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A 360-degree overview of body composition in healthy people: Relationships among anthropometry, ultrasonography, and dual-energy x-ray absorptiometry

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Objective: The aim of this study was to test the relationship between anthropometry, ultrasonography, and dual-energy x-ray absorptiometry (DXA) for the assessment of body composition in clinical practice.
Methods: The study was carried out in Italian blood donor volunteers belonging to five different age groups (18–70 y old; 25 men and 25 women per group; N = 250 participants; n = 125 men, n = 125 women). A complete history was collected and routine blood analyses were performed to confirm healthy status. All participants were submitted to whole-body DXA (tricompartmental analysis, regional, and total body), ultrasonography (abdominal adiposity evaluation), and anthropometric measurements. DXA was used as gold standard and its biomarkers were taken as reference for fat–lean mass balance, central–peripheral fat distribution, central or visceral fat, and subcutaneous fat.
Results: Anthropometric and ultrasound parameters were closely associated with most of DXA parameters. Composite markers representative of central and abdominal visceral fat compartments were significantly correlated with waist circumference, waist-to-hip ratio, and intra-abdominal fat thickness by ultrasound, in both men and women ($P < 0.025$). As expected, subcutaneous depots were significantly correlated with maximum subcutaneous fat thickness measured by ultrasonography ($P < 0.025$).
Conclusions: Both anthropometry and ultrasonography provide a reliable estimate of visceral adipose tissue in a non-obese population compared with DXA, whereas anthropometry prediction of subcutaneous adiposity is weak. Physicians should be aware of the limits of these techniques for the assessment of body composition.

Introduction

The study of body composition is devoted to the quantification and the distribution of body elements at different levels [1,2], specifically organized into five levels of increasing complexity: Atomic, molecular, cellular, organ tissue, whole body [3]. Several techniques are available to assess body composition at each level. The lack of available, acceptable, or accurate clinical tools has long limited body composition analysis to research settings or selective clinical studies. Today, whole-body, molecular, and organ tissue levels are the most commonly investigated areas as a result of the availability of anthropometric methods and to improved performance of largely available imaging techniques [4].

Dual-energy x-ray absorptiometry (DXA) is a reference technique for the assessment of body composition [5–7]. DXA measurements are based on a three-compartment model, i.e., fat mass (FM), non-bone lean mass (LM), and bone mineral content, measured at whole-body level or regionally, together with bone

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mineral density. DXA is accurate, reproducible, fast, relatively inexpensive and safe, with very low radiation dose to exposed individuals [5,8]. All these advantages make this densitometric method ideal for clinical use and longitudinal studies, in both adults and children [9]. A strong correlation has been demonstrated between DXA parameters and computed tomography (CT) or magnetic resonance imaging data [10]. New software was recently proposed to quantify the visceral fat compartment (android visceral fat) by DXA; the results compare favorably with CT [11]. In addition, bioelectrical impedance analysis (BIA) is gaining popularity in studying body composition at molecular level because of its improved accuracy and new technical features [12].

Ultrasonography has a role in studying body composition at whole-body and organ tissue levels, providing a direct measure of visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT) thicknesses at different axial sections of the abdomen; this feature overcomes some limits of anthropometry and conventional DXA instruments. Because of its accuracy, reproducibility and close-at-hand availability [13], ultrasonography is the ideal technique for the assessment of fat changes in response to treatment [13].

Among anthropometric measurements, waist circumference, hip circumference, waist-to-hip ratio and body mass index (BMI) represent the most common indexes used in clinical practice for the study of body composition. Anthropometric data are easy to obtain and cost-effective but suffer from low accuracy and reproducibility [14]. Furthermore, anthropometry often shows a lack of correlation with VAT and SAT measurements [15].

Very few studies have considered an integration of all the techniques just mentioned [16]; the majority of them confronted two techniques [17–23]. Additionally, the studies often suffered from a limited sample size and the lack of strictly selective inclusion criteria. A few studies focused on obese populations [15,22], others on specific age ranges [20,23]. To our knowledge, no comparison of the three techniques has been carried out in a well-controlled healthy population.

The aim of this work was to define the relationship among the different methods for body composition analysis (i.e., anthropometry, ultrasonography, and DXA) in a clinical setting, considering DXA parameters as gold standard.

Materials and methods

Study population

We prospectively recruited individuals aged 18 to 70 y old among the blood donors of our hospital, to reach a sex- and age-balanced population of 250 participants. All recruited individuals were normal-weight or overweight (BMI between 18 and 30 kg/m^2 according to World Health Organization criteria). Participants with external or internal medical devices, or those who had recently been submitted to diagnostic tests using nuclides or barium or radiopaque substances were excluded. Diseases potentially affecting the distribution of fat and lean compartments were ruled out at anamnesis.

The present study represents the core of a research project on body composition assessment in healthy people. The full list of selection criteria used to define the healthy status was described previously, reporting the changes of DXA parameters with aging [24]. The research was approved by our Institutional Review Board and was carried out according to the principles of the Declaration of Helsinki. All participants signed an informed consent before enrollment.

All measurements were performed during the same day. Techniques and methods for body composition assessment, as well as the statistical analyses, are described here.

Anthropometry

Height and weight were measured barefoot, with participants wearing underwear and a cloth gown, to the nearest 0.1 cm and 0.1 kg, respectively, using a mechanical balance with altimeter (Seca 711, Seca GmbH & Co Kg, Germany). BMI was calculated as weight/height^2 (kg/m^2). Waist circumference was measured at the midpoint between the lowest rib on the sides and the iliac crest; hip circumference was measured at the level of the femoral great trochanter; waist-to-hip ratio also was calculated (Fig. 1A). Circumferences were measured in centimeters using a flexible plastic tape to the nearest 0.1 cm, in standing participants at the end of a normal expiration.

Ultrasonography

The distribution pattern of abdominal fat was determined by several abdominal fat thickness parameters (Fig. 1B). Scans were performed using conventional ultrasonographic equipment (Technos MPX, Esaote, Italy); all measurements were acquired with participants in a supine position with arms at sides, at the end of a normal expiration.

Maximum preperitoneal fat thickness (MaxPFT) was determined below the xiphoid process in the epigastric region, on the xiphoumbilical line, as the major distance between the anterior surface of the peritoneum covering the liver (left lobe) and the posterior surface of the linea alba. Minimum subcutaneous fat thickness (MinSFT) was measured at the same anatomic region. Maximum subcutaneous fat thickness was assessed at two different sites on the linea alba, 2 cm over and 2 cm below the umbilicus ($MaxSFT_{upper}$ and $MaxSFT_{lower}$, respectively). MinSFT, $MaxSFT_{upper}$, and $MaxSFT_{lower}$ were defined as the distance between the anterior surface of the linea alba and the fat–skin barrier.

Intra-abdominal fat thickness (IFT) was measured as the distance between the anterior wall of the aorta and the posterior surface of the linea alba, 2 cm below the umbilicus (as for $MaxSFT_{upper}$).

MaxPFT, MinSFT, $MaxSFT_{upper}$, and $MaxSFT_{lower}$ were measured using a linear probe (7.5 MHz) kept perpendicular to the skin and hand pressure on the abdomen as light as possible, to avoid compression of fat layers; IFT was assessed using a convex probe (3.5 MHz) [25].

The aorto-mesenteric thickness was assessed using a convex probe, 2 cm below the aorto-mesenteric bifurcation as the distance between the anterior margin of the aorta and the posterior profile of the superior mesenteric artery [26].

Several adiposity indexes were also calculated: a) preperitoneal circumference, as the difference between waist circumference and $MaxSFT_{upper}$ multiplied by 2 π [25]; b) wall fat index, as the ratio between MaxPFT and MinSFT [25]; c) medium abdominal fat index, as the ratio between IFT and $MaxSFT_{upper}$.

Dual-energy x-ray absorptiometry

A whole-body DXA scan was performed to measure total and regional body composition using a new fan-beam densitometer (Lunar iDXA, Madison, WI, USA; enCORE^{TM} 2011 software version 13.6). The scanner was calibrated daily using a standard calibration block supplied by the manufacturer. All metal items were removed before densitometry. Participants were placed in a supine position with arms at sides slightly separated from the trunk and correctly centered on the scanning field. Region of interests were defined by the analytical program including six different corporeal districts: Total body, trunk, upper limbs, lower limbs, android region (a portion of the abdomen included between the line joining the two superior iliac crests and extended cranially up to the 20% of the distance between this line and the chin), and gynoid region (a portion of legs from the femoral great trochanter, directed caudally up to a distance double of the android region). For each region, DXA scanned the weight (in g) of total mass, FM, LM, and bone mineral content.

Visceral fat analysis was performed by CoreScan, a new software option for the assessment of visceral fat (mass and volume) in the android region [11]. The measurement of SAT thickness at both sides of the android region allowed the software to map the total SAT compartment. The amount of android VAT was derived by subtracting SAT from total android FM (Fig. 1C).

Design of comparisons

The relationship between parameters derived from the different techniques was investigated with DXA as reference technique. In particular, total body FM/LM (*a*), android/gynoid FM (*b*), android FM/LM (*c*), VAT (*d*), VAT/SAT (*e*), and SAT (*f*) were considered as the pivotal markers of body composition, in terms of general mass balance (*a*), central/peripheral distribution of FM (*b*), central or VAT compartment (*c*, *d*, and *e* for fat abdominal distribution), and SAT depot (*f*), respectively. Anthropometric and ultrasound parameters were analyzed to find the best predictors of DXA markers of body composition.

Statistical analysis

The normal distribution of our sample population was tested by skewness and kurtosis; normal ranges were considered for values between −2 and +2. Data are reported as frequencies or mean and standard deviation (±SD). Pearson's test was used to evaluate the correlations between the body