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ORIGINAL ARTICLE

Body Mass Index, the Most Widely Used But Also Widely Criticized Index: Would a Criterion Standard Measure of Total Body Fat Be a Better Predictor of Cardiovascular Disease Mortality?

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Abstract

Objectives: To examine whether an accurate measure (using a criterion standard method) of total body fat would be a better predictor of cardiovascular disease (CVD) mortality than body mass index (BMI).

Participants and Methods: A total of 60,335 participants were examined between January 1, 1979, and December 31, 2003, and then followed-up for a mean follow-up period of 15.2 years. Body mass index was estimated using standard procedures. Body composition indices (ie, body fat percentage [BF%], fat mass index [FMI], fat-free mass [FFM], and FFM index [FFMI]) were derived from either skinfold thicknesses or hydrostatic weighing. For exact comparisons, the indices studied were categorized identically using sex-specific percentiles.

Results: Compared with a medium BMI, a very high BMI was associated with a hazard ratio (HR) of 2.7 (95% CI, 2.1-3.3) for CVD mortality, which was a stronger association than for BF% or FMI (ie, HR, 1.6; 95% CI, 1.3-1.9 and HR, 2.2; 95% CI, 1.8-2.7, respectively). Compared with a medium FFMI, a very high FFMI was associated with an HR of 2.2 (95% CI, 1.7-2.7) for CVD mortality, with these estimates being markedly smaller for FFM (ie, HR, 1.2; 95% CI, 0.9-1.6). When the analyses were restricted only to the sample assessed with hydrostatic weighing (N=29,959, 51.7%), the results were similar, with even slightly larger differences in favor of BMI (ie, HR, 3.0; 95% CI, 2.2-4.0) compared with BF% and FMI (ie, HR, 1.5; 95% CI, 1.2-1.9 and HR, 2.1; 95% CI, 1.6-2.7, respectively). We estimated Harrell's c-index as an indicator of discriminating/predictive ability of these models and observed that the c-index for models including BMI was significantly higher than that for models including BF% or FMI ($P<.005$ for all).

Conclusion: The simple and inexpensive measure of BMI can be as clinically important as, or even more than, total adiposity measures assessed using accurate, complex, and expensive methods. Physiological explanations for these findings are discussed.

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Obesity is a major public health concern in most countries around the world. There is a vast amount of data supporting an increased risk of cardiovascular disease (CVD) mortality and reduced survival associated with overweight and obesity.[1] Although this notion is generally well accepted in public health and clinical settings, the literature on this topic is extremely controversial.[2] In fact, a number of studies have recently reported that in certain conditions, especially in individuals with CVD, obesity might be related to a lower risk of mortality, the so-called obesity-mortality paradox.[3] In addition, the systematic review and meta-analysis performed by Flegal et al[4] concluded that overweight is associated with a reduced risk of mortality as compared with normal weight, whereas mild or class I obesity was associated with a trend toward better survival. Ahima and Lazar[5] discussed this phenomenon and concluded that the effect of a high body mass index (BMI) on mortality is in question and that better metrics are needed.

Before investigating which are the best indices to measure obesity in relation to future

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health, the fundamental question of what obesity really means deserves discussion. Although many scientists and other readers would assert that obesity means an excess of adiposity, measured by body fat percentage (BF%), others would suggest that most of what we currently know about the adverse effects of obesity on health is actually based on BMI-defined obesity. Therefore, obesity could also mean an excess of body weight, which is what BMI directly measures.

Although it is internationally accepted that the definition of obesity is based on BMI (ie, $\geq$30 kg/m^2), this traditional anthropometric index is strongly criticized for its lack of ability to distinguish between fat and lean tissues. There is no doubt that BMI includes an estimation error when assessing total adiposity. Based on this and on the assumption that it is the excess of adiposity that predicts mortality, it would be expected that more accurate measures of total adiposity, such as BF% or fat mass index (FMI; defined as fat mass in kilograms divided by height in meters squared), would be stronger predictors of death than is BMI. For the purpose of the present study, we reviewed the literature on this topic and searched whether there was any study performing a direct comparison of BMI and BF% as predictors of CVD mortality or all-cause mortality. We found that most longitudinal studies examining mortality outcomes have used BMI as an exposure for a simple reason that weight and height are easy and inexpensive to measure. In addition, to perform exact comparisons, both variables should be handled statistically in an identical way (eg, sex-specific percentiles); using standard cut points (eg, BMI $\geq$30 kg/m^2 and BF% $\geq$25 for men or $\geq$35 for women for obesity) would lead to a different distribution of participants into BMI and BF% groups, which would hamper accurate and direct comparisons. In this context, the Aerobics Center Longitudinal Study (ACLS) includes an accurate measure of total body fat (ie, using a criterion standard method in $\sim$30,000 men and women) as well as BMI in the baseline examination,[6-8] providing a unique opportunity to address the present study question. The present study, therefore, aimed to examine whether an accurate measure of total body fat would be a better predictor of CVD mortality and all-cause mortality than is BMI. In addition, we tested which of the following conditions more strongly predict CVD mortality and all-cause mortality: an excess of body weight, an excess of body fat, or an excess of fat-free mass (FFM).

PARTICIPANTS AND METHODS

Study Design and Participants

The ACLS is a prospective epidemiologic investigation of adult men and women[7,9,10]; participants are mostly whites (98%), are well-educated, and have worked in executive or professional positions.[11] All participants completed a detailed questionnaire and underwent an extensive clinical evaluation, including physical examination, fasting blood chemistry analyses, personal and family health history, body composition, smoking and alcohol use, and a maximal exercise treadmill test between January 1, 1979, and December 31, 2003. All participants provided written informed consent, and the study protocol was approved annually by the institutional review board of the Cooper Institute.

Exclusion criteria for the present analyses were as follows: (1) existing CVD or cancer at baseline (n=1021, 1.6%); (2) less than 1 year of follow-up (n=1064, 1.7%); and (3) incomplete data on BMI, BF%, and all confounders (n=1272, 2.0%). The rationale why participants with less than 1 year of follow-up were excluded is based on the fact that persons dying during the first year are likely to have a preexisting occult disease that confounds the relation between the risk factor under study and mortality. Excluding persons dying during the first years of follow-up purportedly reduces this confounding effect and is a widely used technique especially in the field of obesity.[12] Based on these criteria, a total of 3357 participants (5.3%) aged 20 years or older at baseline were excluded. The final sample included 60,335 participants (26.7% women) for the analyses.

Baseline Examination

As described previously,[9] height and weight were measured using a stadiometer and a standard scale. Waist circumference (WC) was obtained at the level of the umbilicus with a plastic anthropometric tape. Body mass index was calculated as weight in kilograms divided

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