

The Body Mass Index: the Good, the Bad, and the Horrid

BARRY BOGIN AND INES VARELA-SILVA

Centre for Global Health and Human Development, School of Sport, Exercise and Health Sciences, Loughborough University, United Kingdom

Summary

The Body Mass Index (BMI) was developed to estimate the risk for overweight in large samples of people from the wealthy, heavily industrialized nations of Western Europe and North America. When used for this purpose the BMI is, generally, a good tool to estimate overweight. The BMI is a bad tool when used to estimate fatness prior to the onset of the obesity epidemic in 1980 because BMI cannot distinguish between fat and lean tissue and there was, generally, lower levels of fatness in the general population before that date. The BMI is also a bad tool when used to estimate fatness for individuals in any nation or in any group of people. The BMI was never intended to be used for individual diagnosis. The BMI becomes a horrid tool to estimate fatness or health risk when used in some groups of people, such as high-level athletes, body building enthusiasts, people engaged in jobs with strenuous physical activity, and in groups suffering from the nutritional double-burden of very short stature with high body fatness.

Keywords: BMI, body composition, nutritional dual-burden, Maya

Introduction

*There was a little girl,
Who had a little curl,
Right in the middle of her forehead.
When she was good,
She was very good indeed,
But when she was bad she was horrid.*

By Henry Wadsworth Longfellow, 1807–1882

The Body Mass Index, abbreviated BMI, is a widely used ratio of weight-for-height. BMI is calculated as [weight in kilograms / (height in meters)²]. Similar to the subject of Longfellow's poem, when BMI is used appropriately it is 'very good indeed.' When BMI is used inappropriately the consequences range from 'bad to horrid'.

The 'Good' of BMI

Lambert Adolphe Quetelet (1796–1874) published the first statistically complete studies of the growth in height and weight of children. Quetelet was the first researcher to make use of the concept of the "normal curve" (commonly called today the normal distribution or "bell-shaped" curve) to describe the distribution of his growth measurements, and he also emphasized the importance of measuring samples of children, rather than individuals, to assess normal variation in growth. In 1832 Quetelet proposed that normal body weight

measured in kilograms was proportional to the square of the height measured in meters (Quetelet 1832). This ratio was given the name Quetelet Index (QI). By the mid-20th Century the QI or other related weight-for-height ratios were used by some human biology researchers to assess fatness and by the life insurance industry to apportion risk and insurance premiums (Dublin *et al.* 1937, Billewicz *et al.* 1962, Khosla and Lowe 1967).

Eknoyan (2008: p 48) reviews the use of Quetelet's Index and reports that, "One of the first studies to confirm the validity of the Quetelet Index in epidemiological studies comprised data gathered during the fourth examination of the Framingham study [Florey 1970]. In a subsequent comparative study of available indices of relative weight and obesity published in 1972, Ancel Keys (1904–2004) confirmed the validity of the Quetelet Index and named it the Body Mass Index (BMI) ..." (Keys *et al.* 1972). The importance of the Framingham Study must be stressed. It was one of the first well-designed epidemiological investigations of the causes of heart disease, which was then, as now, a major public health concern. The prominence of Ancel Keys in nutritional science and public health policy must also be stressed. Together, the fear of heart disease and the reputation of Keys elevated the BMI to international prominence.

Higher BMI scores indicate that an individual has relatively more weight-for-height than a person with a lower score. The value of BMI indicates only this and does not provide any information about body

composition, that is, relative amounts of lean tissue versus fat tissue. Even so, in the general population of the wealthier nations of Europe, North America, Australia, New Zealand, and Japan a higher BMI score usually indicates more body fatness. This is due to the lack of physical activity and, often, excessive food consumption of the majority of people in these nations. In special groups within the population, such as highly trained athletes or body building enthusiasts, a higher BMI score may be due to increased muscle mass. In the middle and low income nations of Africa, Asia, and the Americas the transitions in diet and labor patterns which emulate those of the rich nations are bringing about greater fatness of the population. In general, BMI serves well to assess this rising tide of fatness, overweight and obesity.

The 'Bad' of BMI

This application of BMI may be useful to assess relative fatness for large groups of people, but the BMI of individual people should not be interpreted in this manner. Quetelet never intended that his Index be used for individuals – he developed the index for large samples so that he could construct and interpret the distribution of height-for-weight along normal curves. Keys *et al.* (1972) warned that the BMI should not be used for individual diagnosis due to complex effects of age and sex in the mathematical determination of the value of the BMI and the poor precision of that value to predict health problems of an individual. Today we know that ethnicity also has important effects on the determination of BMI values, desirable weight, and fatness (Razak *et al.* 2007). Indeed, sex, age, and ethnicity all interact to further confound the meaning of individual BMI values.

There are many critiques of the misuse of BMI when applied to individuals. Ross and Eiben (2002: p. 49), "...draw attention to some embarrassing evidence..." in the literature showing that a common BMI scale for men and women is a mathematical artifact which does not relate to empirical biology, that BMI may not predict the sum of skinfolds much better than chance, and that BMI cannot distinguish fat from muscle. A graph available online at http://en.wikipedia.org/wiki/File:Correlation_between_BMI_and_Percent_Body_Fat_for_Men_in_NCHS%27_NHANES_1994_Data.PNG, prepared by Mark Warren and based on data from Romero-Corral *et al.* (2006), shows that use of the BMI mis-classifies the body fatness of 24.6% of adult men in the United States measured for the National Health and Nutrition Examination Survey, 1994 (sample size = 8550). Some

men are classified by BMI as having excess adiposity when by more direct measures of %body fat they are within the desirable range, while others have 'normal' BMI with excess fatness.

Despite the inappropriateness of BMI for use with the individual person it continues to be used in this way quite commonly in research and clinical practice. One researcher/practitioner writes, "The best documented measure of obesity is the body mass index (BMI)... which is now used almost universally in adults and increasingly in children" (Cole 2003). It is easy to find online BMI calculators which allow people to discover their BMI and use this value to diagnose their risk for heart disease, diabetes, anorexia nervosa and other ailments without any professional medical supervision. BMI is everywhere. A search of PubMed using the term 'BMI' finds 60,840 articles dating back to 1978. A search using the terms 'BMI + fatness' scored 21,588 results, the first on the list being titled, *Body Mass Index and Calculator: Understand Calorie Count of Important Foods and Keep Meals Under 300 Calories* by Steve Ryder. Assuming that Ryder's use of 'Calories' mean kilocalories, the first author of this paper (BB) would need to eat nine such 300 kcal meals a day to meet his energy needs.

A good deal of skepticism in the BMI was generated by the work of Stanley Garn (1922–2007). Garn was our colleague at the University of Michigan and by the late 1970s he was voicing concern about the misuse of the BMI. A few years later he published the article "Three limitations of the body mass index" (Garn *et al.* 1986). The three limitations of BMI to assess fatness are: 1) BMI is not independent from stature. As a ratio, the calculation of BMI should yield the same result for all combinations of identical weight-for-height. Garn *et al.* showed this is not true as there is a change in the correlation between stature and the BMI from about +0.30 for children to an average of -0.12 for women 20–39 years old; 2) people of the same height have different BMI values according to frame size and relative leg length. People with narrower chests and/or longer legs relative to their total height have lower BMI values; 3) the BMI cannot distinguish between the amount of lean tissue and fat tissue of a person's body. This is not only a problem for athletes versus sedentary people of the same height and weight but also is part of the cause for ethnic, age and sex effects on the BMI.

All three of the limitations highlighted by Garn and colleagues are, in fact, interrelated. Greater stature may be associated with a narrower skeletal frame, and frame size may be associated with total muscle mass. The effects of relative leg length have been especially well studied and subsequent work confirms that when

matched for total stature, the people with relatively short legs have higher BMI regardless of their percentage of body fatness (Norgan and Jones 1995, Deurenberg and Deurenberg-Yap, 2003, Bogin and Beydoun 2007, Bogin and Varela-Silva 2008). The study by Bogin and Beydoun analyzed the data for adults 20.00–49.99 years old from the Third National Health and Nutrition Examination Survey, 1988–1994. This is a nationally representative population survey and includes men and women of European (White), African (Black) and Mexican ancestry. The relative leg length effect on the BMI is statistically significant for both sexes and all three ancestry/ethnic groups. It is important to note, however, that in terms of statistical magnitude the most important variable associated with the BMI of these people is the sum of four skinfolds (subscapular, triceps, suprailiac, thigh). The ‘sum of skinfolds’ variable explains about 74% and 87% of the variance in BMI values in the different combinations of sex-ancestry (e.g. Black women, Mexican men, etc.). This lends credence to the ‘good’ of BMI. The relative leg length variable explains an additional 4% of the variance in BMI, and this hints at the ‘bad’ of BMI.

Even though the statistical effect size of relative leg length on BMI is small, compared with the effect of fatness as measured by skinfolds, that effect is both statistically and biologically real and important. In the United States men and women with relatively shorter legs carry more subcutaneous fat, as measured by the sum of four skinfolds, than adults with relatively longer legs. Why this is so is not understood at present. Bogin and Beydoun (2007) offer a possible explanation based on research in human life history biology. In brief, they propose that poor nutrition and health during the pre-natal, infancy and childhood stages of growth results in relatively shorter legs and a modified physiology which tends to store body fat when excess energy is available (Varela-Silva *et al.* 2007, Bogin and Varela-Silva 2010). No matter what the cause, the leg length effect, along with sex, ethnicity, age, physical activity and many other factors may help explain why the adiposity of nearly 25% of men in the United States is mis-classified by BMI.

The ‘Horrid’ of BMI

In the second edition of the book *Patterns of Human Growth* (Bogin 1999) the BMI is mentioned only nine times across 398 pages of text. The nine references are all in relation to an analysis of The National Child Development Study of the Great Britain, a longitudinal study of growth in height and weight. Data from this

study are based on the population of all infants born in England, Scotland, and Wales during March 3rd to 9th, 1958. Lasker and Mascie-Taylor (1989) published the mean height, weight, and BMI of these boys and girls at ages seven, 11, and 16 years stratified by the social class of the male head of household. Lasker and Mascie-Taylor (1996) also published mean heights at age 23 years for these same samples. There are two to three thousand individuals in each age group. “In Britain, social class is officially ascribed on the basis of the occupation of the male head of the household ... the Registrar General’s 5-fold class designations ... are ... social class I – professional; II –intermediate; III –skilled; IV – semi-skilled; and V – unskilled ...” (Lasker and Mascie-Taylor 1989, p. 1). Lasker and Mascie-Taylor find that mean stature and weight are significantly related to social class, and decline, generally, from social class I and II to V at each age (Figure 1 A and B). Male or female sex is also a significant influence on height and weight, with girls and women being, on average, shorter and lighter than boys and men. There was no SEX by SES interactions in any statistical analysis, and only the data for males are shown here. The statistical impact of the social class effect on stature and weight is achieved by age seven years, and is then maintained through age 23 years.

In contrast to the SES related pattern for height and weight by social class over time, BMI follows a different trend. At age 7 and 11 years all social classes are about equal, with classes II and IV at bit higher than the others. Between ages 11 and 16 years there is a clear change in the pattern for mean BMI values. Lasker and Mascie-Taylor report that the three lower social classes, III, IV, and V, have greater increases in BMI compared with social classes I and II. The change in BMI by social class, “... is due mostly to the taller stature of social class I [and II] youths of both sexes, not to the obesity of those of [lower] social class ...” (p. 5). None of the social classes is obese in the current usage of that word, so I believe the authors mean the fatness of the different social classes when using the word ‘obesity.’ Indeed, none are ‘fat’, that is overweight, by current references for BMI. The range of mean BMIs at age 16 years for all social classes is 19.9 – 21.1, which are at or below the 50th percentile of BMI for 16 year olds in the United States measured from 1971 to 1980 (Frisancho 1990). BMIs in this range are considered ‘healthy.’

One question from these British data is, if greater BMI is not measuring fatness then what is it measuring? A possibility is a hypothesis offered by Christian Aßmann and Michael Hermanussen (in press) that there is a socially and psychologically influenced community-based target for height and other body size dimensions.

Their hypothesis builds on empirical research that Insulin-like Growth Factor-1 (IGF-1) levels in the blood are associated with social position. IGF-1 is a major promoter of cellular growth and people with more IGF-1 during the years of growth are generally taller. Kumari *et al.* (2008) measured IGF-1 levels in the participants of the 1958 British Birth Cohort – the same sample analysed by Lasker and Mascie-Taylor (1989). Kumari *et al.* looked for associations of IGF-1 with the social position of the participants as measured by their father's or their own occupational class at three time points in childhood and adulthood. They found that low social position is associated with lower levels of IGF-1. Other research finds that social subordination that is associated with depression or low mood in children depressed IGF-1 production (Aßmann and Hermanussen, *in press*). It is possible that IGF-1 is a biomarker which plays an important role in the development of social differences in height, body mass and body composition.

It is also likely that the opportunities for physical activity in play, physical education, and paid labor for the different social classes of these British boys between the ages of 11 and 16 years had a strong effect. The lower social classes likely gained more lean tissue, especially muscle, than did the upper social classes. This would raise BMI, but the BMI cannot tell us if this is the case. As a prominent advocate of the use of BMI writes, "But BMI is actually less than ideal for measuring obesity, as it fails to distinguish between fat mass and muscle mass. When the incidence of obesity first started rising, it is likely that the increase in fat mass was masked by a corresponding reduction in muscle mass. This is particularly true for child obesity, where reduced physical activity, notably time spent watching television, is an important risk factor for obesity. So, the rise in child obesity probably started earlier than 1980, though BMI did not reflect it until later" (Cole 1993, p 165). If this is true, then BMI is not even a good screening tool when used for large population surveys as it fails to detect changes in fatness until it is 'too late' to take preventative action.

Current research in Mexico by our research team reveals a final 'bad to horrid' example of BMI. This example is based on our article, "How Useful Is BMI in Predicting Adiposity Indicators in a Sample of Maya Children and Women with High Levels of Stunting?" (Wilson *et al.* 2011). The applicability of BMI to populations with high levels of stunting has been questioned. Stunting refers to short stature for age and when it occurs in groups of people the stunting is usually caused by inadequate nutritional balance and/or lack of specific essential nutrients. Stunted people can have low levels of body fat, but normal amounts of muscle tissue

for their height. Stunted people may also have disproportionately short legs and a relatively larger trunk length for their height. Any or all of these effects of stunting may increase BMI without an associated increase in body fat.

Our research team includes members from the Centro de Investigacion y de Estudios Avanzados del Instituto Politecnico Nacional (Cinvestav) in Merida, Mexico and Loughborough University in the United Kingdom. We are working with participants from the Maya ethnic group of the Yucatan Peninsula. Our overall research goal is to understand why the Maya people, both children and adults, show high levels of stunting and at the same time high levels of overweight. This combination of short stature and high fatness is known as the nutritional dual-burden. In principle, any group of people that has enough energy intake to grow in fatness should also have enough energy intake to also grow in stature. But, the Maya of Mexico and Central America remain stunted. The Maya are the most numerous of Native American peoples, with between 7–8 million Maya alive today. In rural areas of Mexico and Guatemala the rates of stunting for the Maya exceed 70% of all people.

For one of our projects we recruited a sample of 57 urban Maya schoolchildren, aged 7–9 years (31 boys), and 53 of their mothers, mean age 34.44 (sd = 6.3) years. All of the children and their mothers underwent anthropometric assessments as well as bioelectrical impedance analysis (BIA). The use of BIA is considered a reliable and accurate method to assess percent body fatness (%BF) under fieldwork conditions. Multiple linear regression was performed to determine whether the ability of BMI to predict variation in other adiposity indicators is altered by stunting and sitting height ratio (SHR = sitting height \times 100/total height). The adiposity indicators we used were waist circumference (WC), sum of the triceps and subscapular skinfolds (SSF), upper arm muscle area (UAMA), upper arm fat area (UAFA), and arm fat index (AFI).

We found that 18 (31.6%) of the children were stunted. In all children, BMI significantly predicted measures of abdominal fatness (WC) and total body adiposity (%BF, SSF) but not peripheral adiposity (UAFA, AFI). Stunting status did not modify the power of BMI to predict adiposity indicators. Relative leg length neither significantly moderated nor mediated the effect of BMI on adiposity outcomes. These findings suggest that BMI is an appropriate tool to estimate total and central adiposity in this sample of 7–9-year-old children, but that BMI fails to predict their fatness when only arm anthropometry is measured. This is an important finding because in practice the most common

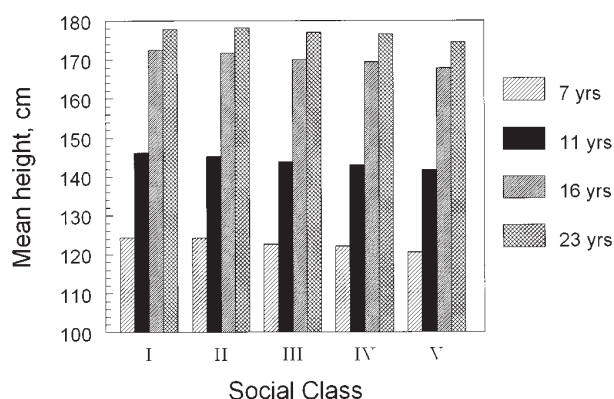


Fig. 1: Mean height of boys born in March 1958 in England, Scotland, and Wales by social class of their father (or male head of the household). Original figures based on data from Lasker and Mascie-Taylor (1989, 1996).

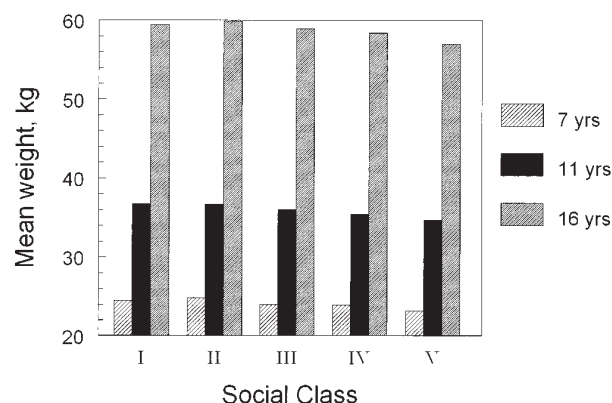


Fig. 2: Mean weight of boys born in England, Scotland, and Wales by social class of their father (or male head of the household). Original figures based on data from Lasker and Mascie-Taylor (1989).

anthropometric measures of nutritional status and health are height and weight, and then arm circumference and triceps skinfold. A lack of correspondence between height and weight, used to calculate BMI, and arm anthropometry would lead to incorrect assessments and ineffective interventions to improve health.

In women, BMI significantly predicted abdominal adiposity (WC) but not peripheral (AFA, AFI) or total body adiposity (%BF). Stunting independently predicted a higher %BF, but did not change the association between BMI and adiposity indicators in any regression model. Relative leg length was neither significant nor altered the association between BMI and any adiposity indicator. BMI appears to be appropriate for use in these adult urban Maya women only to predict abdominal adiposity. Maternal %BF as measured by bioelectrical impedance (BIA) was not well predicted by the BMI. The Maya women participating in our study had BMIs in the range of 25–29.99, which suggests overweight but not obesity. However, the %BF of these women was very high with a mean of 42% as measured by BIA. As such, it is clearly not appropriate to use BMI alone to predict %BF in this sample of adult urban Maya women. If the BMI is used, then it grossly underestimates the levels of obesity in these women and may eliminate them from programs to lower body fatness and improve health.

Conclusion

The Body Mass Index was developed to estimate the risk for overweight in large samples of people from the

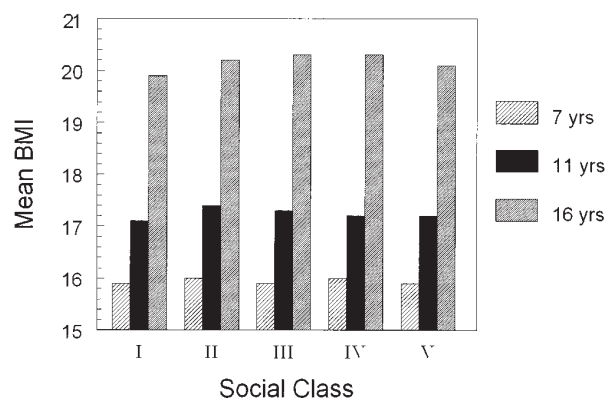


Fig. 3: Mean BMI scores of boys born in England, Scotland, and Wales by social class of their father (or male head of the household). Original figures based on data from Lasker and Mascie-Taylor (1989).

wealthy, heavily industrialized nations of Western Europe and North America. When used for this purpose the BMI is, generally, a good tool to estimate overweight. It may be a good tool to estimate fatness in these same groups of people since the advent of the obesity epidemic, that is, since about the year 1980. The BMI is a bad tool when used to estimate fatness prior to 1980 because BMI cannot distinguish between fat and lean tissue and there was, generally, lower levels of fatness in the general population before that date. The BMI is also a bad tool when used to estimate fatness for individuals in any nation or in any group of people. The

BMI was never intended to be used for individual diagnosis. The BMI becomes a horrid tool to estimate fatness or health risk when used in some groups of people, such as serious athletes, body building enthusiasts, people engaged in jobs with strenuous physical activity, and in groups suffering from the nutritional double-burden of short stature with high body fatness. The Maya people of Merida, Mexico are just one example of this last problem with the BMI. Unfortunately, the majority of low income people in the lesser developed nations of the world are suffering from or at risk to the nutritional double-burden. This makes the BMI a very poor instrument for epidemiological assessment and the apportionment of health intervention resources for the most at-risk segments of the world's population.

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Figures origin

Fig. 1

Original figures based on data from Lasker and Mascie-Taylor (1989, 1996).

Figs 2–3

Original figures based on data from Lasker and Mascie-Taylor (1989).

Address:

Barry Bogin
Centre for Global Health and Human Development
School of Sport, Exercise and Health Sciences
Loughborough University
United Kingdom LE11 3TU
Email: b.a.bogin@lboro.ac.uk
Tel.: (0)1509 228819