Research Article

Open Access CrossMark

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, bioelectrical impedance, plethysmography, body adiposity index, DXA, hydrostatic weighing, anthropometry

Volume 4 Issue 6 - 2016

Aline Biaseto Bernhard, Marco Aurélio Santo, Veruska Magalhães Scabim, Marcela Pires Serafim, Roberto de Cleva

Department of Gastroenterology, University of São Paulo Medical School, Brazil

Correspondence: Roberto de Cleva, Rua Cel. Artur Godói 125, apto 152. Vila Mariana. São Paulo/ São Paulo, Brazil. Zip Code: 04018-050, Tel 55 11 55757391, 55 11 999774502, Email roberto.cleva@uol.com.br

Received: April 26, 2016 | **Published:** July 20, 2016

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 139billion 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), plethysmografy 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 metanalysis, 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, plethysmografy and morbid obesity; Dual-Energy X-Ray Absorptiometry (DXA) and morbid obesity, Bioelectrical Impedance (BIA) and morbid obesity; Body Adiposity Index (BAI) and morbid obesity. 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

Author, publication year and local	Study classification	Descriptors	Sample	BMI (Kg/m²)	Body composition method
Albu et al.[11] New York, USA	Prospective	-	10 women	43±1	DXA, UW
Allison et al.[12] New York, USA	Cross-sectional	obesity; body fat; leptin	30 men and 74 women	59.1±10.1	BIA
Bedogni, et al.[8]	Cross-sectional		57 morbid obese women	37.3 to 55.2	
Bergman et al.[13] California, USA	Retrospective and cross-sectional	Absorptiometry, adiposity, intra abdominal fat, hip circumference, waist-hip ratio	1956 adults	29.5 (17.1 to 71.5)	DXA, anthropometry, BAI.
Braulio et al.[14] Rio de Janeiro, Brazil	Prospective and cross-sectional	Absorptiometry, photon, BIA, skinfold thickness, body composition, obesity, overweight	34 women	32.1±4.3	DXA, BIA equations Segal and Gray
Carvennec et al.[15] Bordeaux, France	Prospective and cross-sectional	Adiposity, BOD POD, changes in weight, plethysmography, air displacement, body composition	5 men and 5 women	39.3±2.,8 (35 to 43.3)	ADP
Deurenberg et al.[16] Wageningen, Netherlands	Cross-sectional	Bioelectrical impedance, obesity, body fat, body composition, water distribution	611 adults	-	BIA
Das[6] Massachusetts, USA	Prospective, longitudinal, prognosis and intervention	3-compartment model	20 women	48.7±8.8	3C (PDA + deuterium dilution; sodium bromide and oxygen 18), BIA, densitometry, UW
Elisha[17] Montreau, Canada	Retrospective, longitudinal and interventional	Obesity, body fat%, hip circumference, DEXA	132 obese pos menopause women	35.0±3.7 (30.0 to 48.5)	BAI, DXA, CT-scan, insulin sensitivity, blood pressure, plasma lipids, CRP
Evans[18] North Carolina, USA	Prospective and cross-sectional	Hydrostatic weighting, body composition, morbid obesity	80 morbid obese women	-	UW with and without head submersion
Galiebter et al. 2013,[19] New York, USA	Prospective and cross-sectional	Body Adiposity Index; Body Mass Index; DXA; BIA; ADP	90 morbid obese women	48.9±9.6 (38.7 to 77.8)	BAI, BIA, DXA, ADP
Gibson et al.[20] New York, USA	Prospective and longitudinal	Body Adiposity Index; Body Mass Index; Roux-en-Y gastric bypass; leptin; insulin; waist circumference	60 morbid obese women	46.5±9.5	BAI, BIA, DXA, ADP
Ginde et al.[21] New York, USA	Prospective and cross-sectional	Body composition, underwater weighting, nutritional assessment, BOD POD	89 men and 34 women	31.5±7.3 (17.5 to 58.4)	ADP, UW
Gray et al.[22] Los Angeles, USA	Cross-sectional	Body composition, bioelectrical impedance, obesity	25 men and 62 women	32.6±0.9 (19.6 to 53.3)	SF-BIA, UW
Heath,[23] Texas, USA	Prospective and cross-sectional	-	16 men and 30 women, both morbid obese	-	UW with and without head submersion, BIA, ADP
Horie et al.[24] Sao Paulo, Brazil	Prospective, cross-sectional and diagnostic test	Severe obesity, BIA, BOD POD, body composition, predictive equations	83 women 36 men	46.88±6.22	BIA, ADP

Citation: Bernhard AB, Santo MA, Scabim VM, et al. Body composition evaluation in severe obesity: a critical review. *Adv Obes Weight Manag Control.* 2016;4(6):159–164. DOI: 10.15406/aowmc.2016.04.00113

Table Continued....

Author, publication year and local	Study classification	Descriptors	Sample	BMI (Kg/m²)	Body composition method
Jiménez & cols,[25] Barcelona, Spain	Prospective and cross-sectional	Morbid obesity, DXA, BIA, body composition	126 women and 33 men	45.6 ±4.9	BIA, DXA
La Forgia et al.[26] Australia	Prospective and cross-sectional	Absorptiometry, body composition, obesity.	6 women 8 men	33.71±3.47 (28.77 to 39.94)	UW, deuterium dilution, DXA
Leal & cols.[27] Espirito Santo, Brazil	Prospective and cross-sectional	Anthropometric methods, BIA, morbid obesity	94 adults	40.86±4.6	BIA, inflammatory markers, anthropometry
Lemacks et al.[28] Chungcheongbuk-do, South Korea	Cross-sectional	BMI, Body adiposity index, Obesity, Postmenopausal women	187 overweight/ obese postmenopausal women	31.8±5.9 (24.0-64.9)	BAI, DXA
Petroni et al.[29] Milan, Italy	Cross-sectional	Body composition, Morbid obesity, Fat mass, Fat-free mass	6 men 3 women	46.6±7.7 (36.4 to 58.8)	ADP, BIA
Sartorio et al.[8] Triste, Italy	Prospective and cross-sectional	Obesity, total body water, extracellular water, BIA analysis	75 women	18 a 48.2	BIA
Swan & McConnell[30] Arizona, USA	Cross-sectional	percent body fat, body composition, skin folds, densitometry, body fat distribution, waist to hip ratio	36 women	25.55±4.5	UW, anthropometry
Thomson et al.[31] Australia	Prospective and cross-sectional	Body composition, body fat, weight loss, BIA analysis, DXA	24 women	29.57±6.1	BIA, DXA

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 invasible 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[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 overweigh and obese women (0.78),[28] but not in obese postmenopausal 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 sensibility 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 & 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) and anthropometry only in women with predominant upper body fat distribution.[30]

Plethysmography

The plethysmography was validated in 123 overweight to morbid obesity individuals (BMI 17.5 to 58.4kg/m^2) with HW with good correlation (p<0,001) for all BMI ranges.[21] A pilot study showed no significant difference with BIA in patients with BMI>40kg/m^2.[29] Another important advantage is that most patients with severe obesity fit in the equipment and are able to perform the required maneuvers.[7,29] Nevertheless, it may interpret water gain as fat gain and overestimate BF. Carvennec et al.,[15] evaluated the ability of plethysmography to detect small changes in body volume. They introduced water, oil or a mixture of both with the obese individual in the equipment. The oil was properly identified as BF. However, increments up to 2liters of water were interpreted as increased BF (each liter overestimates 0.5% of BF). The authors suggested that error should occur because the proximity between the density of water and fat is bigger than between water and FFM. The method significantly overestimated 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]

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.[6] This technique is considered the gold standard to determining body composition but only individuals with reasonable adaptation to aquatic environment can be evaluated.[7] Patients with severe obesity often have underwater discomfort or are unable to perform the necessary procedures to adequate measurement.[6] Furthermore, HW requires highly trained technicians and expensive laboratory equipment.[8] In order to facilitate the application of this technique, HW without head submersion was successfully tested in morbidly obese women.[18] The method was tested later in obese men and women with satisfactory results.[39]

Dual-energy X-ray absorptiometry (DXA)

DXA is a valid method to assess body composition in obese population (28.77-39.94kg/m^2) 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.

Citation: Bernhard AB, Santo MA, Scabim VM, et al. Body composition evaluation in severe obesity: a critical review. *Adv Obes Weight Manag Control.* 2016;4(6):159–164. DOI: 10.15406/aowmc.2016.04.00113

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.

Acknowledgements

None.

Conflict of interest

The author declares no conflict of interest.

References

1. World Health Organization (WHO). *Obesity: preventing and managing the global epidemic*. Geneva: World Health Organization technical report series; 2000. p. 1–253.
2. Ogden CL, Carroll MD, Kit BK, et al. *Prevalence of Obesity in the United States, 2009–2010*. NCHS Data Brief, n82. 2012.
3. Hensrud DD, Klein S. Extreme Obesity: A New Medical Crisis in the United States. *Clin Proc*. 2006;81(10 suppl):S5–S10.
4. http://bvsms.saude.gov.br/bvs/publicacoes/vigitel-brasil-2011-fatores-risco-doencas-cronicas.pd
5. Shah NR, Braverman ER. Measuring Adiposity in Patients: The Utility of Body Mass Index (BMI), Percent Body Fat, and Leptin. *Plos One*. 2012;7(4):e33308.
6. Das SK, Roberts SB, Kehayias JJ, et al. Body composition assessment in extreme obesity and after massive weight loss induced by gastric bypass surgery. *Am J Physiol Endocrinol Metab*. 2003;284(6):1080–1088.
7. Das SK. Body composition measurement in severe obesity. *Curr opin Clin Nutr Metab Care*. 2005;8(6):602–606.
8. Sartorio A, Malavolti M, Agosti F, et al. Body water distribution in severe obesity and its assessment from eight–polar bioelectrical impedance analysis. *Eur J Clin Nutr*. 2005;59(2):155–160.
9. Berentzen T, Sørensen TIA. Effects of Intended Weight Loss on Morbidity and Mortality: Possible Explanations of Controversial Results. *Nutr Rev*. 2006;64(11):502–507.
10. M*ü*ller MJ, Lagerpusch M, Enderle J, et al. Beyond the body mass index: tracking body composition in the pathogenesis of obesity and the metabolic syndrome. *Obes rev*. 2012;13:6–13.
11. Albu J, Smolowitz J, Lichtman S, et al. Composition of Weight Loss in Severely Obese Women:A New Look at Old Methods. *Metabolisam*. 1992;41(10):1068–1074.
12. Allison DB, Nathan JS, Albu JB, et al. Measurement challenges and other practical concerns when studying massively obese individuals. *Int J Eat Disord*. 1998;24(3):275–284.
13. Bergman RN, Stefanovski D, Buchanan TA, et al. A Better Index of Body Adiposity. *Obes*. 2011;19(5):1083–1089.
14. Bráulio VB, Furtado VCS, Silveira MG, et al. Comparison of body composition methods in overweight and obese Brazilian women. *Arq Bras Endocrinol Metab*. 2010;54(4):398–405.
15. Carvennec ML, Fagour C, Adenis–Lamarre E, et al. Body Composition of Obese Subjects by Air Displacement Plethysmography: The Influence of Hydration. *Obes*. 2007;15(1):78–84.
16. Kyle UG, Bosaeus I, Lorenzo ADD, et al. Bioelectrical impedance analysis part II: utilization in clinical practice. *Clin Nutr*. 2004;23(6):1430–1453.
17. Elisha B, Rabasa–Lhoret R, Messier V, et al. Relationship between the body adiposity index and cardiometabolic risk factors in obese postmenopausal women. *Eur J Nutr*. 2012;52(1):145–151.
18. Evans PE, Israel R, Flickinger EG, et al. Hydrostatic Weighting without head submersion in morbidly obese females. *Am J Clin Nut*. 1989;50(2):400–403.
19. Geliebter A, Atalayer D, Flancbaum L, et al. Comparison of Body Adiposity Index (BAI) and Body Mass Index (BMI) with Estimations of % Body Fat in Clinically Severe Obese Women. *Obes*. 2013;21(3):1–10.
20. Gibson CD, Atalayer D, Flancbaum L, et al. Body adiposity index (BAI) correlates with BMI and body fat pre and post–bariatric surgery but is not an adequate substitute for BMI in severely obese women. *Int J Body Compos Res*. 2012;10(1):9–14.
21. Ginde SR, Geliebter A, Rubiano F, et al. Air Displacement Plethysmography: Validation in Overweight and Obese Subjects. *Obes Res*. 2005;13(7):1232–1237.
22. Gray DS, Bray GA, Gemayel N, et al. Effect of obesity on bioelectrical impedance. *Am J Clin Nutr*. 1989;50:255–260.
23. Heath EM, Adams TD, Daines MM, et al. Bioelectrical impedance and hydostatic weighing with and without head submersion in persons who are morbidly obese. *J Am Diet Assoc*. 1998;98(8):869–875.
24. Horie LM, Barbosa–Silva MCG, Torrinhas RS, et al. New body fat prediction equations for severely obese patients. *Clin Nut*. 2008;27(3):350–356.
25. Jiménez A, Omaña W, Flores L, et al. Prediction of Whole–Body and Segmental Body composition by Bioelectrical Impedance in Morbidly Obese Subjects. *Obes Surg*. 2012;22(4):587–593.
26. Laforgia J, Dollman J, Dale MJ, et al. Validation of DXA body composition estimates in obese men and women. *Obes*. 2009;17(4):821–827.
27. Leal AA, Faintuch J, Morais LAC, et al. Bioimpedance Analysis: Should it be Used in Morbid Obesity? *Am J Hum Biol*. 2011;23(3):420–422.
28. Lemacks JL, Liu P, Shin H, et al. Validation of body adiposity index as a measure of obesity in overweight and obese postmenopausal white women and its comparison with body mass index. *Menopause*. 2012;19(11):1277–1279.
29. Petroni ML, Bertoli S, Maggioni M, et al. Feasibility of air plethysmography (BOD POD) in morbid obesity:a pilot study. *Acta Diabetol*. 2003;40(suppl 1):S59–S62.
30. Swan PD, McConnell KE. Anthropometry and bioelectrical impedance inconsistently predicts fatness in women with regional adiposity. *Med Sci Sports Exerc*. 1999;31(7):1068–1075.
31. Thomson R, Brinkwortha GD, Buckley JD, et al. Good agreement between bioelectrical impedance and dual–energy X–ray absorptiometry for estimating changes in body composition during weight loss in overweight young women. *Clin Nut*. 2007;26(6):771–777.
32. Han TS, van Leer EM, Seidell JC, et al. Waist circumference action levels in the identification of cardiovascular risk factors:prevalence study in a random sample. *BJM*. 1995;311(7017):1401–1405.
33. Silva AM, Shen W, Wang Z, et al. Three–compartment model: critical evaluation based on neutron activation analysis. *Am J Physiol Endocrinol Metab*. 2004;287(5):E962–E969.
34. Coppini LZ, Waitzberg DL, Campos ACL. Limitations and validation of bioelectrical impedance analysis in morbidly obese patients. *Curr Opin Clin Nutr Metab Care*. 2005;8(3):329–332.

35. Baumgartner RN, Chumlea WC, Roche AF. Estimation of body composition from bioelectric impedance of body segments. *Am J Clin Nutr*. 1989;50(2):221–227.

36. Lukaski HC, Scheltinga MAR. Improved sensitivity of the tetrapolar bioelectrical impedance technique to assess fluid status and body composition: use of proximal electrode placement. *Age Nutr*. 1994;5:123–132.

37. O'Brien C, Young AJ, Sawka MN. Bioelectrical impedance to estimate changes in hydration status. *Int J Sports Med*. 2002;23:361–366.

38. Gudivaka R, Schoeller DA, Kushner RF, et al. Single–and multifrequency models for bioelectrical impedance analysis of body water compartments. *J Appl Physiol*. 1999;87(3):1087–1096.

39. Foster KR, Lukaski HC. Whole–body impedance–what does it measure? *Am J Clin Nutr*. 1996;64(3 Suppl):388–396.

40. Deurenberg P. Limitations of the bioelectrical impedance method for the assessment of body fat in severe obesity. *Am J Clin Nutr*. 1996;64(3 Suppl):449S–452S.

41. Gupta S, Kapoor S. Body Adiposity Index: Its Relevance and Validity in Assessing Body Fatness of Adults. *ISRN Obes*. 2014;2014:243294.

Citation: Bernhard AB, Santo MA, Scabim VM, et al. Body composition evaluation in severe obesity: a critical review. *Adv Obes Weight Manag Control.* 2016;4(6):159–164. DOI: 10.15406/aowmc.2016.04.00113