
Physical Characteristics at baseline			
Age (years)	18	22	25.6 (23.6, 27.5)
Body mass (kg)	46.7	62.5	54.8 (53.5, 56.1)
Height (m)	1.60	1.70	1.67 (1.65, 1.68)
BMI (kg/m ²)	18.3	21.6	19.8 (19.4, 20.1)
Body fat (%)	15.7	16.2	17.0 (15.7, 18.4)
Calf girth (cm)	31.1	33.1	31.4 (30.7, 31.9)
Training History			
Competitive training years (yrs)	7.3	10.0	7.6 (6.1, 9.1)
Weekly training duration (hrs)	9.5	19.5	12.5 (11.4, 13.8)
Stress Fracture History #	No	Yes	17 (28.8)
Menstrual Function			
Age at menarche (yrs)	13.0	16.0	14.0 (13.5, 14.5)
Bone Mineral Density (Z-scores)			
Total body	0.7	0.8	0.8 (0.6, 1.0)
Lumbar spine (L1-L4)	0.3	0.2	-0.2 (-0.5, 0.1)
Femoral neck	2.0	1.3	1.0 (0.8, 1.2)
Distal radius	-1.2	-0.3	-0.7 (-0.9, -0.6)
Bone Geometry			
CSA (mm ²)	154	177	155 (150, 160)
Min neck width (mm)	25.8	30.6	28.5 (28.0, 29.1)
Section modulus (mm ³)	529	801	641 (610, 671)
Isometric knee extensor force (kg)			
Peak right	38.6	42.7	38.8 (37.0, 40.5)
Peak left	35.5	28.3	36.9 (35.0, 38.8)
Dietary Intake			
Total energy (kcal)	3350	2008	2668 (2426, 2911)
Carbohydrates (%)	51	40	54 (53, 56)
Protein (%)	18	21	19 (17, 20)
Fat (%)	31	39	27 (25, 29)

Eating Psychopathology and Exercise Cognitions

EDE-Q (global Score)	0.4	3.0	1.4 (1.1, 1.7)
CET (Global Score)	1.9	3.3	2.6 (2.4, 2.7)

All results reported for the stress fracture cases as the mean and for the non-stress fracture group mean (95% CI) than otherwise stated.

reported as number of athletes with a history of stress fracture (%)

Figure 1: Illustrates the baseline recruitment and overall withdrawal rate of the study.