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Validity of weight loss to estimate improvement in body composition in individuals attending a wellness center

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Abstract

The accuracy of weight loss in estimating successful changes in body composition (BC), namely fat mass loss, is not known and was addressed in our study.

To assess the correlation between change in body weight and change in fat mass (FM), fat % and fat-free mass (FFM), 465 participants (41% male; 41±13years), who met the criteria for weight change at a wellness center, underwent air-displacement plethysmography. Body weight and BC were measured at the same time. We categorized the change in body weight, FM and FFM as an *increase* if there was >1 kg gain, a *decrease* if there was >1 kg loss and *no change* if the difference was ≤1 kg. We estimated the diagnostic performance of weight change to identify improvement in BC. After a median time of 132 days, 255 people who lost >1 kg of weight, 216(84.7%) had lost >1 kg of FM, but 69(27.1%) had lost >1 kg of FFM. Of the 143 people with no weight change, 42(29.4%) had actually lost >1kg of FM. Of the 67 who gained >1 kg of weight at follow-up, in 23(34.3%) this was due to an increase in FFM but not in FM. Weight change had a NPV of 73%. Mean weight change was 2.4 kg.

Our results indicate that favorable improvements in BC may go undetected in almost 1/3 of people whose weight remains the same and in 1/3 of people who gain weight after attending a wellness center. These results underscore the potential role of BC measurements in people attempting lifestyle changes.

Introduction

Obesity represents a national epidemic with two-thirds of the US population being obese or overweight. [1] It has been well established that obesity is linked to increased health risks and mortality. [2, 3] Attempts to reduce the obesity epidemic have focused on weight loss programs composed of a restrictive-caloric diet, physical activity, pharmacotherapy, surgery

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Disclosures

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or a combination of these. [4] Currently, major health organizations promote a combination of a healthy diet and exercise to prevent type 2 diabetes, cardiovascular diseases and many other ailments. Given the public health significance of obesity, it is not surprising that the percentage of people attempting lifestyle changes has increased over the last three decades. [5, 6] Interestingly, physical activity has shown to significantly improve cardiovascular risk factors despite little or no weight loss, suggesting that those who start an exercise program may lose fat and gain muscle mass without a substantial net change in weight. [7, 8] In contrast, weight loss through very low-caloric or liquid protein diets and surgery have been associated with loss of lean mass with minimal change in body fat percent and an increased risk for sarcopenia. Therefore, it is very plausible that individuals who start an exercise program, or restrict their caloric intake would receive an inaccurate estimation of change in their body composition (BC) when using body weight alone. [9, 10] In support of this premise, several studies have challenged the diagnostic accuracy of the BMI to identify adiposity. [11, 12] It has been shown that within the same category of BMI, inactive individuals have larger waist circumferences than their active counterpart. [13] A recent meta-analysis of the performance of BMI to identify adiposity showed a high specificity but a low sensitivity to identify excess adiposity, misdiagnosing nearly 50% of the people in the pooled estimates of diagnostic accuracy. [14] However, few studies have actually looked at the accuracy of using BMI longitudinally to detect favorable changes in BC. [15] The objective of this study was to examine the accuracy of body weight and BMI changes to identify improvement in BC as measured by air-displacement plethysmography (ADP).

Methods and Procedures

Subjects

Participants in this retrospective cohort were adults attending the Mayo Clinic Dan Abraham Healthy Living Center, an onsite wellness facility that promotes aerobic fitness, healthy nutrition, musculoskeletal conditioning, as well as weight and stress management to approximately 16,000 members. Members are eligible for BC testing at any time during their enrollment at the wellness center, free of charge. In our study, we identified all consecutive BC tests by ADP using the BOD POD (Life Measurement Instruments; Concord CA.) In addition, we restricted the analysis to participants who were ≥ 18 years old who had a minimum of 2 measurements of BC at least 1 month apart but no more than 12 months apart. For standardization purposes, if more than 2 tests were available we chose the first test and the test closest to the membership follow-up survey.

All participants were instructed to avoid eating 4 hours prior to testing, to limit caffeine and nicotine intake 4 hours prior to the test, and to avoid strenuous physical activity 12 hours prior to the test. The study was approved by the Institutional Review Board at Mayo Clinic.

Anthropometric Measurements

Height was measured in centimeters and rounded to the nearest 0.5 cm against a wall stadiometer (seca gmbh & co.kg., Hamburg, Germany) with the subject in the standing position without shoes. Participants were weighed on an electronic scale (Tanita Corporation; Tokyo, Japan) with an accuracy of ± 0.01 kg and a resolution of 1 gram, which

is calibrated once every day. Body composition with ADP using the BOD POD was performed with the participants wearing minimal fitting clothing consisting of spandex shorts for males and spandex shorts and tops for females. A swimming cap was worn to minimize hair volume. [16]

The BOD POD was calibrated before each test with the chamber empty and then against a standardized cylinder, giving two calibration points in a linear relationship in which the line can be extrapolated for the unknown volume of the participant. For all participants, a predicted average thoracic volume by Crapo equation was used. According to a study by McCrory, *et al.* [17] there is no significant difference between the measured average thoracic volume and the predicted average thoracic volume in adults. The body volume was measured directly by subtraction of the interior volume of the empty chamber versus the volume when the individual is inside determined by applying the gas law ($p_1V_1=p_2V_2$). Total fat mass (FM) and total fat-free mass (FFM) were calculated by the following

equations: Siri [18], for the general population $\text{Body Fat} = \left(\frac{4.95}{\rho} - 4.50 \right) \times 100$, Brozek [19], for participants with a BMI > 40 $\text{Body Fat} = \left(\frac{4.57}{\rho} - 4.142 \right) \times 100$. Schutte [20], for African American males $\text{Body Fat} = \left(\frac{4.374}{\rho} - 3.928 \right) \times 100$ and Ortiz [21], for African American females $\text{Body Fat} = \left(\frac{4.83}{\rho} - 4.37 \right) \times 100$. These formulas are based on the 2 compartment model that assumes the body is composed only of FM and FFM, the latter including mineral, aqueous and protein. The equations translate total body density (ρ) into percent body fat. Percent lean mass is then calculated by subtracting the percent body fat from 100 percent. FM and FFM mass in kilograms are calculated by dividing the corresponding percentages by 100. Although this method would overestimate fat mass in a person with a mineral density higher than average, it is highly reproducible with variations less than $\pm 1\%$. [22, 23]

Statistical Analysis

To assess test-retest variability we compared the results of two measurements performed 5 minutes apart in a sample of 20 participants. This was determined by the mean difference $\pm$ SD. We calculated the intra – observer technical error of measurement (TEM) according to the method by Norton and Olds. The method reflects an accuracy index derived from the standard deviation between repeated measurements. We did the calculation on a sample of 13 volunteers who had two tests, each performed, on two consecutive days using the following formula: $\text{Absolute TEM} = \frac{\sqrt{\sum di^2}}{2n}$, where:

d= deviation or the difference between the first and second measurement.

$\sum di^2$ = the sum of the deviations raised to the second power.

n= number of volunteers.

The absolute TEM is then converted to relative TEM which is expressed in percentage with the following formula: $\text{Relative TEM} = \frac{\text{Absolute TEM}}{V_{AV}}$, where:

VAV= variable average value. This value is the sum of the mean weight between the two measurements for each volunteer divided by the number of volunteers.

To assess the correlation between change over time in weight and change in BC, Pearson's correlation coefficients were calculated between each pair of the following variables: fat mass change, fat-free mass change, fat percent change; and weight change. Participants were divided in three categories according to the change in body weight, FM and FFM and stratified by gender. The categories were: *increase* if there was > 1 kg gain, a *decrease* if there was > 1 kg loss and *no change* if the difference between the two measurements was 1 kg of gain or loss. For fat percent change we categorized as *increase* if there was > 1% gain, a *decrease* if there was > 1% loss and *no change* if the difference was 1% of gain or loss. We chose a cut-off point of 1 kg and 1% for fat percent, because smaller changes (any absolute change different than zero) would include individuals with change in lean and fat mass that would be within the range of error and because changes 1 kg would have no meaningful clinical significance. We assessed frequencies and calculated percentages between each pair of the variables according to each category of change. We used univariate logistic regression and constructed receiver operating characteristic curves (ROC) to assess the performance of weight changes greater than 1 kg to detect improvement in body composition, namely fat loss and decrease in fat percent. We also performed a stratified analysis by gender and by using 50 years of age as cutoff. Sensitivity was calculated as number of true positives/ true positives + false negatives (TP/TP+FN); specificity as number of true negatives/ true negatives + false positives (TN/TN+ FP); positive predictive value as number of true positives/ true positives + false positives (TP/TP+ FP); and negative predictive value as number of true negatives/ true negatives + false negatives (TN/TN + FN). We used multiple linear regression to assess for the effect of age, gender, difference in days between tests and visit-to-the-facility ratio, on the association between body fat change as predictor for body weight change. All statistical analyses were calculated using JMP v.8 (SAS Institute, Inc., Cary, NC, USA).

Results

The test-retest variability for BOD POD showed a mean difference for FM of 1.1 grams $\pm$ 55; a mean difference for FFM of 1 gram $\pm$ 56; and a mean difference for weight change of 100 milligrams $\pm$ 35. The technical error of measurement was 0.36%, details are shown in Table 2. Our final sample consisted of 465 participants who completed two BC assessments. Data are presented as means $\pm$ SD for continuous variables unless otherwise specified. Lifestyle baseline variables and history of hypertension, diabetes, hypercholesterolemia, tobacco use and overweight were available in 69% (322) of the participants; descriptive variables are shown in Table 1. Mean body weight change was 2.4 kg. Weight change correlated positively with body FM change ($r=0.83$), FFM change ($r=0.23$) and fat percent change ($r=0.65$), all statistically significant ($p<0.0001$) as shown in Figure 1. Of 255 people who lost >1 kg of weight, 216 (84.7%) had lost >1 kg of FM, but 69 (27.1%) had lost >1 kg of FFM. Of the 143 people with no weight change, 42 (29.4%) had actually lost >1kg of body FM. Of the 67 who gained >1 kg of weight at follow-up, in 23 (34.3%) this was due to an increase in FFM but not in FM. Distribution details of FM, fat% and FFM change according to weight change are seen in Figure 2. The diagnostic performance of a voluntary

weight loss of > 1 kg to detect improvement in BC in the overall sample and in the subgroups analyzed is displayed in Table 3. For none of the subgroups, the negative predictive value was better than 80%.

Discussion

This study showed a significant positive correlation between weight change and improvement in body composition, when measured using standard tests of linear association. These correlations were much higher for body fat mass change and lowest for fat-free mass change. When data were categorized to determine the diagnostic performance of weight change to detect improvement in body composition, the results were not very favorable for simple weight measurements. We observed that improvement in BC may go undetected in one third of the wellness participants if relying solely on body weight changes. These results show a high specificity for weight loss to detect fat loss but a low sensitivity and a low negative predictive value for overall changes in body composition. These results also support our hypothesis that a significant percentage of individuals without a detectable weight loss after engaging in a lifestyle change program still experience improvement in their body composition.

There are several implications from these results. First, people engaging a lifestyle program who intentionally lose weight, can be reassured that their BC would very likely improve as about 80% of people who lost weight had a decrease in body fat mass and percent. Thus, BC measurement might not add a lot of information for subjects who successfully lose weight in a program that involves exercise and nutritional changes. By the other hand, the frustration that people experience whenever they fail to achieve the recommended weight loss after engaging in a lifestyle modification program with nutritional and components could potentially hamper their enthusiasm and contribute to a high attrition rate associated with lifestyle modification programs. [24]

Based on our results, weight changes may not detect variations in body fat and fat-free mass, representing a limitation for using body weight alone to assess body composition changes, particularly if the fat mass loss was modest.

The accuracy of weight changes to assess improvement in body composition has, to our knowledge, only been assessed in a handful of studies. Kyle and colleagues studied the relationship between weight changes and BC changes using BIA in a sample of 400 healthy volunteers and demonstrated that active individuals were more likely to lose body fat when they gained weight as compared to inactive individuals. The authors emphasized that small weight changes could be associated with a significant change in body fat. [15] Weight change in that study was assessed after one year and again at three years. Newman and colleagues assessed weight and lean mass change in a sample of 2163 adults aged 70 – 79 over 4 years and showed that with weight loss a greater proportion of lean mass was lost than was gained with weight gain. Highlighting that, weight loss in the elderly might accelerate sarcopenia. [25] None of these studies explored the performance of weight change as sensitivity, specificity, NPV or PPV; also none looked at short-term weight fluctuations.

Furthermore, recent studies have shown that increased physical activity - as recommended by major professional and scientific organizations - improve the risk of CVD and DM2 even in the subset of people labeled as “no weight changers”. [26]

This study had several limitations. We did not have detailed or quantitative information on the amount and type of physical activity done at the wellness center or at home. Also, we had no information on measures of central obesity which is particularly associated with metabolic dysregulation. It is possible that people with important improvement in BC but little or no weight change, indeed had significant reduction in waist circumference or waist to hip ratios. Data was collected in a wellness facility, thus we did not have clinical data to correlate the improvement in body composition and changes in lipids, glucose and other clinically relevant measurements; or to determine if improvement in BC despite little or no weight change was associated with the expected improvement in measures of metabolic dysregulation. Our study did not use dual energy X-ray absorptiometry (DXA) which is the method of choice to assess body fat content and distribution when compared to four-compartment models in experimental settings; however ADP is a test easy to perform, quick, involves no radiation, and has been previously validated as a reliable and reproducible method. [27-29] Weyers and colleagues reported that in overweight people both DXA and ADP measure changes in body composition after small to moderate weight loss to the same extent and with similar sensitivity. [30] Ginde and colleagues validated the accuracy of body density measured by ADP when compared to underwater weighing in subjects ranging from normal weight to severely obese. Finally, the estimation of changes in fat-free mass may have been overestimated in subjects who might had exercised before the BOD POD and not reported despite the advise to abstain from exercising before the BOD POD measurement, in these subjects, fat-free mass loss could be due to extracellular fluid shifts to some extent. However, Le Carbenec, studied previously the effects of hydration with oil, water or mixed (oil + water) loads. He used 1, 2 and 4 liters loads and concluded that only with loads larger than 2 liters, water was detected as FFM. The overestimation was less than 1 kilogram.

Despite the limitations, our results add to previous cross-sectional reports addressing the accuracy of BMI to detect adiposity. [12] Frankenfield and colleagues reported that, using body fat mass as criterion for obesity, people with a BMI of at least 30 kg/m² are obese; however a significant amount of people with BMI below 30 are also obese and misclassified by BMI. [31] Heymsfield and colleagues, with the use of MRI showed that men had more skeletal muscle mass than adipose tissue at all levels of BMI when compared to women and that this variation in muscularity implies a mechanistic basis for the observed nonspecificity of BMI. [10]

Body composition assessment may be a valuable method to assess an individual's fatness status and potentially understand the role that fat content has on cardiometabolic risk. [32-34] Body composition indexes of fat mass and fat-free mass have been proposed in order to assess weight changes during physical activity, weight loss or gain, and ageing; however they have not been implemented. [33]

In summary, this study demonstrates that weight loss is a good indicator of body fat loss, but the negative predictive value is limited in people engaging a lifestyle modification program. Measuring BC may have a role in this setting.

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Figure 1. Correlations for change in body fat mass, fat-free mass and body fat percent
 Weight change was defined as a gain or loss greater than 1 Kg of total body weight. Body fat mass and fat-free mass change was defined as a gain or loss greater than 1 Kg of total body fat mass and fat-free mass respectively. Fat percent change was defined as a gain or loss greater than 1% body fat. Change was calculated by subtracting the baseline values to the follow-up values.

Figure 2. Distribution of body fat mass, fat-free mass and fat% change between categories of weight change

Distribution details between categories of weight change: weight loss if loss was > 1 Kg at follow-up, no change if weight change was $\pm$ 1 Kg at follow-up and weight gain if gain was > 1 Kg at follow-up.

^aMore than 1 Kg gain of fat or fat-free mass or > 1% gain of fat %. ^bMore than 1 Kg loss of fat or fat-free mass, or > 1% loss of fat %. Δ = change.

Percentages in the y axis represent the entire sample of N= 465.

Variables	All	Females	Males
Gender			
Females	276 (59%)		
Male	189 (41%)		
Age (yr)	41 (13)	40 (12.6)	41 (13.5)
Weight (kg)	80.2 (18.7)	72.3 (15.8)	92 (16.7)
Height (cm)	170.7 (9.9)	164.8 (6.7)	179 (0.1)
BMI	27.4 (5.3)	26.6 (5.5)	28.7 (4.8)
Fat %	31.2 (10)	34.6 (9.3)	26.4 (8.8)
Median time between tests in days	132 (84-189)	120 (81-190)	143 (84-189)

Variables	Fat loss (kg)	Fat % loss
AUC	0.89	0.83
Sensitivity	75% (199/265)	70% (184/263)
Specificity	89% (178/200)	85% (172/202)
Positive predictive value	90% (199/221)	86% (184/214)
Negative predictive value	73% (178/244)	69% (172/251)