Practical considerations for body composition assessment of adults with class II/III obesity using bioelectrical impedance analysis or dual-energy X-ray absorptiometry.

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Abstract

Purpose of Review: To explore the practical considerations for body composition assessment of adults with class II/III obesity. Studies assessing adults (18-64 years) with a body mass index (BMI) ≥ 35 kg/m^2 with bioelectrical impedance analysis (BIA) and/or dual-energy X-ray absorptiometry (DXA) were included. **Recent Findings:** Twelve studies met inclusion criteria. Five considerations were identified: variances in equipment and technology; equipment weight capacity; subject positioning; tissue penetration; and total body hydration. In subjects with BMI ≥ 35 kg/m^2, BIA overestimated fat free mass with scaling errors as BMI increased. DXA provided accurate and reliable body composition measures, but equipment-related barriers prevented assessment of some taller, wider and heavier subjects. **Summary:** BIA is an unreliable method to assess body composition in class II/III obesity. Advancements in DXA technology (e.g. iDXA), methodology (e.g. subject positioning, longer scan times) and more inclusive testing criteria (e.g. use equipment limits not just BMI) may improve access and understanding of body composition in this cohort.

Key Words: bioelectrical impedance analysis; body composition; fat mass; dual energy X-ray absorptiometry; lean soft tissue; obesity.

Introduction

Obesity defined as a body mass index [BMI] ≥ 30 kg/m^2 affects one in three adults in the United States (US) [1] and Canada [2]. There are three classes of obesity: class I (BMI 30-34.9 kg/m^2), class II (BMI 35-39.9 kg/m^2) and class III (BMI ≥ 40kg/m^2) [3]. Class III obesity affects 2.5% of Canadian and 6.4% of American adults, impacting more women (3% Canada, 8.3% US) than men (2% Canada, 4.4% US), and is associated with the highest level of health risk [1, 2].

BMI is commonly used to identify those at increased health risk and as referral criteria for obesity treatment, including bariatric surgery (e.g. BMI ≥35 kg/m^2) [4]. Although quick and easy to determine, BMI is a proxy measure for adiposity; it cannot estimate or quantify fat mass nor determine the presence of conditions such as sarcopenia (lower muscle mass and function). Sarcopenia is most associated with older adults [5], but it can occur across all age and BMI categories [6] and in healthy middle-aged adults [7]. Body composition analysis is needed to quantify fat mass (FM) and fat-free mass (FFM), including the components of FFM, specifically bone, lean soft tissue (LST) and total body water (TBW). Although there is great emphasis on FM in obesity, the amount of FFM is essential to health. A desirable outcome of obesity treatment is to not just reduce total body weight, but to achieve a reduction in FM while preserving FFM. Lower FFM combined with higher FM, known as sarcopenic obesity, is linked with increased morbidity and mortality [8].

Validated methods and tools for the assessment of body composition have been developed to objectively quantify FM and FFM. The two most commonly used tools for body composition analysis in clinical and research settings are bioelectrical impedance analysis (BIA) and dual-energy X-ray absorptiometry (DXA), respectively. Clinicians and researchers are increasingly interested in the assessment of body composition as part of the obesity treatment plan to help inform treatment decisions and optimize patient outcomes. To provide some background on these methods in the context of obesity, a brief overview of BIA and DXA is included. Interested readers may want to review the following tutorials: a two-part series on BIA published by Kyle et al. [9, 10], LST imaging including BIA and DXA by Prado & Heymsfield [11], and body composition tools for assessment of adult malnutrition by Earthman [12].

Bioelectrical Impedance Analysis

BIA is commonly used in a clinical setting because the equipment is small, portable, affordable, and relatively easy to use requiring minimal training. BIA utilizes a mild electrical current (single or multi-frequency waves) to measure differences in resistance and reactance between tissue types based upon water and electrolytes content. Population-specific regression equations are used to estimate FM and FFM, usually based in the relation between TBW and FFM. If normal-weight regression equations are used for subjects with obesity, measurement errors from abnormal tissue density and hydration can result.

Foundational to the technology, two important assumptions are made: 1) the body is a consistent cylinder [9, 10] and 2) tissue hydration status is constant (73.2%) [13] and the ratio of extracellular water (ECW) to intracellular water (ICW) is a consistent proportion (1/3). Obesity challenges both of these assumptions. With obesity, there can be variance in FM distribution (e.g. central vs. peripheral, android vs. gynoid [14]), and fluid distribution (e.g. edema, lymphedema) or altered body shape (e.g. shortened limbs or amputees [10]), resulting in body segments not shaped as a consistent cylinder.

For the second assumption, tissue hydration status is not a constant across BMI categories. Obesity is associated with a state of general "overhydration", with excess TBW and an increased ratio of ECW relative to ICW. The hydration status of FFM is elevated, one study measured 75.6% using isotope dilution [15]. Elevated TBW and ECW will result in errors of overestimation of FFM and thereby underestimation of FM, with lower accuracy at higher levels of obesity [14, 16].

Another challenge with BIA and obesity is the fact that single frequency (50 kHz) waves cannot fully penetrate the cell membrane. Only some of the ICW is included in the TBW values, resulting in an overestimation of TBW and FFM and underestimation of FM [17]. Although multiple-frequency waves can improve tissue penetration, the altered ratio of ECW:ICW and increased resistance of ICW still result in overestimation of FFM in subjects with obesity [17, 16]. A summary of the measurement errors using BIA in subjects with obesity is presented in **Table 1**. In the 2004 European Society for Parenteral and Enteral Nutrition (ESPEN) Guidelines, BIA assessment was determined to have questionable validity for FFM and FM when BMI > 34 kg/m^2 [10].

Dual-energy X-ray Absorptiometry

DXA utilizes x-rays (photons with two different energy levels) to measure the attenuation (i.e. energy absorbed) by each tissue type. FM and FFM (which includes separate measures for bone and LST) are measured for the whole body or segments of interest such as appendicular skeletal muscle mass (ASM= sum of the LST from the limbs, a surrogate measurement of total muscle mass). DXA provides an accurate and safe assessment of body composition, with minimal radiation exposure and provides measurement of more components than BIA. DXA is commonly used in research or clinical diagnostic settings (e.g. bone density), as it requires trained technicians, a large dedicated room space and capital expenditure. The precision and reliability of DXA leads it to be the reference method for body composition analysis [11].

Although BIA and DXA have been extensively used in "healthy" populations (i.e. normal BMI 18.5-24.9 kg/m^2) and older adults (e.g. for bone density studies), these tools are less commonly used in adults with class II/III obesity. One of the benefits of DXA over BIA is the ability to assess bone density, which is now recommended for patients after bariatric surgery [4]. Measurements of body composition in this cohort can enhance assessment and risk stratification of the complex and diverse chronic disease of obesity, including identification of sarcopenic obesity (i.e. low muscle mass and high adiposity) and osteosarcopenic obesity [6, 18, 7, 19]. Understanding the barriers to body composition assessment can support patient care management with evidence-based practice tools and identify opportunities for future research.

Literature Search Methodology

The purpose of this review was to identify recent studies assessing body composition in adults (18-64 years) with class II /III obesity (BMI $\geq$ 35 kg/m^2) and explore practical considerations for use of the two most commonly used body composition methods, BIA and DXA. A literature search was conducted using Medline, Scopus and Web of Science databases for studies published from 01 October 2005 to 31 October 2015 that measured body composition with BIA and/or DXA of adults (18-64 years) with a BMI $\geq$35 kg/m^2. Studies including children (17 years or less), older adults (65 years or more), subjects with a BMI <35 kg/m^2 or cancer, were excluded.

Twelve studies published met inclusion criteria; nine studies used a single method, either BIA (five studies) [20-24] or DXA (four studies) [25-28], while three of the 12 studies compared BIA to DXA [29-31]. Of the eight BIA studies, five utilized a single frequency wave (50 kHz) [29, 20-23] and three utilized multi-frequency waves [30, 24, 31]. Of the seven DXA studies, five used the standard DXA technology [29-31, 26, 28] and two studies used newer iDXA technology [25, 27]. In total, there were 920 subjects (77.7% female) and six of the 12 studies included post-bariatric surgery subjects (n=500, 69.2% roux-en-Y gastric bypass).

Defining Obesity: Comparing BMI to Percentage of Fat Mass (%FM)

Obesity can be defined by %FM based upon body composition analysis. There are several published cut-points for %FM that are sex-specific [32]. Frankenfield et al. [21] used BIA (n=141, BMI 15.9-93.4 kg/m^2) to explore the accuracy and specificity of BMI to identify subjects that exceed the %FM cut-points. All subjects with obesity (approximately 40% of the sample) exceeded the %FM cut-points (>25% for males and >30% for females), showing BMI ≥ 30 kg/m^2 had a high sensitivity and accuracy to identify excess adiposity. For subjects with a BMI <30 kg/m^2, 46% of females and 30% of males exceeded %FM cut points. The authors noted alterations in FM and FFM were identified across all BMI categories, supporting the notion that BMI alone can misclassify subjects at increased health risk due to unfavourable body composition [21].

Barriers to Assessment of Adults with Class II/III Obesity

Methodological and equipment-related limitations for the assessment of adults with class II/III obesity were identified. These barriers to assessment of body composition in this clinical cohort were clustered into five key areas: differences in equipment and technology; equipment weight capacity; subject positioning; total body water; and tissue penetration.

Differences in equipment and technology

In the selected studies, five countries (Brazil, Canada, France, Italy, United States of America) were represented. Eight different BIA models and four different DXA models from two manufacturers (Hologic, GE Healthcare) were used. The software versions were not often reported, which is important as software upgrades occur more often than hardware. The difference in equipment is inevitable, considering the number of countries, different manufacturers, product advancements, different times of procurement and publication. It is important to keep in mind there are differences in technique, measurement and study samples, impacting the outcome data and comparisons of studies [12].

Equipment weight capacity

Both BIA and DXA require measured total body weight to determine body composition. A weigh scale is often integrated into the equipment, with weight capacity limits in place by the manufacturer. A summary of weight capacity limits for different full body DXA models is found in **Table 2**. A separate or “stand-alone” scale may also be used to measure body weight. All reviewed studies reported measured weights. Only four of the eight BIA studies indicated the use of a stand-alone weigh scale and no BIA studies reported the scale weight capacity. Compared to the DXA studies, subjects with the highest weights were included in the BIA studies (maximum 214.0 kg [20]). Weight and BMI were used as exclusion criteria from DXA studies due to equipment weight capacity limits. Five of the seven DXA studies reported the weight capacities from 120 to 160 kg [29, 30, 26] with the recently commercialized iDXA limits of 182 kg [27] up to 204 kg [25]. Two of the seven DXA studies did not report equipment weight capacity, instead, used BMI > 40 kg/m^2 as a surrogate marker for exclusion [31, 28].

Equipment weight capacity limits the available data on subjects with class II/III obesity and validation of body composition tools in this cohort. Due to individual variance in height and weight, use of BMI alone may unnecessarily exclude some subjects from DXA. Assessment and reporting subject anthropometrics for each limiting factor may improve inclusion criteria and access to those excluded from DXA measurements based upon BMI alone. In addition, reporting exclusion criteria based upon anthropometrics could help clinicians determine if body composition analysis is feasible for their patient.

Subject positioning

For segmental BIA models, the electrodes are contact points integrated into the standing scale and handgrips. Subjects are required to stand with legs separated (45 degrees) and hold the handgrips with arms extended (30 degrees) to ensure limb separation while maintaining adequate skin contact with the electrodes [10]. Utilization of the two-point method to measure impedance of the lower (i.e. foot-to-foot) or upper body (i.e. hand-to-hand) segments can produce estimation errors for whole body composition. Four- to eight-point electrode placements are required for whole body BIA assessment. With this method, individual electrodes are placed directly upon the skin, permitting measurement in either a standing or supine position.

Any skin contact, either between the legs or the arms and torso, results in measurement errors (up to 18% [33]). For some subjects with obesity, it may not be possible to achieve leg separation while maintaining foot contact with the electrodes on a narrow standing platform. The reviewed BIA studies provided limited methodology or descriptions for subject positioning, with one exception. Frankenfield et al. provided details to achieve limb separation, including placement of a dry towel to avoid skin-to-skin contact [21]. No study reported on the subjects' ability to stand or sustain the required body position for the BIA test.

For DXA, subjects are required to lie still in a supine position while the scan arm moves across the subject for the length of the instrument bed. The subject's supine length (height), width and depth must fit within the DXA scan area limits. Dimension limits of different full body DXA models are summarized in **Table 2**. In the reviewed DXA studies, scan arm height and supine body depth were not reported. Just one study measured body depth, with supine anterior/posterior thickness >25 cm used as exclusion criteria [31]. Although waist circumference was reported in one study [29], this measure is taken from a standing position, it could not be substituted for *supine* width or depth. Although the supine length dimension of DXA models (198 cm) is sufficient to accommodate most North American adults (95th percentile, age 20 years and older for women=173.7 cm, men=188.2 cm [34]), some taller subjects may still be excluded. Validated techniques for scanning taller subjects (e.g. bent knees) within normal BMI ranges could be explored for class II/III subjects [35].

To assess wider subjects, "reflection positioning" has been used [36]. The subject is positioned off-center (typically towards the right-side of the scan bed) to include the torso and right arm, with the lower portion of the left arm positioned outside of the scan area. Based upon the bilateral symmetry of the human body, the values of the right arm are used to "reflect" the left arm values. This alternative method was validated by Tataranni et al. (n=183, BMI 17.7-52.8

kg/m^2) with low predictive errors for %FM (r^2=.90 [SEE=4.1%]), FFM (r^2=.89 [SEE=3.72 kg]) and FM (r^2=.95 [SEE=3.57 kg]) [37]. Similar values were recorded for all three measurements between right and left sides. In the reviewed studies, only one discussed this method. Carver et al. examined 65 subjects with class III obesity (BMI 49 ± 6 kg/m^2); 51% required reflection positioning for whole body composition analysis despite wider scan bed limits with iDXA [25].

Rothney et al. used an alternative method for assessment of wider subjects. This study explored measuring either the left or right half of the body (i.e. half-body scans also called hemi-scans) as a proxy for a full body measurement by iDXA. The half-body scans of 52 subjects (BMI 30.4 - 41.0 kg/m^2) were validated against their whole-body scans for within-subject (>97%) and within-group (> 99.9%) variances for total FM, %FM and LST (all $r^2 < 0.033$). A small variance with increased bone mass consistent with handedness (+30 g, 1%) was measured [27]. In this study, half-body scans provided a valid method using DXA to assess subjects that exceed supine width limits. The maximum BMI in this study was 41 kg/m^2, only representing the lowest range of class III obesity. Both studies utilized iDXA, with larger scan bed area and weight capacity, permitting imaging of subjects with wider, thicker, and heavier body dimensions [25, 27]. Further validation is required of the half-body scan method with class III subjects.

Total body water

Two of the eight BIA studies reviewed reported %TBW. De Freitas et al. compared single-frequency (50 kHz) BIA (Quantum II, RLJ Systems) for 36 patients before and 6 months after bariatric surgery. Before surgery, TBW was 36.1± 4.8 % (29-48%) with an increase to 45.0 ± 5.8% (36-58%) at 6 months after surgery [20]. Nicoletti et al. used single-frequency (50 kHz) BIA (101-Q, RLJ Systems) for 43 women before and annually for four years after bariatric surgery. The %TBW was 33.1± 3.8 % before surgery, with an increase to 48.5 ± 6.7% at one year and 46.6 ± 6.7% at year four. Both studies showed a reduced hydration status both before and after bariatric surgery, with trends for %TBW to increase after bariatric surgery. Studies on body composition of adults with class II/III obesity without bariatric surgery are needed.

Tissue penetration

For DXA, the x-ray beams must be able to penetrate (attenuate) the body in order to differentiate the tissues measured. Tissue depth is important; attenuation errors occur when tissue depths exceed 25 cm, resulting in an underestimation of FM. To account for this, some DXA models can increase scan time (i.e. use “slow” or “thick” mode) to improve attenuation and scan accuracy. No study reviewed specifically discussed wave frequency or attenuation in context of their results. For one iDXA study, longer scan modes (13 vs. 7 minutes) were reported to enhance tissue penetration and reduce measurement errors although the type of errors were not specified [25]. Due to increased DXA scan time, subjects have a small but increased radiation exposure and may become too uncomfortable to sustain a still, supine position. This may present a barrier for assessment in some subjects.

Comparing BIA to DXA

Three of the reviewed studies completed cross-sectional validations of BIA to DXA measurements [29-31]. Bedogni et al. compared measures of FM using single-frequency (50 Hz) BIA to DXA (GE Lunar Prodigy) and utilized an obese-specific regression equation (validated by Jimenez et al. using iDXA n=159, 79% female) to determine FM from impedance values in women (n= 57, BMI 37.3- 55.2 kg/m^2) [29]. The BIA measurements were not reliable (%FM levels of agreement -4.9% to 8.2%), leading investigators to conclude that BIA, even with an obese-specific equation, was not interchangeable with DXA. The use of a different BIA device from the Jimenez’s validated equation can justify the lack of accuracy found in Bedogni’s study.

The second study by Faria et al. compared FM measurements of 73 subjects (89% female, BMI 40.17 ± 4.08 kg/m^2) using a multi-frequency BIA (InBody 720) and DXA. Both methods to measure FM produced an “almost perfect correlation”, however BIA significantly underestimated FM (-2.05 kg [p<0.0001]) or -1.16% [p<0.0001]) and overestimated FFM (1.28 kg [p=0.0007], or 1.61% [p<0.0001]) compared to DXA. These results, in contrast to the authors’ conclusions, suggest that BIA was not accurate enough for research or application to clinical practice in an obese cohort or for individual assessment [30].

In the third study, Shafer et al. utilized an eight-point, segmental, multi-frequency BIA (Inbody 320) to compare %FM measures to those obtained from DXA (Hologic QDR Delphi-W) in 132 subjects (n= 42 with BMI 30-39 kg/m^2, class III obesity excluded). In subjects with class I/II obesity, BIA overestimated %FM (3.40 ± 0.39) with increased error as %FM increased (r=0.424, *P*<0.0001) with limits of agreement ranging from -5.7% to 7.2% FM. This study concluded BIA was not a reliable tool to measure body composition in an adult cohort with class I/II obesity [31].

In all three studies, BIA results were not consistent with DXA with the rate of error increasing with higher adiposity, with the maximum BMI studied was 55.2 kg/m^2. Although the Bland-Altman analysis reported for each study demonstrated agreement between BIA and DXA for some individuals, there was overall high variability and estimation bias, making individual measurements unreliable [31, 30, 29]. Each study excluded subjects due to equipment weight limitations (120 kg[30], 130 kg[29], BMI <40 kg/m^2 [31]), restricting the data available from subjects with class III obesity.

Additional Considerations

A few considerations are highlighted to inform future research and clinical practice.

Males are underrepresented. Male subjects often represent less than 20% in both clinical obesity practice and research obesity literature. Compared to females, males have more FFM and potentially are at increased risk of greater FFM loss during weight loss [38]. Further research is required not only for body composition of men with obesity, but the possible barriers leading to underrepresentation in treatment and research.

Data on subjects with higher BMI in Class III obesity is limited or lacking. Many studies either collate results for all class III subjects or exclude subjects with BMI >40 kg/m^2 or who exceed equipment limits. Our understanding of body composition at higher levels of obesity as a result is very limited. Unlike other BMI categories with a narrow five-point range, class III obesity has the widest range, with no upper limit above 40 kg/m^2. Stratifying results within class III could enhance the understanding of body composition within class III and at extremes of BMI.

The % FFM can increase, despite loss of FFM (kg). Reporting of body composition results can be misleading; for the same subject or group, FFM could be reported as both a loss and a gain. For example, Ciangura et al. examined the body composition of patients before and after bariatric surgery. In the first three months post surgery, subjects lost LST mass [a component of FFM] at a rate of -2.3 ± 1.2 kg/month, however when reported as a percentage relative to FM,

%FFM increased by 2.8% [26]. This study demonstrated post-surgical subjects lost FFM at a specific rate and the time frame. However, it could be misinterpreted that subjects *increased* lean tissue after surgery because %FFM increased. Subjects who are actually losing FFM mass may not be identified as at risk, impacting assessment and treatment decisions. The reported preservation or increase in %FFM after weight loss is confounded by a possible elevation in TBW, contributing to a *relative* change compared to %FM [21]. The rate of error was proportional to body weight, increasing at higher body weights. When examining the outcome data for body composition during weight loss, the absolute changes in FFM independent of FM and BMI (e.g. appendicular skeletal muscle by height [m^2], from DXA) may better marker of FFM changes.[8]

Conclusions

Although extensive research and reviews on body composition are reported in the literature, relatively few studies using BIA and/or DXA including subjects with class II/III obesity were identified. In general, both BIA and DXA can provide relatively safe, quick and non-invasive measures of body composition.

It is easy to understand the interest of clinicians in BIA; it is inexpensive, portable, low risk, able to accommodate people with larger body dimensions and requires minimal training or expertise. Anthropometric measures and BMI are important but have limited value for body composition. BIA can estimate adiposity better than BMI when BMI < 35 kg/m^2, but there are methodological problems for subjects with class II/III obesity limiting the reliability for body composition.

DXA can provide accurate and reliable measures of body composition, yet equipment-related barriers have limited assessment of heavier, taller and wider subjects. As demonstrated with iDXA and half-body scans, advancements with equipment, technology and methodology permit assessment of more people with class II/III obesity. Accurate and reliable assessments of body composition in this cohort are important to help determine health risk in more adults with class III obesity and contribute to understanding of the longer-term effects of this disease and treatment. Further studies are needed to measure body composition with DXA at initiation and at several points during interventions to support individualized obesity treatment, risk reduction and outcome optimization. Longitudinal studies of body composition across interventions and phases of treatment (loss, maintenance, gain/regain) should also be considered, to optimize patient care.

Acknowledgements The authors appreciate the support of Drs. Catherine Field and Sarah Elliott for their review of an early draft of the manuscript.

Compliance with Ethics Guidelines

Conflict of Interest None of the authors declare a conflict of interest for this manuscript.

Human and Animal Rights This article does not contain any studies with human or animal subjects performed by any of the authors.

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Table 1. Summary of errors associated with assessing body composition using bioelectrical impedance analysis (BIA) in subjects with class II/III obesity.

	Fat Mass	**Fat-Free Mass**
Increased TBW (>73.2%)	Underestimated	Overestimated
Increased ECW	Underestimated	Overestimated
Use of normal-weight regression prediction formulas	Underestimated	Overestimated
Use of two vs. eight electrodes	Underestimated	Overestimated
Use of single (50 kHz) vs. multi-frequency waves	Underestimated	Overestimated

TBW: total body water; ECW: extracellular water; kHz: kilohertz

Table 2. Scan area dimensions and subject weight capacity of full body dual-energy X-ray absorptiometers (DXA) from two manufacturers.

	Hologic, Inc[39-41]		GE Healthcare[42]	
Scan area			DXP, Prodigy	Lunar iDXA
Length, cm	All models	195	DXP 195 Prodigy 197.7	197.7
Width, cm	All models	65	60	66
Weight capacity, kg	Delphi, QDR, Explorer: Discovery A,W: Prior to 03/05 03/05 to 04-07 After 04/07 Horizon:	136 159 182 204 204	DXP: 136 Prodigy: 160	204