

Body composition: evaluation methods

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SUMMARY

Many different techniques have been used since the initiation of the first anthropometric studies. Analysis of body composition is based on different types of body partitioning, ranging from the traditional model, which considers that there are two body compartments, through multicompartamental models. There are essentially two types of analytical methods: direct methods, or those based on cadaver dissection, and indirect or "in vivo" methods. The first techniques used and intended to measure body fat are fundamentally anthropometry and hydrodensometry. Based on the body's electric conductance, bioelectrical impedance is used, but the possibility of measuring the absorption of energy particles by tissues has given way to absorptiometry techniques, first using an isotopic and then a radiological source. Currently, the advantages offered by DXA photonic dual absorptiometry make it the most appropriate and widely-used technique, for measuring body composition in individuals of different ages and sexes.

Key words: Component – Compartment – Body composition

BODY COMPOSITION

The interest of human beings in their bodies dates back to cave drawings and carved representations of humans (with excellent symmetry with respect to the vertical axis of the body)

dating back to the Palaeolithic Age (Martín, 1978), and since then and up to present times knowledge of body composition has been an important area of interest.

Humans' innate curiosity about their body composition is as old as life itself: "What are we made of?" The answer to this question can be found in ancient dualist theories, where an imbalance of a given factor could purportedly lead to physical or mental disorders (Guerra, 1982).

Hippocrates of Kos (460-370 b.c.) gave medicine a rational basis by separating it from speculation with no practical basis (breaking with the tradition of medicine linked to religion). With his "four humours" theory, he explained that an imbalance of one of the humours would be the cause of certain disorders. Later, Galen (129-200) marked the position, quantity, shape, and function of each part of the body, and indicated that anatomical parts are dissimilar from one another but that there are also similar parts that are the basic constituents of the parts, such as the muscle, bone, fat or cartilage, which Galen related to the four elements described by Hippocrates.

Individuals are now viewed as a whole, the result of a combination of the physical characteristics of the subject that can be observed (constitution) and a set of mental characteristics (personality). The problem of constitution and of constitutional types has been studied by many authors (Hallé, Thomas, Rostan...). The most widely accepted constitutional classification is that of the German psychiatrist, Kretschmer, from 1955.

According to anthropometry (human measurement), which 100 years ago gave rise to research

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into body composition, each person has a certain physical shape, since this technique evaluates the characteristics of the size, shape, proportion and composition of the human body. Each individual has a different biotype, or somatotype, which can be classified according to its shape, since each individual has the same components but in different proportions: Endomorphic, with a tendency toward obesity, a predominance of the abdomen over the thorax, short neck, rounded outline, slow metabolism, small amounts of muscle mass and relative by short extremities; Mesomorphic, where muscle mass predominates, with long bones, very fast metabolism and a broad thorax; Ectomorphic, with a predominance of linear shapes, low fat percentage, little muscle mass, high metabolism and long, fragile bones.

Tissue biopsy analysis has long been a part of medical practice and has contributed to our basic knowledge of the physiology and metabolism of the human body. While the technique is relatively simple, it is not free of risks and is not always pleasant for patients.

Modern studies of body composition arose from the research done by Moulton in 1923 of water and fat in animals. Subsequently, Mitchell in 1945, Widdowson in 1951 and Forbes in 1956 studied the chemical composition of six human cadavers; their data are still valid (Ruiz, 1994).

In 1921, Matiegka (Matiegka, 1921) proposed a method for the anthropometric estimation of the weight of the skin with subcutaneous adipose tissue, skeletal muscle, bone and residual tissue (organs and entrails) in the human body. This method was later validated by cadaver dissection research on individuals between 55 and 94 years of age conducted in Brussels by Clarys, Martin and Drinkwater between 1979 and 1980 (Clarys et al., 1984).

The cadaver studies conducted in the twentieth century were conducted on fetuses, children and adults, but there are no data in these studies on young individuals. In 1985 Knight et al. conducted a cadaver analysis on two adults that aimed at determining total body nitrogen, but none of the new *in vivo* methodologies has been directly verified with the analysis of human cadavers (Ellis KJ, 2000).

Principal components such as fat, total body water, bone minerals, non-osseous minerals and proteins have also been obtained from cadaver analyses; glycogen is difficult to determine because it weighs so little and because of rapid post-mortem autolysis.

While research into body composition began about 100 years ago with the use of anthropometric measurements, a revolution in the field of body composition took place some 40 years ago with the introduction of the concept of body compartments, and the appearance of techniques such as densitometry and increasingly precise instruments. This has been supported by

information technology, which has made possible to store data and compare results (Rodríguez et al., 1998).

In order to analyse body composition, the human body can be divided into various measurable components using a number of different techniques, depending on the compartmental model.

In general, the analysis of body composition is based on two ways of partitioning the body: one is by "chemical components", which considers that humans are composed of water, fat, proteins and minerals; the other is by "compartments", i.e., components defined by the measurement method employed, which may not necessarily coincide with specific anatomical structures (Ruiz, 1994).

The model traditionally used to evaluate body composition is the two-compartment model, which considers that the human body is composed a fat mass (FM) part and residual tissue, which falls into the part known as the fat-free mass (FFM). The development and application of this biocompartmental model has been accelerated by the close relationship between excess body fat and the risk of the appearance of cardiovascular diseases (Björntorp, 1992; Roche, 1992; Senti et al., 2000). Nevertheless, the FFM compartment is very heterogeneous and has led to the appearance of models that consider three or more compartments, known as multicompartmental models. The FFM is then divided into two parts: one watery and the other solid, composed primarily of proteins and minerals. While the evaluation of the bone mineral compartment is easy and accessible, the same cannot be said of protein mass, which is why the FFM has been further divided into three basic cellular compartments –body cell mass (BCM), extracellular water fluid (ECW) and extracellular solids (ECS)– to form a compartmental model with four components. In any case, errors in the estimation of these compartments become errors in the final estimation of fatty mass, since it is considered that the FM is the difference between body weight and the FFM.

It is well known that the human body is a hierarchical organization of different components, starting with chemicals, followed by cells (first units of shape), tissue, organs and systems. Thus, the human body can be divided into five levels with clearly defined components for each of them (Wang et al., 1992; Ellis, 2000):

At the first or atomic level, atoms are considered to be the building blocks of the body.

At the second or molecular level, the elements from the level below are grouped into molecules to form chemical compounds, which are in turn grouped together based on the similarity of the molecules: water, lipids, proteins and glycogen. The four predominant chemical elements in living beings are: oxygen, carbon, nitrogen and hydrogen, which account for 96

percent of body weight. Because of their features, they are ideal for defining the chemical structure of the body since they form very stable covalent links. Water is the most abundant chemical compound. Most proteins are found inside cells. Glycogen (where carbohydrates are stored) is found primarily in muscles and the liver.

From a physiological point of view, lipids can be classified as essential when they are part of cellular membranes and non-essential which they provide energy and thermal insulation. The latter correspond to the term fat mass.

At the third or cellular level, in order to make all of these elements viable and thus establish a metabolic machine, a barrier is formed to separate them from the external milieu and build a system that enables reproduction and metabolic control. At this cellular level, the body is considered to be composed of cells, extracellular solids and extracellular liquids.

At the fourth, or tissue level, the previous level is organized by grouping cells with similar physiological characteristics together to form tissue; hence the different spaces with chemical, anatomical and functional individuality and the fact that the composition of the body is not evenly distributed (Ortiz, 1986). The most important specific tissues in body composition are osseous, adipose and muscular tissue (Terán, 1999; Katch and Katch, 1984).

The fifth or total body level: up to this level, body composition is analogous in groups of animals, but this is the level that differentiates man from all other species and that refers to body size, shape and proportions; i.e., to constitutional characteristics. The changes occurring at lower levels are manifested at total body level (Wang et al., 1992). In the adult individual, there should be a dynamic equilibrium of body composition, accepting under normal circumstances a minimum variation in body weight (10%) over a long period of time (20 years); in this constant state of body composition there should be a stable proportion between the different components of each level (Terán, 1999).

Many compartmental models have been used to study body composition, such as the four-compartment model: fat, non-fat, mineral and water (Revilla et al., 1992); since the watery component is completely dependent on the non-fat compartment, it can be calculated using the Brozek formula (Lukaski, 1987), as corroborated by other authors (Heymsfield, 1990).

EVALUATION METHODS

There are basically two methods for evaluating body composition: direct methods, which consist of cadaver dissection, with obvious limitations, and indirect methods, also known as "in vivo", which are based on obtaining a non-measurable

parameter by using several formulae or equations involving a measurable parameter and assuming a constant relationship between both variables (Wang et al., 1992).

Both conventional radiography and radiogrammetry or radiographic densitometry can be used to measure bone mass.

Simple radiology was the method used initially to evaluate skeletal status, but the suspicion of bone mass loss only appears when such loss is greater than 30% of bone mass (Pons and Guañabens, 2000; Pons and del Río, 1989; López and Hawkins, 1994; Gómez et al., 1997; García, 1999; Rodríguez and de la Fuente, 1999). It is therefore not a valid method for bone quantification, since the interpretation is completely subjective and the technique is subject to variations in the processing of the x-rays; the quality of the beam, etc.

Radiogrammetry is based on morphological measurement of the thickness of the bone cortex. Its usefulness is limited since the measurements are taken in areas composed primarily of cortical bone: usually at the level of the second metacarpal (Hawkins and Prieto, 1993). Finding the relationship between the thickness of the cortical bone and the medullar area is the main method for quantifying bone mass (Gómez et al., 1997). This technique is not error-free (variation in the placement of the hand; it only evaluates bone in peripheral locations of the skeleton) and owing to its low accuracy and precision its use in patients is limited, and it is mainly used as a research tool to gather epidemiological data (Ostelere et al., 1991).

Anthropometry and classical densitometric techniques – hydrodensitometry and plethysmography – are used to measure body fat mass.

Anthropometry offers a bicompartamental vision of the body, measuring fat mass and fat-free mass. It is used to research growth (Forriol and Pascual, 1990), obesity (Vitores et al., 1993), nutritional status, state of health and the physical condition of athletes specializing in different sports (Lapieza et al., 1986; González et al., 1998). The most commonly used anthropometric parameters are those that draw a relationship between weight and height.

The most frequently used densitometric method for determining body density is hydrodensitometry or "underwater weighing" (Deurenberg, 1992), which is based on the principle of flotation known since Archimedes (287-212 b.c.).

In 1942, Behnke was a pioneer in these studies (Behnke et al., 1942), by proposing that body volume could be determined using the principle of Archimedes based on underwater weighing. Body density can be calculated if its mass and volume are known, since density = mass / volume; body volume is obtained directly from the volume of water displaced or by subtracting body mass in the water from body mass in the air, in which case the individual must be

completely submerged (Ellis and Nichols, 1993) and in maximum exhalation (Kath and Kath, 1984). Errors in measuring weight in the water are reduced if each subject is weighed 10 times and the average of the last three values obtained is used in the calculations (Roche, 1987).

Once the density is known, the percentage of fat is obtained, mainly by using the Siri equations (Siri, 1961) (% fat = $495/D-450$) and Brozek equations (Brozek et al., 1963) (% fat = $457/D-414.2$).

To do so, it is assumed that the body is composed of two compartments (bicompartamental model) and that each of them has a constant density: a fat compartment (0.90 gr/ml) and a lean body mass (1.10 gr/ml), values based on previous cadaver analysis (Deurenberg, 1992). Despite this the constant density of the tissues making up the lean body mass is refuted by the cadaver studies of other authors (Clarys et al., 1984; Martin, 1984; Martin et al., 1986).

Furthermore, this density may vary, depending on individual characteristics such as ethnicity (Durning, 1995) and the state of hydration of the subject (Cañete et al., 1994). It must also be ensured that this technique is not applied to subgroups of the population, such as children under the age of 8 (Roche, 1987), pregnant women, adolescents, obese people or sick people, particularly malnourished people or those with other organic fluid imbalances (Beddoe, 1995), including the bedridden, the elderly and people who have difficulty moving (León et al., 1996). In these cases it is recommended that plethysmography be used as an alternative method (Ruiz, 1994; Jebb et al., 1993), a method thoroughly described by Garrow (Garrow et al., 1979).

Fat density varies with temperature owing to its high thermal expansion rate (Cañete et al., 1994) and the margin of error for body fat using hydrodensometry is 3% of body weight (Deurenberg, 1992). In addition to this, the volume of air trapped in the body (lungs and abdominal cavity) must be subtracted from the total body volume by making corrections using gas measurement procedures. In children, the residual volume is used to determine the air in the lungs, although in older people it is better to measure the total pulmonary capacity, which results in fewer errors in the calculation of the percentage of body fat (Latin et al., 1986). According to radiological studies, it is assumed that the intestinal volume for a fasting subject is 100 ml (Buskirk, 1961).

Bioelectrical impedance (BIA) is a method based on the electrical conductance of the body most commonly used.

It is based on the opposition of body tissues to the passage of a single-frequency electrical current (50 kHz), a property which depends on water content and electrolytes. The fat-free mass contains the majority of body electrolytes and

liquids, making it a good conductor, with fat mass acting as an insulator. This is based on the assumption that total body water is a fixed part of the fat free mass. It gives a direct estimate of body water and makes it possible to estimate the fat free mass, assuming that this is 73% water. Once the fat free mass has been obtained, the fat mass is obtained by calculating the difference compared to the total weight.

The measurement is taken using electrodes placed on the hands and feet in a decubitus supine position, with no metal objects, fasting and with the bladder empty (no liquids taken in the four hours prior to the test). The patient should not have done any intensive exercise in the 24 hours prior to the test. These measures are intended to achieve a stable hydroelectrical situation. The work of Núñez (Núñez et al., 1994) on body composition in young women reflects the good correlation between studies using BIA and anthropometry, which is why those authors propose this technique as an alternative for measuring body composition in homogeneous population groups with stable weight, although others do not favour using it on obese and very thin individuals (Gray et al., 1989; Vansant et al., 1994).

Since tissue hydration status changes with age, the use of this technique requires specific formulae for different age groups and sexes (Martín and Galdós, 1993). It is therefore not recommended for use in situations of dehydration (Dal Cin et al., 1992).

BIA is therefore a precise, simple, inexpensive method that can be applied to stable patients and healthy subjects. It is even portable and can be used with bedridden patients (Pencharz et al., 1990), although owing to its sensitivity to hydric changes in the body (dehydration or water retention) errors may be incurred.

Other methods, such as absorptiometric methods, estimate the density of different tissues by measuring the absorption of energy particles by the tissues and then calculating the different tissue masses. Depending on the energy sources, either isotopic absorptiometry or radiological absorptiometry can be used. These systems were first used to measure the quantity of osseous tissue, bearing in mind that it is not structurally homogeneous since cortical bone represents 80% of bone mass and trabecular bone the remaining 20%. Since the trabecular component is closest to the bone marrow and has a larger area and a greater degree of vascularization than cortical bone, it is more susceptible to change since it is metabolically more active. Therefore, a change in the amount of trabecular bone is an earlier and more sensitive indicator of changes in bone mass (Pons and del Río, 1989).

In 1963, Cameron and Sorenson (Cameron and Sorenson, 1963) proposed the use of single photon absorptiometry (SPA) to quantify the

bone mass of the appendicular skeleton *in vivo*, this being the first commercially available technique for the non-invasive measurement of bone mineral density. The method uses a radioactive isotope as a source, which may be iodine-125 or americium-241, issuing at 27.3 Kev and 59.6 Kev respectively. The exploration can only be done in areas where the thickness of the soft tissue is limited and constant. The area to be explored (forearm or heel bone) is submerged in water (Borrel and Peris, 2000) or wrapped in a hose (Lozano, 1993). This method is not predictive of what may be happening in more interesting bone areas, such as the spine or the thighbone (Nollá et al., 1995), since it primarily determines cortical bone (López and Hawkins, 1994). The area most commonly used for the measurement is the distal third of the radius, which is 95% cortical bone (Genant et al., 1993), but the information obtained on trabecular bone is better if the technique is performed on the calcaneus (Lozano, 1993).

Dual photon absorptiometry (DPA) was used for the first time in 1965 in Great Britain by Reed (Reed, 1966) to quantify the bone mineral content in areas previously inaccessible to SPA. It uses the photon radiation of two different energies, americium-241, which emits at 59.6 Kev, and cesium-137, which emits at 662 Kev. The absorption of americium-241 radiation is sensitive to the atomic number, so the presence of calcium dominates bone studies. The absorption of cesium-137 radiation is not sensitive to the atomic number and is determined by the mass of the material through which the ray passes. Hence, a comparison of the two transmissions provides a measurement of the calcium in the area explored by the ray. The method was consolidated in 1975 with the use of gadolinium-153, which emits photons at 44 Kev and 100 Kev (Wilson and Madsen, 1975). This method measures the bone mass of the entire skeleton and thanks to its two photopeaks it makes it possible to distinguish the attenuation due to soft tissues from that caused by bone tissue. However, the exploration is lengthy (approximately one hour) (Ruiz, 1994) and its precision decreases because the radioactive source, which has an average life of 242 days (Lozano, 1993), deteriorates and must be replaced. This technique has therefore given way to dual x-ray absorptiometry (DXA).

In 1970, Krokowski, based on the same principles as DPA, replaced the isotopic source with a radiological source (Kowalchuk and Dalinka, 1998).

Thus, the DXA (dual x-ray absorptiometry) system appeared on the market in 1987 (Genant et al., 1994) and while all DXA equipment is based on the same physical principles (dual energy x-ray source, a detector and computer system), the instruments made by different manufactures are different in terms of equipment

design, calibration systems, the filtering system for producing the two different photopeaks and the analysis algorithms. Therefore, the measurements taken by one piece of equipment and another may differ slightly, making it recommendable to conduct a series of studies with the same densitometer (Nollá et al., 1995). The differences in the results published led to the creation of the International DXA Standardization Committee (IDSC) to develop formulae for converting and transforming the results obtained from different devices into comparable values (Genant et al., 1994). There are currently three companies that distribute this equipment: Hologic Inc., Waltham, MA; Lunar Radiation Corp., Madison, WI and Norland Corp., Fort Atkinson, Wisconsin.

Thanks to the use of x rays as an electronic source of photons, significant progress has been made over other systems in terms of image quality, precision and the reproducibility of results; in terms of quality, because of the higher exchange of photons generated and because of finer collimation, which improves the accuracy of the bone margins and reduces analysis time (Cullum et al., 1989; Lukaski, 1993; Roig and Nolla, 1992; Fischer, 1993; Genant et al., 1993). As regards precision, it is much better than DPA at measuring the bone density of the spine and overall skeleton (Haarbo et al., 1991), with an error precision (variation rate) of 1-2% (Lozano, 1993; Gómez, 1997; García, 1999; Harrison et al., 1995) and an accuracy rate of 5-10% (Borrel and Peris, 2000). It therefore offers excellent precision and accuracy, not only for measuring bone mineral but also for measuring body fat and fat-free mass (Lukaski, 1993). Hence, the most important and fundamental aspect of DXA is that in addition to being a very valuable technique for determining bone mass, it offers the possibility of measuring the body's fat or non-fat component (Fischer, 1993; Blake and Fogelman, 1998; Rodríguez, 1999). Unlike other methods, it provides information about the entire body and about body segments measured separately. It can detect minor changes in the body mass of an individual, even in those cases in that weight changes are less than 2.5 kg (Lands et al., 1996; Going et al., 1993), making it a practical tool for the longitudinal assessment of weight modification.

Another advantage of DXA is the variation among and between observers (Thomsen et al., 1998), which makes it very useful in clinical studies (Valero et al., 1994).

Since the radiation dose is minimal (Pons and del Río, 1991; Boot et al., 1997; Harrison et al., 1995; Nejh et al., 1999) - even less than the dose received from natural radiation (Lewis et al., 1994) - its use with paediatric patients (Pons and del Río, 1991; Venkatamarán and Ahluwalia, 1992) and adolescents (Boot et al., 1997) is fully justified. Its use in paediatric medicine is impor-

tant for obtaining reference data on healthy newborns and for evaluating the effects of an altered gestation on subsequent development (Lukaski, 1993). However, its use on obese subjects weighing more than 100 Kg requires a longer exploration time and thus involves a source of error (Heymsfield et al., 1989).

Comparing DXA with bioelectrical impedance, the latter affords lower body fat percentages in obese children (Eisenkölbl et al., 2001).

As an alternative to DXA, some recent publications have recommended the use of plethysmography in certain very specific population groups (Fields and Hunter, 2004; Ballard et al., 2004).

In view of the above, it can be said that DXA is a non-invasive, fast method that is risk-free for the subject and highly appropriate for studying body composition in individuals of different ages and sexes (Tsutsumi et al., 1993). While it is still questioned by some authors (Roubenoff et al., 1993; Kohrt, 1995), there are many more who defend this technique as the best one currently available for measuring body composition (Pons and del Río, 1991; Barrera et al., 1997; Zions, 1995; Cullum et al., 1989; Thomsen et al., 1998; Haarbo et al., 1991; Lukaski, 1993; Boot et al., 1997; Slosman et al., 1992). Ever since it first appeared, there has been a constant stream of publications discussing its indications, methodology, interpretation of the results, and declarations of agreement (Roig and Nolla, 1992; Hawkins and Prieto, 1993; Kanis et al., 1996; Miller et al., 1996; Blake et al., 1997; Barán et al., 1997; Gómez et al., 1997; Guañabens, 1998; Levis and Altman, 1998; Mirsky and Einhorn, 1998; Nolla, 1998; Thomsen et al., 1998; Leib et al., 2004; Lewiecki et al., 2004; Writing Group for the ISCD Position Development Conference, 2004 a,b,c,d,e,f).

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