International Journal of Obesity (2008) 32, S56–S59
 0307-0565/08 $30.00
www.nature.com/ijo

ORIGINAL ARTICLE

BMI-related errors in the measurement of obesity

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Body mass index (BMI) has various deficiencies as a measure of obesity, especially when the BMI measure is based on self-reported height and weight. BMI is an indirect measure of body fat compared with more direct approaches such as bioelectrical impedance. Moreover, BMI does not necessarily reflect the changes that occur with age. The proportion of body fat increases with age, whereas muscle mass decreases, but corresponding changes in height, weight and BMI may not reflect changes in body fat and muscle mass. Both the sensitivity and specificity of BMI have been shown to be poor. Additionally, the relation between BMI and percentage of body fat is not linear and differs for men and women. The consequences of the errors in the measurement of obesity with BMI depend on whether they are differential or nondifferential. Differential misclassification, a potentially greater problem in case–control and cross-sectional studies than in prospective cohort studies, can produce a bias toward or away from the null. Nondifferential misclassification produces a bias toward the null for a dichotomous exposure; for measures of exposure that are not dichotomous, the bias may be away from the null. In short, the use of BMI as a measure of obesity can introduce misclassification problems that may result in important bias in estimating the effects related to obesity.
International Journal of Obesity (2008) **32**, S56–S59; doi:10.1038/ijo.2008.87

Keywords: measurement error; body mass index; misclassification; bias

Introduction

Body mass index (BMI) as a measure of obesity is imperfect. First introduced in the mid-1800s, BMI—an index based on height and weight—has been used to measure body fat. Although it is an indirect measure, research results suggest that it is correlated with direct measures such as underwater weighing (densitometry) and dual-energy x-ray absorptiometry (DEXA).

As a measure of body fat, however, BMI has serious flaws. It does not, for example, take age, sex, bone structure, fat distribution or muscle mass into consideration. For these reasons and others, BMI can misrepresent the quantity it is used to measure. There are three main issues to consider when using BMI, namely (1) errors stemming from the fact that BMI is an indirect measure of obesity, (2) errors in self-reported data and (3) the poor sensitivity and specificity of BMI. These problems result in misclassification of individuals with respect to body fat, and that misclassification, can in turn, introduce bias in studies that deal with body fat, such as those estimating the effects of obesity on health outcomes.

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An indirect measure of obesity

BMI is defined as weight divided by height squared (kg/m^2). As it is based on only weight and height, BMI does not measure body fat directly. As an indirect measure of obesity, BMI has several drawbacks. For example, a person's percentage of body fat is known to increase with age, whereas muscle mass decreases, but the person's weight and height do not necessarily reflect such changes in body fat and muscle mass (Figure 1). Some elderly persons who are portly but have low muscle mass have normal or even low BMI scores, an underestimation of body fat. Also, lean persons with high muscle mass, such as athletes, sometimes have high BMI scores, an overestimation of body fat.

Furthermore, the relation between BMI and percentage of body fat is nonlinear, which gives the impression that some people with considerably different BMIs have identical or nearly identical percentages of body fat. Another problem is that the correspondence between BMI and body fat differs for men and women. That is, a man and woman could have the same height and weight and thus have identical BMI scores, but the woman would most likely have a greater percentage of body fat (Figure 2).

Self-reported data

Self-reported data are often inaccurate. The use of self-reported height and weight leads to considerable errors in studies relying on BMI,[3] in contrast to the use of data

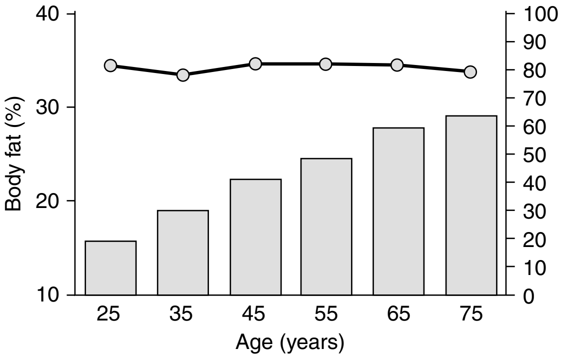

Figure 1 Body fat (columns, measured against left *Y*-axis) increases and muscle mass decreases with age. Weight (line, measured against right *Y*-axis), height and BMI may not reflect these changes.[1] Copyright, Institute of Physics and Engineering in Medicine, 1987. Reproduced with permission.

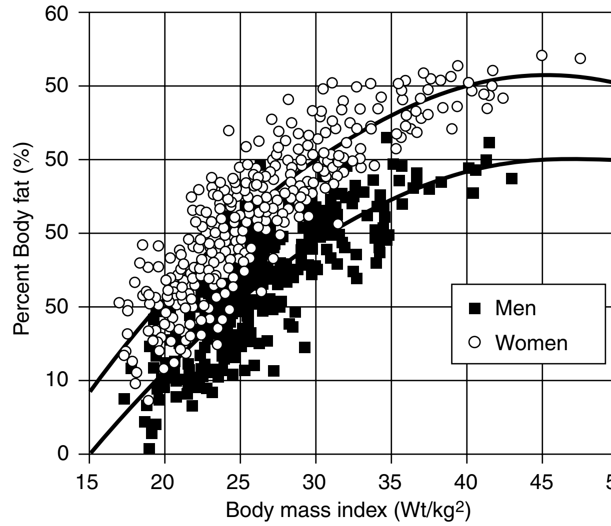

Figure 2 The relation between BMI and percentage of body fat is not linear and differs for males and females. Reproduced from Jackson *et al.*[2] with permission.

obtained through more objective measurements, such as DEXA, which use x-rays to measure total body fat content; impedance, which is based on instruments used to measure percentage of body fat; and densitometry.

Sensitivity and specificity of BMI

In one study,[4] the investigators, using either DEXA or densitometry as the reference method, compared BMI and an impedance-based measurement of body fat percentage. They defined obesity as percentage of body fat greater than 25% in men and 35% in women. They found considerable error when using BMI as a measure of obesity. Regarding specificity, 8% of all men and 7% of all women were incorrectly classified as obese using standard BMI cutoff points. Corresponding values for the impedance-based method were 5% of men and 4% of women. Sensitivity was even worse. About 41% of men and 32% of women had false-negative results using BMI. The impedance methods produced false-negative results for 44% of men and 24% of women.

Effects of errors in measurement

When assessing obesity and its health effects, the consequences of errors in measuring BMI depend on whether the errors are differential (dependent on other study variables) or nondifferential (independent of other study variables). If body fat is overestimated or underestimated to a greater extent for people who are counted in the numerator of an outcome measure than for those in the denominator, then the potential for bias may be much worse than if there is nondifferential error. The bias could be in either direction and may be difficult to assess except through reasonable sensitivity analyses.

Differential misclassification is a greater problem in case–control and cross-sectional studies than in prospective cohort studies. It is less of a problem in cohort studies because, if BMI is determined before the outcome develops, errors in BMI are not likely to be related to the outcome or to errors in measuring the outcome. Nevertheless, the relevant BMI information may be much closer in time to the outcome than baseline values of BMI, and if measures of the relevant BMI values are obtained, they may come at a time when there are predictors of the outcome already present that could make the errors differential. For example, people at high risk of cardiovascular disease could overestimate or underestimate their weight to a greater extent as they become aware of their risk status. Thus, cohort studies could also face differential misclassification.

Nondifferential misclassification may produce a bias toward the null for a dichotomous exposure. Misclassification of a dichotomous exposure metric can be defined by its sensitivity and specificity in measuring true exposure. For BMI, which has poor sensitivity and specificity for measuring obesity, there can be substantial bias toward the null when using it as a measure of obesity.

Consider a hypothetical case in which no errors are made in measuring obesity in a population of 1 million people, of whom 5% are actually obese. Suppose the risk of a given outcome (such as death within a certain time period) is 2% in obese people and 1% in those who are not obese; in other words, obesity doubles the risk of the outcome. The risk ratio is 2.0, and the risk difference is 1%. The attributable proportion is 50% in the obese population but is slightly less than 2.5% in the population as a whole, assuming that no confounding factor is present (Figure 3).

If the true risk ratio, with perfect sensitivity and specificity, is 2.0, then the risk ratio is affected very little as the sensitivity of the BMI measure decreases. Note that if sensitivity decreases so that, for example, only half of those

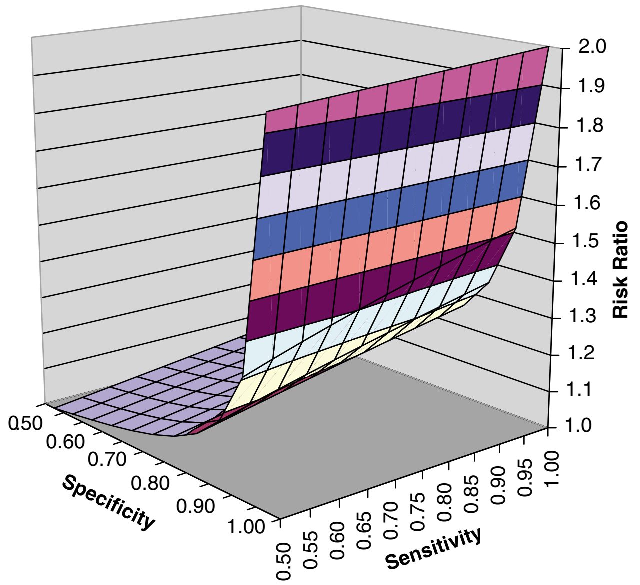

Figure 3 Bias in the risk ratio from nondifferential misclassification of a dichotomous exposure indicator as a function of its sensitivity and specificity.

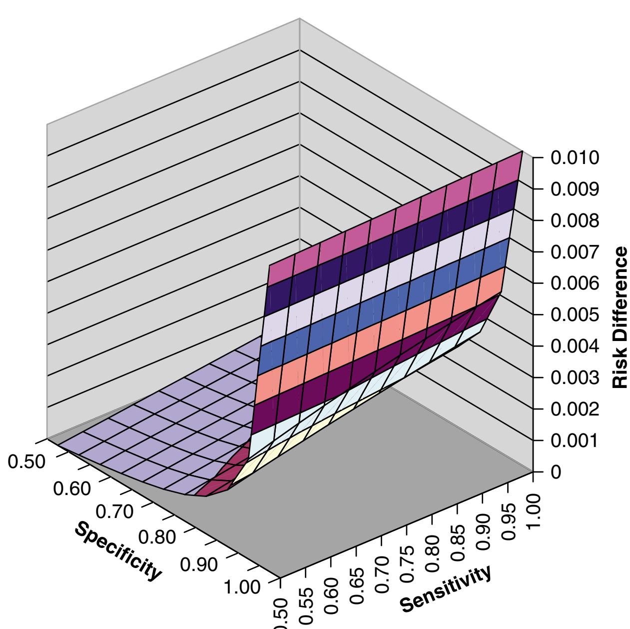

Figure 4 Bias in the risk difference from nondifferential misclassification of a dichotomous exposure indicator as a function of its sensitivity and specificity.

who are obese are identified, the relative risk will still be determined to be 2.0 (assuming that 2.0 is the correct value). If the specificity is imperfect, however, the bias is great even for small decreases in specificity because the group of people identified as obese will include many who actually are not. Thus, errors in specificity dilute the risk ratio dramatically. Figure 3 illustrates that the dependence of the risk ratio on

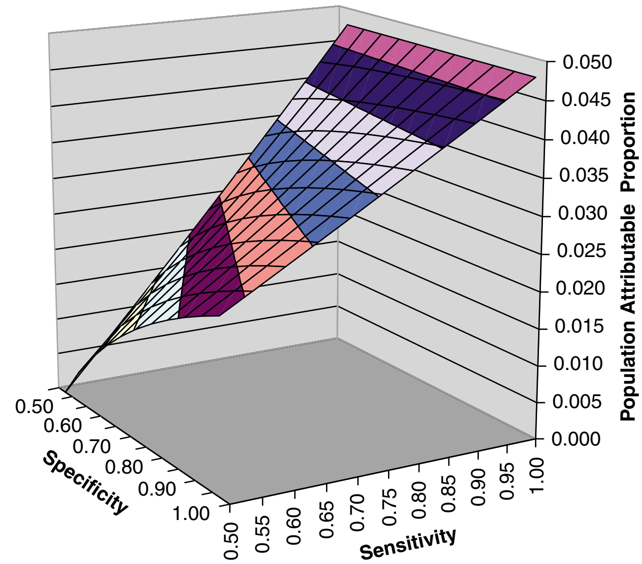

Figure 5 Effect of bias from nondifferential misclassification of exposure on population-attributable proportion.

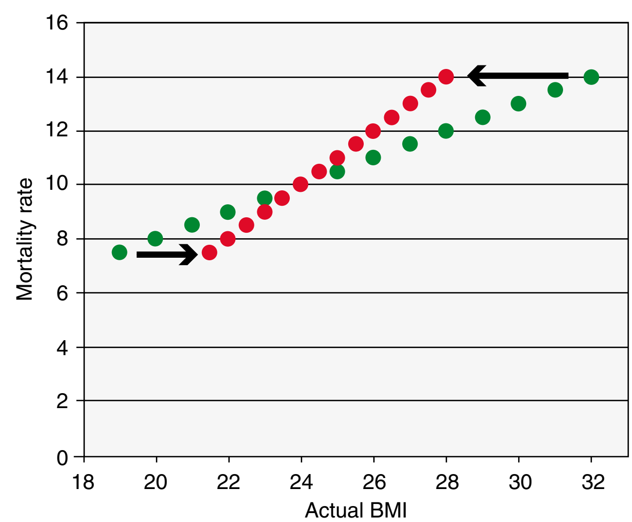

Figure 6 Effect of nondifferential errors in BMI can be a bias away from the null when BMI is not dichotomized. The green points in the figure indicate the true BMI values, and the red points indicate the incorrect values, which are reported as being closer to the average than the true values. The result of such errors is to exaggerate the slope of the relation between BMI and mortality.

specificity is much stronger than the dependence on sensitivity. A similar relation holds for the risk difference (Figure 4).

The situation is different for the population-attributable proportion. If sensitivity is perfect, no bias occurs in this measure, regardless of imperfect specificity, but with decreasing sensitivity, the amount of bias becomes increasingly dependent on specificity (Figure 5). As shown in Figures 3–5, reductions in specificity and sensitivity can produce substantial biases toward the null with nondifferential misclassification.

When the exposure measure is not dichotomous, the effect of nondifferential misclassification is not guaranteed to be a bias toward the null. Suppose that BMI is linearly related to mortality rate, those who had high or low weight reported values closer to the average, with their errors in reporting being proportional to the discrepancy between their actual weight and the average weight. The result would be that the relation between reported BMI and mortality would be an exaggeration of the relation between actual BMI and mortality, as indicated in Figure 6.

Conclusion

BMI as a measure of body fat is inaccurate and can lead to bias in measuring the effects of obesity on health outcomes. Beyond errors stemming from self-report inaccuracies, the problems stem from the fact that BMI does not take into account: (1) the difference between fat and nonfat mass such as bone and muscle; (2) the changes in body composition that occur with age; and (3) the time relation between obesity and the outcome being measured. Any calculations of risk ratios, risk differences or attributable proportions will reflect the error inherent in BMI as a measure of obesity and potentially be biased.

Conflict of interest

The author declared no financial interests.

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