Body Composition Evaluation in Severe Obesity: A Critical Review

Abstract

Background: There is no consensus about the best method to conduct body composition assessment in patients with severe obesity. A simple, accurate, reproducible and inexpensive method is desirable.

Methods: A systematic review of the literature was made in PubMed, Virtual Health Library and Embase about methods for body composition assessment in severe obesity.

Results: The literature search produced 433 studies but only 24 meet the inclusion criteria. In methods traditionally used changes in body format, body density and composition of body components determined errors. More reliable methods such as Dual-energy X-ray Absorptiometry (DXA) and Hydrostatic Weighing have limited use in morbid obese individuals due to equipment availability, cost and technical difficulties determined by morbid obesity. Plethysmography seems effective, but it may overestimate body fat. Bioelectric Impedance Analysis (BIA) with specific equations minimizes underestimation of body fat. Anthropometry has doubt effectiveness, but the recent suggest Body Adiposity Index (BAI) is an inexpensive and noninvasive method that seems to be accurate in morbid obesity patients.

Conclusion: BIA (with specific equations) and BAI are inexpensive and noninvasive methods available worldwide and could be routinely used for body fat estimation.

Keywords: Severe obesity; Body composition; Fat mass; Fat free mass; Bioelectric impedance; plethysmography; Body adiposity index; DXA; Hydrostatic weighing; Anthropometry

Abbreviations: BIA: Bioelectrical Impedance; BIVA: Bioimpedance Vector Analysis; DXA: Dual-energy X-ray Absorptiometry; ADP: BOD POD; Plethysmography; BAI: Body Adiposity Index; CRP: C - reactive protein; SF-BIA: Single Frequency Bioelectrical Impedance; UW: Underwater Weighing; 3C: Three Compartment Model; BMI: Body Mass Index; HW: Hydrostatic Weighing

Introduction

Obesity is growing worldwide and affects approximately 35.7% of the United States population over 20 years (5% with severe obesity), being directly responsible for 112,000 to 365,000 deaths annually, with an estimated cost of 139 billion dollars [1-3]. In Brazil, 49% of the population is overweight (50.1% of men and 48% of women) and 14.8% is obese (12.4% of men and 16.9% of women) [4]. Nevertheless, these prevalence rates should be even higher since Body Mass Index (BMI) may underestimate its presence in about 39% of cases [5]. Severe obesity is characterized by important changes in body compartments when compared to overweight or eutrophic individuals [6,7]. Besides excessive fat deposition, there is an increase in Extracellular (ECW) to Intracellular Water (ICW) and ECW to Total Body Water (TBW) ratio [6,8]. These changes determine several limitations to methods commonly used to evaluate body composition in Eutrophy, overweight or obesity [7]. The Dual-Energy X-Ray Absorptiometry (DXA), plethysmography and In Vivo Neutron Activation (IVNA) systems cannot accommodate subjects with severe obesity and frequently these patients are not able to perform the required maneuvers necessary to body fat determination in Hydrostatic Weighing (HW).

Body composition assessment is important to evaluate effectiveness of strategies to reduce Body Fat (BF) in patients with severe obesity and an easy, disposable and inexpensive method is desirable [9,10]. We developed a critical review of advantages and limitations of the main methods for body composition evaluation in patients with severe obesity.

Methodology

This study was a critical review of the literature, without metaanalysis, to evaluate methods for body composition evaluation in severe obesity.

Search strategy

We conducted an electronic database search in Virtual Health Library, Embase and PubMed to identify relevant articles published between January 1985 and July 2014 by consulting the following descriptors: body composition and morbid obesity, anthropometry and morbid obesity, Hydrostatic Weighing (HW) and morbid obesity, plethysmogry and morbid...
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The principal investigator analyzed the articles identified by the search strategy, strictly following the inclusion criteria: full text, target population (humans and adults), type of study (retrospective and prospective clinical trials) and language (English). Such strategies have been taken in order to maximize search results.

Results

The literature search produced 608 articles, leaving 433 articles after duplicates were removed. Most of the articles found in databases did not evaluate methods for body composition assessment. In most studies, body composition was correlated to metabolic disorders, metabolic syndrome or micronutrients deficiency in severe obesity. Another large group of studies evaluated the relationship between body composition and associated disorders (cancer, cardiovascular diseases, diabetes, sleep apnea, asthma and arthrosis). Some studies investigated drugs, exercise or diet effects on comorbidities or effects of body composition in surgical results. Another group of studies analyzed genetic determinants of obesity. Only 24 articles evaluated the methods of body composition determination in patients with severe obesity. The characteristics of the selected articles are described in Table 1.

Table 1: Characteristics of selected articles.

<table>
<thead>
<tr>
<th>Author, Publication Year and Local</th>
<th>Study Classification</th>
<th>Descriptors</th>
<th>Sample</th>
<th>BMI (Kg/m²)</th>
<th>Body Composition Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albu et al. [11] New York, USA</td>
<td>Prospective</td>
<td>-</td>
<td>10 women</td>
<td>43±1</td>
<td>DXA, UW</td>
</tr>
<tr>
<td>Allison et al. [12] New York, USA</td>
<td>Cross-sectional</td>
<td>obesity; body fat; leptin</td>
<td>30 men and 74 women</td>
<td>59.1 ± 10.1</td>
<td>BIA</td>
</tr>
<tr>
<td>Bedogni, et al. [8]</td>
<td>Cross-sectional</td>
<td>57 morbid obese women</td>
<td>37.3 to 55.2</td>
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<tr>
<td>Bergman et al. [13] California, USA</td>
<td>Retrospective and cross-sectional</td>
<td>Absorptiometry, adiposity, intra abdominal fat, hip circumference, waist-hip ratio</td>
<td>1956 adults</td>
<td>29.5 (17.1 to 71.5)</td>
<td>DXA, anthropometry, BAI</td>
</tr>
<tr>
<td>Braulio et al. [14] Rio de Janeiro, Brazil</td>
<td>Prospective and cross-sectional</td>
<td>Absorptiometry, photon, BIA, skinfold thickness, body composition, obesity, overweight</td>
<td>34 women</td>
<td>32.1 ± 4.3</td>
<td>DXA, BIA equations Segal and Gray</td>
</tr>
<tr>
<td>Carvennec et al. [15] Bordeaux, France</td>
<td>Prospective and cross-sectional</td>
<td>Adiposity, BOD POD, changes in weight, plethysmography, air displacement, body composition</td>
<td>5 men and 5 women</td>
<td>39.3±2.8 (35 to 43.3)</td>
<td>ADP</td>
</tr>
<tr>
<td>Deurenberg et al. [16] Wageningen, Netherlands</td>
<td>Cross-sectional</td>
<td>Bioelectrical impedance, obesity, body fat, body composition, water distribution</td>
<td>611 adults</td>
<td>-</td>
<td>BIA</td>
</tr>
<tr>
<td>Das [6] Massachusetts, USA</td>
<td>Prospective, longitudinal, prognosis and intervention</td>
<td>3-compartment model</td>
<td>20 women</td>
<td>48.7±8.8</td>
<td>3C (PDA + deuterium dilution; sodium bromide and oxygen 18), BIA, densitometry, UW</td>
</tr>
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</table>

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<table>
<thead>
<tr>
<th>Authors</th>
<th>Study Location</th>
<th>Study Design</th>
<th>Outcome Measures</th>
<th>Participant Details</th>
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<tr>
<td>Elisha [17] Montreau, Canada</td>
<td>Retrospective, longitudinal and interventional</td>
<td>Obesity, body fat%, hip circumference, DEXA</td>
<td>132 obese postmenopause women</td>
<td>35.0±3.7 (30.0 to 48.5)</td>
<td>BAI, DXA, CT-scan, insulin sensitivity, blood pressure, plasma lipids, CRP</td>
</tr>
<tr>
<td>Evans [18] North Carolina, USA</td>
<td>Prospective and cross-sectional</td>
<td>Hydrostatic weighting, body composition, morbid obesity</td>
<td>80 morbid obese women</td>
<td>-</td>
<td>UW with and without head submersion</td>
</tr>
<tr>
<td>Galiebter et al. 2013, [19] New York, USA</td>
<td>Prospective and cross-sectional</td>
<td>Body Adiposity Index; Body Mass Index; DXA; BIA; ADP</td>
<td>90 morbid obese women</td>
<td>48.9±9.6 (38.7 to 77.8)</td>
<td>BAI, BIA, DXA, ADP</td>
</tr>
<tr>
<td>Gibson et al. [20] New York, USA</td>
<td>Prospective and longitudinal</td>
<td>Body Adiposity Index; Body Mass Index; Roux-en-Y gastric bypass; leptin; insulin; waist circumference</td>
<td>60 morbid obese women</td>
<td>46.5±9.5</td>
<td>BAI, BIA, DXA, ADP</td>
</tr>
<tr>
<td>Ginde et al. [21] New York, USA</td>
<td>Prospective and cross-sectional</td>
<td>Body composition, underwater weighting, nutritional assessment, BOD POD</td>
<td>89 men and 34 women</td>
<td>31.5±7.3 (17.5 to 58.4)</td>
<td>ADP, UW</td>
</tr>
<tr>
<td>Gray et al. [22] Los Angeles, USA</td>
<td>Cross-sectional</td>
<td>Body composition, bioelectrical impedance, obesity</td>
<td>25 men and 62 women</td>
<td>32.6 ± 0.9 (19.6 to 53.3)</td>
<td>SF-BIA, UW</td>
</tr>
<tr>
<td>Heath, [23] Texas, USA</td>
<td>Prospective and cross-sectional</td>
<td>-</td>
<td>16 men and 30 women, both morbid obese</td>
<td>-</td>
<td>UW with and without head submersion, BIA, ADP</td>
</tr>
<tr>
<td>Horie et al. [24] Sao Paulo, Brazil</td>
<td>Prospective, cross-sectional and diagnostic test</td>
<td>Severe obesity, BIA, BOD POD, body composition, predictive equations</td>
<td>83 women 36 men</td>
<td>46.88±6.22</td>
<td>BIA, ADP</td>
</tr>
<tr>
<td>Jiménez &amp; cols. [25] Barcelona, Spain</td>
<td>Prospective and cross-sectional</td>
<td>Morbid obesity, DXA, BIA, body composition</td>
<td>126 women and 33 men</td>
<td>45.6 ± 4.9</td>
<td>BIA, DXA</td>
</tr>
<tr>
<td>La Forgia et al. [26] Australia</td>
<td>Prospective and cross-sectional</td>
<td>Absorptiometry, body composition, obesity</td>
<td>6 women 8 men</td>
<td>33.71±3.47 (28.77 to 39.94)</td>
<td>UW, deuterium dilution, DXA</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Study</th>
<th>Region</th>
<th>Study Design</th>
<th>Methods</th>
<th>Participants</th>
<th>BMIs</th>
<th>Measurement</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leal &amp; cols. [27]</td>
<td>Espirito Santo, Brazil</td>
<td>Prospective and cross-sectional</td>
<td>Anthropometric methods, BIA, morbid obesity</td>
<td>94 adults</td>
<td>40.86±4.6</td>
<td>BIA, inflammatory markers, anthropometry</td>
<td></td>
</tr>
<tr>
<td>Lemacks et al. [28]</td>
<td>Chungcheongbuk-do, South Korea</td>
<td>Cross-sectional</td>
<td>BMI, Body adiposity index, Obesity, Postmenopausal women</td>
<td>187 overweight/obese postmenopausal women</td>
<td>31.8±5.9 (24.0-64.9)</td>
<td>BAI, DXA</td>
<td></td>
</tr>
<tr>
<td>Petroni et al. [29]</td>
<td>Milan, Italy</td>
<td>Cross-sectional</td>
<td>Body composition, Morbid obesity, Fat mass, Fat-free mass</td>
<td>6 men 3 women</td>
<td>46.6±7.7 (36.4 to 58.8)</td>
<td>ADP, BIA</td>
<td></td>
</tr>
<tr>
<td>Sartorio et al. [8]</td>
<td>Triste, Italy</td>
<td>Prospective and cross-sectional</td>
<td>Obesity, total body water, extracellular water, BIA analysis</td>
<td>75 women</td>
<td>18 a 48.2</td>
<td>BIA</td>
<td></td>
</tr>
<tr>
<td>Swan &amp; McConnell [30]</td>
<td>Arizona, USA</td>
<td>Cross-sectional</td>
<td>percent body fat, body composition, skin folds, densitometry, body fat distribution, waist to hip ratio</td>
<td>36 women</td>
<td>25.55±4.5</td>
<td>UW, anthropometry</td>
<td></td>
</tr>
<tr>
<td>Thomson et al. [31]</td>
<td>Australia</td>
<td>Prospective and cross-sectional</td>
<td>Body composition, body fat, weight loss, BIA analysis, DXA</td>
<td>24 women</td>
<td>29.57±6.1</td>
<td>BIA, DXA</td>
<td></td>
</tr>
</tbody>
</table>

BIA: Bioelectrical Impedance; BIVA: Bioimpedance Vector Analysis; DXA: Dual-energy X-ray Absorptiometry; ADP: BOD POD: Plethysmography; BAI: Body Adiposity Index; CRP: C-Reactive Protein; SF-BIA: Single Frequency Bioelectrical Impedance; UW: Underwater Weighing; 3C: Three Compartment Model

Discussion

Excessive BF is associated with morbidity and mortality in severe obesity. After surgical treatment, effectiveness of weight loss has strong correlation with changes in body composition (fat and lean mass), emphasizing the importance of its evaluation by a simple, accurate, reproducible and inexpensive method [9-32]. There are three different models of body compartments used for body composition assessment: two compartment (2C) model (Fat Mass and Fat Free Mass), three compartment (3C) model (Fat Mass, Total Body Water and Dry Fat Free Mass) and four compartment (4C) model (Fat Mass, Total Body Water, minerals and residual)[6,7]. The traditional 2C model divides the body into fat and Fat Free Mass (FFM). The assumption that FFM has a constant density in health and disease subjects is an important limitation of the model. The FFM includes protein, TBW, mineral tissue (soft tissue and bone) and glycogen. Then, any difference in the proportions of these components will lead to FM or FFM estimation errors [6]. There are some methods that can be used to determine FM in this model such as anthropometry, bioelectrical impedance, plethysmography or HW [7].

Siri (1956 e 1961) developed the 3C model adding TBW in the 2C model, since hydration state could affect the values of FFM in body composition assessments. Siri assumed that FFM consisted in TBW and a combination of total body protein and total body mineral (Fat Free Dry Mass) [6]. This model requires one method to determine FM and FFM, as HW or plethysmography, and another to determine TBW, as isotope dilution [33]. 3C model is a reliable but unavailable and expensive method to estimate FM and FFM in patients with severe obesity. The four compartment model divides the body into fat, water, minerals (soft tissue and bone) and residual. This model also requires a combination of more than one method: one to estimate body density (HW or plethysmography), other method to estimate body water and another to estimate minerals content. The estimation of minerals content of the human body became possible by In Vivo Neutron Activation (IVNA) analysis or Dual-Energy X-Ray Absorptiometry (DXA). However, both methods are expensive and equipments systems cannot accommodate subjects patients with severe obesity [33].

Bioelectrical impedance analysis (BIA)

BIA estimates body compartments (FM and FFM) measuring tissue impedance based on a cylindrical body model with constant conductivity [27]. It is an easy, portable, inexpensive, and non invasive method [27,34]. The body compartments present...
different resistance to electrical current passage. Bone and fat present low conductivity while muscle and other tissues (rich in water and electrolytes) easily allow the electric current passage [27]. The resistance is proportional to the length and inversely proportional to the cross sectional area [27]. Therefore, members contribute more than the trunk to the impedance. The arm, leg and trunk contribute with 6%, 16% and 49% of body weight although they contribute with 43%, 48% and 9% of body resistance, respectively [16,34-36]. The main limitation of BIA is significant changes in body water [36,37]. Excessive water contend will be interpreted as FFM (BF underestimation) [6,8], with major error observed with single frequency (SF-BIA) in comparison to multifrequency BIA (MF-BIA) [31,38]. The frequency used in SF-BIA (50kHz) does not adequately penetrate the cell membrane, estimating ECW in spite of TBW [39], confounding BIA results [40]. Deurenberg P [40] suggested that the tissues may present changes in electrical properties in obese state caused by increased TBW and ECW and different body geometry, with consequent underestimation of BF. Most studies report that BIA significantly underestimates BF in severe obese individuals [6,14,22,25,31,41]. The equations proposed to calculate body composition by BIA resistance are group specific [35] and generally inappropriate in populations with severe obesity. Nevertheless, Horie-Waitzberg [24] proposed specific equations to this population using the resistance provided by the SF-BIA (50 or 100kHz) with high specificity and sensitivity when compared to plethysmography. Jimenez, et al. [25] developed equations to a SF-BIA to estimate total and segmental BF with good correlation to DXA (p<0,001). Gray, et al [22] also suggested equations to be used in a SF-BIA to estimate FFM in subjects with more than 48%BF based on HW. These equations seem to minimize underestimation of body fat in MO population.

**Anthropometric measurements**

Skin fold thickness estimates body fat based on the fact that approximately half of the body fat content is deposited under the skin [35]. The main limitation in severe obesity is skinfold size that often exceeds caliper capacity (equipment used to measure skin fold thickness) [33].

Waist (WC) and Hip (HC) circumferences also presents technical problems such as the difficulty in identifying bony prominences that defines the measure location and the wide layer of abdominal fat that declines to the hip [12].

Body Adiposity Index (BAI) was developed by Bergman, et al. [13] to BF estimation based only on anthropometric measurements. It was developed and validated in non-Caucasian subjects and is possible adequate to populations of Central and South America [13]. The reproducibility of BAI compared with DEXA was good in BF range of 30 to 55%. It overestimates BF in 3.1 to 4.1% when DXA-BF is between 30 to 45% and underestimating 2.6 to 4.3% when DXA-BF is between 45 to 55% [13]. In severe obese women, BAI had a good correlation with BIA (0.86 [13] and 0.87 [19]) and plethysmography (0.71 [20] and 0.73 [19]), but not with DXA (0.39 [20] and 0.42 [20]). BAI also had good agreement (p<0,001) with DXA in overweight and obese women (0.78) [28], but not in obese menopausal women (0.6) [17]. BAI also proved advantageous for predicting cardiovascular risk in obese postmenopausal women, correlating with insulin sensitivity, CRP, leptin and visceral fat [17]. BAI also had good sensitivity and specificity to predict hypertension, better than WC, WHR and BMI in Indians of diverse body composition [40]. The major advantage of BAI is its noninvasive methodology and low cost since it requires only two simple anthropometric measurements, without need of specific mechanical or electronic equipments [13]. Another important limitation is that equations available to estimates BF were developed on eutrophy, overweight or Grade 1 obesity individuals [12]. The fat distribution (lower or upper body) also determines problems since different fat distribution needs different equations [12]. Swan and McConnell [30] tested five different equations in women with different fat distribution based on nine skin folds. They found good agreement between

**Hydrostatic weighing (HW)**

HW defines body volume by difference between body mass measured in land and underwater (after full exhalation) [33]. It had good agreement (p<0,001) with 3C model to measure BF in patients with severe obesity when compared with 3C model [using plethysmography and oxygen 18 isotope]. Nevertheless, the method is expensive, complex and is not largely available [7].

**Dual-energy X-ray absorptiometry (DXA)**

DXA is a valid method to assess body composition in obese population (28.77-39.94kg/m²) and had a good correlation with the 4C model (body density by HW, bone density by DXA and TBW by deuterium dilution). Nevertheless, a wide individual variability was observed between the methods [26]. In a group of ten MO
patients it had good agreement (p<0.01) with 4C e 3C models (Body Density by HW, bone density by DXA and TBW by triturated water). It was able to evaluate changes in BF during weight loss [11]. The method has some limitations in MO, since their results can be “masked” by assuming constant values of hydration (73.2%) and potassium in FFM and errors can occur when the body depth exceed 20 to 25cm [6,7]. Furthermore, the method is expensive, present operational complexity and frequently the individual size and body mass exceeds the limit of equipment in severe obesity [6].

Conclusion

The challenge of assessing body composition in morbid obesity is not completely solved in daily clinical practice. The methods recommended to eutrophic health population, such as DXA and HW, have limited use due to equipment availability, cost and technical difficulties determined by MO. Skin folds thickness and body circumferences have doubt effectiveness. Plethysmography is a method of restricted accessibility and presents some limitations related to excess ECW and may overestimate BF. BIA contains several limitations, most of them related to changes in the composition of FFM, excess ECW and changes in body format, all contributing to BF underestimation but specific equations developed for MO population seems to minimize these problems. Simple, available and no expensive methods (as BIA and BAI) simplify clinical evaluation and determine better evaluation of MO before and after clinical or surgical treatment of severe obesity.

Authors Contribution

ABB searched for the articles and wrote the manuscript. Authors RC, MAS, VMS and MPS contributed with the design of the research, interpretation of the articles and review of the manuscript. This article is part of a project that is supported by São Paulo Research Foundation (FAPESP), grant 2012/22159-9.

References


