Body composition measurement in severe obesity

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Purpose of review

Severe obesity is accompanied by large increases in fat mass and alterations in the composition of fat free mass, in particular total body water and its extracellular compartment. The physical size limitations imposed by severe obesity, and variations in body composition from that of normal weight, pose tremendous challenges to the measurement of body composition. This review focuses on some of the methodological and practical issues associated with the use of common body composition methods, and identifies available published information on feasible methods for use in the severely obese.

Recent findings

There is little published research regarding what body composition methods can be used with confidence in the severely obese populations. A simple three-compartment model combining measurements of body density by air displacement plethysmography and total body water by bio-electrical impedance can provide measurements of percentage body fat in the severely obese that are comparable with a traditional, highly technical three-compartment model requiring facilities such as isotope ratio mass spectrometry along with a substantial technical expertise.

Summary

This review highlights some of the basic challenges faced by researchers and clinicians when conducting body composition assessments in severely obese patients. A simple three-compartment model that is accurate and easy to perform appears to be promising for use in this population. Further research is needed, however, on this and other feasible methods of body composition assessment in a diverse group of severely obese people.

Keywords

body composition, 3-compartment models, extracellular water, severe obesity

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Abbreviations

BIA	bio-electrical impedance analysis
ECW	extracellular water
FFM	fat free mass
ICW	intracellular water
MRI	magnetic resonance imaging
TBW	total body water

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Introduction

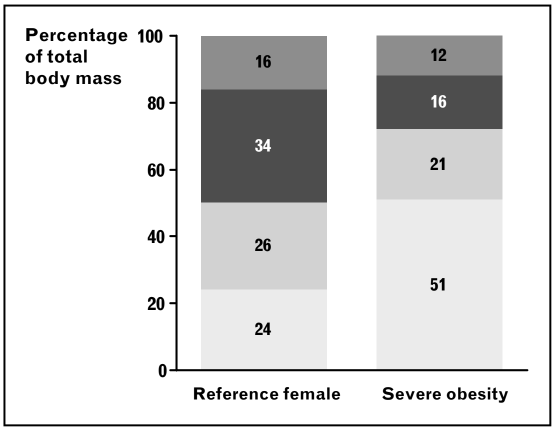
As the prevalence of overweight and obesity continues to increase worldwide [1] the developed parts of the world are faced with a progressive rise in the number of people who are severely obese (defined as a body mass index $\geq$ 35 kg/m^2 [2,3]). In the United States alone this number has increased threefold in the last four decades, and over 4% of adults are now classified as severely obese [4,5]. One consequence of this demographic shift is that there is now a need for evaluating the body composition of severely obese individuals, both in clinical practice and as part of research evaluating the efficacy of different treatment programs. Severe obesity is characterized by large alterations in body compartments in comparison to overweight or non-obese people. In addition to the increased adipose tissue mass, an overall increase in total body hydration, and in particular, an expansion of the extracellular water (ECW) volume relative to intracellular water (ICW) volume, often accompanies this physiologic state (Fig. 1) [6]. Accurate and precise routine measurement of body composition in this population is challenging, however, and there is little published research on what body composition methods can be used with confidence either for groups of subjects or for individuals [6–8,9••].

Methodological challenges and practical concerns

> *"Measure what can be measured, and make measurable what cannot be measured"*
>
> *Galileo Galilei*

Before any measurement in this population can be performed, it is important to consider the testing environment. This includes proximity of testing equipment since severely obese people often have difficulty with ambulation, ensuring adequate size of hospital/clinic gowns and robes, having wider chairs available, facilitating entry to and exit from testing equipment and knowing that the chosen testing equipment will accommodate a severely obese person.

Figure 1. Body composition in severe obesity in comparison with the reference normal weight



The details for the calculation of body compartments for the reference woman and for severely obese women were described previously [6]. Solids ■; ICW, intracellular water ■; ECW, extracellular water ■; Fat mass ■.

Anthropometric assessments, although simple and inexpensive, are often difficult to perform in the severely obese. Height may be measured using a standard wall-mounted stadiometer. With regards to weight, however, careful selection is required for weight scales that must measure the range of body weights in severe obesity, are accurate, precise, reliable, and have platforms that are wide enough to allow for the severely obese person to stand comfortably. Skin-fold measures are often technically difficult to perform in the severely obese and are limited by the lack of suitable reference standards since most equations are developed for normal weight or less obese individuals. Waist circumference measured at the level of the umbilicus, and hip circumference measured as the maximal circumference at the level of the buttocks [6] can be obtained using quilting tapes and two trained personnel (one to spot the tape measure). It may prove to be challenging, however, to identify a waist line in severe obesity [10], and the drooping abdominal fat may interfere with the hip circumference measurement.

Bioelectrical impedance analysis (BIA) using single or multi-frequency BIA or bioelectrical impedance spectroscopy is popular due to its non-invasiveness, portability, safety and most importantly its relatively low cost. BIA measures the body impedance using electrodes that are connected from one leg to the other leg, or to the arm, to form a circuit for the current to pass through. The impedance measure is used to predict total body water (TBW) and fat free mass (FFM) [11]; fat mass is obtained using the difference between weight and FFM. BIA, however, is based on the assumption that the body behaves as a cylindrical conductor with a uniform cross-sectional area and that the human body has a homogenous composition with a specific resistance that is constant throughout the conductor [12]. Single frequency BIA may not be accurate in severely obese persons due to altered electrical properties of tissues [13] which does not allow for complete penetration of the electrical current. The overall effect in subjects with a high ECW/ICW ratio and an increased TBW would be an overestimation of FFM and an underestimation of fat mass thus affecting the validation and interpretation of the impedance measure. These issues have been discussed in detail previously [13,14•]. The relative accuracy of the BIA method for body composition assessment in the severely obese is also limited by the lack of population specific equations. The accuracy of the predicted measure is largely dependent on the type of equation used. In a study looking at the use of different body composition methods in severe obesity [6], it was shown that BIA was highly dependent on the equations used to calculate percentage body fat, with the Lukaski *et al.* equation [15] having provided mean percentage body fat values closest to the reference method in the severely obese. It should be noted, however, that BIA can be used in three-compartment models (see below) to provide a more reliable measure of body composition. Additionally BIA alone appears to be more strongly associated with percentage body fat than body mass index [6] and therefore could be more widely used as a screening tool to measure body fatness in clinical practice and in population-based research.

Densitometric methods such as air displacement plethysmography (BOD POD; Life Measurement Inc, Concord, California, USA), the method and principles of which are described elsewhere [16], appear to be a promising approach for use in the severely obese [6,17]. Measurements can be conducted with the subject in a Lycra-style swim cap and minimal skin-tight shorts or closely fitting underwear [6,17], which is often more practical in severely obese patients in whom the use of tight shorts is not feasible. The concern that the large body size might impose difficulty in the lung volume measurement appears to be unfounded since the severely obese can perform pulmonary plethymosgraphy quite effortlessly and subjects are also able to fit into the instrument without any difficulty [6,17]. The ease and speed with which measurements can be obtained and other considerations (for example if quantifying fat mass loss is the objective) make air displacement plethysmography an attractive option for measurement of body composition in the severely obese. The utility of this two-compartment method is further enhanced when it is used in conjunction with a TBW measurement to obtain a three-compartment model (see below) that is accurate, precise, and relatively easy to use [6].

Hydrostatic weighing or underwater weighing is time and labor intensive and often disliked by very severely obese subjects. Discomfort, apprehension about being tested in the water tank, inability to perform the maneuvers required for satisfactory testing, and other such physical constraints are often common problems with using the test in this population [6].

Magnetic resonance imaging (MRI) is well suited for imaging severely obese patients, because the radio frequency used does not have difficulty in penetrating large amounts of adipose tissue as do ionizing radiation or sound waves [18]. Previously, conventional MRI devices were limited by the gantry size and the table weight limit. The development of open-configuration magnetic resonance scanners have allowed improved patient access and near real-time imaging. Further the newer low field magnetic resonance imagers with a larger gantry size and greater weight capacity have opened up the potential for imaging the severely obese [18–20] who could not be evaluated previously by standard MRI or computerized tomography. Computerized tomography like MRI is often used to determine body fat distribution in the visceral and subcutaneous depots [21] for which scans specific to the region of interest are obtained. Whole-body scans using these methods are often cost prohibitive and the concerns over exposure to radiation (in the case of computerized tomography) make these methods somewhat unsuitable for routine use.

Dual energy X-ray absorptiometry and in-vivo neutron activation are often used as reference techniques [22] in non-obese and moderately obese subjects, but severely obese subjects frequently exceed the weight limits of the instruments and in some cases cannot physically fit into the measurement compartment. Total body potassium assessments using the (^{40}K) whole body counter assume that the potassium content of FFM is a constant and this assumption may be affected by the hydration related changes in severe obesity [7]. Moreover, (^{40}K) whole body counters are available in few laboratories worldwide and would not be easy to set up for widespread clinical use.

Isotope dilution techniques can be used to measure total body water in the severely obese. If body composition assessment is the only objective it is common practice to use deuterium labeled water (^2H_2O) alone to obtain a measure of TBW. In studies looking at total energy expenditure a mixed dose containing ^2H_2O and water labeled with oxygen-18 ($H_2{}^{18}O$) is administered and TBW can be assessed from the dilution spaces of both ^2H_2O and $H_2{}^{18}O$. TBW calculated as a volume measurement can be converted to kilograms using the conversion factor of 0.99336 (density of water at normal body temperature). In a study by Das *et al.* [6] it was observed that the isotope dilution method to measure TBW gave slightly higher values for percentage body fat than the three-compartment models when a standard hydration factor was used, due to high hydration in the severely obese state (mean water percent in FFM was 75.6% compared to the reference value of 73.8%). The relative accuracy of the dilution techniques for the group of subjects as a whole was improved by using the group-mean measured hydration coefficient for FFM in the severely obese. In the absence of accepted published values for different population groups, however, a measurement of actual hydration may be required for each population studied and this would require technically demanding measurements of TBW. Additionally, in the same study [6] FFM hydration appeared to be associated with the mean difference in percentage body fat of some of the tested methods as compared with the reference method, in the severely obese, further indicating the need for population specific values for FFM hydration.

The intravenous sodium bromide method can be used to accurately assess ECW, a body compartment that is largely altered in the severely obese [6]. The details of the use of this method including analyses have been described previously [6,23,24]. ECW is a physiologically important body compartment because it provides an environment for oxygen and nutrient transport and a route for clearance of cell metabolism [23]. Bromide, like chloride, distributes itself in the extracelluar space in the body and has the advantage of good absorption, slow excretion and only moderate penetration into tissue [23]. In the first few hours following administration, bromide appears to penetrate the red blood cells primarily and ECW can be calculated from the increase in bromide concentration between baseline and mean post-dose blood samples and the amount of bromide injected after applying the appropriate correction factors [24,25]. ECW calculated as a volume measurement is converted to kilograms using the conversion factor of 0.99336 (density of water at normal body temperature) [23]. It must be noted that in the severely obese bromide equilibrates quite completely in the extracellular space by 2 h and so a mean of 2, 3 and 4-h post-dose measurements can be used for the calculation of dilution space [6]. Sodium bromide is the most accurate method as it allows, when measured simultaneously with deuterium, partitioning of the ICW and ECW compartments. ICW can be calculated as the difference between TBW and ECW.

Three compartment models have been used increasingly since first proposed by Siri in 1961 [26]. Many of the commonly used two-compartment body composition methods like hydrostatic weighing, isotope dilution, air displacement plethysmography (BOD POD) and BIA rely on a known and constant composition of FFM. The extreme hydration-related deviations from normal that are observed in severely obese states [27] may invalidate assumptions underlying traditional reference methods [26,28]. A three-compartment model allows for substantial improvements in accuracy over two-compartment models because, unlike two-compartment models, it does not rely on assumptions of standard hydration (0.738 [28]) or FFM density (1.1 g/cm^3 [26]) for its validity. Using this model, measurements of body density and TBW are combined to achieve an estimate of body composition that is more accurate and precise than with either measurement alone [26]. Traditionally, measurement of body density has been made by hydrostatic weighing, and TBW by isotope dilution. Hydrostatic weighing, however, is difficult to perform in many severely obese subjects due to their physical size, and isotope dilution requires specialized equipment (isotope ratio mass spectrometers) and highly trained personnel, making these methods unsuitable for routine use. Alternative three-compartment models combining simpler methods such as body density using skin folds and TBW using BIA have been reported previously in normal weight populations by some groups [29,30] and only more recently the feasibility of such models has been reported in the severely obese [6]. A study by Das *et al.* [6] showed for the first time that a three-compartment model combining determinations of body density by air displacement plethysmography with determinations of TBW by BIA (using the equation of Kushner and Schoeller [11]) provided values for percentage body fat in the severely obese that were in close agreement with values determined by the reference method. The reference method for percent body fat in this study [6] was a three-compartment model using TBW determined by $H_2{}^{18}O$ and body density determined by air displacement plethysmography. Other three-compartment estimates of percentage body fat were also calculated, using body density by air displacement plethysmography and TBW by either ^2H_2O dilution or BIA (TBW prediction equations of Kushner and Schoeller [11]). Also, this study [6] used the three-compartment model of Siri [26] that was modified by Modlesky *et al.* [31], incorporating body density (d) and TBW as a fraction of body weight (w) to calculate percentage body fat as $2.1176/d - 0.78w - 1.351$, and FFM was calculated as the difference between body weight and fat mass. The modification by Modlesky *et al.* [31] incorporates the assumption that the mineral to protein in the fat free body is a constant (6.8/19.4) based on Brozek's work [28], while the original equation by Siri [26,32] assumes that the mineral to protein ratio is 5:12. Silva and colleagues [9••] further address some of the issues concerning assumptions in the classic Siri three-compartment model including that of the mineral to protein ratio and propose revised models for prediction of body composition at higher body weights. These models need to be validated in severely obese populations before they are widely used.

Conclusion

Severe obesity poses challenges to the measurement of body composition due to altered body hydration, large individual variations in the hydration state, other potential alterations in the composition of FFM [27,33,34] and physical size limitations. Using a variety of techniques including three-compartment models combining methods such as air displacement plethysmography and BIA that are commercially available, technically simple to perform and minimally invasive, it is possible to obtain accurate and reliable measures of body composition including fat and FFM. Further studies are needed to confirm the broad utility of these assessments of body composition, including the three-compartment models and other newer methodologies in severely obese populations.

References and recommended reading

Papers of particular interest, published within the annual period of review have been highlighted as
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- •• of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 649–650).

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