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POSITION ARTICLE AND GUIDELINES

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Official position of the Brazilian Association of Bone Assessment and Metabolism (ABRASSO) on the evaluation of body composition by densitometry: part I (technical aspects)—general concepts, indications, acquisition, and analysis

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Abstract

Objective: To review the technical aspects of body composition assessment by dual-energy X-ray absorptiometry (DXA) and other methods based on the most recent scientific evidence.

Materials and methods: This Official Position is a result of efforts by the Scientific Committee of the Brazilian Association of Bone Assessment and Metabolism (*Associação Brasileira de Avaliação Óssea e Osteometabolismo*, ABRASSO) and health care professionals with expertise in body composition assessment who were invited to contribute to the preparation of this document. The authors searched current databases for relevant publications. In this first part of the Official Position, the authors discuss the different methods and parameters used for body composition assessment, general principles of DXA, and aspects of the acquisition and analysis of DXA scans.

Conclusion: Considering aspects of accuracy, precision, cost, duration, and ability to evaluate all three compartments, DXA is considered the gold-standard method for body composition assessment, particularly for the evaluation of fat mass. In order to ensure reliable, adequate, and reproducible DXA reports, great attention is required regarding quality control procedures, preparation, removal of external artifacts, imaging acquisition, and data analysis and interpretation.

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Background of body composition assessment

The most accurate approach to measuring body composition in humans is by direct chemical analysis of cadavers, as described by Mitchell et al. in a classic study published in 1945 [1]. This and other studies in cadavers have advanced the techniques for in vivo assessment of body composition.

One of the first methods developed for in vivo body composition assessment was underwater weighing, a method based on the Archimedes' principle (i.e., the buoyant force that water exerts on an immersed object is equal to the weight of water that the object displaces). For some time, this remained the primary method applied for measurement of body density and volume, and several new approaches were later developed based on this concept [2].

Behnke conceived the human body as having two compartments, fat and fat-free mass, each with assumed stable densities of 0.900 g/cm^3 and 1.095 g/cm^3, respectively. By measuring body mass underwater and on land along with residual lung volume, Behnke was able to derive an estimate of body volume and density that, based on the two-compartment model, could be used to calculate fat-free mass and fat mass. Siri made adjustments to the density values applied by Behnke, assuming the densities of fat (mostly ether-extractable triglyceride) and fat-free mass at 37 °C to be 0.900 g/cm^3 and 1.100 g/cm^3, respectively [1]. Later, researchers reduced the mean body temperature to 36 °C and adjusted the fat density to 0.9007 g/cm^3. For several decades, Siri's original temperature-corrected model combined with underwater weighing was often considered the gold-standard method for molecular-level, body composition research [1].

At a certain point, it became clear that the various assumptions involved in the two-compartment model were not appropriate when examining subjects across wide age ranges, and particularly between groups differing in terms of sex and ethnicity [2].

Siri and others recognized the limitations of the two-compartment underwater weighing model and introduced refinements to that model. The new proposed model added total body water to the two-compartment molecular-level model to create a three-compartment model consisting of fat, water, and non-fat solids (mineral and protein), the latter referred to as residual mass [1]. In this new configuration of a three-compartment model, the density of the combined residual mass component was assumed to be 1.565 g/cm^3, reflecting the density of protein (1.34 g/cm^3) and minerals (3.00 g/cm^3) [1].

In 1971, Cohn & Dombrowski used in vivo neutron activation analysis and whole-body counting to measure total body nitrogen, calcium, phosphorus, sodium, and chlorine [1]. The chemical analysis obtained by neutron activation whole-body multi-compartment models was similar to the chemical analysis of human cadavers performed in the early years of body composition research [2].

Body composition components at atomic, molecular, cellular, and tissue-system levels can be mathematically formulated as algebraic equations for each level, comprising the four fundamental equations that serve as the basis for the formulation of multi-compartment models [2].

Figure 1 shows the models of body composition. In the two-compartment model (2-C), the body is divided into "fat" and "fat-free" mass compartments. In the three-compartment model (3-C), the fat-free compartment is divided into bone and lean mass. In the four-compartment model (4-C), the lean mass compartment is divided into protein and water compartments. With the more recent development of DXA technology, the assessment of a three-compartment molecular level (i.e., fat, lean soft tissue, and bone mineral) became possible. The lean soft

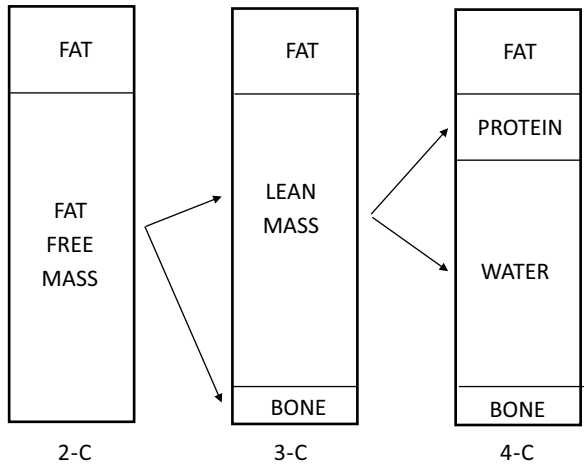


Fig. 1 Models of body composition. In the two-compartment model (2-C), the body is divided into "fat" and "fat-free" mass compartments. In the three-compartment model (3-C), the fat-free compartment is divided into bone and lean mass. In the four-compartment model (4-C), the lean mass compartment is divided into protein and water compartments

tissue component corresponds to water, protein, glycogen, and soft tissue minerals [2].

Materials and methods

This document is a result of efforts by the Brazilian Association of Bone Assessment and Metabolism (*Associação Brasileira de Avaliação Óssea e Osteometabolismo*/Brazilian Society on Bone and Osteometabolism Evaluation, ABRASSO) for the development of recommendations based on the current evidence available in the scientific literature regarding measurement of body composition using DXA. The ABRASSO Scientific Committee invited experts in the field to contribute to the preparation of this document. The authors were invited by ABRASSO to provide scientific information on body composition measurements. ABRASSO was chosen as the official organization for the preparation of this document considering its national expression and the fact that it congregates professionals from several medical areas related to bone and mineral metabolism (rheumatology, endocrinology, gynecology, orthopedics, geriatric and gerontology, physiatry, sports medicine and rehabilitation, nephrology, infectious diseases, pediatrics, veterinary medicine) along with supporting health care professionals (nutritionists, dietitians, biomedical scientists, biologists, pharmacists, physical therapists, psychologists, and basic researchers). The main criteria for inviting collaborators were their areas of expertise, contributions to the field, association with medical organizations related to the topics covered in this document, publication of papers, and practical management on the covered topic, thus fulfilling the endorsement by ABRASSO and other participating medical societies. The invited authors were divided into small groups (with 2 to 6 authors per group), according to their areas of expertise and questions to be addressed. Additionally, all the authors composed the steering committee for the development of the study that resulted in the present document and designed the protocol to address specific questions related to the applicability of body composition measurements (including technical and practical issues). All the authors wrote the manuscript with input from each other, critically reviewed the manuscript, and approved its final version for submission (fulfilling the criteria for authorship). None of the authors had a conflict of interest to disclose related to the topic of body composition measurements, and all of them participated actively in the discussions and are responsible for the reported research.

The aim of this position statement is to answer routine questions about body composition assessment and serve as a guideline for clinicians and researchers in Brazil. The authors searched current databases for relevant publications and described their findings below using a narrative review format. The search strategy was similar among all authors and was conducted by each group using the electronic databases MEDLINE (via PubMed), Embase, and SciELO. The expressions used included "adult and pediatric normative data," "lean mass measurements," "fat mass measurements," "basic area and technical science," "other anthropometrical measurements," "other non-DXA body composition measurements," among others. The authors also searched for other potential studies not retrieved by the search strategies by consulting review articles, meta-analyses/systematic reviews, and guidelines issued by specialty societies, particularly the International Society for Clinical Densitometry (ISCD) Official Position. To increase the search sensitivity, MeSH search terms were used for clinical conditions and therapeutic interventions but not for comparators or outcomes. Only studies published in Portuguese, English, and Spanish were considered. The search was limited to studies published between January 1st, 2000, and July 31st, 2021. The search in each electronic database included the following descriptors (key words): "body composition measurements," "DXA," "other measurements NO DXA," "skinfold," "plethysmography," "ultrasound," "computed tomography," "magnetic resonance imaging," "bioelectrical impedance analysis," "absorptiometry," "X-ray," "methodology," "artifacts," "technical procedures," "fat mass," "bone mass," "lean mass," "sarcopenia," "DXA," "clinical conditions," "elderly," "obesity," "adiposity," "children and adolescents," "HIV," "animals," "physical parameters," "transgenders," "Brazilian normality data," and "clinical applicability." Due to the extent of the position statement, it was divided into two parts. Part I was dedicated to a revision of methods for evaluation of body composition and their technical aspects, and Part II focused on the interpretation of results and clinical applications.

A total of 120 articles were reviewed for the preparation of this first part of the Position Statement. All articles were carefully analyzed, first by the groups of collaborators (all experts in body composition assessment using DXA) and then by the ABRASSO Steering Committee. Using electronic correspondence (email), the collaborators in each group discussed the articles based on their expertise until they reached a consensus regarding the best current scientific evidence. The final questions presented in this first part of the Position Statement were chosen by the collaborators and the ABRASSO Steering Committee and were based on the main questions and problems encountered in clinical practice concerning the technical aspects of body composition assessment by DXA and are presented in the following sections: general concepts, indications, acquisition, and analysis. Finally, the collaborators and the ABRASSO Steering Committee prepared a statement answering each question based on

current scientific evidence. Using a Likert scale, the final agreement level (from 0 to 100%) was reached through electronic voting among all collaborators for all six statements (Table 1).

Section I: General Aspects Of Methods And Parameters For Evaluation Of Body Composition

1. What other parameters and methods are available for body composition assessment in addition to DXA?

(a) Anthropometric measurements

Anthropometry is a method for measuring body size and proportions. Anthropometric measurements can replace methods of body composition assessment since these measurements estimate fat and muscle mass through equations. Anthropometric measurements do not require medium or large size equipment and are relatively well known, easy to obtain, and accurate, as long as proper protocols are followed and measurements are obtained by well-trained professionals. The most frequently used anthropometric measurements are circumferences and skinfold thickness.

- Skinfold thickness: indicating obesity when increased, measurements of skinfold thickness consider the relationship between fat located in deposits below the skin (40–60% of total body fat) and internal fat or body density. The main skinfold measurement sites are the triceps, biceps, subscapular, suprailiac, pectoral, forearm, midaxillary, abdominal, thigh, and calf. Of these, the triceps skinfold is the most used for assessment of nutritional status. The percentage of body fat can be calculated by several equations using the sum of skinfold thickness measured at different sites [3]. The use of skinfold measurement as a diagnostic method is limited by its reduced reproducibility owing to large intraobserver and interobserver variability, use of different calipers and anatomic sites chosen for the measurement, and variations in the technique used for pinching the skin [4, 5]. Proper skinfold measurement includes gentle grasping of the skinfold and underlying subcutaneous adipose tissue between the left thumb and index finger, separating both from the underlying muscle. The skinfold should be grasped 2.0 cm above the place where the measurement is taken. The jaws of the calipers should be placed perpendicular to the length of the fold. The skinfold thickness should be measured to the nearest 0.1 mm, while the fingers continue to hold the skinfold. The caliper measurement must be read about 3 s after the caliper tension is released [6].
- Waist circumference: reflects the visceral fat content and is also associated with total body fat. For measurement of waist circumference, a flexible and inextensible measuring tape is placed around the abdomen, midway between the iliac crest and the last rib [7]. Proposed waist circumference cutoff values differ in Caucasian individuals and in populations in Asia, China, and Japan. In the absence of a specific cutoff point for the Brazilian population, the use of values adopted for the Asian population are recommended. Thus, waist circumference values ≥ 90 cm in men and ≥ 80 cm in women are considered to have the best agreement with risk factors for cardiovascular disease and diabetes mellitus [8].
- Hip circumference: another indicator of obesity when increased, although the value of this measurement in predicting disease risk and mortality is still controversial [9]. Hip circumference is measured using a flexible and inextensible measuring tape positioned at the maximum circumference of the gluteal region. The interpretation of the adequacy of the hip circumference is usually performed by the waist/hip ratio (WHR). Cutoff points for WHR also vary among populations. However, the World Health Organization (WHO) [10] considers the WHR as one of the criteria to characterize metabolic syndrome, using cutoff values of 0.90 for men and 0.85 for women.
- Mid-upper arm circumference: an indicator of caloric malnutrition when reduced, is considered a good predictor of mortality risk in hospitalized patients. A study conducted in the US has shown that mid-upper arm circumference < 23.2 cm in men and < 23.0 cm in women correspond to a body mass index (BMI) < 18.5 kg/m^2 [11].
- Calf circumference: considering the substantial volume of skeletal muscle located in the lower limbs, calf muscle depletion is a good indicator of muscle loss, functional ability, and risk of fragility [12, 13]. In a Brazilian, cross-sectional, population-based study of individuals older than 60 years, Barbosa-Silva et al. found that a calf circumference ≤ 34 cm in men and ≤ 33 cm in women indicate low appendicular skeletal muscle mass index [14].

(b) Plethysmography

Air-displacement plethysmography is a two-compartment model for body composition assessment that, similar to underwater weighing, estimates fat mass and fat-free mass based on body volume and density. The most used system in adults is the BOD POD. The difference between plethysmography and underwater weighing is in the use of air displacement instead of water displacement for measurement of body volume in the former [15], based on the physical principles of Boyle's

Table 1 Statements from the Official Position of the Brazilian Association of Bone Assessment and Metabolism (ABRASSO) regarding technical aspects of body composition measurements using dual-energy X-ray absorptiometry (DXA), along with the levels of agreement (interrater reliability) among the statement's collaborators

Question	Statement	Level of agreement (%)
1. What other parameters and methods are available for body composition assessment in addition to DXA?	Available non-DXA methods for assessment of body composition parameters include anthropometric measurements (weight, height, BMI, skinfold thickness, waist circumference, hip circumference, mid-upper arm circumference, calf circumference), air-displacement plethysmography, bioelectrical impedance, ultrasonography, computed tomography, and magnetic resonance imaging	100
2. What are the indications and contraindications of body composition assessment using densitometry?	Considering aspects of accuracy, precision, cost, duration, and regional distribution of fat and lean mass, DXA is considered the gold-standard method for body composition assessment. This method is recommended for assessment of fat mass even in patients with different diseases but remains under investigation for assessment of lean mass The clinical indications for body composition measurements using DXA are several, but the main ones are obesity, weight loss, dietary protein supplementation in athletes, sarcopenia, use of antiretroviral agents associated with risk of lipodystrophy in individuals with acquired immunodeficiency virus (HIV) infection, stratification of cardiovascular risk, physical training, injury rehabilitation, nutritional disturbances, growth hormone deficiency, thyroid disorders, hypogonadism, estrogen/androgen therapy, glucocorticoid therapy, malabsorption syndromes, eating disorders, and measurement of lean mass for drug dose calculation Contraindications for DXA scanning include pregnancy, patient's weight or height above the limit allowed for the equipment or inability to remain still throughout the examination, recent administration of contrast material, and image artifacts	98
3. What are the technical principles of DXA for body composition assessment?	Total body DXA acquisition is relatively fast and takes on average 5–20 min depending on the equipment and the individual's body proportions. The radiation emitted during body composition assessment varies by equipment from 0.15 to 4.7 μSv The equipment for DXA scanning consists of a computer system, an exam table, detectors, and a tube that emits X-rays at two different intensities (high = above 70 keV; low = 39–50 keV). The attenuation coefficient of the difference between the two dual-energy levels (R value) estimates the bone mineral content based on the atomic level of each compartment of the body (mineral, soft tissue, and water)	100

Table 1 (continued)

Question	Statement	Level of agreement (%)
4. Which precautions should be taken before DXA scanning?	The principles of X-ray protection are based on the duration of exposure, distance from the source, and shielding (protection barriers), according to the ALARA principle. The DXA examination involves a low effective radiation dose (1 mSv for the entire body); therefore, radiation protection is not necessary for professionals involved in whole-body DXA scanning. However, identification, evaluation, analysis, and implementation of measures to reduce the time of direct exposure and increase the distance between the radiation source and the operator are recommended Weight and height should be measured using a medical scale The room temperature is recommended to be maintained between 21 and 24 °C, and the humidity between 20 and 60% Overnight fasting offers the best condition for reproducible DXA scanning results. Heavy fluid intake and large meals should be avoided before the exam During DXA scanning, the patient must wear light clothes (e.g., sports clothing) or a gown provided by the densitometry service. Clothing with dense metal or plastic should be avoided, and accessories (e.g., earrings, rings, watch, bracelets, etc.) should be removed Patients with large breasts projecting over the upper limbs (e.g., those with obesity or gigantomastia) may use a breast adjustment band without a zipper or metal. Bladder emptying is also recommended. Potential artifacts should be removed whenever possible Patients who recently received oral barium contrast, which interferes with DXA results, should be asked to postpone the scanning until 1 week after the use of the contrast. Additional time may be required for complete intestinal cleaning in patients with constipation. Iodinated contrasts used for CT scanning and radioisotopes also interfere with DXA results and require a 1-week delay before scanning In patients with external non-removable artifacts (e.g., cardiac pacemaker and vascular, orthopedic, mammary, or gluteal prostheses), consistent positioning and analysis are important for longitudinal reproducibility Motion artifacts should be avoided, and when present, the scanning should be performed again	99
5. How is the image acquisition protocol?	The patient should be positioned with the body centered on the DXA scanning table, with the center table line used as a reference for aligning the patient. The patient's hand palms should face down and be placed at least 1 cm from the body; if this is not possible, the hands can be placed sideways. The feet must be kept in a neutral position, the upper limbs in a straight or slight angle, the chin upwards in a neutral position, and the head close to the upper limit of the examination table, without exceeding it. Consistency in hand placement at each center is essential for longitudinal monitoring since changes in hand placement could result in changes in tissue measurement The manufacturer Hologic recommends that both legs are kept apart and in internal rotation throughout the entire exam. In contrast, the legs must be kept together with the use of a Velcro strap to reduce movement in GE-Lunar DXA systems	100

Table 1 (continued)

Question	Statement	Level of agreement (%)
6. How is the analysis protocol?	Consistent patient positioning and analysis are the most important factors to minimize measurement errors. Despite slight differences between manufacturers regarding DXA analysis software in terms of movement and segmentation of subregions in ROI markers, the recommendations for the positioning of subregion ROIs are comparable between manufacturers The ROI lines must be positioned as follows: 1. Head: immediately below the chin 2. Arms: in both glenoid joints, verifying that the lines are separating the arms and hands from the rest of the body, passing through the glenoid 3. Spine: adjusted as close as possible to the vertebrae 4. Pelvis: the upper line must touch the iliac crests, and both oblique lines must pass through the femoral necks without contact with the ischium 5. Legs: hands andforearms must be separated from the legs 6. Between-legs: should follow the division between the legs	100

Law of Gases, i.e., volume and pressure are inversely proportional in isothermal conditions. Air-displacement plethysmography, thus, allows for indirect measurement of total body volume [16] by estimating the volume of air displaced within a chamber (plethysmograph). The duration of the test is about 5 min [17]. During the test, the patient must wear a bathing suit or gym clothes (close-fitting to the body) and a swim cap, since the air trapped in the clothes or hair can affect the result of the test. All objects attached to the body (e.g., rings, necklace, watch, etc.) must be removed to avoid interfering with the body volume measurement.

Total body density can be used to estimate body composition. The percentage of fat and the fat-free mass can be determined by the Siri equation, which is the most frequently used formula for this purpose (fat percentage = 495/density − 450) [18]. The equipment software calculates the percentage of fat based on body volume, body density, and (measured or estimated) thoracic gas volume. From the calculated percentage of fat, the software estimates the fat-free mass and fat mass, as well as the percentage of fat-free mass.

A review study has shown that the within-subject coefficient of variation of the percentage of body fat across studies varies between 1.7 and 4.5% within a day and from 2.0 to 2.3% between days [16]. These coefficients are similar to those found with other methods including DXA [16], and studies have demonstrated a good correlation between the methods. A study comparing BOD POD versus underwater weighing in 123 overweight and obese individuals (according to BMI) showed that the percentage of fat estimated by the Siri equation correlated highly between the methods ($r = 0.94$, $p < 0.001$) [19, 20]. Compared to underwater weighing, the BOD POD has the advantage of not requiring immersion in water, increasing convenience, especially for elderly patients and in certain clinical situations. Another study showed a correlation between BOD POD and DXA in terms of estimating body fat percentage in patients with normal and overweight BMI. However, there was a significant difference between both methods at extremes of BMI distribution, in which the percentage of fat measured by the BOD POD was overestimated by up to 13.2% in underweight individuals and underestimated by − 8.51% in overweight/obese individuals [21].

In summary, air-displacement plethysmography is a valid, reliable, and accurate two-compartment method for body composition assessment, and is both safe and easy to perform, avoiding exposure of the patient to radiation. However, this method is not as widely available as others, including DXA and bioelectrical impedance.

(c) Bioelectrical impedance

In clinical practice, bioelectrical impedance is one of the most used methods for body composition assessment. Convenient, safe, and relatively inexpensive, bioelectrical impedance is a doubly indirect method for estimating body composition [22].

In bioelectrical impedance, body compartments are estimated from the flow of a low amplitude electrical current passing through the body, in which the body offers resistance ("impedance") to the current flow. Impedance is composed of two components, resistance (R), related to the quantity of water and electrolytes, and reactance (Xc), related to the amount of cell membranes. R and Xc values are used in predictive equations developed to estimate body compartments (lean mass) and fluids (total body water) based on reference methods for body

composition. Accurate measurements must respect some basic assumptions, including a lean mass hydration constant of around 73.2% and a relationship between the length of the trunk and the length of the legs. In healthy individuals without water or body shape abnormalities and with a BMI between 16 and 34 kg/m^2, bioelectrical impedance may be considered a good alternative method for body composition assessment, provided that the predictive equations are specific for the population studied [22].

Currently, several bioelectrical impedance devices using different methodologies are commercially available, and the most common are 50-kHz frequency devices. Multiple frequency devices have emerged recently, including some with enabled bioimpedance spectroscopy.

Most devices use equations developed for specific populations while taking into account other variables, including sex, age, height, and weight, while other devices consider exercise level for estimation of body compartments. Optimal results, as those reported in the literature, are obtained when these equations are used in populations with characteristics similar to those of the populations in which the equations were built and in healthy individuals, i.e., the equations used should be the most appropriate for the population being studied. Regardless of the type of bioelectrical impedance device used, better results are obtained in studies including groups of individuals (in which the accuracy of the average results is better), while individual results vary widely [23]. According to some authors, bioelectrical impedance should be used as an alternative for body composition assessment in cross-sectional or longitudinal population studies; at an individual level, this method should be used only sparsely to monitor body composition and should not be used for the purpose of diagnosis or to detect changes in body composition [24].

Bioelectrical impedance should be avoided in clinical situations with variable tissue hydration (obesity and fluid overload) since the results in these situations may contain significant errors [25].

Excess body fat (obesity) and decreased lean mass (myopenia), as well as the association of both (sarcopenic obesity) are associated with several clinical and surgical complications. Bioelectrical impedance has been used to diagnose these three conditions and is one of the suggested methods to diagnose sarcopenia in a clinical setting in the absence of other methods, including computed tomography (CT) and magnetic resonance imaging (MRI) [26]. However, the accuracy of the results from bioelectrical impedance depends on the type of device, along with the use of equations and cutoff values specific to the population analyzed [27]. Although current reference values are able to detect changes in body composition assessed by bioelectrical impedance [28], these values originate from healthy populations and are specific to each device, so caution is advised when bioelectrical impedance is used in clinical practice [25]. Of note, a study comparing results obtained by two different bioelectrical impedance devices showed poor agreement between both ($\kappa = 0.19$) in terms of identifying patients with lean mass index below normal [29].

Despite the limitations of bioelectrical impedance, especially in patients with obesity or acute and chronic diseases, this method remains one of the only options for body composition assessment at the bedside [30]. The patient should always be used as his or her own control in sequential evaluations, and the method should not be used to identify specific changes in body composition since not enough data is available to validate the use of bioelectrical impedance in specific clinical situations [25].

(d) Ultrasonography

Ultrasonography has some advantages compared with other methods for body composition assessment. Compared with DXA, ultrasonography is advantageous in terms of cost and portability, facilitating the practice of fieldwork and evaluation of immobilized individuals. In this sense, ultrasonography can be an option for body composition assessment.

Ultrasonography for body composition assessment follows the same principles used for other ultrasonographic evaluations in clinical practice. The transducer generates an ultrasound pulse from piezoelectric crystals that, depending on the type of tissue (fat, muscle, or bone), reflects a specific echo that is captured back by the transducer. Each reflected wave is represented by a dot, and all dots combined compose a grayscale image. The wavelength and frequency of the ultrasound are important factors in this process [31]. Ultrasonography devices can produce images in different types of modes. For body composition analysis, the two most used modes are A-Mode (A is for "amplitude"), which creates a one-dimensional image using software specific for body composition analysis, and B-Mode (B is for "brightness"), which creates two-dimensional images and is the most frequently used mode in ultrasonographic studies and body composition. The first reports on the use of ultrasonography to assess fat mass are from the 1960s [32].

The standardized sites for analyses of body composition using ultrasonography vary according to studies. For assessment of fat, the sites (ranging from three to nine) are usually the same as those used for skinfold thickness measurement. For assessment of muscle mass, different sites are recommended (quadriceps, gastrocnemius medialis, soleus, tibialis anterior, biceps brachii, and

triceps brachii) [33]. Of note, the pressure applied by the transducer on the body surface can influence the measurement of the thickness of the subcutaneous tissue and muscle. The application of excessive pressure results in a false reduction in tissue thickness, underestimating the final result. The parameters that can be evaluated by this method include quantitative and qualitative assessment of muscle mass through muscle thickness and echogenicity, respectively, as well as analysis of subcutaneous and visceral fat.

A study in 76 young adults (mean age 22 years) evaluating the agreement of a three-site versus a seven-site method in predicting body fat by ultrasonography found that both methods had comparable accuracy [34]. Another study validating the use of ultrasonography applied to body fat measurement in 89 volunteers of both sexes (mean age 48.4 years and mean BMI 28.5 kg/m^2) compared the measurements obtained with ultrasonography, DXA, bioelectrical impedance, and air-displacement plethysmography, and found that ultrasonography correlated better with DXA in both men and women [35]. Similarly, another study including 70 high school wrestlers compared the measurement of fat-free mass at three sites using ultrasonography (subcutaneous fat thickness) versus underwater weighing and skinfold measurement and showed that ultrasonography had a good correlation with underwater weighing but not with skinfold measurement [36].

In summary, ultrasonography is a site-specific method and is unable to assess the entire body for composition analysis. Ultrasonography is a promising method for body composition assessment but is operator-dependent and requires training. Additionally, well-defined protocols in terms of optimal sites for assessment of fat and muscle mass, as well as reference or cutoff values for wide clinical application of ultrasonography in body composition assessment, are still lacking. For assessment of fat mass, ultrasonography also lacks method standardization and cutoff values [37–39]. No data exist to support its validity in adult patient populations [25].

(e) Computed tomography

One of the most accurate imaging methods, CT is the gold standard for body composition assessment at a tissue-organ level. The use of CT for body composition assessment in the clinical setting has grown exponentially in recent years due to the high accuracy and precision of the images obtained by this method. Cross-sectional CT imaging allows for the identification of two compartments that are important for body composition assessment, the skeletal muscle and the adipose tissue. This method also allows the identification of subcutaneous, visceral, and intramuscular adipose tissue (Fig. 2) [40, 41].

To produce an image, CT emits ionizing radiation that is attenuated by different body tissues, generating a series of values that are captured, registered, and mathematically processed by computer software, reconstructing the image of a section of the human body [41]. Discrimination between different types of tissues in CT images is possible due to differences in tissue density and radiation attenuation power (Hounsfield units), generating less dense (black) or more dense (white) images [42, 43]. Bone, muscle, adipose, and visceral tissues present different Hounsfield units, allowing their identification in the generated images (Fig. 2). Subsequently, the tissue area (cm^2) is calculated by multiplying the number of pixels of a specific tissue by its surface area [43, 44].

The third lumbar vertebra (L3) has been used as a reference for body composition assessment using CT [44]. In addition to identifying the body compartments mentioned in the paragraphs above, CT also allows the estimation of total body skeletal muscle mass using prediction equations [45, 46], as well as the assessment of lean soft tissue and fat-free mass in patients with cancer [47]. Assessment of muscle attenuation can inform about the presence of myosteatosis (fatty infiltration of the skeletal muscle), which may be considered a marker of muscle "quality" and is associated with worse outcomes in specific clinical situations such as cancer.

As with other methods of body composition assessment, CT has some limitations. The dose of radiation generated during the exam is high and considered unsafe for repeated evaluations. Also, exposing healthy individuals to radiation for the sole purpose of assessing body composition is considered unethical. Depending on the individual's size, the image may be incomplete, and the body compartments may be inaccurately represented. The need for proper software and trained operators pose additional limitations [43].

In view of the above, CT images are most commonly used retrospectively since they are often present in medical records as part of the patients' routine evaluation. Clinical situations in which CT images are available include cancer [48–51], respiratory failure [52], and aortic stenosis; CT is also frequently obtained from trauma patients in intensive care units [53]. However, when strategically planned and depending on the clinical condition studied, prospective studies using CT for body composition assessment can also be conducted. A limitation of retrospective analyses of images obtained from patients' records is that the images often do not include the region of interest (ROI) for body composition assessment (L3). Considering the limited evidence in terms of use of other techniques to estimate body composition and the fact

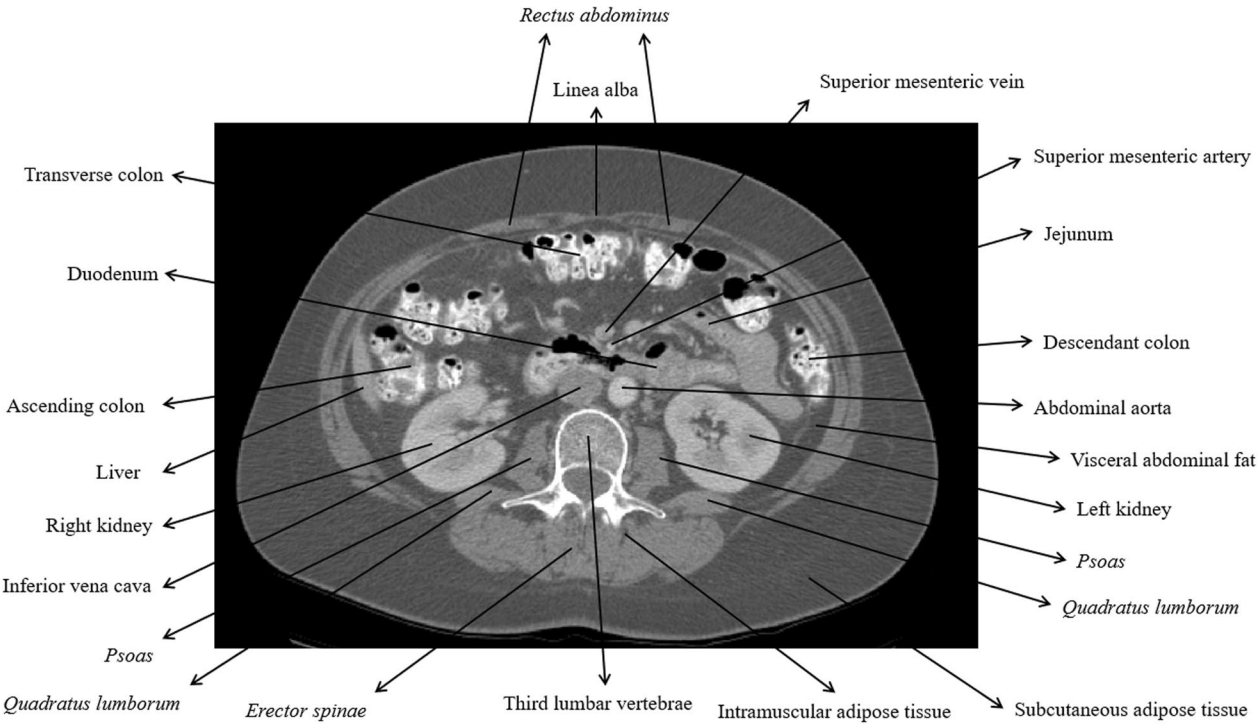


Fig. 2 Tissues and structures located in a computed tomography section at the level of the third lumbar vertebra

that estimates of total body muscle mass based only on L3 may be limited, caution is suggested when the CT measurements are extrapolated to other body areas different than L3 [49].

(f) Magnetic resonance

Considered the most versatile among all techniques for diagnostic imaging, MRI has the superior advantage of not involving ionizing radiation. Like CT, MRI can be used for quantitative measurement of body components. Additionally, MRI can be used for qualitative assessment of lipids [54] in tissues and functional studies, such as the uptake of phosphate by the muscle [55].

The construction of images obtained by MRI is based on the generation of a magnetic field and alignment of hydrogen nuclei. A radiofrequency pulse is emitted from the scanner, and some of the energy generated is absorbed by hydrogen protons in different tissues and released when the pulse is dissipated. The released energy sensitizes the equipment detector, which produces an image of the area of interest, or the area of the body scanned. The recognition of different tissues is based on differences in their physical and chemical properties, especially hydrogen density and relaxation time [54, 56]. Figure 3 shows an abdominal section indicating areas with subcutaneous and visceral adipose tissue.

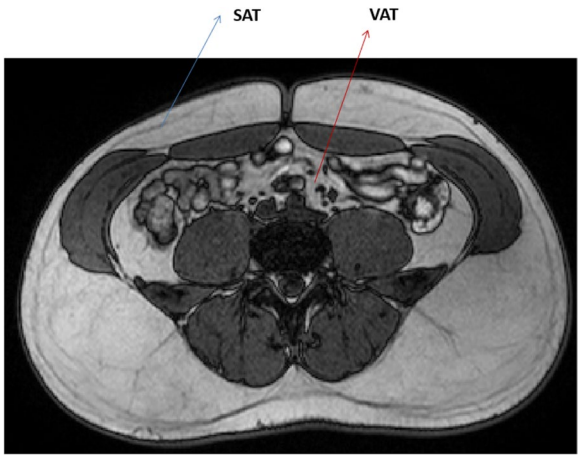


Fig. 3 Distribution of subcutaneous (SAT) and visceral (VAT) adipose tissue in magnetic resonance imaging

Even though MRI is a well-standardized technique for quantitative assessment of body composition in animals, there is limited data validating this technique for body composition assessment in humans [57]. Despite that, MRI has recognized measurement accuracy [58], although it may underestimate, even if slightly, the measurement of body fat [59]. MRI is the gold-standard technique for estimating visceral adipose tissue, which

is considered one of the most important components related to insulin resistance, metabolic syndrome, and cardiovascular diseases [60]. MRI is currently also the gold-standard method for quantification of bone marrow fat and has contributed to substantial advances in the recognition of physiological situations and diseases in which gain or loss variations in bone mass are related to variations in the expansion of bone marrow adiposity [61–63].

The technique of spectroscopy applied to MRI allows for qualitative and functional assessments of both fat and muscle tissue. This technique has been widely used in studies evaluating saturated and unsaturated lipids in the bone marrow. Figure 4 shows the results of an MRI spectroscopy obtained at L3; with this method, it is possible to estimate the fractions of water, as well as those of saturated and unsaturated fat. Recent studies suggest that an increase in saturated lipids in the bone marrow is associated with a higher risk of fracture [64].

This technique also has important limitations, including the high cost of the equipment, requirement for a specialized technician to program the equipment, and need for imaging processing. Another important aspect of the use of MRI for assessment of total body composition is the interference of respiratory movements in the acquisition of the image and the time required to perform the tests.

Statement 1

Available non-DXA methods for assessment of body composition parameters include anthropometric measurements (weight, height, BMI, skinfold thickness, waist circumference, hip circumference, mid-upper arm circumference, calf circumference), air-displacement plethysmography, bioelectrical impedance, ultrasonography, computed tomography, and magnetic resonance imaging.

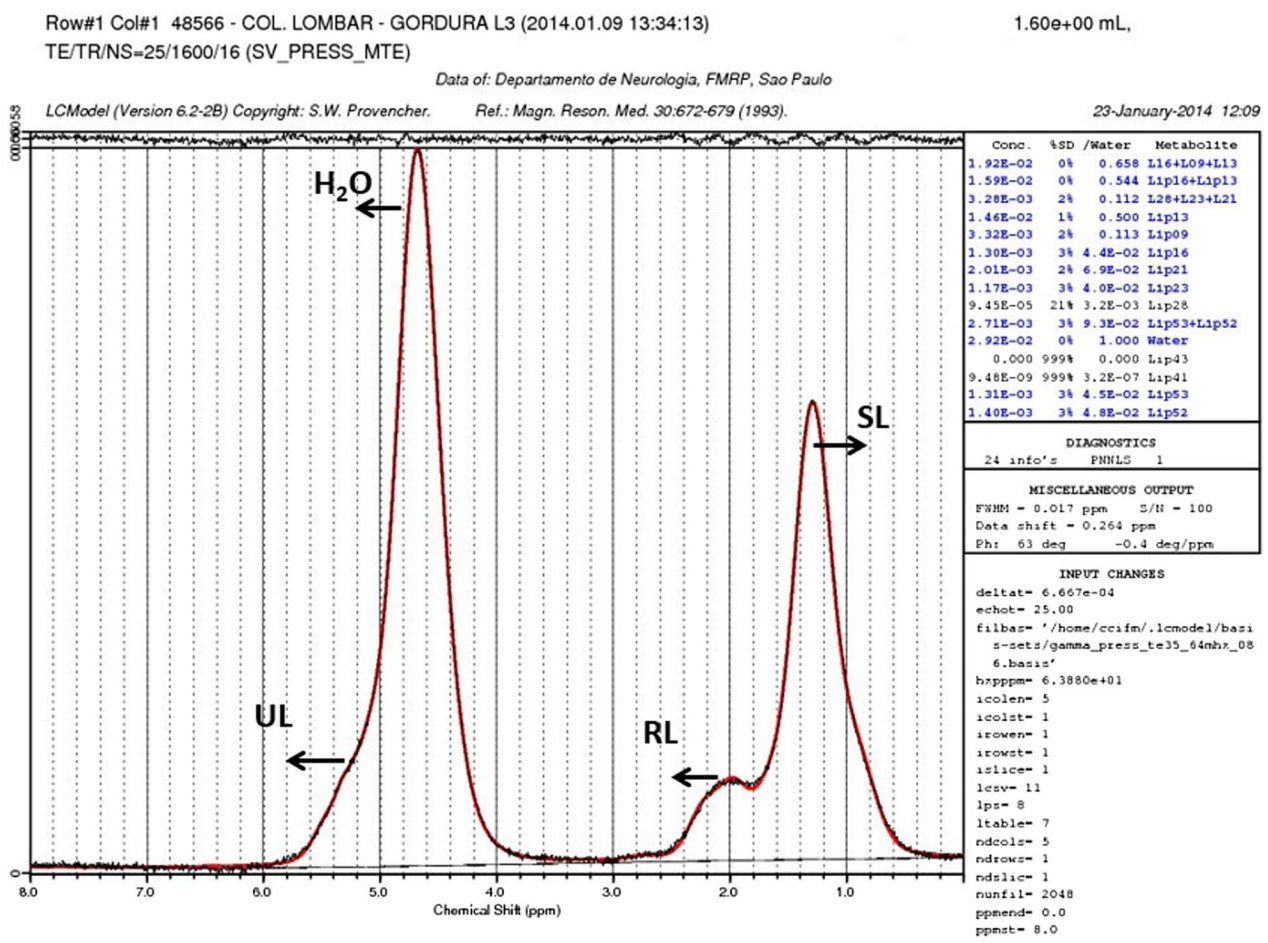


Fig. 4 Magnetic resonance spectroscopy of the third lumbar vertebra (L3)

Section II: general aspects of body composition assessment by densitometry

This section discusses fundamental details of proper DXA scanning, including indications and contraindications, technique, preparation, and imaging acquisition and analysis.

2. What are the indications and contraindications of body composition assessment using densitometry?

Although several recommendations exist, no consensus is available on the absolute indications for body composition assessment by DXA. A consensus in this regard is absent even in the ISCD Official Position [65, 66]. Considering aspects of accuracy, precision, cost, duration, and regional distribution of fat and lean mass, DXA is considered the gold-standard method for body composition assessment [67]. This method is recommended for assessment of fat mass even in patients with different diseases but remains under investigation for assessment of lean mass [25, 65].

(a) Indications

- Obesity: measurement of adipose tissue (fat mass index and/or percent fat mass) with DXA may be useful for stratification of risk of cardiometabolic outcomes. However, specific thresholds defining obesity according to age and ethnicity based on DXA results have not yet been established. Measurement of lean and fat mass [68–70] can also be useful in assessing the patient's cardiovascular risk and motivation to lose weight. This topic will be further discussed in the section on measurement of adiposity.
- Weight loss and athletes receiving dietary protein supplementation: patients on diet and exercise programs or following a pharmacological, supplemental, or surgical (bariatric) strategy can be assessed with DXA for more accurate measurement of each compartment (fat, lean, or bone mass). However, the weight limitations of individual equipment must be considered [71–73].
- Sarcopenia: body composition can be assessed with DXA in patients with certain risks, such as decreased muscle strength and function, decreased mobility, recurrent falls, unintentional weight loss, malnutrition, prolonged hospitalization, depression, immobilization, chronic wasting syndromes (chronic heart failure, chronic obstructive pulmonary disease, renal failure, rheumatoid arthritis, and cancer) in association with the evaluation of functional and physiological aging-related parameters [26, 65].
- People with acquired immunodeficiency virus (HIV) using antiretroviral agents associated with a risk of lipodystrophy (stavudine, zidovudine, and protease and integrase inhibitors): for assessment of fat distribution [74–76].

(b) Contraindications for DXA scanning [65]

- Pregnancy: DXA scanning is not recommended during pregnancy. Even though the radiation exposure is low during the procedure, the risk of exposure to the fetus is unknown.
- Technical limitations of DXA for total body composition assessment: these limitations include the patient's weight above the limit allowed for the equipment or inability to remain still throughout the examination, recent administration of contrast material, and image artifacts (Sections 4d and 6d of the present document discuss the topic of image artifacts in more details).

(c) Potential clinical use of DXA for body composition assessment

Most clinical studies assessing body composition with DXA have included a small number of patients and lack validation of outcomes or cost-effectiveness analysis. In contrast, DXA has been shown to be useful for body composition assessment in the following circumstances:

- Internal medicine: stratification of cardiovascular risk [77].
- Sports medicine: physical training, injury rehabilitation, nutrition [78].
- Endocrinology: growth hormone deficiency, thyroid disorders, hypogonadism, estrogen/androgen therapy, glucocorticoid therapy [79].
- Gastroenterology: malabsorption syndromes, eating disorders [80, 81].
- Pharmacology: measurement of lean mass for drug dose calculation [82].

Statement 2

Considering aspects of accuracy, precision, cost, duration, and regional distribution of fat and lean mass, DXA is considered the gold-standard method for body composition assessment. This method is recommended for assessment of fat mass even in patients with different diseases but remains under investigation for assessment of lean mass.

The clinical indications for body composition measurements using DXA are several, but the main ones are obesity, weight loss, dietary protein supplementation in athletes, sarcopenia, use of antiretroviral agents associated with risk of lipodystrophy in individuals with acquired immunodeficiency virus (HIV) infection, stratification of cardiovascular risk, physical training, injury rehabilitation, nutritional disturbances, growth hormone deficiency, thyroid disorders, hypogonadism, estrogen/androgen therapy, glucocorticoid therapy, malabsorption syndromes, eating disorders, and measurement of lean mass for drug dose calculation.

Contraindications for DXA scanning include pregnancy, patient's weight or height above the limit allowed for the equipment or inability to remain still throughout the examination, recent administration of contrast material, and image artifacts.

3. What are the technical principles of DXA for body composition assessment?

Created in the 1980s, DXA was first approved in clinical practice for assessment of fracture risk (1988) and is currently one of the main tools for the detection of osteoporosis through analysis of lumbar spine, femur, and forearm bone mineral density [83]. Over the last decades, the use of DXA has expanded to include accurate and precise total body assessment and body composition analysis based on the three-compartment model—lean mass, fat (or body fat) mass, and bone mass [67, 84]—and to become the reference method for in vivo evaluation of body composition in clinical practice [85, 86].

Total body DXA acquisition is relatively fast (5 to 20 min on average), depending on the equipment and body proportions of the individual, and has a good cost–benefit ratio. The radiation emitted during body composition assessment varies by equipment from 0.15 to 4.7 µSv. These radiation levels are lower than those emitted during plain chest radiograph (32 µSv) (Tables 2 and 3) [87].

Table 2 Effective radiation dose (µSv) in whole-body DXA exams in Hologic Discovery W, Discovery A, and GE-Lunar Prodigy devices [96, 97]

Age	Discovery A	Discovery W	GE-Lunar Prodigy
Neonate	8.9	–	0.25
1 year	7.5	–	0.22
5 years	5.2	10.5	0.19
10 years	4.8	9.6	0.15
15 years	4.2	8.4	–
Adults	4.2	8.4	–

Table 3 Effective radiation doses (µSv) from ambient exposure, DXA scanning, and radiographic tests [96, 98]

Exam	Dose
Lunar iDXA (standard model)	4.7 µSv*
Natural background radiation	0.3–1.4 µSv per day (1–5 mSv per year) **
Intraoral dental radiograph	5 µSv *
Abdominal X-rays	20–190 µSv*
Chest X-rays (posteroanterior and lateral)	32–60 µSv*
Lateral X-rays of the thoracic or lumbar spine	300 µSv*
Mammography	400 µSv*

*Radiation level depending on the technique used and the exposed area.
**Radiation level according to the altitude and type of soil, among other factors

The equipment for DXA scanning consists of a computer system, an exam table, detectors, and a tube that emits X-rays at two different intensities, high (above 70 keV) and low (39–50 keV) (Fig. 5). X-rays consist of photon particles carried by electromagnetic energy that undergo greater or lesser attenuation in intensity depending on the density of the tissues that they cross, either soft tissues (fat and fat-free mass) or bone. The attenuation coefficient of the difference between the two energy levels estimates the bone mineral content, while the ratio between the attenuation of high and low energy levels (R value) estimates the composition of soft tissues (muscle, fat, skin, and water) [88, 89].

Soft tissues have low density and allow more passage of photons (reduced attenuation), while tissues with high density (e.g., bone) allow less passage of photons (greater attenuation). To estimate the amount of fat and fat-free mass, DXA measures the difference in attenuation levels between the two photon energy beams in boneless areas of the body, usually the tissue adjacent to the bone. In this case, the ratio (R value) of the attenuation of the two energy beams is linearly related to the proportion of fat in the soft tissue. It is only after the attenuation of the X-ray beams has been analyzed in areas with soft tissue and bone, as well as areas with soft tissue alone, that the remaining analyses of fat mass, lean mass, and bone mineral mass can be performed. Of note, the evaluation of each compartment is done through an interaction between the two X-ray beams and the atomic number (Z) of each tissue. The greater the atomic number, the greater the R value. Thus, fat, which is richer in hydrogen ($Z=1$) and carbon ($Z=6$) atoms, has a lower R value than lean mass, which consists of nitrogen atoms ($Z=7$), and the skeleton, which is predominantly rich in mineralized tissue, including magnesium atoms ($Z=12$), phosphorus

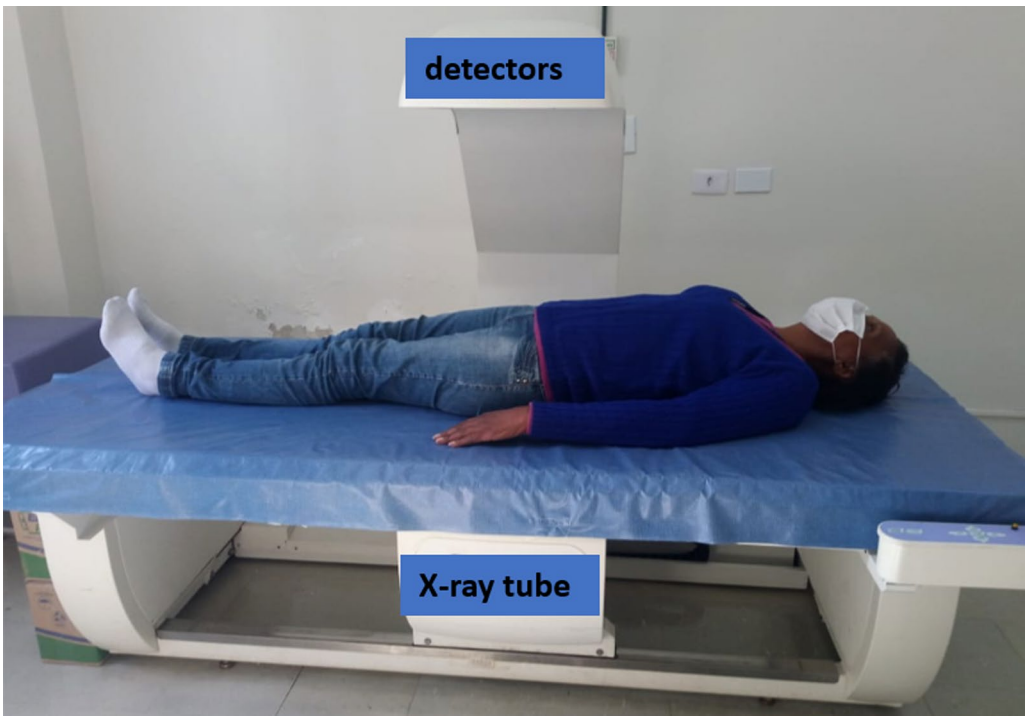


Fig. 5 Fundamental principles of dual-energy X-ray absorptiometry (DXA): the X-ray source located at the base of the equipment emits high and low energy X-ray beams that are captured by the detectors for assessment of interaction and differences between the three compartments evaluated by DXA

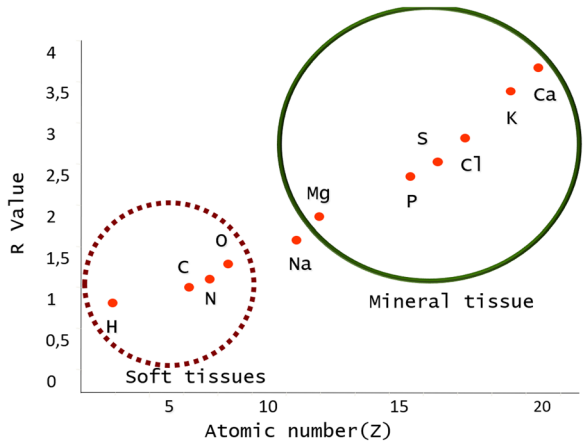


Fig. 6 R value according to the atomic number (Z) of soft and mineralized tissues

Table 4 R value according to the interaction between low and high energy X-ray beams and the atomic number (Z) and mass (A) of each tissue element

Element	Z	A	40 keV	70 keV	R value
H	1	1.008	0.3458	0.3175	1.0891
C	6	12	0.2047	0.1678	1.2199
N	7	14	0.2246	0.1722	1.3043
O	8	16	0.2533	0.1788	1.4167
Na	11	23	0.3851	0.2022	1.9045
Mg	12	24.3	0.4704	0.2244	2.0963
P	15	31	0.7784	0.2839	2.7418
S	16	32.1	0.9507	0.3258	2.9180
Cl	17	35.5	1.100	0.3491	3.1510
K	19	39.1	1.484	0.4297	3.4536
Ca	20	40.1	1.792	0.5059	3.5422

(Z = 15), and calcium (Z = 20) (Fig. 6, Tables 4 and 5) [88, 89].

The percentage of fat estimated by DXA correlates highly (r = 0.98) with the elemental composition measured by in vivo neutron activation whole-body analysis [90].

Limitations in DXA use are related to the technical characteristics of the method itself, including the consideration that bone and adjacent tissues have a fixed and similar amount of fat [65]. Thus, the precision of soft tissue measurement may differ in areas of interest with bone (arms, legs, and chest) compared with those without bone, since only a few pixels are available

Table 5 R value according to the composition of each body tissue

Component	40 keV	70 keV	R value
Fatty acids	0.22–0.23	~0.18	1.20–1.22
Triglycerides	~0.22	~0.18	~1.21
Protein	0.2363	0.1831	1.2906
Glycogen	0.2375	0.1825	1.3010
Water	0.2636	0.1942	1.3572
Extracellular fluid	0.2673	0.1946	1.3736
Intracellular fluid	0.2107	0.1955	1.3862
Soft tissue minerals	0.7685	0.2824	2.7213
Bone mineral	0.9039	0.3159	2.8617
Calcium hydroxyapatite	0.9632	0.3283	2.9339

in the latter for a direct calculation of fat and lean mass. Another problem is that increased thickness in areas of interest (e.g., excessive adiposity, ascites) decreases the ratio of the attenuation of high and low energy photons, a phenomenon known as beam hardening [91]. Errors due to beam hardening occur in the presence of preferential attenuation of low-energy X-rays (e.g., increased tissue thickness) diverting the spectral distribution to higher-energy photons, resulting in an apparent higher fat content. The DXA software assumes that calibration phantoms are able to correct the beam hardening phenomenon. However, in obese people, the correction of beam hardening by calibration phantoms can underestimate the fat mass. Finally, the software assumes that lean mass has fixed hydration (73% on average) and electrolyte content. Although lean mass hydration may vary (67–85%) in some situations, the total fat percentage remains unchanged. In cases with substantially increased hydration (e.g., patients with ascites or edema), the ratio of attenuation of high and low energy X-rays is compromised, affecting the resulting percentage of fat [87–89, 92–94].

Statement 3

Total body DXA acquisition is relatively fast and takes on average 5–20 min depending on the equipment and the individual's body proportions. The radiation emitted during body composition assessment varies by equipment from 0.15 to 4.7 μSv.

The equipment for DXA scanning consists of a computer system, an exam table, detectors, and a tube that emits X-rays at two different intensities (high = above 70 keV; low = 39–50 keV). The attenuation coefficient of the difference between the two dual-energy levels (R value) estimates the bone mineral content based on the atomic level of each compartment of the body (mineral, soft tissue, and water).

Section III: recommendations for acquisition and analysis

4. Which precautions should be taken before DXA scanning?

(a) X-ray protection

The Brazilian Health Surveillance Secretariat regulates and establishes the basic requirements for radiological protection in radiodiagnosis. These requirements are set to protect the health of patients, professionals involved in the examinations, and members of the public, and are based on radioprotection standards set by the Institute of Radioprotection and Dosimetry of the National Commission of Nuclear Energy (CNEN), which follow the International Atomic Energy Agency (IAEA) guidelines. The standards are based on three basic points: duration (of exposure), distance (from the source), and shielding (protection barriers), governed by the As Low As Reasonably Achievable (ALARA) principle, i.e., the radiation exposure should be as low as reasonably possible [95].

- Radiation doses in DXA scanning and the patient

The radiation exposure in DXA scanning depends on the equipment (model and technology), acquisition technique, and patient's characteristics such as age and body thickness (Table 2) [96–98].

With DXA scanning, the effective radiation dose to the patient is small compared with the maximum annual radiation dose allowed for members of the public (1 mSv for the entire body, excluding exposures for medical and dental reasons) [95]. This level of exposure may be comparable to or lower than the level of radiation obtained in 1 week of exposure to natural radiation (Table 3).

In women of reproductive age about to undergo DXA scanning, pregnancy should be ruled out. If pregnancy is confirmed, the exam should be suspended despite emitting low radiation, since DXA scanning is not an emergency procedure and can wait until after delivery and breastfeeding.

Precautions for reducing the radiation dose for the patient and members of the public should include adequate training of the team and use of appropriate technique to reduce patient repositioning and repeat acquisition due to invalidated segments. The presence of a person accompanying the patient in the examination room should be avoided, but if necessary and required close to the examination table, the person should wear a protective apron.

- Radiation dose for professionals involved in DXA scanning (physicians and technicians)

Generally, the chance of deterministic effects (below a threshold in which detectable clinical effects do not occur) is small, except for interventional procedures. Adherence to the ALARA guiding principle of radiation safety must be followed, reducing the occurrence of stochastic effects for patients and technicians, which may occur even at low radiation doses (stochastic effects occur by chance, generally without a maximum dose level, and are proportional to the dose, but the gravity of the effect is independent of the dose received). Thus, identification, evaluation, analysis, and implementation of measures to reduce the time of direct exposure and increase the distance between the radiation source and the operator are recommended. Of note, radiation protection is not necessary for professionals involved in DXA scanning, even during whole-body scanning [92–95].

Scattered radiation in DXA is small and difficult to detect. For distances greater than 1 m from the equipment table, the radiation dose is usually insignificant (regardless of ambient background radiation). Radiation doses for professionals involved in DXA scanning are small compared to the maximum allowable occupational exposure dose: 50 mSv/year (50,000 Sv/year) for total body, not to exceed 20 mSv in 5 consecutive years [95]. Patel et al. found an annual dose well below the recommended limit for members of the public when measured 1 m from the exam table (less than 1 μSv/hour for the Lunar DPX and Hologic QDR-1000 equipment) (Table 6) [99]. In contrast, the results for the fan-beam equipment Hologic QDR-2000 plus and QDR-4500 were close to the limit of 5 mSv/year for the supervised area. In workstations located approximately 2 m from the patient, Waddington & Marsden estimated the annualized radiation dose that an operator would likely receive over 1 year and concluded that it was consistent with a total body annual dose < 1 mSv for the Hologic QDR-4500 device [100].

(b) Examination room: medical scale, stadiometer, temperature, and humidity

In terms of the test environment, the document Volume 3—Support for Diagnosis and Therapy of the Architectural Planning of Functional Health Care Systems of the Ministry of Health [101] provides information regarding the minimum and average size of the room, minimum floor-to-ceiling height, flooring and ceiling surfaces, door size and surface, and ambient and infrastructure conditions. The patients' weight and height must be measured before the exam and added to the DXA software. These data are important, considering that the selection of the radiation beam for the exam depends on the patient's abdominal thickness. If the correct weight is not recorded, the system may select an inappropriate beam for the patient, affecting the result of the exam. In this case, the patient must return for new image acquisition with the appropriate beam. Weight and height should be measured using a medical scale. In children and adolescents, height should be measured preferably with a stadiometer. The room temperature is recommended to be maintained between 21 and 24 °C and the humidity between 20 and 60% [101].

Table 6 Ambient dose equivalent averaged over 1 h at 1 m from the patient, using DXA systems at maximum patient throughput [99]

Device	Dose (μSv/h)
Lunar DPX	0.012
Hologic QDR-1000	0.12
Hologic QDR-2000 Plus	2.1
Hologic QDR-4500	2.4

(c) Clothing and preparation

Body composition is influenced by hydration and gastrointestinal content. Standardized measurement conditions—time of day, premeasured food intake, and physical activity level—must be implemented during DXA evaluation to minimize result variability [102]. Overnight fasting offers the best condition for reproducible DXA scanning results. Heavy fluid intake and large meals should be avoided before the exam.

External artifacts and metal garments should be avoided as they may interfere in different ways with body composition analysis by DXA. However, consistent information regarding the real burden of external artifacts is lacking. It is plausible to consider that some types of dense or synthetic textiles (e.g., shiny polyester, wool, and blend denim) and fabrics with varying thickness may absorb radiation and, thereby, affect DXA measurements of bone and soft tissue mass [103]. Therefore, we recommend that patients wear light clothes (e.g., sports clothing) or a gown provided by the densitometry service during DXA scanning. Clothes with dense metal or plastic should be avoided, and accessories (e.g., earrings, rings, watch, bracelets, etc.) should be removed. Patients with large breasts projecting over the upper limbs (e.g., those with obesity or gigantomastia) may use a breast adjustment band without a zipper or metal. Bladder emptying is also recommended.

(d) Artifacts

Potential sources of artifacts should be removed whenever possible. Patients who recently received oral barium contrast, which interferes with DXA results, should be asked to postpone the scanning until 1 week after the use of the contrast. Additional time may be required for

complete intestinal cleaning in patients with constipation. Iodinated contrasts used for CT scanning and radioisotopes also interfere with DXA results and require a 1-week delay before scanning [65, 104, 105]. Of note, the use of gadolinium does not cause relevant interference on body composition assessment by DXA [67, 106].

In patients with external artifacts that cannot be removed (e.g., cardiac pacemaker and vascular, orthopedic, mammary, or gluteal prostheses), consistent positioning and analysis are important for longitudinal reproducibility. Motion artifacts are usually prevented by ensuring that the subject is comfortably positioned, receives clear instructions, and is reminded not to talk or move and to lay still and breathe normally. If motion artifacts are detected during the acquisition, the scan should be stopped and restarted [102].

(e) Weight and height limitations for each manufacturer and model

The maximum weight and height values vary by manufacturer and system model, as shown in Table 7 [107].

Statement 4

The principles of X-ray protection are based on the duration of exposure, distance from the source, and shielding (protection barriers), according to the ALARA principle. The DXA examination involves a low effective radiation dose (1 mSv for the entire body); therefore, radiation protection is not necessary for professionals involved in whole-body DXA scanning. However, identification, evaluation, analysis, and implementation of measures to reduce the time of direct exposure and increase the distance between the radiation source and the operator are recommended.

Table 7 Maximum patient weight and table height and depth for different models of DXA systems (adapted from Reference [107])

Model	Patient weight (kg)	Table length (cm)	Table depth (cm)
Lunar iDXA	205.0	197.5	66.0
Lunar Prodigy	159.0	197.5	60.0
Lunar DPX-NT	136.0	195.0	57.6
Hologic Discovery A	205.0	195.6	67.0
Hologic Discovery W/Wi	205.0	195.6	65.0
Hologic QDR 4500 A	136.0	195.6	67.0
Hologic QDR 4500 W/Wi	136.0	195.6	65.0
Norland XR	114.0	193.0	64.0
Norland Elite	283.5	228.0	137.0

Weight and height should be measured using a medical scale.

The room temperature is recommended to be maintained between 21 and 24 °C and the humidity between 20 and 60%.

Overnight fasting offers the best condition for reproducible DXA scanning results. Heavy fluid intake and large meals should be avoided before the exam.

During DXA scanning, the patient must wear light clothes (e.g., sports clothing) or a gown provided by the densitometry service. Clothing with dense metal or plastic should be avoided, and accessories (e.g., earrings, rings, watch, bracelets, etc.) should be removed.

Patients with large breasts projecting over the upper limbs (e.g., those with obesity or gigantomastia) may use a breast adjustment band without a zipper or metal. Bladder emptying is also recommended. Potential artifacts should be removed whenever possible.

Patients who recently received oral barium contrast, which interferes with DXA results, should be asked to postpone the scanning until 1 week after the use of the contrast. Additional time may be required for complete intestinal cleaning in patients with constipation. Iodinated contrasts used for CT scanning and radioisotopes also interfere with DXA results and require a 1-week delay before scanning.

In patients with external non-removable artifacts (e.g., cardiac pacemaker and vascular, orthopedic, mammary, or gluteal prostheses), consistent positioning and analysis are important for longitudinal reproducibility.

Motion artifacts should be avoided, and when present, the scanning should be performed again.

5. How is the image acquisition protocol?

The patient should be positioned on the DXA scanning table preferably following the method used in the NHANES study. The patient's body should be centered on the table, with the center table line used as a reference for aligning the patient. The patient's hand palms should face down and be placed at least 1 cm from the body; if this is not possible, the hands can be placed sideways. The feet must be kept in a neutral position, the upper limbs in a straight or slight angle, the chin upwards in a neutral position, and the head close to the upper limit of the examination table, without exceeding it [102, 108, 109]. Consistency in hand placement at each center is essential for longitudinal monitoring since changes in hand placement could result in changes in tissue measurement. For example, when the hands change from a prone to a midprone position, total body DXA scans are not comparable in terms of total bone mineral density, Z-scores, arm regional fat mass, or precision error [109].

The manufacturer Hologic recommends that both legs are kept apart and in internal rotation throughout the entire exam (Fig. 7). In contrast, the legs must be kept together with the use of a Velcro strap to reduce movement in GE-Lunar DXA systems, following the NHANES study recommendation (Fig. 8) [110]. Radiolucent pillows or wedges for head or knee support may be used by patients unable to lay flat. However, the elevation of the head or limbs may cause magnification errors because most DXA systems assume the body to be lying flat without positioning aids [102, 110].

For systems with software that estimates visceral fat, it is important to remember that for visceral adipose tissue measurement, the patient's hands should not touch the legs, and a small gap (at least 3 cm) should separate the arms and the trunk. The patient's arms should be within the lines of the scanning area on the table pad [111, 112].

If the patient's body is wider than the dimensions of the acquisition area, the upper left limb may be removed from the acquisition area, and the mirror image (GE-Lunar) or reflex mode (Hologic) may be activated in the software ("offset scanning," i.e., the patient's midsagittal line is offset from the table midline to allow complete scanning of both the right limbs and trunk). The software copies the results of the completely scanned side and replaces the incompletely visualized limb values as needed. A compilation of three studies in GE-Lunar and Norland systems has shown that this procedure does not add any major errors to the evaluated parameters [102].

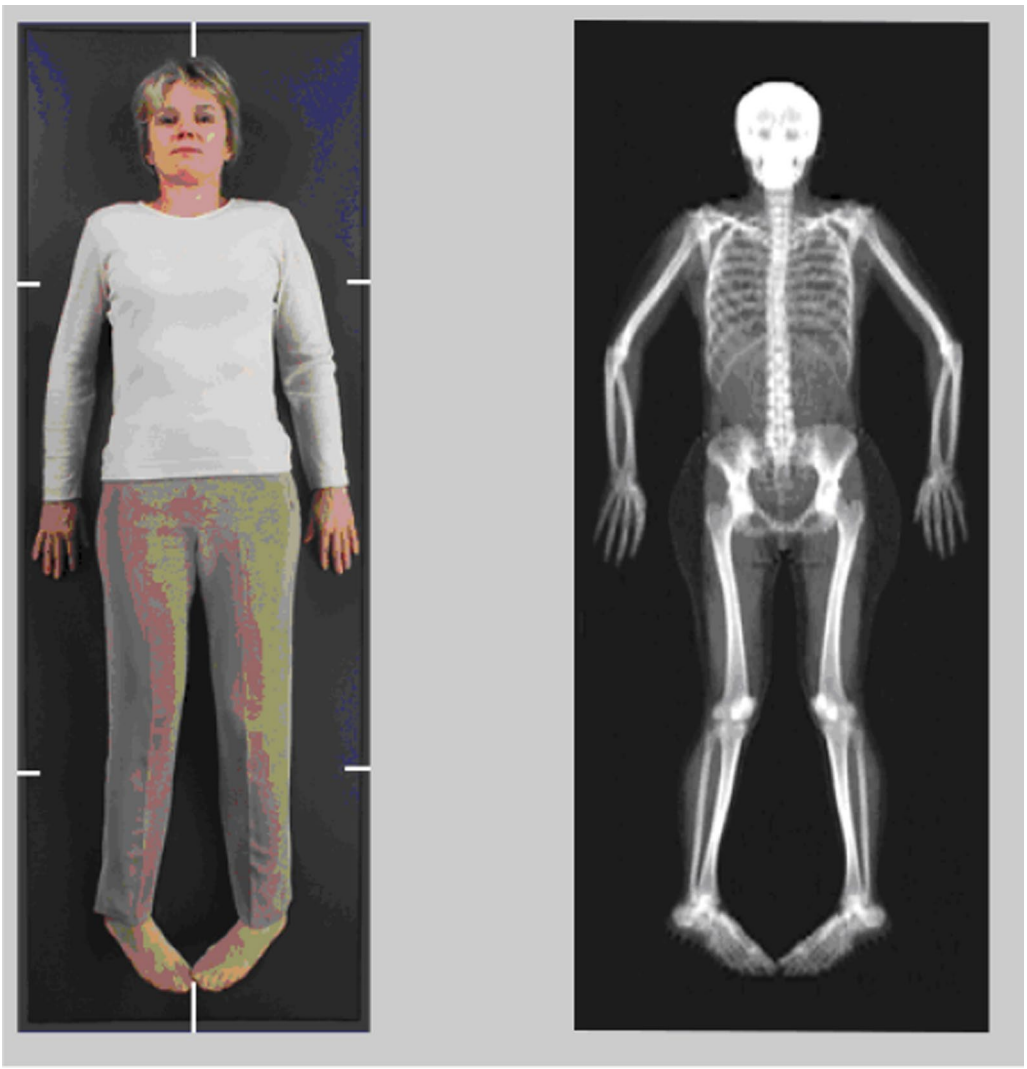


Fig. 7 Correct patient alignment according to the manufacturer of Hologic systems

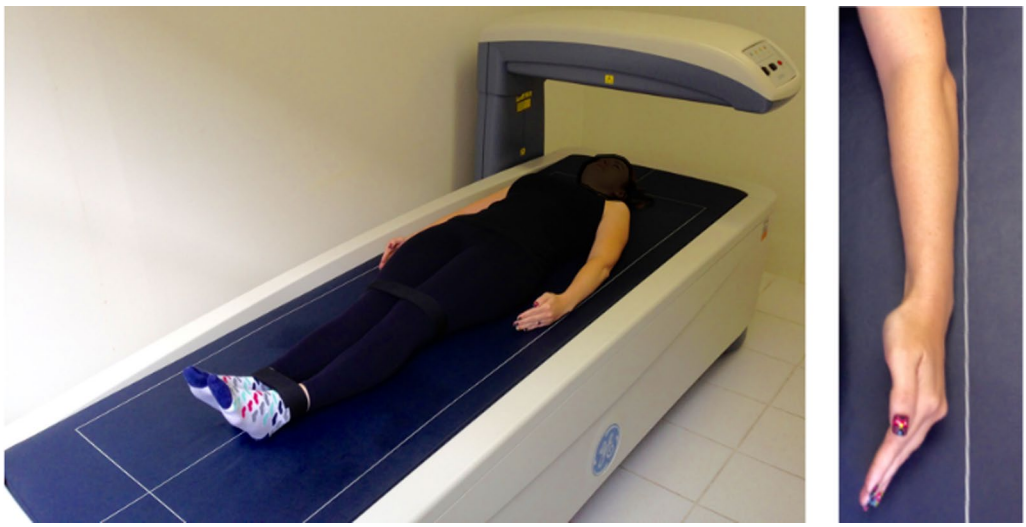


Fig. 8 Correct patient alignment according to the manufacturer of GE-Lunar systems

A recent systematic review of seven studies evaluating DXA acquisition in individuals taller than the scan area concluded that the sum of two DXA scans and the adoption of a knee-bent position are valid alternatives to evaluate individuals using pencil-beam and fan-beam Hologic systems, although this conclusion needs further investigation [113]. According to the ISCD, either the patient's head or feet can be excluded in tall individuals, and omitting part of the head is better for appendicular results, which are important in measurements of lean mass index (as discussed in Section II of this Official Position) [114].

In scanning patients with flaccid or bulky breasts, the breast tissue resting on the arms generates an artifact, as mentioned above. This occurs due to the overlapping of fat and glandular breast tissue resting on the lateral portion of the trunk during image acquisition. This artifact leads to an error in the segmental results, increasing the fat mass of the arms. In these cases, a strap made with radiolucent material and Velcro at the ends can be used to support the breasts. The band must be positioned on the chest area with the individual standing, making sure that the breast tissue remains over the chest area and does not rest on the arms during the examination. The Velcro must be firmly attached, and the standard position described above must be followed.

Statement 5

The patient should be positioned with the body centered on the DXA scanning table, with the center table line used as a reference for aligning the patient. The patient's hand palms should face down and be placed at least 1 cm from the body; if this is not possible, the hands can be placed sideways. The feet must be kept in a neutral position, the upper limbs in a straight or slight angle, the chin upwards in a neutral position, and the head close to the upper limit of the examination table, without exceeding it. Consistency in hand placement at each center is essential for longitudinal monitoring since changes in hand placement could result in changes in tissue measurement.

The manufacturer Hologic recommends that both legs are kept apart and in internal rotation throughout the entire exam. In contrast, the legs must be kept together with the use of a Velcro strap to reduce movement in GE-Lunar DXA systems.

6. How is the analysis protocol?

Consistent patient positioning and analysis are the most important factors to minimize measurement errors. Despite slight differences between manufacturers regarding DXA analysis software in terms of movement and segmentation of subregions in ROI markers, the recommendations for the positioning of subregion ROIs are comparable between manufacturers. Consistency in ROI placement is what matters most [102].

When the image is ready and the analysis tool is running, the system performs automatic ROI adjustment. Whenever the lines dividing the segments are not correctly aligned, as shown in Fig. 9, they must be readjusted to avoid interfering with the final result [115].

According to the manufacturers, the ROI lines must be positioned as follows (Fig. 9) [110]:

1. Head: immediately below the chin.

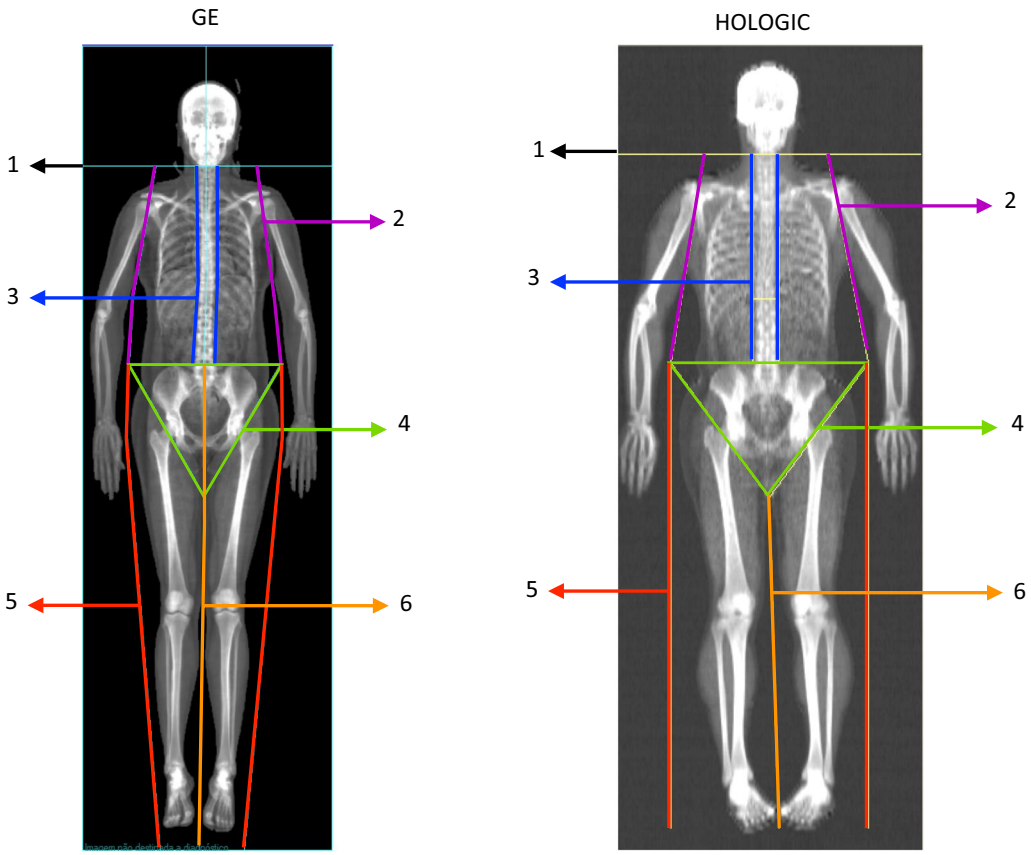


Fig. 9 Analysis and positioning of ROI lines according to manufacturers

2. Arms: in both glenoid joints, verifying that the lines are separating the arms and hands from the rest of the body, passing through the glenoid.
3. Spine: adjusted as close as possible to the vertebrae.
4. Pelvis: the upper line must touch the iliac crests, and both oblique lines must pass through the femoral necks without contact with the ischium.
5. Legs: hands and forearms must be separated from the legs.
6. Between-legs: should follow the division between the legs.

- Analyses of special cases

(a) Obese/estimated values

When part of the patient's left side is not acquired in the scan, adequate acquisition of the right hemibody is recommended. When generating the results, the system will include the symbol (e) or a reference (... [1]) next to the segment that was left out from the image in the GE-Lunar and Hologic devices, respectively, and copy the segment from the corresponding contralateral member (Fig. 10).

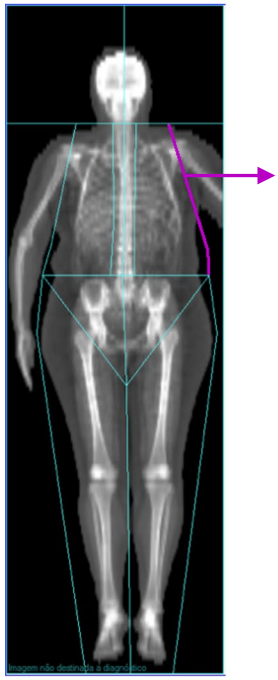
(b) Amputees

In patients with incomplete amputation, the system describes the results from both sides. However, if the amputation is complete, the system may read that as an "offset" acquisition and automatically mirror the results. In this case, "offset scanning" must be deactivated for accurate results [116].

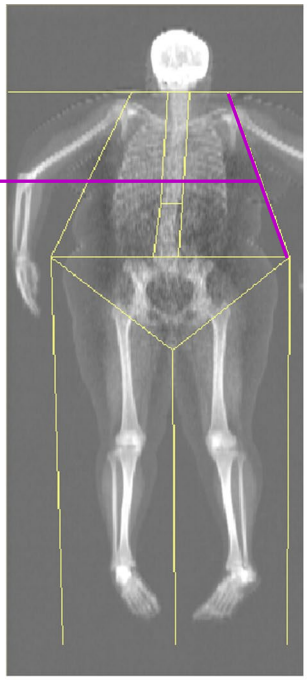
In cases of amputees and other circumstances, including those of patients with sequelae from stroke or with other neuromuscular disorders, the results must be interpreted with caution, considering the differences between the hemibodies and the mass of the affected appendicular compartments, which also directly interferes with the indexes that use the lean appendicular mass, total fat mass, and total body mass.

(c) Diseases with water retention:

Diseases with water retention overestimate lean mass and affect the measurement of body composition by DXA [117, 118]. In this situation, the DXA report should



The entire area on the right side of the line (left arm) will not be considered, and the software will copy the values of the right segment.



GE

	Região	Mass Total (kg)	Tecido (g)	Gordo (g)	Magro (g)
(e)	Braços	9,6	9.291	4.671	4.620
	Braço direito	4,8	4.646	2.335	2.310
(e)	Braço esquerdo	4,8	4.646	2.335	2.310
	Pernas	34,6	33.626	16.655	16.971
	Perna direita	17,2	16.763	8.269	8.494
	Perna esquerda	17,4	16.863	8.386	8.477
	Tronco	46,5	45.649	22.773	22.876
	Lado direito do tronco	22,5	22.122	10.838	11.284
	Lado esquerdo do tronco	24,0	23.527	11.935	11.592
	Andróide	6,9	6.864	3.602	3.262
	Ginóide	15,0	14.715	7.799	6.917
(e)	Total	95,2	92.506	45.040	47.466

HOLOGIC

Body Composition Results

Region	Fat Mass (g)	Lean + BMC (g)	Total Mass (g)
L Arm	4384	2605	6988
R Arm	4384	2605	6988
Trunk	35652	32465	68117
L Leg	9091	8074	17166
R Leg	9004	8426	17430
Subtotal	62514	54175	116688
Head	1118	3411	4528
Total	**63632**	**57585**	**121217**
Android (A)	6695	5919	12614
Gynoid (G)	9101	9922	19022

Fig. 10 Offset scanning in the GE-Lunar and Hologic systems

mention that water retention could affect the accuracy of the measurement.

(d) Artifacts

According to the current literature, software neutralization tools should not be used to counteract potential non-removable external artifacts. First, evidence has not shown relevant interference of non-removable external artifacts on whole-body composition analysis at baseline or in longitudinal measurements. Second, considering the importance of the appendicular lean mass in the final report, neutralization tools can affect the precision, reproducibility, and accuracy of this parameter. Still, all non-removable artifacts should be reported to the patient and the physician. Based on these considerations, we recommend against the use of software tools to neutralize external artifacts (e.g., cardiac pacemaker and vascular, orthopedic, mammary, or gluteal prostheses) during whole-body composition analysis by DXA [119].

Statement 6

Consistent patient positioning and analysis are the most important factors to minimize measurement errors. Despite slight differences between manufacturers regarding DXA analysis software in terms of movement and segmentation of subregions in ROI markers, the recommendations for the positioning of subregion ROIs are comparable between manufacturers.

The ROI lines must be positioned as follows:

1. Head: immediately below the chin.

2. Arms: in both glenoid joints, verifying that the lines are separating the arms and hands from the rest of the body, passing through the glenoid.
3. Spine: adjusted as close as possible to the vertebrae.
4. Pelvis: the upper line must touch the iliac crests, and both oblique lines must pass through the femoral necks without contact with the ischium.
5. Legs: hands and forearms must be separated from the legs.
6. Between-legs: should follow the division between the legs.

Finally, the clinical utility of DXA for body composition assessment is highly dependent on the quality of the scan acquisition, analysis, and interpretation. Unfortunately, errors are common in clinical practice and are potentially harmful to the patient, while poor-quality DXA scans and reports may impact the patient's diagnosis and treatment. Best practices in DXA require an understanding of potential sources of errors, including instrument calibration, recognition of confounding artifacts, and issues related to positioning or analysis [120].

Conclusions

In conclusion, DXA is a three-compartment molecular model that includes fat, lean soft tissue (water, protein, glycogen, and soft tissue minerals), and bone mineral content. Considering aspects of accuracy, precision, cost, duration, and regional distribution, DXA is considered an excellent method for evaluation of body composition when compared with other methods such as plethysmography, bioelectrical impedance, and ultrasonography, especially in the evaluation of fat mass. Assessment of body composition by DXA can be useful in patients with obesity or hormonal, nutritional, or neuromuscular disorders, as well as in sports medicine, with little exposure of the patient to radiation. For reliable, adequate, and reproducible reports, great attention is required to aspects related to quality control procedures, preparation, removal of external artifacts, acquisition, analysis, and data interpretation.

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BSEP, LAM, HKMA, HPA, MCG and CMMdP, CLP, IMdA, FJAdP, JLCB, B-HA, MU, GCdS, LMCdM and MdP contributed with each of the items. MCG and CMMdP contributed with a critical analysis. SSM, MdMP were the concievers of the manuscript and made a final revision. All authors read and approved the final manuscript.

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