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Original article

Body fat mass assessment and obesity classification: a review of the available methods for adiposity estimation

Gabriele Castelnuovo[1], *Begoña de Cuevillas*[2], *Santiago Navas-Carretero*[2,3,4] *and J. Alfredo Martínez*[2,3,4,5]

[1]University of Milan, 20122 Milan, Italy
[2]Department of Nutrition, Food Sciences and Physiology, Center for Nutrition Research, University of Navarra, 31008 Pamplona, Spain
[3]IdisNA Health Research Institute of Navarra, Pamplona, Spain
[4]CIBERobn, Obesity and Nutrition, Instituto de Salud Carlos III, Madrid, Spain
[5]Precision Nutrition Program, Research Institute on Food and Health Sciences IMDEA Food, 28049 Madrid, Spain.

Summary. Obesity is a growing public health problem, which often leads to severe comorbidities that can reduce quality of life and living expectancy. Overweight is caused by a greater food intake compared to the energy expenditure, which involves an excessive deposition of body fat. The distribution of adipose tissue also varies depending on sex, whereas men usually show android-type obesity, or visceral adiposity, women exhibit more commonly a deposition of fat involving the gynoid gluteo-femoral or subcutaneous type. Overweight and obesity are accompanied by a series of clinical manifestations, being the most common hyperglycemia, hypertriglyceridemia and high blood pressure, which may depend on body fat distribution. Consequently, not only promoting initiatives to adopt a healthy lifestyle based on recommended dietary models and an active living is necessary, but also having reliable techniques for body fat determination. Besides the Body Mass Index (BMI), whose limits on the correct quantification of body fat are known, nowadays diverse approaches for fat measurement are available. In addition, the assessment of body fat could be achieved also through complex methods such as Bioelectric Impedance Analysis (BIA), Dual-Energy X-Ray Absorptiometry (DXA) and Total Body Electrical Conductivity (TOBEC), which may be complemented by approaches to categorize/differentiate obese individuals through classification systems and scores. Indeed, adequate measurement of fat is required for obesity characterization and for management purposes as reported in this review.

Keywords: obesity, body composition, fat mass, anthropometry

Introduction

According to WHO 2016 data (1), worldwide obesity has tripled in the last 40 years, reaching over 1.9 billion overweight adults and 650 million obese adults (39% and 13% of the population, respectively). The excess of adiposity in childhood is set at around 41 million for children under 5 years, and above 340 million (18% of the population) for those between 5-19 years (2). For a long time, obesity and being overweight were only considered problems of developed regions, however, the phenomenon is continuously expanding, and it is not uncommon to find transition countries featuring simultaneously problems of undernutrition and obesity (3). Two common forms of obesity have been defined, one being primary (or essential) obesity, which arises from a chronic imbalance between excessive caloric intake (4) and reduced energy expenditure (5), whose subsidiary causes are related to multifactorial etiologies, where the interaction of the genetic make-up (from 5-70% of the influence) and environmental factors (6) may be involved.

Secondarily, weight excess which affects about 3-5% of the overweight/obese population is caused by a known pathological condition such as monogenic origin (7), endocrinological disturbances and iatrogenic side-effects associated with the administrations of drugs (8), among others.

Obesity is a severe medical and physiopathological condition characterized by an excessive body weight-for-height due to the accumulation of adipose tissue (9). Excessive fat accumulation leads to negative consequences in personal quality of life and nutritional well-being, life expectancy, public health and sanitary costs (10,11), as well as a higher incidence of non-communicable chronic diseases and clinical outcomes (12). In fact, the enlargement on the adipose tissue favors the onset of serious clinical manifestations or morbid conditions (13) such as insulin resistance, type 2 diabetes mellitus, hypertension, dyslipidemia, cardiovascular diseases, musculoskeletal disorders and cancers (14), which can be related to fat accumulation and to the anatomical location of adiposity (15), which need to be adequately assessed.

While obesity can be qualitatively referred, as the excessive accumulation of adipose tissue, it is important to be able to find an approach for a reliable quantification of body fat, which is accurate, precise and reproducible (16) to achieve a personalized management of this condition, requiring a valid estimation of adiposity distribution.

Interestingly, for clinical purposes, obesity has been classified as android (or visceral), which is characterized by a large adipose deposition in the abdominal area, gynoid (or subcutaneous), with the deposition of adipose tissue in the gluteal-femoral area and mixed, with homogeneous distribution over the whole body (17) with different impact on morbidity and mortality (18). Another categorization can be based on nutritypes, depending mainly on age, sex, physical activity and fat mass (19), which is highlighted through the definition of cut-off points of waist circumference (WC) and TyG index (WC-TyG). In this context, the hypertriglyceridemic waist phenotype has a negative influence on a person's quality of life, influencing the onset of metabolic syndrome (MetS) related features (20). Additionally, the Framingham Risk Score method evaluates the risk of cardiovascular disease (21), while the Obesity Surgery Mortality Risk Score (OS-MRS) classifies the risk of mortality in 3 groups depending on the obese/overweight phenotype (22).

As the importance of accurately estimating an individual's body fat becomes evident, the purpose of this manuscript is to analyze and appraise some of the available methods (anthropometric and complex approaches) that allow reliable and reproducible classifications of obesity and the quantification of body fat, under qualitative and quantitative scopes. Furthermore, a second objective is to examine approaches able to categorize obesity depending on the type of fat distribution and in the severity of fat accumulation related manifestations for individualized management of the excessive fat reserves.

Methods

A narrative review was conducted through a search of the scientific literature to collect methods for body fat measurements and to provide a global view of obesity classification approaches. Due to the broad thematic field, it was decided not to conduct a formal systematic review, but a structural screening (23).

Data searching process

A pre-defined search was conducted during March/April 2019, where PubMed and ScienceDirect databases were the screening engines through which all references were accessed, using as keywords 'obesity', 'fat', 'body fat assessment', 'body fat estimation in human', 'body fat measures', 'body fat percentage', 'predicting body fat equation', 'measures of obesity', 'adiposity estimation' and 'adiposity assessment', where more than 4900 items have appeared and analyzed. Relevant research, originals and review articles were selected based on the title and abstract, or from the full text when information in the abstract and title was absent or unclear. In addition, the World Health Organization web page was consulted when necessary (24). The research was further extended by seeking sources cited in the selected publications, according to the authors criteria for relevance and adaptability to the study.

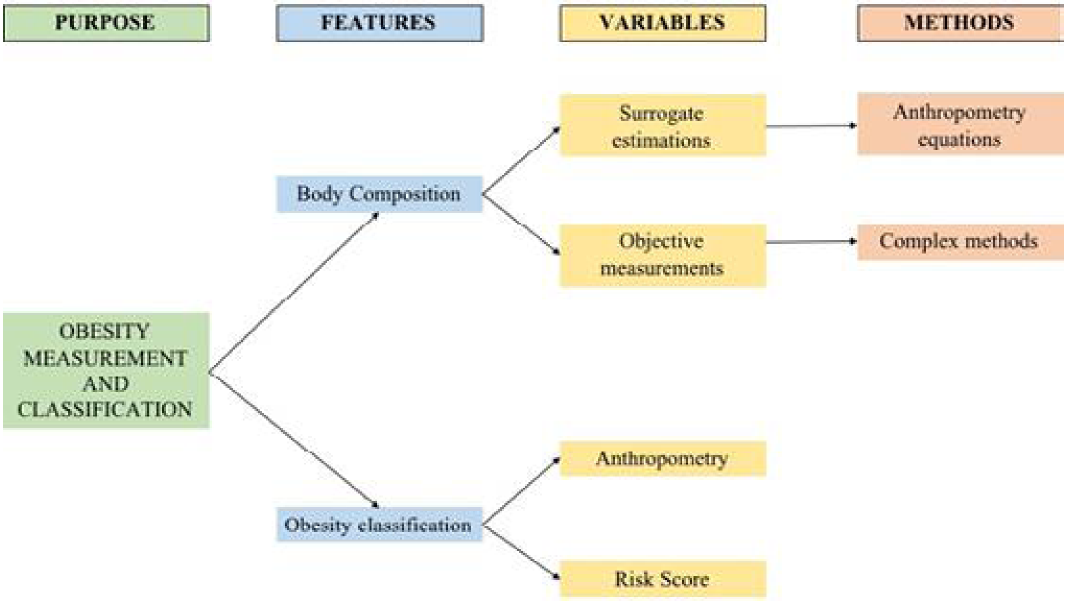

Figure 1. Flow chart of the process carried out for the achievement of the review.

The references were selected according to an inclusion criteria that covered the entire adult world population (or at least Caucasian), with validity for both sexes and written in English or Spanish language (25). Indexes that can be used to classify obesity, anthropometric tools for measuring the body fat percentage and complex techniques with direct measurement of adipose tissue have been selected. Consequently, animals, children, athletes, elderly, gender-specific tools and other languages terms were excluded.

Results

Following these search criteria for the adult population, the results obtained were distributed into 3 tables according to the variables. For the anthropometrics measures, 18 references were retrieved, complying with the inclusion criteria, to draw up the Table 1 consisting in 16 indexes for the calculation of fat mass proportions. These methods can be differentiated according to the variables that are considered for subsequent quantification. There are formulas that provide an estimation of the percentage of fat mass with variations depending on sex, formulas that do not take into consideration the sex of the person, and formulas that consider the sex when calculating fat mass. In this last search, two groups can be distinguished: one including sex as a variable in the equation, and the other that use two different equations based on sex (Table 1).

When calculating fat mass, most of the formulas accounting sex as a variable in the equation are based on age, BMI and gender, giving a score of 0 in women and 1 in men, or vice versa. There are also other equations that besides being based on these parameters also include waist circumference, where the score is 1 for men and 0 for women variables. Of the final set of equations that incorporate the sex variable, one is based only on sex and anthropometric parameters and the other additionally takes into account skinfold thickness. There are formulas that give an estimation of the percentage of fat mass with two variations depending on sex. Some of them are based only on the BMI, others on age and different skinfold thicknesses, and a last one based on age and waist circumference.

Concerning complex methods for fat assessment (Table 2), 16 references were found to measure body fat. Among these, the most important difference was

Table 1. Anthropometric based equations for the prediction of humans' body fat percentage.

TOOL/FACTORS	FEATURES/EQUATIONS	REFERENCES
Age, BMI, sex	FM%= −44.988 + (0.503 x age) + (10.689 x sex) + (3.172 x BMI) − (0.026 x BMI^2) + (0.181 x BMI x sex) − (0.02 x BMI x age) − (0.005 x BMI^2 x sex) +(0.00021 x BMI^2 x age)	Gomez-Ambrosi et al. (2012)
Abdominal circumference, age, BMI, sex, waist circumference	• FM% = -2.519 + 1.533 x (BMI) − 11.7 x (sex) • FM% = - 6.137 + 95.859 x (WHtR – W) – 0.08 x (Age) – 13.295 x (Sex) • FM% = - 8.339 + 92.701 x (WHtR – A) – 0.078 x (Age) – 11.062 x (Sex)	Kagawa et al. (2008)
Age, BMI, sex	FM% = 1.20 x BMI + 0.23 x age - 10.8 x sex - 5.4	Deurenberg et al. (1991)
Age, skinfold thickness	• FM% (Men)= (age x 0.1) + (logtricepsSF x 7.6) + (logmidaxillaSF x 8.8) + (logsuprspinaleSF x 11.9) - 11.3 • FM% (Women)= (age x 0.1) + (logabdominalG x 39.4) + (logmidaxillaSF x 4.9) + (logbicepsSF x 11) + (logmedialcalfSF x 9.1) -73.5	Leahy et al. (2013)
BMI	• FM% (Men) = (3.76 × BMI) − (0.04 × BMI^2) − 47.80 • FM% (Women) = (4.35 × BMI) − (0.05× BMI^2) − 46.24	Jackson et al. (2002)
Age, waist circumference	• FM% = (Men) = 0.567 x waist + 0.101 x age − 31.8 • FM% = (Women) = 0.439 x waist + 0.221 x age − 9.4	Lean et al. (1996)
Age, BMI, sex	FM% = 64.5 - 848 x (1/BMI) + 0.079 x age - 16.4 x sex + 0.05 x sex x age + 39.0 x sex x (1/BMI)	Gallagher et al. (2000)
Age, skinfold thickness	• FM% = (0.29288 x sum of skinfolds) - (0.0005 x square of the sum of skinfolds) + (0.15845 x age) – 5.76377 x (Σ abdominal, triceps, thigh, and suprailiac skinfolds) • FM% = (0.41563 x sum of skinfolds) - (0.00112 x square of the sum of skinfolds) + (0.03661 x age) + 4.03653 x (Σ abdominal, triceps, and suprailiac skinfolds)	Jackson and Pollock (1978); Jackson et al. (1980)
BMI	• FM% (Men) = (1.34 x BMI) - 12.7 • FM% (Women) = (1.37 x BMI) - 3.47	Durnin and Womersley (1974)
Sex, skinfold thickness	• FM% = -0.615 - 10.948 x sex + 0.321 x waist circumference + 0.502 x hips circumference - 0.39 x forearm circumference - 19.768 x height; • FM% = -27.787 - 5.515 x sex - 8.419 x height + 0.145 x waist circumference + 0.270 x hips circumference + 7.509 x log thigh skinfold + 20.090 x log (bicep + tricep +suprailiac + subscapular) - 0.445 x forearm circumference	Kanellakis et al. (2017)
Skinfolds thickness for the quantification of body fat mass (%)	• FM% = (495 / Body Density) - 450 1. Men: D=1.1125025-0.0013125(x^3) + 0.0000055(x^3)^2 – 0.0002440(x^4) 2. Women: D=1.089733-0.0009245(x^3) + 0.0000025(x^3)^2 – 0.0000979(x^4)	Jackson and Pollock (1985)
Body adiposity index (BAI) based on height, hip circumference	FM% = [Hip circumference/height$^{1.5}$] - 18	Bergman et al. (2011)
Modified body adiposity index (MBAI) based on BAI	FM % = 23.6 + 0.5 x (BAI)	Bernhard et al. (2017)
Body roundness index (BRI) based on height, waist circumference	BRI=364.2–365.5 × $\sqrt{1–[(WC/(2\pi))^2/(0.5\text{height})^2]}$ Values score is from 1 to 20	Thomas et al. (2013)
Siri Equation based on density, skinfolds thickness	FM% = (4.95/BD - 4.50) x 100 • Men: 1.11-0.062 logST • Women: 1.13-0.077 logST, where BD = body density; ST= skinfold triceps	Siri (1961)
Brozek et al. Equation based on density, skinfolds thickness	FM% = (4.57/BD - 4.142) x 100, where BD = body density 1.0668 + 0.0212 x sex – 0.0356 $\log_{10}$ (triceps + biceps + subscapular + iliac crest)	Brožek (1966); Visser et al. (1994)

Abdominal circumference (cm); age (years); BMI (kg/m^2); body density (g/cm^3); height (m); hip circumference (cm); sex (men=0, women=1 in the first equation; men=1, women=0 in the second, the third, the seventh, the tenth and the sixteenth equation); waist circumference (cm); x^3 (in men: sum of chest, triceps, and subscapular skinfolds (mm); in women: sum of triceps, suprailium, and abdominal skinfolds (mm)); x^4 (age in years).

Table 2. Body fat achievement in humans through the use of complex methods.

TOOL/METHODOLOGY	FEATURES	REFERENCES
Dual-energy X-ray absorptiometry (DXA)	Technique that uses X-rays to evaluate the bone mineral mass, and also lean and fat mass	Plank (2005)
Bioelectric impedance analysis (BIA)	Indirect method of evaluating lean and fat mass based on the electric current transmission	Kyle et al. (2004)
Near-infrared interactance (NIR)	Estimation of the variation of chemical bonds subjected under wavelength excitation (3 and 780 **μm**)	Brooke-Wavell et al. (1995)
Ultrasound (US)	Measurement of body fat that distinguishes the subcutaneous fat from the visceral one	Bielemann et al. (2016)
Computed tomography (CT)	Snapshots for evaluating the total area of abdominal fat	Saeed et al. (2017)
Hydrostatic weighing (HW)	Fat and lean mass of an individual, quantified weighing him both in the air and in the water	Clark, Kuta, and Sullivan (1993)
Air-displacement plethysmography (ADP)	Densitometric technique that uses air displacement to evaluate body composition	Fields, Goran, and McCrory (2002)
3-D body scanner	A scanning technology producing 3D model, that allows the study of anthropometric measures	Ng et al. (2016)
Isotope dilution method	Body composition evaluation through the quantification of chemical substances concentrations	Wong et al. (1988)
Hydrometry (total body water)	A deuterium oxide dilution to quantify body composition	Van Loan et al. (1990)
Total body potassium (TBK)	Body composition estimation using potassium-40 measurements within the cell	Davies et al. (1996)
Magnetic resonance imaging (MRI)	Imaging of the body using magnetic field and radio waves	Baum et al. (2016)
Total body electrical conductivity (TOBEC)	Body composition calculation through the use of an electromagnetic field	Presta et al. (1983)
Urine creatinine output	Urine creatinine content (mg/24h) is a proxy index for the estimation of muscle mass	Forbes and Bruining (1976)
Neutron activation	Measurement of fat percentage based on the activation of the excited states of the neutrons	Cohn et al. (1984)
Fat soluble gas	Evaluation of total body fat based on the solubility of gases and concentrations estimation	Perl, Lesser, and Steele (1960)

Table 3. Overweight and obesity classification, with related comorbidity risks due to the excessive body weight.

TOOL	FEATURES/CHARACTERISTICS	REFERENCES
Body mass index (BMI)	Biometric indicator of obesity measured considering weight (kg) and height (m): BW/BH^2 • Underweight: < 18.5 (Kg/m^2) • Normal weight: 18.5-24.9 (Kg/m^2) • Overweight: 25-29.9 (Kg/m^2) • Class I obesity: 30-34.9 (Kg/m^2) • Class II obesity: 35-39.9 (Kg/m^2) • Class III obesity: ≥ 40 (Kg/m^2)	Chiquete et al. (2014); WHO (2019)
Edmonton Obesity Staging System (EOSS)	Allows to categorize the subjects on the risks related to body weight, according to a clinical analysis • Stage 0 obesity: No signs of comorbidities • Stage 1 obesity: Mild signs of comorbidities • Stage 2 obesity: Moderate signs of comorbidities • Stage 3 obesity: Significant signs of comorbidities • Stage 4 obesity: Severe signs of comorbidities	Sharma and Kushner (2009); Martínez Urbistondo and Martínez (2017)
Framingham Risk Score	Evaluates the influence of obesity on the future cardiovascular risk (10 years) using a detailed algorithm divided by gender based on variables such as sex, age, cholesterol total, C-HDL, PAS, habit to smoke, DM, antihypertensive treatment	Lloyd-Jones et al. (2004) Xu et al. (2019)
Obesity Surgery Mortality Risk Score (OS-MRS)	Method to classify the mortality risk of obese patients undergoing weight loss surgery • Arterial hypertension • Age • Sex • Body mass index • Risk factors for pulmonary thromboembolism Risk group: •A (low risk) 0-1; •B (moderate risk) 2-3; •C (high risk) 4-5	DeMaria, Portenier, and Wolfe (2007)no clinically useful scoring system is available to stratify the mortality risk for patients undergoing gastric bypass (GBP García-García et al. (2017)
Sagittal abdominal diameter (SAD)	Abdominal diameter measurement as index of the amount of fat in the intestinal area SAD>25cm may be used as a risk-assessment tool	Rådholm et al. (2017) Zamboni et al. (1998)
Waist circumference (WC)	WC cut-off values for abdominal obesity are: Woman > 88 cm; Men > 102 cm There are two forms of obesity: android (or visceral) or ginoid (subcutaneous)	WHO (2004) Carranza Leon et al. (2016)
Neck Circumference (NC)	A neck circumference >35.5 cm in men and >32 cm in women should be considered the cutoff point for overweight/obesity	Hingorjo, Qureshi, and Mehdi (2012)
Waist to height Ratio (WHtR)	Relationships between the waist circumference and height Waist circumference (cm) / Height (cm) Obese men and women defined by a WHtR > 0.5	Ashwell and Hsieh (2005)
Waist to hip Ratio (WHR)	Calculated as: Waist circumference (cm) / Hip circumference (cm) To be at risk of obesity, WHR cut-off values are >1.0 in men and >0.85 in women To be at risk of cardiovascular disease, WHR cut-off values are >0.95 in men and >0.8 in women	WHO (2004) Croft et al. (1995)
Conicity index (CI)	Measurement of central obesity, using waist circumference (m), height (m) and weight (kg) CI = waist circumference (m) / [0.109 x √ (weight (kg) / height (m)]	Valdez (1991) Ehrampoush et al. (2017)

based on the procedures, on the costs of the equipment, and on the different principles of the measurement, where the equipment for measuring fat mass are based. These tools are clearly the most expensive, but they provide a more reliable assessment of body composition.

Finally, the focus of our research allowed to select 16 references concerning obesity categorization and nutritypes/obesotype (Table 3), that are important for obesity classification. The most used index to classify obesity is the body mass index (BMI), based on the individual weight and height, allowing to estimate adiposity in both men and women. In addition to the definition of the BMI cut-off values for overweight and obesity, there are methods that make possible the classification of obese subjects into groups based on the relative risk of comorbidity due to excess body weight, as the Edmonton Obesity Staging System (EOSS), which classify obesity in a five-item score based on risk factors, representing a reliable scale for the prediction of mortality, the Framingham Risk Score (FRS), an algorithm used to the 10-year cardiovascular risk estimation of an individual due to the influence of obesity and the Obesity Surgery Mortality Risk Score (OS-MRS), which assesses people into 3 groups basing on the risk of mortality as a consequence of weight loss surgery.

Discussion

Obesity results from complex interactions between unbalanced dietary habits, physical inactivity, genetic factors, socioeconomic status, and cultural factors that are accompanied by diverse comorbidities, which often require chronic treatments (26). This disease is a public health problem with a huge worldwide incidence that has nearly tripled since 1975, causing major risk of non-communicable diseases such as cardiovascular events, diabetes, musculoskeletal disorders and some cancers (1).

Initially, obesity management is based on educating maladaptive eating habits and insufficient physical activity, accompanied by psychological support to favor diet/regime compliance (27). When these treatments prove to be inefficient, it is possible to prescribe drugs aimed at weight loss and maintenance like Orlistat and Liraglutide (28). In the presence of severe obesity and proven failure to follow energy restricted diets, or an eventual pharmacological response, it may be necessary to apply surgical therapies such as Gastric banding, Gastric Bypass, or Gastric Balloon (29), where body fat evaluation is required to follow the treatment outcome.

Due to the complexity of obesity features, there are numerous classification methods, such as those based not only on anthropometrics (30), which are useful to indirectly measure body fat proportions; but in complex methods (31) to measure adipose tissue or nutritypes/obesotype (20), which allow the categorization of individuals according to phenotypical and lifestyle factors related to excessive adiposity.

The assessment of body fat through skinfold thickness is a highly utilized method due to recognized simplicity and low cost (32). The main drawback of measuring skinfold thickness, which evaluates subcutaneous fat without considering the visceral depots, is not only due to the variability depending on the different personnel that performs the evaluation, but also due to the inefficient opening of the caliper and the difficulty in grabbing skinfolds in the obese (33). For these reasons and others, numerous equations have been developed over the years to determine fat mass percentage. One of such equations was devised by Jackson and Pollock (34) and designed to estimate body density based on the sum of the chest, triceps and subscapular skinfolds in men, and triceps, suprailium and abdominal skinfolds in women, which is then converted into a percentage of fat mass using the Siri equation (35). In this context, the Siri and Brozek methods are some of the traditional approaches that are employed for quantifying fat mass percentages through the calculated body density which, among different strategies, can be assessed using triceps skinfolds for Siri, or the sum of the triceps, biceps, subscapular fold and iliac crest for Brozek method (36), as described by Visser et al. equation (37).

Thus, Body Adiposity Index (BAI) makes an estimation based on the height and circumference of the hip (38), while Body Roundness Index (BRI) takes into account waist circumference and height (39). From the BAI, a modified formula called Modified

Body Adiposity Index (MBAI) can be obtained, allowing the more accurate calculation of body fat without the limitations of BAI (40).

As previously mentioned, the predictive formulas of body fat percentage differ according to the variables considered, including age, BMI and gender (41,42,43), with the possibility of merging the waist circumference (44), anthropometry and skinfold thickness (45). Furthermore, the equations that are differentiated for the sex, could consist only on BMI (46,47), on age and skinfold thickness (48,49,50), and on age and waist circumference (51).

There are a number of tools and instrument that measure body composition such as those using imaging such as Dual-energy X-ray absorptiometry (DXA) and Computed tomography (CT). Both offer information on body composition, with DXA being more complete, complex, requires trained personnel, and with higher cost and execution time, but also provides information on bone density (52,53). On the other hand, bioelectrical impedance analysis (BIA) and total body electrical conductivity (TOBEC) estimate body composition through electrical conductivity. BIA allows to reach reliable results quickly, inexpensively and radiations-free (54), while TOBEC is a least used method due to its high cost, despite high precision (55,56). Given the growing application of BIA as a method of measuring body composition, studying the accuracy, intra-individual variability and repeatability is necessary to improve interpretation (57). Alternatively, near-infrared interactance (NIR), is an inexpensive, easy and fast method, although it is not precise enough, which uses the light of several wavelengths to discriminate fat/muscle tissues content (58). Finally, ultrasound is a low cost method, where high trained personnel uses sound waves to measure fat and muscle thicknesses in humans in a non-invasive and radiation-free ways (59).

Furthermore, both hydrostatic weighing (HW) and air displacement plethysmography (ADP) are considered reference techniques of densitometry for body composition assessment. The difference between them is that ADP uses air displacement, being a quick, safe and automated process (60), while HW uses water immersion, resulting useful for research, but less applicable due the principle of utilization and cost (61). Another way to measure body composition is through the 3D body scanner, which provides a suitable graphical representation of the body in a relatively inexpensive, radiation-free and automated collection of hundreds of measurements (62). Magnetic resonance imaging (MRI) permits to obtain information about the structure and composition of the body to be analyzed through the properties of the atomic nuclei, which is a non-invasive method with the limitations of being expensive, slow and still on an experimental stage (63).

Another precise method is isotope dilution, based on adding a known amount of an isotopic rich substance to quantify the amount of the chemical content in a body (64), which is inconvenient for clinical use. Total body water (TBW) or hydrometry and total body potassium (TBK) are two costly methods of isotopic dilution commonly used for the estimation of body composition (65). The first is safe and based on the principle that water is distributed in all parts of the body except body fat (66) and the second, which is faster and more precise, focuses on the principle that the proportion of total potassium found in human tissue is quite constant (67).

By evaluating the level of the urinary creatinine output, it can be estimated the muscle mass of a subject, and consequently measure the body composition in a non-invasive way (68). Neutron activation analysis provides direct measurement of total body elements in the human body, based on the activation of the excited states of the neutrons (69). A direct calculation of total body fat is based on the absorption from a closed respiratory system of cyclopropane, a fat-soluble gas. Despite being a proved successful method in rats, it is difficult to apply in humans (70).

All of these indexes provide the estimation of fat mass percentage, while others are used to classify obesity (71). The most commonly used index for obesity classification is BMI (72), which can gauge the fat content of a subject (73), taking into account the weight and height (74), with the limitation of not directly considering the body composition of the person (75). The classification of the severity of the physiological condition of the individual in categories ranges from underweight to severe obesity (76,77). Other methods of classification are those that measure the relative risk of diseases due to excessive body weight. An example of this is the Edmonton Obesity Staging System (EOSS), which let us categorize obese people based on the presence of dysfunctions associated with excessive adipose tissue (78,79). Using a detailed gender-specific algorithm, with the Framingham Risk Score (FRS), an estimation of the obesity influence on the future 10 years cardiovascular risk for the possible development of a coronary heart disease is achievable, where the limitation of this scale is the failure in predicting cardiovascular events (21,80). The Obesity Surgery Mortality Risk Score (OS-MRS) could be a useful tool to assess patients undergoing body weight loss surgery into 3 groups based on the risk of mortality, as it is based on the risk of developing postoperative complications (22,81).

Furthermore, obesity can be classified by taking into consideration body circumference such as waist circumference (82,83), neck circumference (84), sagittal abdominal diameter (85,86), hip circumference and parameters such as height and weight. Some of them are used together to obtain indices such as Waist-to-Height Ratio (87), Waist to Hip Ratio (81,88) and Conicity Index (89,90), related to morbidity risks associated to obesity.

To sum up, the predictive equations for body fat percentage are highly used since they do not require specific material, are cheap as they are based on anthropometry and may consider variables such as sex and age, although they do not provide the perfect measurement. Complex methods provide more reliable information but are more expensive and require specific devices. Finally, the scores for the classification of obesity turn out to be good indexes for the subdivision of overweight or obese subjects into categories, linked to the risk of comorbidity or even mortality for diagnosing and management purposes.

Conclusion

The early identification of excess body fat could help to promote health worldwide, which explain that the analysis of body composition is of great interest. There are numerous available techniques that safely and suitably provide information on body composition in humans throughout a lifetime, but no gold standard has been yet recognized. All these methods are useful for quantifying and classifying obesity, allowing the calculation and risk prediction of the consequences associated with excessive body fat. Nowadays, BMI is the predominant tool when calculating body composition, however, it has some limitations. Therefore, knowing the advantages and disadvantages of the different methods of body fat measurement could allow us to determine and select the most suitable technique for each type of need, diagnosing classification and for monitoring clinical outcomes of subjects with excessive adiposity.

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References

1. World Health Organization. Obesity and overweight. 2018. Available at: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight.
2. Arroyo-Johnson C, Mincey KD. Obesity epidemiology trends by race/ethnicity, gender, and education: National Health Interview Survey, 1997–2012. Gastroenterol Clin North Am 2016; 45(4): 571.
3. Salmasi L, Celidoni M. Investigating the poverty-obesity paradox in Europe. Econ Hum Biol 2017; 26: 70–85.
4. Rosenheck R. Fast food consumption and increased caloric intake: A systematic review of a trajectory towards weight gain and obesity risk. Obes Rev 2008; 9(6): 535–47.
5. Goedecke JH, Micklesfield LK. The Effect of Exercise on Obesity, Body Fat Distribution and Risk for Type 2 Diabetes. Diabetes Phys Act 2014; 60: 82–93.
6. McAllister EJ, Dhurandhar NV, Keith SW, et al. Ten putative contributors to the obesity epidemic. Crit Rev Food Sci Nutr 2009; 49(10): 868–913.
7. Kaur Y, de Souza RJ, Gibson WT, Meyre D. A systematic review of genetic syndromes with obesity. Obes Rev 2017; 18(6): 603–34.
8. Verhaegen AA, Van Gaal LF. Drug-induced obesity and its metabolic consequences: a review with a focus on

mechanisms and possible therapeutic options. J Endocrinol Invest 2017; 40(11): 1165–74.

9. Labib M. The investigation and management of obesity. J Clin Pathol 2003; 56(1): 17–25.
10. Peeters A, Barendregt JJ, Willekens F, Mackenbach JP, Mamun A Al, Bonneux L. Obesity in Adulthood and Its Consequences for Life Expectancy: A Life-Table Analysis. Ann Intern Med 2003; 138(1): 24.
11. Cawley J, Meyerhoefer C. The medical care costs of obesity: An instrumental variables approach. J Health Econ 2012; 31(1): 219–30.
12. Billingsley HE, Carbone S, Lavie CJ. Dietary Fats and Chronic Noncommunicable Diseases. Nutrients 2018; 10(10).
13. Khaodhiar L, McCowen KC, Blackburn GL. Obesity and its comorbid conditions. Clin Cornerstone 1999; 2(3): 17–31.
14. Calle EE, Rodriguez C, Walker-Thurmond K, Thun MJ. Overweight, Obesity, and Mortality from Cancer in a Prospectively Studied Cohort of U.S. Adults. N Engl J Med 2003; 348(17): 1625–38.
15. Freisling H, Arnold M, Soerjomataram I, et al. Comparison of general obesity and measures of body fat distribution in older adults in relation to cancer risk: meta-analysis of individual participant data of seven prospective cohorts in Europe. Br J Cancer 2017; 116(11): 1486–97.
16. Lee SY, Gallagher D. Assessment methods in human body composition. Curr Opin Clin Nutr Metab Care 2008; 11(5): 566–72.
17. Samsell L, Regier M, Walton C, Cottrell L. Importance of Android/Gynoid Fat Ratio in Predicting Metabolic and Cardiovascular Disease Risk in Normal Weight as well as Overweight and Obese Children. J Obes 2014; 2014: 1–7.
18. Abdelaal M, le Roux CW, Docherty NG. Morbidity and mortality associated with obesity. Ann Transl Med 2017; 5(7): 161–161.
19. Forbes GB. Body Fat Content Influences the Body Composition Response to Nutrition and Exercise. Ann N Y Acad Sci 2006; 904(1): 359–65.
20. de Cuevillas B, Alvarez-Alvarez I, Cuervo M, Fernández-Montero A, Navas-Carretero S, Martínez JA. Definition of Nutritionally qualitative categorizing (proto)nutritypes and a pilot quantitative nutrimeter for mirroring nutritional wellbeing based on a quality of life health related questionnaire. Nutr Hosp 2019; ([Impress]).
21. Zhang H, Yu C, Guan Q, et al. Viscus fat area contributes to the Framingham 10-year general cardiovascular disease risk in patients with type 2 diabetes mellitus. Life Sci 2019; 220: 69–75.
22. García-García ML, Martín-Lorenzo JG, Lirón-Ruiz R, Torralba-Martínez JA, García-López JA, Aguayo-Albasini JL. Failure of the Obesity Surgery Mortality Risk Score (OS-MRS) to Predict Postoperative Complications After Bariatric Surgery. A Single-Center Series and Systematic Review. Obes Surg 2017; 27(6): 1423–9.
23. 23. Cronin P, Ryan F, Coughlan M. Undertaking a literature review: a step-by-step approach. Br J Nurs 2008; 17(1): 38–43.
24. Gasparyan AY, Ayvazyan L, Blackmore H, Kitas GD. Writing a narrative biomedical review: considerations for authors, peer reviewers, and editors. Rheumatol Int 2011; 31(11): 1409–17.
25. Agarwal N, Dewan P. Writing a Review Article: Making Sense of the Jumble. Indian Pediatr 2016; 53(8): 715–20.
26. Apovian CM. Obesity: definition, comorbidities, causes, and burden. Am J Manag Care 2016; 22(7 Suppl): s176-85.
27. Webb VL, Wadden TA. Intensive Lifestyle Intervention for Obesity: Principles, Practices, and Results. Gastroenterology 2017; 152(7): 1752–64.
28. Saunders KH, Umashanker D, Igel LI, Kumar RB, Aronne LJ. Obesity Pharmacotherapy. Med Clin North Am 2018; 102(1): 135–48.
29. Kahan S. Overweight and obesity management strategies. Am J Manag Care 2016; 22(7 Suppl): s186-96.
30. Kamadjeu RM, Edwards R, Atanga JS, Kiawi EC, Unwin N, Mbanya J-C. Anthropometry measures and prevalence of obesity in the urban adult population of Cameroon: an update from the Cameroon Burden of Diabetes Baseline Survey. BMC Public Health 2006; 6: 228.
31. Duren DL, Sherwood RJ, Czerwinski SA, et al. Body Composition Methods: Comparisons and Interpretation. J Diabetes Sci and Technol 2008; 2(6): 1139-46.
32. Kamimura MA, Avesani CM, Cendoroglo M, Canziani MEF, Draibe SA, Cuppari L. Comparison of skinfold thicknesses and bioelectrical impedance analysis with dual-energy X-ray absorptiometry for the assessment of body fat in patients on long-term haemodialysis therapy. Nephrol Dial Transplant 2003; 18(1): 101–5.
33. Ruiz De Eguilaz MH, Martínez De Morentín B, Pérez-Diez S, Navas-Carretero S, Martínez JA. Estudio comparativo de medidas de composición corporal por absorciometría dual de rayos X, bioimpedancia y pliegues cutańeos en mujeres. An la Real Acad Nac Farm 2010; 76(2): 209–22.
34. Jackson AS, Pollock ML. Practical assessment of body composition. Phys Sportsmed 1985; 13(5): 76–90.
35. Siri WE. Body composition from fluid spaces and density: analysis of methods. 1961. Nutrition 9(5): 480–91.
36. Brožek J. Body composition: Models and estimation equations. Am J Phys Anthropol 1966; 24(2): 239–46.
37. Visser M, Heuvel E Van Den, Deurenberg P. Prediction equations for the estimation of body composition in the elderly using anthropometric data. Br J Nutr 1994; 71(6): 823–33.
38. Bergman RN, Stefanovski D, Buchanan TA, et al. A Better Index of Body Adiposity. Obesity 2011; 19(5): 1083–9.
39. McDougall A, Bredlau C, Mueller M, et al. Relationships between body roundness with body fat and visceral adipose tissue emerging from a new geometrical model. Obesity 2013; 21(11): 2264–71.

40. Bernhard AB, Scabim VM, Serafim MP, Gadducci AV, Santo MA, de Cleva R. Modified body adiposity index for body fat estimation in severe obesity. J Hum Nutr Diet 2017; 30(2): 177–84.
41. Deurenberg P, Weststrate JA, Seidell JC. Body mass index as a measure of body fatness: age- and sex-specific prediction formulas. Br J Nutr 1991; 65(2): 105–14.
42. Gallagher D, Heymsfield SB, Heo M, Jebb SA, Murgatroyd PR, Sakamoto Y. Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index. Am J Clin Nutr 2000; 72(3): 694–701.
43. Gomez-Ambrosi J, Silva C, Catalan V, et al. Clinical Usefulness of a New Equation for Estimating Body Fat. Diabetes Care 2012; 35(2): 383–8.
44. Kagawa M, Byrne NM, Hills AP. Comparison of body fat estimation using waist:height ratio using different 'waist' measurements in Australian adults. Br J Nutr 2008; 100(5): 1135–41.
45. Kanellakis S, Skoufas E, Khudokonenko V, et al. Development and validation of two equations based on anthropometry, estimating body fat for the Greek adult population. Obesity 2017; 25(2): 408–16.
46. Jackson AS, Stanforth PR, Gagnon J, et al. The effect of sex, age and race on estimating percentage body fat from body mass index: The Heritage Family Study. Int J Obes Relat Metab Disord 2002; 26(6): 789–96.
47. Durnin JVGA, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 Years. Br J Nutr 1974; 32(01): 77–97.
48. Leahy S, O'Neill C, Sohun R, Toomey C, Jakeman P. Generalised equations for the prediction of percentage body fat by anthropometry in adult men and women aged 18–81 years. Br J Nutr 2013; 109(4): 678–85.
49. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. Br J Nutr 1978; 40(3): 497–504.
50. Jackson AS, Pollock ML, Ward A. Generalized equations for predicting body density of women. Med Sci Sports Exerc 1980; 12(3): 175–81.
51. Lean ME, Han TS, Deurenberg P. Predicting body composition by densitometry from simple anthropometric measurements. Am J Clin Nutr 1996; 63(1): 4–14.
52. Plank LD. Dual-energy X-ray absorptiometry and body composition. Curr Opin Clin Nutr Metab Care 2005; 8(3): 305–9.
53. Hoffe S, Saeed N, Shridhar R, Chuong M, Almhanna K, Meredith K. CT-based assessment of visceral adiposity and outcomes for esophageal adenocarcinoma. J Gastrointest Oncol 2017; 8(5): 833–41.
54. Kyle UG, Bosaeus I, De Lorenzo AD, et al. Bioelectrical impedance analysis--part I: review of principles and methods. Clin Nutr 2004; 23(5): 1226–43.
55. Presta E, Wang J, Harrison GG, Björntorp P, Harker WH, Van Itallie TB. Measurement of total body electrical conductivity: a new method for estimation of body composition. Am J Clin Nutr 1983; 37(5): 735–9.
56. Casanova Román M. Técnicas de valoración del estado nutricional. Vox Paedriatr 2003; 11.1: 26-35.
57. Pérez S, Parra MD, Martínez de Morentin BE, Rodríguez CM, Martínez JA. Evaluación de la variabilidad intraindividual de la medida de composición corporal mediante bioimpedancia en voluntarias sanas y su relación con el índice de masa corporal y el pliegue tricipital. Enferm Clin 2005; 15(6): 343–7.
58. Brooke-Wavell K, Jones PR, Norgan NG, Hardman AE. Evaluation of near infra-red interactance for assessment of subcutaneous and total body fat. Eur J Clin Nutr 1995; 49(1): 57–65.
59. Bielemann RM, Gonzalez MC, Barbosa-Silva TG, et al. Estimation of body fat in adults using a portable A-mode ultrasound. Nutrition 2016; 32(4): 441–6.
60. Fields DA, Goran MI, McCrory MA. Body-composition assessment via air-displacement plethysmography in adults and children: a review. Am J Clin Nutr 2002; 75(3): 453–67.
61. Clark RR, Kuta JM, Sullivan JC. Prediction of percent body fat in adult males using dual energy x-ray absorptiometry, skinfolds, and hydrostatic weighing. Med Sci Sports Exerc 1993; 25(4): 528–35.
62. Ng BK, Hinton BJ, Fan B, Kanaya AM, Shepherd JA. Clinical anthropometrics and body composition from 3D whole-body surface scans. Eur J Clin Nutr 2016; 70(11): 1265–70.
63. Cordes C, Franz D, Hauner H, et al. MR-based assessment of body fat distribution and characteristics. Eur J Radiol 2016; 85(8): 1512–8.
64. Wong WW, Cochran WJ, Klish WJ, et al. Body fat in normal adults estimated by oxygen-18- and deuterium-dilution and by anthropometry: a comparison. Eur J Clin Nutr 1988; 42(3): 233–42.
65. Bruce A, Andersson M, Arvidsson B, Isaksson B. Body composition. Prediction of normal body potassium, body water and body fat in adults on the basis of body height, body weight and age. Scand J Clin Lab Invest 1980; 40(5): 461–73.
66. Van Loan MD, Boileau RA, Slaughter MH, et al. Association of bioelectrical resistance with estimates of fat-free mass determined by densitometry and hydrometry. Am J Hum Biol 1990; 2(3): 219–26.
67. Davies JS, Bell W, Evans W, Villis RJ, Scanlon MF. Body composition derived from whole body counting of potassium in growth hormone-deficient adults: a possible low intracellular potassium concentration. J Clin Endocrinol Metab 1996; 81(5): 1720–3.
68. Forbes GB, Bruining GJ. Urinary creatinine excretion and lean body mass. Am J Clin Nutr 1976; 29(12): 1359–66.
69. Cohn SH, Vaswani AN, Yasumura S, Yuen K, Ellis KJ. Improved models for determination of body fat by in vivo neutron activation. Am J Clin Nutr 1984; 40(2): 255–9.
70. Perl W, Lesser GT, Steele JM. The kinetics of distribution of the fat-soluble inert gas cyclopropane in the body. Biophys J 1960; 1: 111–35.

71. Seidell JC, Flegal KM. Assessing obesity: classification and epidemiology. Vol. 53, Britijh M.dical Bulletin. 1997.
72. Antonopoulos AS, Oikonomou EK, Antoniades C, Tousoulis D. From the BMI paradox to the obesity paradox: the obesity-mortality association in coronary heart disease. Obes Rev 2016; 17(10): 989–1000.
73. Marković-Jovanović SR, Stolić RV, Jovanović AN. The reliability of body mass index in the diagnosis of obesity and metabolic risk in children. J Pediatr Endocrinol Metab 2015; 28(5–6): 515–23.
74. Chiquete E, Ruiz-Sandoval JL, Ochoa-Guzmán A, et al. The Quételet index revisited in children and adults. Endocrinol y Nutr 2014; 61(2): 87–92.
75. Frankenfield DC, Rowe WA, Cooney RN, Smith JS, Becker D. Limits of body mass index to detect obesity and predict body composition. Nutrition 2001; 17(1): 26–30.
76. World Health Organization. Body mass index - BMI. 2019. Available at: http://www.euro.who.int/en/health-topics/disease-prevention/nutrition/a-healthy-lifestyle/body-mass-index-bmi
77. Ricci MA, De Vuono S, Scavizzi M, Gentili A, Lupattelli G. Facing Morbid Obesity. Angiology 2016; 67(4): 391–7.
78. Sharma AM, Kushner RF. A proposed clinical staging system for obesity. Int J Obes 2009; 33(3): 289–95.
79. Martínez-Urbistondo D, Martínez JA. Utilidad del cuestionario «Edmonton Obesity Staging System» para el desarrollo de la nutrición médica de precisión. Rev Clin Esp 2017; 217(2): 97–8.
80. Lloyd-Jones DM, Wilson PW, Larson MG, et al. Framingham risk score and prediction of lifetime risk for coronary heart disease. Am J Cardiol 2004; 94(1): 20–4.
81. DeMaria EJ, Portenier D, Wolfe L. Obesity surgery mortality risk score: proposal for a clinically useful score to predict mortality risk in patients undergoing gastric bypass. Surg Obes Relat Dis 2007; 3(2): 134–40.
82. World Health Organization. Obesity: Preventing and Managing the Global Epidemic. Report of a WHO Consultation. World Health Organ Tech Rep Ser. Who 2004; 1–253.
83. Carranza Leon BG, Jensen MD, Hartman JJ, Jensen TB. Self-Measured vs Professionally Measured Waist Circumference. Ann Fam Med 2016; 14(3): 262–6.
84. Hingorjo MR, Qureshi MA, Mehdi A. Neck circumference as a useful marker of obesity: a comparison with body mass index and waist circumference. J Pak Med Assoc 2012; 62(1): 36–40.
85. Rådholm K, Tengblad A, Dahlén E, et al. The impact of using sagittal abdominal diameter to predict major cardiovascular events in European patients with type 2 diabetes. Nutr Metab Cardiovasc Dis 2017; 27(5): 418–22.
86. Zamboni M, Turcato E, Armellini F, et al. Sagittal abdominal diameter as a practical predictor of visceral fat. Int J Obes 1998; 22(7): 655–60.
87. Ashwell M, Hsieh SD. Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. Int J Food Sci Nutr 2005; 56(5): 303–7.
88. Croft JB, Keenan NL, Sheridan DP, Wheeler FC, Speers MA. Waist-to-hip ratio in a biracial population: measurement, implications, and cautions for using guidelines to define high risk for cardiovascular disease. J Am Diet Assoc 1995; 95(1): 60–4.
89. Valdez R. A simple model-based index of abdominal adiposity. J Clin Epidemiol 1991; 44(9): 955–6.
90. Ehrampoush E, Arasteh P, Homayounfar R, et al. New anthropometric indices or old ones: Which is the better predictor of body fat? Diabetes Metab Syndr Clin Res Rev 2017; 11(4): 257–63.

Correspondence:
J. Alfredo Martínez
Department of Nutrition, Food Sciences and Physiology, Center for Nutrition Research, University of Navarra, 31008 Pamplona, Spain
IdisNA Health Research Institute of Navarra, Pamplona, Spain
CIBERObn, Obesity and Nutrition, Instituto de Salud Carlos III, Madrid, Spain
Precision Nutrition Program, Research Institute on Food and Health Sciences IMDEA Food, 28049 Madrid, Spain
Phone: + 34 948425600
Ext. 80-624
E-mail: jalfmtz@unav.es