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Body composition assessment in individuals with class II/III obesity: a narrative review

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Abstract

Background Individuals with class II/III obesity have a high percentage of body fat. Assessing body composition in cases of severe obesity can be difficult and controversial both in clinical practice and scientific research. Thus, it is essential to explore the different aspects of evaluating body composition and to discuss the available methods to assess it in this population.

Aims To summarise and discuss the methods used to measure body composition in adults with class II/III obesity and their potential in clinical practice and scientific research.

Methods This is a narrative review using data from PubMed, Scielo, and Lilacs databases. Original articles on body composition analysis in adults with class II/III obesity i.e., a BMI ≥ 35 kg/m^2 were eligible. Body composition assessment methods were analysed and described.

Results Some imaging methods produced significantly accurate results. Dual-energy X-ray absorptiometry (DXA) significantly produces accurate results and has been used in clinical studies. However, due to its high cost, it is not applicable in clinical practice. Multifrequency bioelectrical impedance analysis (BIA) has good accuracy and is more appropriate for clinical practice than other methods. We have highlighted several aspects of the importance and applicability of performing body composition analysis in individuals with class II/III obesity.

Conclusion DXA has been considered the most adequate method for clinical research. Multifrequency BIA may be a viable alternative to DXA for use in clinical practice. Assessing body composition and its components is important for people with class II/III obesity. It can help improve the effectiveness of interventions and clinical treatments, especially in reducing the risk of losing muscle mass. Muscle loss can cause sarcopenic obesity and other clinical complications, so understanding body composition is crucial. Assessing body composition can also help understand the impact of interventions on bones and avoid clinical complications.

Keywords Severe obesity, Body composition, Analysis methods, Health interventions, Morbid mortality

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Introduction

Obesity is a global public health problem. Its incidence has been increasing at higher levels, particularly classes II and III i.e., body mass index [BMI] ≥ 35 kg/m^2, which is also called severe obesity [1]. Approximately 126 million (5.0%) women and 58 million (2.3%) men have class II/III obesity [1]. The exponential growth of this class of obesity in recent years is alarming due to the directly proportional increase in the risk of morbimortality [2, 3].

Methods for assessing body composition in overweight and class I obesity individuals are available. However, these methods become more challenging to use accurately in individuals with class II and III obesity, due to excess adipose tissue, which makes it difficult to measure lean mass. As a result, many experts avoid using these methods in clinical practice and research. Nevertheless, given that individuals with class II/III obesity face more severe health risks and the prevalence of this condition has increased significantly in recent years, it is important to consider ways to evaluate body composition in these individuals.

Individuals with class II/III obesity experience significant changes in their body composition. These changes include an excess of extracellular water and fat mass [4], which are often linked to various medical conditions such as hypertension, diabetes, cardiovascular diseases, dyslipidaemia, sleep apnoea, musculoskeletal diseases, and certain types of cancer [5–8] Given the increased risk of death and other comorbidities associated with class II/III obesity, it is important to evaluate the details of the health status of these individuals and perform routine outpatient follow-ups, including body composition and biochemical tests, to assess weight change, BMI, and other cardiovascular risk variables [9].

Body composition analysis is based on water and electrolyte concentrations, body tissue density, biological interrelationships, and distribution of components and tissues [9]. In individuals with a BMI greater than 35 kg/m2, there is excess adipose tissue, which poses challenges for certain body composition methods [10]

Considering the above context, the following questions remain relevant: Should health professionals assess the body composition of individuals with class II/III obesity? What is the most viable method in clinical settings? What is the most effective method to be used by researchers? These questions remain controversial and this review will discuss all the aspects involved. Thus, the aims of this study were: i) to discuss and synthesise the evidence of the methods used to measure body composition in adults with class II/III obesity (bioimpedance, DXA, plethysmography, hydrostatic weighing, magnetic resonance imaging, computed tomography, and ultrasonography), their limitations and advantages; ii) and the potential use these methods in clinical practice and scientific research. Ultimately, we aimed to clarify the importance of assessing body composition in individuals with class II/III obesity and provide answers to relevant questions.

Materials and methods

This is a narrative review based on international scientific evidence published through scientific articles that described the methods for assessing the body composition of adults with class II/III obesity. Studies reporting BMI > 35 kg/m^2, i.e., class II/III obesity [11] were included. BMI and waist circumference (WC) were only used when diagnosing obesity.

The search for articles was performed using the National Library of Medicine, United States (PubMed), Scientific Electronic Library Online, and Latin American & Caribbean Health Sciences Literature databases. The descriptors or keywords used were as follows: Air Displacement Plethysmography, Anthropometry, Bioelectrical Impedance Analysis, Body Composition, Body Mass Index, Dual Energy X-Ray Absorptiometry, Magnetic Resonance Imaging, Obesity, Severe Obesity and Tomography. The authors critically evaluated the eligibility of all articles. The methods were analysed and applied according to the characteristics, limitations, and advantages of individuals with class II/III obesity. There were no restrictions on languages or years of publication. Titles and abstracts were analysed to determine whether the study would be included in our review, and the full reading of the article was performed later. The reference lists of the articles used in the search were also analysed to identify studies that were potentially missed during the search.

Result and discussion

Body composition assessment methods

Some methods for assessing body composition in individuals with class II/III obesity and their applicability will be discussed below.

The skin fold method was not included due to solid scientific evidence advising against its use in this population [12, 13]. Despite a consensus in the literature that hydrostatic weighing is the gold standard method, this technique is not viable in clinical practice.

Bioimpedance

Body composition analysis by electrical bioimpedance analysis (BIA) is based on different levels of electrical conduction in tissues exposed to frequency currents [14] and is considered a complementary method to anthropometry [15]. BIA assessment of the body composition of normally hydrated individuals with obesity may represent valid support to better characterize the nutritional status of this population [16]. This technique has a relatively lower cost compared to other imaging techniques, such as dual-energy X-ray absorptiometry (DXA), plethysmography, magnetic resonance imaging, or computed tomography. There is a good correlation between the Multifrequency Bioelectrical Impedance Analysis BIA and DXA in individuals with obesity [17]. Although BIA is a non-invasive technique [14], with ease of use and portability, its accuracy can be affected by variables such as food, water, alcoholic beverage intake, physical activity, menstrual cycle, and equipment used [18].

Bipolar and tetrapolar techniques are currently available, the latter is more advantageous considering the former's resistance and reactance data. Furthermore, the bipolar technique tends to provide reading errors [19] and performs only segmental analysis (trunk, lower, or upper limbs), whereas the tetrapolar technique performs a whole-body analysis.

The bioimpedance device provides measurements in the form of body fat, fat-free mass, and water distribution [20]. The passage of low-amplitude currents in the body does not determine body composition directly, the latter is established by the resistance and reactance values that subsequently detect extracellular water, intracellular water, and phase angle [21]. Fat-free mass is estimated by equations specific to sex and age, whereas fat mass is estimated by subtracting body weight from the value found for the former [22].

The ohmmeter is the equipment used to obtain information about resistance and reactance and may emit currents in two ways: single frequency or multifrequency [14]. In single-frequency ohmmeters, impedance may estimate fat-free mass but does not determine or differentiate extra and intracellular fractions of water [23]. This would be a limitation for the use of this technique in individuals with class II/III obesity due to the changes in the amount of intra- and extracellular water. However, single-frequency bioimpedance, commonly used in clinical practice may not be as accurate in individuals with class II and III obesity [10]. Still, the multifrequency models may estimate intra- and extracellular water fractions because of applying different frequencies [24].

A total of 15 studies that used bioimpedance to assess the body composition of adults with class II/III obesity were found [17, 20, 25–37]. Some of them regard multifrequency BIA as a valid technique for the analysis of individuals with BMI > 34 kg/m^2 [17, 20, 29, 37]. Multifrequency BIA is an alternative method to DXA for assessing body composition in individuals with class II/III obesity, demonstrating an almost perfect correlation (intraclass correlation coefficient = 0.832) in the evaluation of fat (kg) and fat-free mass (kg) [20]. BIA may overestimate the results of the appendicular lean mass assessment, however, the use of specific equations for individuals with BMI > 35 kg/m^2 reduces the bias [17, 37]. Compared to plethysmography, which is the second-best method for assessing individuals with class II/III obesity, the standard equation for multifrequency BIA overestimated body fat in women by 1.3 kg and0 men at 5.6 kg ($p < 0.05$) [29]. However, after the development of a new predictive equation for BIA, the body fat of these individuals was predicted with greater accuracy, precision, and agreement. This finding highlights the importance of taking into consideration the formula used in the BIA measurement to reduce errors when estimating body composition [17, 29, 37].

Furthermore, for greater precision in measurements, adhering to a standardised protocol for carrying out the BIA is essential. The measures taken to increase the accuracy of the examination are described in two phases: the preparatory measures and those taken at the time of the measurement [38]. The BIA standardisation protocol is described Table 1.

Dual-energy X-ray absorptiometry

DXA is a reference method for the assessment of obese individuals [39] that may evaluate body composition through low radiation emission [9], estimating fat mass, fat-free mass, and bone mineral density [40]. This method is considered fast and easy since it takes approximately 10 to 20 min, and requires minimal patient cooperation [17, 41].

Compared to hydrostatic weighing, DXA is less influenced by the quantity of body water [42] and is more accessible compared to computed tomography and magnetic resonance imaging [43]. In addition, this technique presents high accuracy in assessing visceral adipose tissue (VAT) to track individual changes [44], sensitivity, and quantified assessment in body regions [45, 46]. For the comparison of VAT between individuals in cross-sectional and longitudinal scientific investigations, DXA did not present validity. A recent study compared the results of magnetic resonance imaging and DXA demonstrated that DXA underestimates the amount of VAT and pointed out the resonance as a better tool [47]. However, is not always clinically applicable, considering its high cost [48].

Regarding its limitations, DXA estimates less precise measurements for soft tissues located in the trunk compared to the limbs [49]. Another limitation is that some equipment has restrictions on body weight, width, thickness, and length [9], which can result in errors in estimating body composition in individuals with obesity. In cases where the individual's dimensions are greater than the edges of the device, it may be positioned such that only one side of the body is included in the evaluation using

Table 1 Protocol for standardizing electrical bioimpedance measurement

Conduct measurements consistently at the same time of day
Avoid
Consuming substantial meals within 2–4 h before
Coffee intake up to 8 h before
Alcohol consumption within the 48 h preceding
Fluid intake to > 1% of body mass 2 h before
Restrict
Engaging in vigorous physical activity (> 12 h)
Use of diuretic medications seven days in advance
At the time of the exam
Empty the bladder immediately before (within 30 min)
Remove metallic jewellery before
Adhere to a standardized resting period (typically 5–10 min) in the supine position before, aimed at stabilizing blood pressure
Maintain consistent limb positioning away from the body (arm-trunk angles: 10° ± 5°; leg-trunk angles: 15° ± 5°)
Prepare the skin surface by depilation and cleansing with an alcohol solution. Ensure the absence of skin lesions at electrode sites
Utilize electrodes compliant with manufacturer specifications. Store electrodes properly, employing thermal insulation to preserve gel integrity
Position electrodes according to manufacturer guidelines or literature instructions. Ensure a minimum separation of 5 cm between the current source and voltage-sensing electrodes
Maintain thermoneutral environmental conditions (consistent ambient temperature and humidity)
Equipment performance
Perform calibration verification of technical instrumentation
Isolate metallic objects and other electronic devices, maintaining a minimum distance of 50 cm
Measure height or body segment length with precision to the nearest 0.5 cm
Measure weight with precision to the nearest 0.1 kg
Employ exclusively validated prediction models (equations) for the utilized equipment or ensure adequate calibration of the instrument

Table adapted from Sthan et. al. (2012) [38]

the Hemiscan technique [50]. It must also be considered that DXA has a lower resolution compared to computed tomography and magnetic resonance imaging since it presents two-dimensional images and a higher coefficient of variation [43].

Five studies evaluated the body composition of individuals with class II/III obesity using DXA [17, 33, 34, 51, 52]. Although used in several studies as a reference method [31, 32], the problems encountered in the application of this method are more prevalent as BMI increases for extreme classifications of obesity (BMI ≥ 40 kg/m^2) [46]. The ability to support these individuals varies according to the model of the densitometry equipment [41], which should be taken into consideration when evaluating individuals with class II/III obesity.

Plethysmography

This method uses air displacement to estimate body volume [53] and like hydrostatic weighing estimates body density which is subsequently transformed into body fat percentage. However, in comparison with hydrostatic weighing, plethysmography has more advantages, as individuals are assessed by air displacement and not by water immersion [9].

Although plethysmography assesses individuals with (a maximum weight of 250 kg) and is considered a relatively fast method, its costs are high [54]. It is rarely used on individuals with a high BMI as they are uncomfortable and reluctant to undergo this procedure [9]. In addition, there may be errors in the estimates of body composition parameters when evaluating individuals with class II/III obesity.

The use of plethysmography to assess the body composition of individuals with class II/III obesity was identified in four studies [34, 52, 55, 56]. Two of them suggest that plethysmography may be an appropriate method to assess the body composition of individuals with obesity [55, 56]. However, according to Hames et al. [52], in individuals with class II/III obesity (BMI between 41.1 and 51.5 kg/m^2) the fat-free mass assessed by plethysmography, is significantly lower than that estimated by DXA ($p = 0.022$), whereas for individuals with BMI between 30.3 and 39.2 kg/m^2, there are no significant differences ($p = 0.836$) [52]. In the same study, as BMI increases, body fat percentage values are overestimated by plethysmography [52]. Based on Bedogni et al. [34] the above methods present divergent results in the analysis of the body composition in morbidly obese women.

Hydrostatic weighing

This is a validated method used to estimate the percentage of body fat through water displaced by the volume of the body assessed, therefore estimating total body volume [57]. Despite its high accuracy [58], this method depends on the body assessed and presents difficulties when evaluating individuals with obesity since there are problems in immersing such individuals in water [9].

Four studies have evaluated this method for body composition analysis of individuals with class II/III obesity [10, 35, 59, 60]. In a study conducted on this population, participants observed discomfort and required specialized equipment and highly trained evaluators. Moreover, physical limitations because of the individual's body size were observed [10] and the accuracy of the method may be affected by variables, such as time of day, menstrual cycle, medications, and physical activity [58, 59]. Furthermore, this method is expensive [57], time-consuming, and requires adaptation to liquid medium, precise equipment, ample installation space, and induces apprehension in individuals with class II/III obesity during the examination [10]. Due to its limitations, it is not practical to use the traditional hydrostatic weighing method in clinical settings or scientific research. However, studies have found that a modified version of this method, without submerging the head, can be a suitable alternative. This modified method is accurate, acceptable, and convenient for assessing body composition. [35].

Magnetic resonance imaging

Magnetic resonance imaging is a technique that identifies tissue volumes through "image slices" [49] to determine inter-/intramuscular adipose tissue.

The main advantage of this technique is the ability to estimate parameters regionally, and it is considered an accurate method for estimating intra-abdominal adipose tissue [49]. It is used to identify both visceral and subcutaneous fatty tissues [21], in addition to fatty and skeletal muscle tissues [61], and is considered more accurate compared to cadaver dissection [62]. However, it is an excessively expensive and difficult-to-access method [15, 63] and cannot be performed in individuals with large body sizes [9].

Three studies have evaluated the usefulness of magnetic resonance imaging in the body composition analysis of adults with class II/III obesity [31, 37, 64]. The results from these studies suggest that magnetic resonance imaging may be a good imaging method for visceral fat analysis in post-bariatric individuals [32, 37].

Computed tomography

Computed tomography provides two-dimensional cross-sectional images of the body [65] and can be performed in individuals with large body sizes [9]. Similar to magnetic resonance imaging, it has a high cost [14] and is a difficult-to-access method [63].

This technique is particularly useful when detecting fat infiltrates in liver tissue or skeletal muscle [66], which would be specifically important for detecting sarcopenia with intramuscular fat. Computed tomography is considered more accurate compared to cadaver dissection [62] and can be used to identify both visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT) [21]. However, due to its high radiation levels [11], its applicability and use are limited [67], although it has been used to measure intra-abdominal fat [9].

Ultrasonography

This method converts electric energy into sound waves, passing through tissues and quantifying the thickness of adipose and muscle tissues [65]. As a result of its high costs and technical difficulties, the application of this method for body composition assessment is not feasible [65].

Only one study evaluated this technique for body composition analysis of individuals with class II/III obesity was identified. This article reported a high correlation between ultrasonography and computed tomography in the determination of visceral ($r = 0.95$; $p < 0.05$) and subcutaneous fats ($r = 0.72$; $p < 0.05$) [37, 68].

To the best of our knowledge, only two studies [35, 60] have compared hydrostatic weighing, which is considered the most accurate method for body assessment, with other methods in individuals with class II/III obesity. Due to the difficulties of submerging individuals with obesity, especially those with class II/III obesity, it is more common to find articles that investigate the accuracy of other methods such as DEXA, computed tomography, or magnetic resonance imaging [34, 44, 62, 66, 68, 69].

Table 2 displays the limitations, advantages, accuracy, and use of different techniques for body composition analysis of individuals with class II/III obesity.

Should body composition in individuals with class II/III obesity be evaluated?

Previous studies have shown that evaluating body composition becomes more challenging when dealing with class II/III obesity. This is due to the limitations imposed by severe obesity on physical size, as well as changes in the composition of fat-free mass. As a result, many clinicians tend to avoid performing such assessments [10, 16, 53]. Considering all the aspects described above on the advantages and disadvantages of each method, it

Table 2 Limitations, advantages, accuracy, and use of different techniques for body composition analysis of individuals with class II/III obesity

Technique	Limitations	Advantages	Validation in relation to hydrostatic weighing	Type of method	Reference	Recommendation
Single-frequency BIA	Neither determines nor differentiates extra- and intracellular water fractions, has low precision, and performs only segmental analysis	Has a low cost, is non-invasive, and easy to transport and handle	Not validate	Double-indirect	[14, 23, 57]	Not recommended
Multifrequency BIA	Has accuracy that can be affected by food intake, water intake, alcoholic beverage consumption, physical activity, menstrual cycle, and equipment used	Is more accessible compared to other techniques, non-invasive to evaluated individuals, easy to transport and handle and allows an estimation of intra- and extracellular water fractions	High accuracy	Double-indirect	[14, 24, 35, 57, 70]	Recommended as long as care is taken to prepare the individual
Dual-energy X-ray absorptiometry	May not be performed in significantly heavy individuals (width, thickness, length, and equipment must be considered) and has a high cost	Has low radiation emission, is quick and easy, requires minimum cooperation of evaluated individuals, and demonstrates precision and sensitivity	High accuracy	Indirect	[9, 39, 41, 48, 69]	Recommended Accurate High cost
Plethysmography	Has a high cost, low acceptability for obese individuals and tends to underestimate fat-free mass and overestimate fat mass and percentage of fat	Avoids aversion of evaluated individuals compared to hydrostatic weighing, accommodates heavy individuals, and is a relatively quick method	High accuracy	Indirect	[9, 52, 54, 71]	Recommended Can overestimate % BF Infeasible due to its high cost and acceptability
Hydrostatic weighing	Involves difficulties in submerging obese individuals, entails discomfort and apprehension, Inability to perform manoeuvres during the test and physical limitations, requires specialized equipment, highly trained evaluators, and ample installation space	Has high accuracy	-	Indirect	[9, 10, 57, 58]	Recommended Infeasible due to its high cost and low acceptability

Table 2 (continued)

Technique	Limitations	Advantages	Validation in relation to hydrostatic weighing	Type of method	Reference	Recommendation
Magnetic resonance imaging	Has a high cost, difficult-to-access method, and cannot be performed in individuals with large body sizes	Is able to estimate parameters regionally, accurate when estimating intra-abdominal adipose tissue and identifies visceral and subcutaneous adipose tissue, in addition to adipose and skeletal muscle tissue	High accuracy	Indirect	[9, 15, 22, 49, 61, 63, 72]	Recommended Accurate Ability to differentiate VAT and SAT Significantly high cost
Computed tomography	Has a high cost, difficult-to-access method, and exposes individuals to high radiation doses	May be performed in individuals with large body sizes. It is useful for the detection of fat infiltrates, and identifies visceral and subcutaneous adipose tissues	High accuracy	Indirect	[9, 15, 21, 63, 71]	Recommended Low acceptability Radiation exposure Ability to differentiate VAT and SAT Significantly high cost
Ultrasonography	Has a high cost and technical difficulties	Has higher correlation than computed tomography in the determination of visceral fat	Moderation accuracy	Indirect	[12, 65, 68]	Recommended High cost

is necessary to evaluate the objective of measuring the body composition of individuals with class II/III obesity, considering that these individuals have a high body fat percentage.

Using only BMI to assess obesity is questionable [49], as it does not identify or discriminate body components [61]. Using BMI, an individual with high lean mass, such as a weightlifter, may be considered obese since BMI does not measure body fat but body mass as a whole. On the other hand, WC reflects abdominal adiposity and is a good parameter to monitor the increase and decrease of abdominal fat, but it does not discriminate body composition [73].

Although all individuals with class II/III obesity have high body mass and fat [74], it is important to distinguish the different components of body composition and evaluate the percentage of fat mass, fat-free mass, and bone mineral density in these individuals [75–78]. Considering that there is a strong association between body composition parameters, mortality in individuals with BMI ≥ 35 kg/m [2, 3], which means class II/III obesity, and several comorbidities, such as hypertension, diabetes, cardiovascular diseases, dyslipidaemias, and cancer [5, 6, 8, 79], the evaluation of body composition in this population is essential. A detailed body fat percentage evaluation, in combination with the other components, allows for a follow-up of the clinical status of these individuals, detection of health risks [74], prevention of unfavourable outcomes, and assessment of the results of different pharmacological and non-pharmacological interventions [74–76]. However, determining the body composition of individuals with class II/III obesity is especially more pertinent for those who are undergoing weight loss treatment, whether surgical [66] or not, monitoring changes in both body fat and the occurrence of unwanted losses of lean mass [76, 80].

Furthermore, changes in the body composition of these individuals, such as increased body adiposity and changes in lean mass, may imply the development of sarcopenic obesity [76], bone fragility [75, 81], higher cardiometabolic risk, and reduced functionality [74]. Class II/III obesity is considered a low-grade chronic inflammation caused by hypertrophy and/or hyperplasia of adipocytes as well as by macrophage infiltrates observed in response to oxidative stress caused by excess fat [82, 83]. Therefore, chronic inflammation observed in these individuals affects bone mass due to reduced osteoblast activity and increased osteoclast hyperactivity [75]. It also increases cardiometabolic risk [74, 77, 78]. Interventions focused exclusively on body weight loss in individuals with class II/III obesity may lead to a reduction of lean mass, leading to sarcopenic obesity [76, 84], which has been associated with frailty and strength reduction [85]. There are also genetic polymorphisms that have been linked to body composition [85, 86]. We emphasised also the significance and practicality of body composition assessment in this population, both concerning the preventive aspects of worsening the clinical condition and monitoring the effectiveness of weight-loss interventions, whether dietary, behavioural, pharmacological, or even surgical [73, 74, 76, 77].

What is the most viable method in clinical practice?

Several methods are available, but not all apply to the population in question. Although some methods produce significantly accurate results, such as computed tomography and magnetic resonance imaging, their high cost makes them impracticable in clinical practice. However, these two methods are the only methods used to evaluate visceral and subcutaneous adipose tissues separately that are relevant information in scientific research. Some methods are more applicable to clinical scenarios due to cost, such as skinfolds, but they have low accuracy in evaluating individuals with class II/III obesity. In addition to being expensive, other methods promote discomfort and low acceptability, such as hydrostatic weighing [10] and plethysmography [9], making them unfeasible in clinical practice.

Despite its high cost, DXA has excellent precision and accuracy for the evaluation of body composition in individuals with class II/III obesity [39]. Multifrequency BIA produces more accurate results compared to DXA and may be considered in clinical practice if specific equations are used for the study population to provide accurate information in clinical scenarios. Furthermore, it is important to measure WC during the follow-up of these individuals since, despite being an anthropometric measure, this reflects visceral fat [73].

What is the most viable method for scientific research?

In research settings, computed tomography, and magnetic resonance imaging, are the only methods that evaluate VAT and SAT separately [21]. However, DXA is the best option to be used as a reference in research for its accuracy and feasibility compared to the other imaging methods.

However, more studies are required to evaluate the accuracy of other imaging methods that are feasible, reliable, and more affordable for assessing body composition in individuals with class II/III obesity.

Strengths and limitations

The study presents a comprehensive comparison of available methods for evaluating body composition in people with class II/III obesity, both in clinical practice and research settings. The study also highlights the significance of evaluating body composition data in this population, which is often overlooked. However, it is important to note that limited studies compare various body assessment methods in individuals with this degree of obesity.

Conclusion

At present, DXA seems to be the best option to be used as a reference method in research due to its accuracy and higher accessibility compared to computed tomography and magnetic resonance imaging. Multifrequency BIA may be a viable alternative to DXA for use in clinical practice, since in the last decade there have been several advances in BIA technology, mainly in multifrequency. Studies have demonstrated that the use of appropriate and specific equations for the obese population minimizes method bias. Few studies have investigated the body composition in individuals with class II/III obesity, and more studies should be conducted because of the importance of either preventing the worsening of their clinical status or monitoring the effectiveness of pharmacological, non-pharmacological, and surgical interventions. Similar aspects should be observed in routine clinical treatments and not only in scientific research. Body composition analysis is crucial for designing interventions for individuals with a BMI ≥ 35 kg/m^2. These interventions aim to reduce weight and fat mass while preserving muscle and bone mass. Finally, it is important to note that although hydrostatic weighing is the gold standard for body assessment of these individuals, it is unfeasible in clinical practice.

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Authors' contributions
EAS, MCRC and CdO formulated to the conception and design of the study; EAS, MCRC, ATdOR, APSR, FMD, ESO, FCC and CdO contributed to the methodologic aspects; EAS, MCRC, ATdOR, APSR, FMD, ESO, FCC and CdO wrote the integrative review; EAS, FCC and CdO carried out a final review of the integrative review. All authors reviewed the manuscript.

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References

1. NCD RISC - Risk Factor Collaboration. Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19·2 million participants. Lancet. 1975;2016(387):1377–96. https://doi.org/10.1016/S0140-6736(16)30054-X.
2. Kitahara CM, Flint AJ, Berrington de Gonzalez A, Bernstein L, Brotzman M, MacInnis RJ, et al. Association between Class III Obesity (BMI of 40–59 kg/m2) and Mortality: A Pooled Analysis of 20 Prospective Studies. PLoS Med. 2014;11:e1001673. https://doi.org/10.1371/journal.pmed.1001673.
3. Di Angelantonio E, Bhupathiraju SN, Wormser D, Gao P, Kaptoge S, de Gonzalez AB, et al. Body-mass index and all-cause mortality: individual-participant-data meta-analysis of 239 prospective studies in four continents. The Lancet. 2016;388:776–86. https://doi.org/10.1016/S0140-6736(16)30175-1.
4. Beechy L, Galpern J, Petrone A, Das SK. Assessment tools in obesity — Psychological measures, diet, activity, and body composition. Physiol Behav. 2012;107:154–71. https://doi.org/10.1016/j.physbeh.2012.04.013.
5. Himes CL, Reynolds SL. Effect of Obesity on Falls, Injury, and Disability. J Am Geriatr Soc. 2012;60:124–9. https://doi.org/10.1111/j.1532-5415.2011.03767.x.
6. Fried M, Yumuk V, Oppert JM, Scopinaro N, Torres A, Weiner R, et al. Interdisciplinary European Guidelines on Metabolic and Bariatric Surgery. Obes Surg. 2014;24:42–55. https://doi.org/10.1007/s11695-013-1079-8.
7. Silveira EA, Kliemann N, Noll M, Sarrafzadegan N, Oliveira C. Visceral obesity and incident cancer and cardiovascular disease: An integrative review of the epidemiological evidence. Obesity Reviews 2021;22. https://doi.org/10.1111/obr.13088.
8. Society AC. Breast Cancer Occurrence 3 Breast Cancer Risk Factors 12 What Is the American Cancer Society Doing about Breast Cancer? 26 Sources of Statistics 30 References 32 n.d.
9. Duren DL, Sherwood RJ, Czerwinski SA, Lee M, Choh AC, Siervogel RM, et al. Body Composition Methods: Comparisons and Interpretation. J Diabetes Sci Technol. 2008;2:1139–46. https://doi.org/10.1177/193229680800200623.
10. Das SK. Body composition measurement in severe obesity. Curr Opin Clin Nutr Metab Care. 2005;8:602–6. https://doi.org/10.1097/01.mco.0000171122.60665.5f.
11. Renquist K. Obesity Classification. Obes Surg. 1997;7:523–523. https://doi.org/10.1381/096089297765555331.
12. Kuczmarski RJ, Fanelli MT, Koch GG. Ultrasonic assessment of body composition in obese adults: Overcoming the limitations of the skinfold caliper. Am J Clin Nutr. 1987;45:717–24. https://doi.org/10.1093/ajcn/45.4.717.
13. Ingle AS, Kashyap NK, Trivedi S, Chaudhary R, Suryavanshi G, Thangaraju P, et al. Assessment of Body Fat Percentage Using B-Mode Ultrasound Technique versus Skinfold Caliper in Obese Healthy Volunteers. Cureus. 2022. https://doi.org/10.7759/cureus.22993.
14. Guedes DP. Procedimentos clínicos utilizados para análise da composição corporal. Revista Brasileira de Cineantropometria e Desempenho Humano 2013;15. https://doi.org/10.5007/1980-0037.2013v15n1p113.
15. Moran JM, Lavado-Garcia JM, Pedrera-Zamorano JD. Methods for nurses to measure body composition. Rev Lat Am Enfermagem. 2011;19:1033–8. https://doi.org/10.1590/S0104-11692011000400024.
16. Brunani A, Perna S, Soranna D, Rondanelli M, Zambon A, Bertoli S, et al. Body composition assessment using bioelectrical impedance analysis (BIA) in a wide cohort of patients affected with mild to severe obesity. Clin Nutr. 2021;40:3973–81. https://doi.org/10.1016/J.CLNU.2021.04.033.

17. Ballesteros-Pomar MD, González-Arnáiz E, Pintor-de-la Maza B, Barajas-Galindo D, Ariadel-Cobo D, González-Roza L, et al. Bioelectrical impedance analysis as an alternative to dual-energy x-ray absorptiometry in the assessment of fat mass and appendicular lean mass in patients with obesity. Nutrition 2022;93. https://doi.org/10.1016/J.NUT.2021.111442.
18. Heyward VH, Cook KL, Hicks VL, Jenkins KA, Quatrochi JA, Wilson WL. Predictive Accuracy of Three Field Methods for Estimating Relative Body Fatness of Nonobese and Obese Women. Int J Sport Nutr. 1992;2:75–86. https://doi.org/10.1123/ijsn.2.1.75.
19. Kyle U. Bioelectrical impedance analysis?part I: review of principles and methods. Clin Nutr. 2004;23:1226–43. https://doi.org/10.1016/j.clnu.2004.06.004.
20. Faria SL, Faria OP, Cardeal MDA, Ito MK. Validation Study of Multi-Frequency Bioelectrical Impedance with Dual-Energy X-ray Absorptiometry Among Obese Patients. Obes Surg. 2014;24:1476–80. https://doi.org/10.1007/s11695-014-1190-5.
21. Smith S, Madden AM. Body composition and functional assessment of nutritional status in adults: a narrative review of imaging, impedance, strength and functional techniques. J Hum Nutr Diet. 2016;29:714–32. https://doi.org/10.1111/jhn.12372.
22. Mialich MS, Sicchieri JMF, Junior AAJ. Analysis of Body Composition: A Critical Review of the Use of Bioelectrical Impedance Analysis. Int J Clin Nutr. 2014;2:1–10. https://doi.org/10.12691/IJCN-2-1-1.
23. Kyle UG, Genton L, Karsegard L, Slosman DO, Pichard C. Single prediction equation for bioelectrical impedance analysis in adults aged 20–94 years. Nutrition. 2001;17:248–53. https://doi.org/10.1016/S0899-9007(00)00553-0.
24. Hannan WJ, Cowen SJ, Fearon KCH, Plester CE, Falconer JS, Richardson RA. Evaluation of Multi-Frequency Bio-Impedance Analysis for the Assessment of Extracellular and Total Body Water in Surgical Patients. Clin Sci. 1994;86:479–85. https://doi.org/10.1042/cs0860479.
25. Beato GC, Ravelli MN, Crisp AH, de Oliveira MRM. Agreement Between Body Composition Assessed by Bioelectrical Impedance Analysis and Doubly Labeled Water in Obese Women Submitted to Bariatric Surgery. Obes Surg. 2019;29:183–9. https://doi.org/10.1007/s11695-018-3505-4.
26. Strain GW, Wang J, Gagner M, Pomp A, Inabnet WB, Heymsfield SB. Bioimpedance for Severe Obesity: Comparing Research Methods for Total Body Water and Resting Energy Expenditure. Obesity. 2008;16:1953–6. https://doi.org/10.1038/oby.2008.321.
27. Sartorio A, Malavolti M, Agosti F, Marinone PG, Caiti O, Battistini N, et al. Body water distribution in severe obesity and its assessment from eight-polar bioelectrical impedance analysis. Eur J Clin Nutr. 2005;59:155–60. https://doi.org/10.1038/sj.ejcn.1602049.
28. Geliebter A, Atalayer D, Flancbaum L, Gibson CD. Comparison of body adiposity index (BAI) and bmi with estimations of % body fat in clinically severe obese women. Obesity. 2013;21:493–8. https://doi.org/10.1002/oby.20264.
29. Horie LM, Gonzalez Barbosa-Silva MC, Torrinhas RS, Túlio de Mello M, Cecconello I, Waitzberg DL. New body fat prediction equations for severely obese patients. Clin Nutr 2008;27:350–6. https://doi.org/10.1016/j.clnu.2008.03.011.
30. Jiménez A, Omaña W, Flores L, Coves MJ, Bellido D, Perea V, et al. Prediction of Whole-Body and Segmental Body Composition by Bioelectrical Impedance in Morbidly Obese Subjects. Obes Surg. 2012;22:587–93. https://doi.org/10.1007/s11695-011-0570-3.
31. Leal AAD, Faintuch J, Morais ÁAC, Noe JAB, Bertollo DM, Morais RC, et al. Bioimpedance analysis: Should it be used in morbid obesity? Am J Hum Biol. 2011;23:420–2. https://doi.org/10.1002/ajhb.21143.
32. Otto M, Färber J, Haneder S, Michaely H, Kienle P, Hasenberg T. Postoperative Changes in Body Composition—Comparison of Bioelectrical Impedance Analysis and Magnetic Resonance Imaging in Bariatric Patients. Obes Surg. 2015;25:302–9. https://doi.org/10.1007/s11695-014-1382-z.
33. Boneva-Asiova Z, Boyanov MA. Body composition analysis by leg-to-leg bioelectrical impedance and dual-energy X-ray absorptiometry in non-obese and obese individuals. Diabetes Obes Metab. 2008;10:1012–8. https://doi.org/10.1111/j.1463-1326.2008.00851.x.
34. Bedogni G, Agosti F, De Col A, Marazzi N, Tagliaferri A, Sartorio A. Comparison of dual-energy X-ray absorptiometry, air displacement plethysmography and bioelectrical impedance analysis for the assessment of body composition in morbidly obese women. Eur J Clin Nutr. 2013;67:1129–32. https://doi.org/10.1038/ejcn.2013.159.
35. Heath EM, Adams TD, Daines MM, Hunt SC. Bioelectric Impedance and Hydrostatic Weighing With and Without Head Submersion in Persons Who are Morbidly Obese. J Am Diet Assoc. 1998;98:869–75. https://doi.org/10.1016/S0002-8223(98)00201-6.
36. Carrasco F, Carrasco Navarro GN, Rojas P, Papapietro K, Salazar G. Body composition assessment before and after weight loss following a Roux-en-Y gastric bypass. Are bioimpedanciometry estimations reliable? Nutr Hosp. 2020;37:1150–6. https://doi.org/10.20960/NH.02942.
37. de Oliveira PAP, Montenegro ACP, Bezerra LRA, da Conceição Chaves de Lemos M, Bandeira F. Body Composition, Serum Sclerostin and Physical Function After Bariatric Surgery: Performance of Dual-Energy X-ray Absorptiometry and Multifrequency Bioelectrical Impedance Analysis. Obes Surg. 2020;30:2957–62. https://doi.org/10.1007/S11695-020-04625-X/FIGURES/1.
38. Stahn A, Terblanche E, Gunga HC. Use of bioelectrical impedance: General principles and overview. Handbook of Anthropometry: Physical Measures of Human Form in Health and Disease 2012:49–90. https://doi.org/10.1007/978-1-4419-1788-1_3/TABLES/3.
39. Hind K, Oldroyd B, Truscott JG. In vivo precision of the GE Lunar iDXA densitometer for the measurement of total body composition and fat distribution in adults. Eur J Clin Nutr. 2011;65:140–2. https://doi.org/10.1038/ejcn.2010.190.
40. Litaker MS, Barbeau P, Humphries MC, Gutin B. Comparison of Hologic QDR-1000/W and 4500W DXA Scanners in 13- to 18-Year Olds. Obes Res. 2003;11:1545–52. https://doi.org/10.1038/oby.2003.206.
41. Toombs RJ, Ducher G, Shepherd JA, De Souza MJ. The Impact of Recent Technological Advances on the Trueness and Precision of DXA to Assess Body Composition. Obesity. 2012;20:30–9. https://doi.org/10.1038/oby.2011.211.
42. Heyward VH. Practical Body Composition Assessment for Children, Adults, and Older Adults. Int J Sport Nutr. 1998;8:285–307. https://doi.org/10.1123/ijsn.8.3.285.
43. Silver HJ, E. Brian Welch, Malcolm J. Avison, Kevin D. Niswender. Imaging body composition in obesity and weight loss: challenges and opportunities. Diabetes Metab Syndr Obes 2010:337. https://doi.org/10.2147/DMSOTT.S9454.
44. Rothney MP, Xia Y, Wacker WK, Martin F, Beaumont M, Rezzi S, et al. Precision of a new tool to measure visceral adipose tissue (VAT) using dual-energy X-Ray absorptiometry (DXA). Obesity 2013;21. https://doi.org/10.1002/oby.20140.
45. Rosenthall L, Falutz J. Estimation of Total-Body and Regional Soft Tissue Composition From DXA Bone Densitometry of the Lumbar Spine and Hip. J Clin Densitom. 2010;13:263–6. https://doi.org/10.1016/j.jocd.2010.05.001.
46. Covey MK, Berry JK, Hacker ED. Regional Body Composition: Cross-calibration of DXA Scanners-QDR4500W and Discovery Wi. Obesity. 2010;18:632–7. https://doi.org/10.1038/oby.2009.420.
47. Ashby-Thompson M, Heshka S, Rizkalla B, Zurlo R, Lemos T, Janumala I, et al. Validity of dual-energy x-ray absorptiometry for estimation of visceral adipose tissue and visceral adipose tissue change after surgery-induced weight loss in women with severe obesity. Obesity (Silver Spring). 2022;30:1057–65. https://doi.org/10.1002/OBY.23415.
48. Kim M, Shinkai S, Murayama H, Mori S. Comparison of segmental multifrequency bioelectrical impedance analysis with dual-energy X-ray absorptiometry for the assessment of body composition in a community-dwelling older population. Geriatr Gerontol Int. 2015;15:1013–22. https://doi.org/10.1111/ggi.12384.
49. Wells JCK. Measuring body composition. Arch Dis Child. 2005;91:612–7. https://doi.org/10.1136/adc.2005.085522.
50. Davidsson L, International Atomic Energy Agency. Dual Energy X Ray Absorptiometry for Bone Mineral Density and Body Composition Assessment. Dual Energy X Ray Absorptiometry for Bone Mineral Density and Body Composition Assessment. 2011;15:1–118.
51. Lima TP, Nicoletti CF, Marchini JS, Junior WS, Nonino CB. Effect of Weight Loss on Bone Mineral Density Determined by Ultrasound of Phalanges in Obese Women After Roux-en-y Gastric Bypass: Conflicting Results With Dual-Energy X-ray Absorptiometry. J Clin Densitom. 2014;17:473–8. https://doi.org/10.1016/j.jocd.2014.08.002.
52. Hames KC, Anthony SJ, Thornton JC, Gallagher D, Goodpaster BH. Body composition analysis by air displacement plethysmography in normal

weight to extremely obese adults. Obesity. 2014;22:1078–84. https://doi.org/10.1002/oby.20655.
53. de Souza RGM, Gomes AC, Prado CMM do, Mota JF. Métodos de análise da composição corporal em adultos obesos. Revista de Nutrição. 2014;27:569–83. https://doi.org/10.1590/1415-52732014000500006.
54. McCrory MA, Gomez TD, Bernauer EM, Molé PA. Evaluation of a new air displacement plethysmograph for measuring human body composition. Med Sci Sports Exerc. 1995;27:1686–91.
55. Ginde SR, Geliebter A, Rubiano F, Silva AM, Wang J, Heshka S, et al. Air displacement plethysmography: validation in overweight and obese subjects. Obes Res. 2005;13:1232–7. https://doi.org/10.1038/oby.2005.146.
56. Petroni ML, Bertoli S, Maggioni M, Morini P, Battezzati A, Tagliaferri MA, et al. Feasibility of air plethysmography (BOD POD) in morbid obesity: a pilot study. Acta Diabetol. 2003;40(Suppl 1):S59-62. https://doi.org/10.1007/s00592-003-0028-8.
57. Heyward VH. Avaliação física e prescrição de exercício: técnicas avançadas. 2013.
58. Wagner DR, Heyward VH. Techniques of body composition assessment: a review of laboratory and field methods. Res Q Exerc Sport. 1999;70:135–49. https://doi.org/10.1080/02701367.1999.10608031.
59. Evans PE, Israel RG, Flickinger EG, O'Brien KF, Donnelly JE. Hydrostatic weighing without head submersion in morbidly obese females. Am J Clin Nutr. 1989;50:400–3. https://doi.org/10.1093/ajcn/50.2.400.
60. Israel RG, Evans P, Pories WJ, O'Brien KF, Donnelly JE. Comparison between two methods of hydrostatic weighing without head submersion in morbidly obese females. Diabetes Res Clin Pract. 1990;10(Suppl 1):S133–6. https://doi.org/10.1016/0168-8227(90)90152-j.
61. Di Sebastiano KM, Mourtzakis M. A critical evaluation of body composition modalities used to assess adipose and skeletal muscle tissue in cancer. Appl Physiol Nutr Metab. 2012;37:811–21. https://doi.org/10.1139/h2012-079.
62. Mitsiopoulos N, Baumgartner RN, Heymsfield SB, Lyons W, Gallagher D, Ross R. Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. J Appl Physiol. 1985;1998(85):115–22. https://doi.org/10.1152/jappl.1998.85.1.115.
63. Quiterio AL, Carnero EA, Silva AM, Bright BC, Sardinha LB. Anthropometric models to predict appendicular lean soft tissue in adolescent athletes. Med Sci Sports Exerc. 2009;41:828–36. https://doi.org/10.1249/MSS.0b013e31818ffe4b.
64. Busetto L, Tregnaghi A, Bussolotto M, Sergi G, Benincà P, Ceccon A, et al. Visceral fat loss evaluated by total body magnetic resonance imaging in obese women operated with laparascopic adjustable silicone gastric banding. Int J Obes Relat Metab Disord. 2000;24:60–9. https://doi.org/10.1038/sj.ijo.0801086.
65. McArdle WD, Katch FI, Katch VL, Taranto G. Fisiologia do exercicio: energia, nutricao e desempenho humano 1998:xxxviii, 695–xxxviii, 695.
66. Goodpaster BH, Thaete FL, Kelley DE. Composition of skeletal muscle evaluated with computed tomography. Ann N Y Acad Sci. 2000;904:18–24. https://doi.org/10.1111/J.1749-6632.2000.TB06416.X.
67. Valensise H, Andreoli A, Lello S, Magnani F, Romanini C, De Lorenzo A. Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. Am J Clin Nutr. 2000;72:796–803. https://doi.org/10.1093/AJCN/72.3.796.
68. Pontiroli AE, Pizzocri P, Giacomelli M, Marchi M, Vedani P, Cucchi E, et al. Ultrasound measurement of visceral and subcutaneous fat in morbidly obese patients before and after laparoscopic adjustable gastric banding: comparison with computerized tomography and with anthropometric measurements. Obes Surg. 2002;12:648–51. https://doi.org/10.1381/096089202321019620.
69. Prior BM, Cureton KJ, Modlesky CM, Evans EM, Sloniger MA, Saunders M, et al. In vivo validation of whole body composition estimates from dual-energy X-ray absorptiometry. J Appl Physiol. 1985;1997(83):623–30. https://doi.org/10.1152/JAPPL.1997.83.2.623.
70. Bartok C, Schoeller DA, Randall Clark R, Sullivan JC, Landry GL. The effect of dehydration on wrestling minimum weight assessment. Med Sci Sports Exerc. 2004;36:160–7. https://doi.org/10.1249/01.MSS.0000106855.47276.CD.
71. Gibby JT, Njeru DK, Cvetko ST, Heiny EL, Creer AR, Gibby WA. Whole-body computed tomography-based body mass and body fat quantification: A comparison to hydrostatic weighing and air displacement plethysmography. J Comput Assist Tomogr. 2017;41:302–8. https://doi.org/10.1097/RCT.0000000000000516.
72. Babb TG, Wyrick BL, DeLorey DS, Chase PJ, Feng MY. Fat distribution and end-expiratory lung volume in lean and obese men and women. Chest. 2008;134:704–11. https://doi.org/10.1378/CHEST.07-1728.
73. Santos AS e. A de C, Rodrigues AP dos S, Rosa LP de S, Noll M, Silveira EA. Traditional Brazilian Diet and Olive Oil Reduce Cardiometabolic Risk Factors in Severely Obese Individuals: A Randomized Trial. Nutrients 2020;12. https://doi.org/10.3390/NU12051413.
74. Silveira EA, Rosa LP de S, de Resende DP, Rodrigues AP dos S, da Costa AC, Rezende AT de O, et al. Positive Effects of Extra-Virgin Olive Oil Supplementation and DietBra on Inflammation and Glycemic Profiles in Adults With Type 2 Diabetes and Class II/III Obesity: A Randomized Clinical Trial. Front Endocrinol (Lausanne) 2022;13. https://doi.org/10.3389/FENDO.2022.841971.
75. Silveira EA, Rosa LP de S, Santos AS e. A de C, Cardoso CK de S, Noll M. Type 2 Diabetes Mellitus in Class II and III Obesity: Prevalence, Associated Factors, and Correlation between Glycemic Parameters and Body Mass Index. Int J Environ Res Public Health 2020;17. https://doi.org/10.3390/IJERPH17113930.
76. Galanakis CG, Daskalakis M, Manios A, Xyda A, Karantanas AH, Melissas J. Computed tomography-based assessment of abdominal adiposity changes and their impact on metabolic alterations following bariatric surgery. World J Surg. 2015;39:417–23. https://doi.org/10.1007/S00268-014-2826-2.
77. Silveira EA, Costa Silveira L, de Souza Cardoso CK, Schmidt A, Silva e Alves de Carvalho Santos A, de Oliveira C, et al. Vitamin D in women with class II/III obesity: Findings from the DieTBra trial. Clin Nutr ESPEN. 2023;55:83–9. https://doi.org/10.1016/J.CLNESP.2023.02.027.
78. Silveira EA, Cardoso CK de S, E Moura L de AN, Mourade AN, Dosantosodrigues AP, de Oliveira C. Serum and dietary vitamin d in individuals with class ii and iii obesity: Prevalence and association with metabolic syndrome. Nutrients. 2021;13:2138. https://doi.org/10.3390/NU13072138/S1.
79. World Health Organization. World health statistics 2012. Geneva: World Health Organization; 2012. Available from: https://www.who.int/publications/i/item/9789241564441.
80. Branco BHM, Bernuci MP, Marques DC, Carvalho IZ, Barrero CAL, de Oliveira FM, et al. Proposal of a normative table for body fat percentages of Brazilian young adults through bioimpedanciometry. J Exerc Rehabil. 2018;14:974–9. https://doi.org/10.12965/JER.1836400.200.
81. Esser N, Legrand-Poels S, Piette J, Scheen AJ, Paquot N. Inflammation as a link between obesity, metabolic syndrome and type 2 diabetes. Diabetes Res Clin Pract. 2014;105:141–50. https://doi.org/10.1016/J.DIABRES.2014.04.006.
82. Haase J, Weyer U, Immig K, Klöting N, Blüher M, Eilers J, et al. Local proliferation of macrophages in adipose tissue during obesity-induced inflammation. Diabetologia. 2014;57:562–71. https://doi.org/10.1007/S00125-013-3139-Y.
83. Goisser S, Kemmler W, Porzel S, Volkert D, Sieber CC, Bollheimer LC, et al. Sarcopenic obesity and complex interventions with nutrition and exercise in community-dwelling older persons–a narrative review. Clin Interv Aging. 2015;10:1267–82. https://doi.org/10.2147/CIA.S82454.
84. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing. 2019;48:16–31. https://doi.org/10.1093/AGEING/AFY169.
85. Rodrigues APS, Rosa LPS, Silveira EA. PPARG2 Pro12Ala polymorphism influences body composition changes in severely obese patients consuming extra virgin olive oil: a randomized clinical trial. Nutr Metab (Lond). 2018;15:1–13. https://doi.org/10.1186/S12986-018-0289-4.
86. Dos Santos Rodrigues AP, Rosa LPS, Da Silva HD, De Paula Silveira-Lacerda E, Silveira EA. The Single Nucleotide Polymorphism PPARG2 Pro12Ala Affects Body Mass Index, Fat Mass, and Blood Pressure in Severely Obese Patients. J Obes 2018;2018. https://doi.org/10.1155/2018/2743081.

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