# Body composition assessment. Critical and methodological analysis*

## Part

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Although not identified as such, *Kinanthropometry* has several antecedents which are as old as the existence of man; whether because of purely material and specific reasons or imperatives (e.g. the selection of the most able warriors or workers) or because of more abstract aesthetic considerations, the human being has always been concerned by the *shape, proportion and composition* of his body.

In both the *Old Testament and the Babylonian Talmud*, as well as the *midrashim*, there are references to the shape, proportions and stature of the human figure. One of the punishments inflicted upon Adam and Eve for their sins was precisely a reduction in stature (Boyd, 1980); something that did not happen just by chance.

The concern and the importance that the human being has always given to his physical constitution can be seen in the inscription of Sargon II, King of Assyria, in his palace at Khorsabad (800 B.C.)...

*...as the gods held me in esteem with the constance of their hearts and, above all the princes, they bestowed great power upon me by* *increasing my stature and strength during my kingdom, in battle and in combat I have been unrivalled...*
(Luckenbill, 1927 - quoted by Boyd, 1980)

And, from very early on, man intuited that the ability to carry out any work or physical exercise was closely related to the amount and proportion of the different tissues that existed in his body. Hence the hippocratic theory of the *four humours*...

*...health is basically determined by the proper relative proportion of the following: blood, yellow bile, black bile and phlegm...*
(Hippocrates, 460-395 B.C.)

...and especially since the official recognition of *Kinanthropometry* as a science was granted by the UNESCO in 1978 ("International Council of Sport and Physical Education", N.G.O., A level committee), the major growth and development of that science is clear to see in the field of physical education, sports medicine and public health in general.
This is a fact that cannot escape all those professionals aware of the need to expand their knowledge and therefore concerned by the eclosion of all new sciences or methods which,

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from educational, preventive or human performance optimization points of view, may offer new ideas and perspectives for improving knowledge of the individual and his functional capacity (figure 1).

## METHODS FOR THE ASSESSMENT OF BODY COMPOSITION. CLASSIFICATION

Of the three basic pillars that constitute the praxis of Kinanthropometry: the study of *proportion, somatotype and body composition*, the latter probably the most important and emblematic one in the field of physical activity and sport in terms of the individual's ability to exert any type of effort being closely related to the greater or lesser presence of fundamental body tissues.

However, the evaluation of body composition may be based on many methods which, besides being conceptually very different, provide different results.

A simple, specific example of this will surprise and no doubt interest the reader. Table 1 shows us an evaluation of body composition performed on the same person, on the same day using different methods (Martin, 1984).

The best approach is probably to analyze the general features of the body composition evaluation methods, whether a *conceptual classification* which, at one and the same time, allows a historical follow-up of its evolution to be done. Thus, all the methods could be covered by three proposals (Ross, Ward, Selby and Porta, 1990):

### A.- Normative-Descriptive
Body mass and adiposity indices generally based on Quetelet's theories and calculations (19th century) from which the renowned *BMI* (Body Mass Index) has derived. This index shall be analyzed at greater length later.

### B.- Densitometric-Extrapolative
Further to the historic antecedent of Archimedes well-known hydrostatic principle, the closest origins can be found in the work done by Behnke, Feen and Welham (1932-39 - quoted by Behnke, 1961) on the specific gravity and density of the human body and the use of its volume as a variable, together with stature and weight. Concepts from which the fundamental model for evaluating the body composition of 2 components derived. These *2 components* are: body fat (BF) and fat-free mass (FFM).

### C.- Proportional-Fractionated
Originating from Matiegka's anatomical studies (1921) and his model of *4 components*: body fat, muscle mass, bone mass and residual mass. Since 1970 this has been modified by the



**Kinanthropometry**
Quantitative correlation between structure and function

| Identification | Specialisation | Application | Field |
|---|---|---|---|
| Kinanthropometry: | To study: | To aid the understanding of: | Incidence: |
| - Movement | - Shape | | - Educational |
| - Man | - Stature | - Growth | - Sports |
| - Measurement | - Proportion | - Exercise | - Medical |
| | - Composition | - Performance | - Social |
| | - Development | - Nutrition | |
| | - Function | | |

*Figure 1*
*Application of Kinanthropometry (Ross, W., 1978).*

*Phantom* proposals of Ross and Wilson (1974), Ross and Marfell-Jones (1991) and the *4 and 5-component* models of Drinkwater (1984) and Kerr (1988), up to the latest digital methods based on the digitalization of images obtained via magnetic resonance.

Undeniably, however, a *classification based on methodological* criteria would give us more rational knowledge about the scientific validity of the methods most employed in evaluating body composition. Thus, we can establish the following classification (figure 2):

### A.- Direct methods
By cadaver dissection. Logically, this is the *only absolutely valid method*, though the obvious functional limitations have restricted studies and the gathering of reference data.

### B.- Direct methods
Also termed *in vivo* methods. These must be considered as indirect because the calculation of one parameter (e.g. the amount of fat) is based on another: total body density, body breadths, body girths, etc., *assuming a theoretical and constant quantitative relationship between all the variables.*
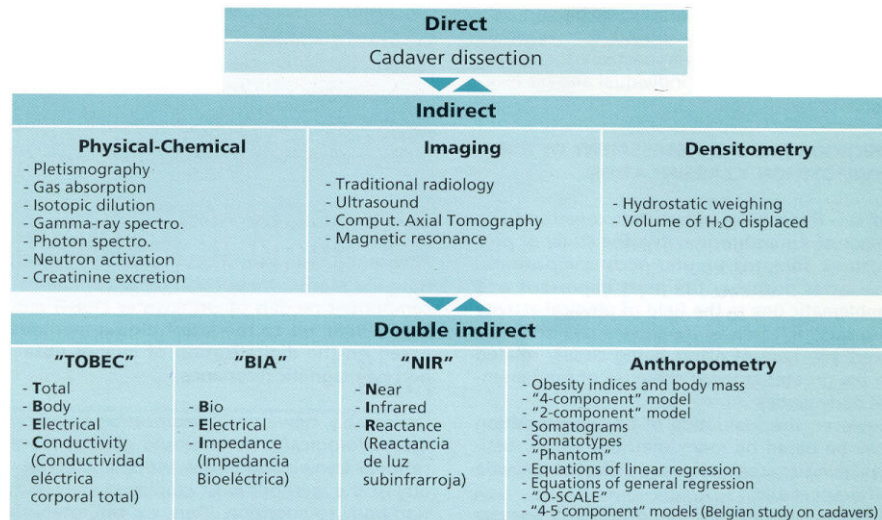
### C.- Double indirect methods
These must be classified as such because they are the results of equations and nomograms which are *in turn derived from some of the indirect methods.*

Anthropometry is a good example since an equation of regression is calculated on the measurement of some parameters and body density of a specific population. In principle this equation allows the percent body fat, muscle mass, bone mass or residual mass of other population groups to be evaluated simply on the basis of measuring skinfolds (figure 3).

*Table 1*
*Analysis of an individual's body composition on the same day (Martin, A., 1984).*

| Method | % Body Fat |
|---|---|
| -$^{42}$K Total body | 21,0 |
| -Anthropometry (Steinkanmp et al.) | 18,5 |
| -BIA (Bioelectrical Impedance Analysis, Presta et al, 1983) | 13,3 |
| -Densitometry (Hydrostatic weighing) | 9,6 |
| -$H_2O$ Total body (Tritiated water) | 6,0 |

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| Direct |
| --- |
| Cadaver dissection |

| Indirect | | |
| --- | --- | --- |
| **Physical-Chemical** | **Imaging** | **Densitometry** |
| - Pletismography<br>- Gas absorption<br>- Isotopic dilution<br>- Gamma-ray spectro.<br>- Photon spectro.<br>- Neutron activation<br>- Creatinine excretion | - Traditional radiology<br>- Ultrasound<br>- Comput. Axial Tomography<br>- Magnetic resonance | - Hydrostatic weighing<br>- Volume of $H_2O$ displaced |

| Double indirect | | | |
| --- | --- | --- | --- |
| **"TOBEC"** | **"BIA"** | **"NIR"** | **Anthropometry** |
| - **T**otal<br>- **B**ody<br>- **E**lectrical<br>- **C**onductivity<br>(Conductividad eléctrica corporal total) | - **B**io<br>- **E**lectrical<br>- **I**mpedance<br>(Impedancia Bioeléctrica) | - **N**ear<br>- **I**nfrared<br>- **R**eactance<br>(Reactancia de luz subinfrarroja) | - Obesity indices and body mass<br>- "4-component" model<br>- "2-component" model<br>- Somatograms<br>- Somatotypes<br>- "Phantom"<br>- Equations of linear regression<br>- Equations of general regression<br>- "O-SCALE"<br>- "4-5 component" models (Belgian study on cadavers) |

DIRECT METHODS

Based on cadaver dissection with the obvious problems inherent to these protocols. The data gathered are of relative validity and very limited due to the scarcity of the studies of this type which have carried out an evaluation of the anthropometry and chemical composition.

Although we can find the first ever reports about this in the works of the German anatomists in the 19th century (Vierord) and later on in the 20th century through the contributions made by Mitchell (1945), Widdowson (1951), Forbes (1953), Alexander (1964), Dempster (1967), Moore (1968), Clauser (1975) - quoted by Martin (1984) and Shephard (1991), *the most important and significant study of anatomical dissection in the field of Kinanthropometry was done at the Free University of Brussels, Belgium, by: Clarys, Drinkwater, Martin and Ross* from October 1979 to June 1980.

**INDIRECT METHODS**

**1.- Chemical methods**
Chemical methods for the evaluation of body composition and more specifically for body fat have antecedents dating back to the 30s in the studies of Von Hevesy and Hofer, and in the studies of the American navy on the diffusion capacity of gaseous nitrogen ($N_2$) in body fat and fluids (Behnke, Feen and Welham, 1942 - quoted by Behnke and Wilmore, 1974).
The *2-component* model originated from these works. A fundamental concept used in many of the body composition evaluation methods. Of these, we should mention *Densitometry* which, up to now, has been the standard or reference method for all the others, and thus it will be subjected to an exhaustive critical analysis later on.
As far as the study of chemical methods is concerned, we should point out that due to their enormity and complexity, the aims of this study will only allow us to perform a

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general analysis of them and, similarly, of the physical methods. The interested reader will be able to find the references for further reading on each method. The major methods are the following:

### 1.1. Isotopic dilution

*The fundamental objective of this method is to measure total body water.* Basically, it consists of injecting or swallowing a marker which, after a period of equilibration (that may take several hours), allows its concentration to be calculated in the blood or urine or, by means of a spectrography, from the beta ray emissions of radioactive isotopes.

Knowing about the quantity of total body water and considering that water does not fix on fat and in turn that lean mass (LM) contains 73.2% water, the different body components can be estimated.

However, the accuracy and validity of this proposal cannot help being relative in that it is based on the *acceptance of the constant that water content in lean mass (73.2%) which has not been sufficiently validated.* This constant was proposed by Rathbun and Pace in 1945, and derived from their studies on pigs. Later studies on 8 cadavers (Widdowson, Forbes, Moore, Mitchell - quoted by Martin, 1984), found the value to be higher: 74.91% (sd=4.95).

### 1.2. Gamma-ray spectrometry

A methods based on the measurement of radioactive isotope emissions of the same elements as the ones whose evaluation is desired. So, for example, to estimate muscle mass on the basis of the measurement of body potassium, the 42-potassium ($^{42}K$) radio-isotope or 40-potassium ($^{40}K$) radio-isotope is used as a marker which, in turn, constitutes 0.012% of the total body K. Bearing in mind that body potassium fixes to lean mass in a constant proportion of 68.1 mEq/kg, it will allow us to determine total body mass.

However, as is the case for isotopic dilution, the validity of this method *is based on the acceptance of a constant value (68.1 mEq/kg) which presents a great deal of variance.* Thus, for example, between the ages of 20 and 90, there may be a difference of 72 to 50 mEq/kg in men and 60 to 47 mEq/kg in women (Forbes, 1987 -quoted by Preuss and Bolin, 1988-).

### 1.3. Neutron activation

This proposal is based on *the ability of some isotopes' nuclei to capture high and low energy neutrons* (thermal).

Using a source of fast neutrons (Fast Neutron Analysis), the fatty mass can be analyzed directly as the fat contains 64% of the body's carbon. The radiation of the Gamma rays (4.4 meV) emitted by the neutrons of the Carbon-

12 isotope is measured (Cohn et al., 1984).

To calculate muscle mass, besides the $^{40}K$ isotope, an evaluation of the total body nitrogen can be used. Nitrogen's nuclei emit very fast Gamma rays (10.8 meV). However, to convert the data concerning nitrogen content in lean mass, *once again we must accept the constant of it (30.1g/kg).*

### 1.4. Photon spectrometry

This method consists in measuring the density and the bone mineral (calcium and phosphorous) or muscle mineral (potassium) content.

This is done by passing Gamma radiation from a low, uniform source through the zone being evaluated (27 keV). The value of the quantity of radiation absorbed shall be directly proportional to the mineral content (Cameron and Sorenson, 1963; Mazes, 1964, 1971 - quoted by Shephard, 1991).

Dual Photon Spectrometry uses much faster photons (44-100 keV) with the big advantage of less radiation (1-3 mrem as opposed to 5 mrem for the normal method).

### 1.5. Creatinine or 3-Methylhistidine excretion

Creatinine is a *creatine metabolite whose proportion is 98% in the muscle.* Taking this value as the constant and measuring its concentration in urine (requiring several continuous samples) or in the plasma which is much quicker and more accurate, the muscle mass can be evaluated since each mg of creatine in the plasma is equivalent to 0.88 kg of muscle (Forbes and Bruining, 1976).

This trouble with this proposal lies in the fact that creatinine excretion maybe affected by: hyperprotein diets, malnutrition, exercise (especially exocentric contractions), etc.

### 2.- Physical methods

All the methods whose *fundamental objective is to calculate total body volume using a pressurised chamber* are termed physical methods. Although all of them are still at the experimental stage, the constitute some of the most novel proposals for estimating body composition. According to Preuss and Bolin (1988), they can classified into:

### 2.1. Acoustic pletismography

This method is based in Helmholtz's law: ...*The resonance frequency of a chamber is inversely proportional to the square of its volume.*

If we place a body inside the chamber and thus reduce its volume, the resonance frequency (100Hz) will increase. Measuring the increase will tell us its volume. Consequently, already knowing its weight, we can establish body density. On the basis of that density and through many of the already existing equations, we will be able to calculate the various body components.

## 2.2. Air displacement

Based on *Boyle's law which relates the pressure and the volume of a body*. Body volume is obtained by varying the pressure of the chamber and, as in the previous method, the different components are evaluated on the basis of the body density calculation.

## 2.3. Helium dilution

This method consists in introducing a small amount of Helium into a pressurised chamber. Controlling the gas's dilution in the air of the empty chamber and the chamber with the body inside allows us to calculate its volume and density.

## 2.4. Soluble gases in the fat

In reality, this proposal should be classified as a physical-chemical method as it is based on the solubility capacity of some noble gases in the adipose tissue yet also requires a pressurised chamber.

To sum up the analysis of the physical-chemical methods, we can conclude as follows:

**a.-** Generally speaking, the infrastructure and the financial cost of the equipment necessary, and the complexity of their protocols mean that these *methods can only be applied in an experimental setting*.
**b.-** Their scientific validity is relative for two particular reasons:

> **b.1.** They use the *2-component* model when it is clear to see that when a fractionated *4 or 5-component* model (body fat, muscle mass, bone mass or residual mass and the skin) would be more valid.
> **b.2.** They are based on *constants which have never been sufficiently validated*.

## 3.- Imaging techniques

## 3.1. Conventional radiology

The use of X-rays allows the subcutaneous tissue, muscle tissue and bone tissue to be quite clearly delimited with proper exposure time and intensity. It was mainly used in the upper member, from

*Figure 4*
*NMR image at umbilical level. We distinguish a reference (Vitamin A) at the place where the abdominal skinfold is taken.*



which very high correlations with total body masses were found. The precursors of this technique were: Stuart and Red (1951) and Garn (1961) - quoted by Behnke and Wilmore (1974). Although used until the beginning of the 70s by renowned authors such as Tanner and Behnke, the lack of contrast between the soft tissues and the dangers due to radiation (greater than 5 mrem) brought about this method's decline (Brozek, 1963).

## 3.2. Ultrasound

This technique is based on the emission of sound through a transducer (piezoelectric crystal). The frequency of the sounds is higher than 40kHz and they are inaudible to the human ear. When they hit the various organs and tissues they bounce back with a different echo. This signal, which is captured by the crystal, is transformed into electrical energy and then processed by a computer. The image is then displayed on a screen as points of different intensities on the grey-scale between white and black.

Development of this method in the field of Kinanthropometry coincided with the downfall of traditional radiology (Haymes et al., 1976). However, neither the advent of the "Bmode" models nor the real time ones which display successive images at a speed of 40 per second have managed to offset the lack of precision and the financial cost. In addition, their correlation with the values obtained by Densitometry is no better than the correlation obtained through measurement of the skinfolds.

## 3.3. Computed Tomography

Also known as CT, this method is a *radiological technique that allows a sequence of images to be obtained for segment of the body or the whole body*.

Basically, it consists in passing an X-ray beam through the area of the body being analyzed. Depending on the density of the tissues it goes through, the attenuation coefficient of the tissues is different. The attenuation coefficient is a value calculated by an emission counter and transformed into images by a computer.

Having a high capacity of anatomical resolution, especially in the hard parts such as the bone, the major drawback is the dangerous ionising radiation (6 scans of one arm account for 40% of the permitted radiation in one year) (Maughan et al., 1984).

The precursors of this technique in the field of kinanthropometry were Heymsfield et al. (1990), Bulke et al. (1979), Borkan et al. (1982) and Maughan et al. (1984).

As far as its precision is concerned, Sjöstrom et al.(1986) found that r=0.99 between the fatty mass values obtained by 40K and CT.

## 3.4. Nuclear Magnetic Resonance

Basically, *nuclear magnetic resonance (NMR) consists in detecting quantifying the magnetiza-*
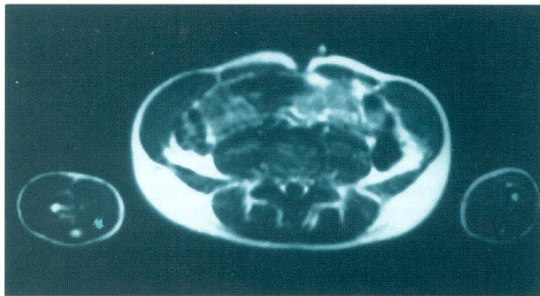
tion variations of a substance, generally Hydrogen nuclei, under the effects of a magnetic field.
To obtain a serial tomographic image of a body area, it has to be exposed to a magnetic field where the Hydrogen nuclei begin to resonate. This assumes absorption of radiofrequency energy that is freed by a process known as "relaxation". During the relaxation process, an electrical signal is induced in a receiving antenna and then processed by a computer to obtain the image.
The physical principles of NMR are due to F. Bloch and E. Purcell, a discovery which earned them the Nobel Prize for Physics in 1952 and which has undeniably been the second great revolution in image analysis since the discovery of the X-rays by Röntgen (Domènech et al., 1984) at the end of the last century.
*Nowadays, interest in NMR lies in the clinical diagnosis on two fronts: through images and through spectroscopy.* The latter, based on a study of nuclei such as $^1H$, $^{23}Na$, $^{31}P$ and $^{13}C$ helps us to gain better knowledge about cellular metabolism, with the interest that holds in both the clinical and sports medicine fields (Gili, 1984).
In the field of body composition evaluation, *the images obtained allow us to clearly differentiate between the soft tissues (fat, muscles and tendons) and the bone structures.*
Fat, because of its high content in Hydrogen nuclei and the biochemical setting they are in gives off a bright signal (white) on which the other tissues stand out. The cortical bone generates a less sharp image due to its low density in Hydrogen nuclei, whereas spongy bone and the bone marrow in particular produce a very high resonance signal due to their high fat content (figure 4).
It is clear to see that nowadays the use of NMR as a method for evaluating body composition can only be considered at experimental level, especially because of its financial cost and the required exposure time. However, its big advantages such as absence of irradiation and artifacts by bone and gas, good resolution and contrast of the soft parts, three-dimensional images, etc., make new exploratory channels and methodological proposals possible. These will undeniably allow us to improve our knowledge and validate the methods for kinanthropometric evaluation (figure 5 and Table 2).
For the above-mentioned reasons, the existing studies are quite recent and scarce. Among others, we would mention Cohn (1985), Dooms et al. (1986), Preuss and Bolin (1988), Hayes (1988), Staten et al. (1989) Seidell et al. (1990), Bachert-Baumann et al. (1990), Ross et al. (1991) and González de Suso, Pujol, Porta, Banquells, Prat and Capdevila (1992).
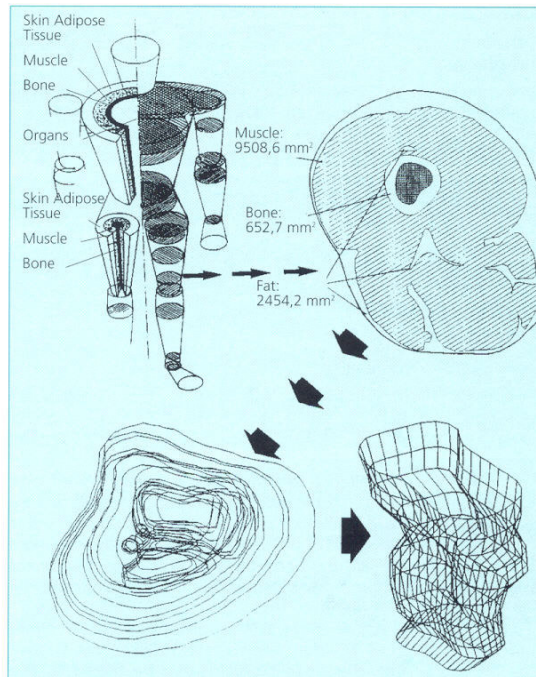


The latter of these studies, together with a doctoral thesis (Porta, J.), carried out with the collaboration of INEFC, Barcelona; CAR, Sant Cugat (Dr. González de Suso); Department of Morphological Sciences of the Faculty of Medicine, Barcelona (Dr. Tejedo) and the Centre Diagnòstic Pedralbes, Barcelona (Drs. Gili, Capdevila and Pujol), we hope to contribute some new key for evaluating body composition.

*Figure 5*
*Methodological proposal for the quantification and three-dimensional modelling of the principal body components.*

## 4.- Densitometry

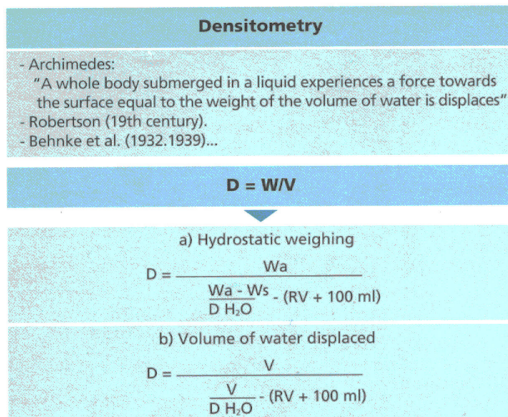Densitometry is undeniably the laboratory method most widely used to evaluate body fat mass and fat-free mass.
*Considered to be the standard method par*

*Table 2*
*Calculation of the percent body fat (%BF) by MRI and Anthropometrically (González de Suso, Pujol, Porta Banquells, Prat and Capdevila, 1992).*

| Sex | | MRI %BF | Yuhasz %BF | Faulkner %BF | Brozek %BF |
|---|---|---|---|---|---|
| Men | Measurement | 7.74 | 6.90* | 10.19** | 6.37*** |
| | Standard deviation | 2.52 | 0.93 | 1.00 | 1.70 |
| | Range | 3.14-12.67 | 5.93-9.33 | 8.98-12.61 | 4.19-10.62 |
| Women | Measurement | 15.05 | 12.81* | 10.82** | 15.87*** |
| | Standard deviation | 3.14 | 2.81 | 1.58 | 2.81 |
| | Range | 9.19-21.20 | 8.47-19.43 | 8.63-14.84 | 11.32-22.30 |

The significant statistical differences are the following:
(*) Between MRI and Yuhasz, P < 0,001 women and P < 0,05 men.
(**) Between MRI and Faulkner, P > 0,001.
(***) Between MRI and Brozek, P > 0,05 women and P > 0,001 men.

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## Densitometry

- Archimedes:
  "A whole body submerged in a liquid experiences a force towards the surface equal to the weight of the volume of water is displaces".
- Robertson (19th century).
- Behnke et al. (1932.1939)...

### D = W/V

a) Hydrostatic weighing

$$D = \frac{Wa}{\frac{Wa - Ws}{D\ H_2O} - (RV + 100\ ml)}$$

b) Volume of water displaced

$$D = \frac{V}{\frac{V}{D\ H_2O} - (RV + 100\ ml)}$$

*Figure 6*
*Theories and formulas of the densitometric method.*
*a) By hydrostatic weighing;*
*b) By the volume of water displaced (Porta, J., 1990).*

excellence to which all the others should look to for their scientific validation, densitometry is based on the "2-component" concept or model: total body fat (BF) and fat-free mass (FFM) or, according to Behnke, lean mass (Lean Body Mass) which also includes essential fat (Behnke, 1961).

Further to the historic antecedent of Archimedes well-known hydrostatic principle (figure 7), the closest origins can be found in the work done by Behnke et al. between 1932 and 1939 about the diffusion of gaseous nitrogen (N2) in the human organism. These studies proved to be determining in the rescue of the American submarine "Squalus" which sank in 1939 to a depth of 150m.

If the degree of floatability of an individual relatively reflects his or her amount of fatty mass in relation to total weight and fat-free mass, it is obvious - in line with the 2-component model, that there is a direct relationship between the density of the human body and its fatty mass content. To find out what its density (D) is, all we need to do is find out what its weight is both in and out of the water, since that is the relationship that exists between the weight and the volume (figure 6).

Once the body density has been established, the percent body fat (%BF) can be found by applying one of the following formulae:

**RATHBUN-PACE** (1945): $\%BF = (\frac{5.548}{D} - 5.044) \times 100$

**SIRI** (1961): $\%BF = (\frac{4.95}{D} - 4.5) \times 100$

**BROZEK** et al. (1963): $\%BF = (\frac{4.57}{D} - 4.142) \times 100$

**BEHNKE** and **WILMORE** (1974): $\%BF = (\frac{4.053}{D} - 4.614) \times 100$

**LOHMAN** (1984)*: $\%BF = \frac{530}{D} - 489$

*(Only for children between the ages of 8 and 12; $d_{LM} = 1.084$g/ml)
$d_{LM}$ = density of lean body mass

However, the claimed scientific validity of Densitometry is very relative as in principle it assumes that the densities of fat and lean mass are constant: 0.9g/ml and 1.1g/ml respectively; an assumption which is incorrect for the following reasons:

**1a.-** Regarding the hypothetical constant density of fat, the value of 0.9g/ml attributed to subcutaneous adipose tissue (Fidanza et al., 1953; Allen et al., 1959 - quoted by Martin, 1984) seems quite logical in that the former is composed almost exclusively of triglycerides. However, it should be borne in mind that the lipids making up the fat mass of other parts of the organism are more heterogenous and, besides triglycerides, may contain phospholipids, esters and lipid derivatives like cholesterol.

So, whereas only 1% of the subcutaneous adipose tissue is composed of cholesterol and phospholipids, the nervous system's fat may contain up to 50% of phospholipids and 25% of cholesterol with respective densities of 1.035g/ml and 1.067g/ml, meaning that the density of the brain's fatty mass would be approximately 1.005g/ml. However, as the amount of fat of the nervous system is only about 200g (Forbes, 1987 - quoted by Shephard, 1991), the error that may derive from using the value of 0.9g/ml for the density of total fatty body mass can be considered minimal, except when it is used for very thin individuals.

**2a.-** Undeniably, however, a more serious error is the one deriving from the consideration that the density of lean mass (LM) (1.1g/ml) is constant. In figure 7, we can see that body density values above 1.1g/ml would result in negative percentages of total body fat mass. Although some of these cases are cited in the available literature (Katch and McArdle, 1983; Pollock and Jackson, 1983; Adams et al., 1982), it is a physiological and anatomically assumption that is impossible to substantiate as, in principle, *the percentage of essential fat alone, without which an individual cannot live, is already 3 or 4%* (Wilmore, 1983).

The fundamental questions is the following: *What is the normal variability of the density of lean mass and how does it affect the estimation of the percentage of fat?*

In principle, it is important to note that the density of lean mass has never been directly measured in humans. The problem must therefore be solved indirectly. This will basically depend on:

**2.1.** *The variability if the relative proportions of its components*: muscle and bone mass, fat-free adipose tissue and organs; the latter two are components that make up the so-called residual mass.

**2.2.** *The variability of the densities of the mentioned components.*

Regarding the problem of the variability of each one of the lean mass components, it is acceptable to say that for an adult population between the ages of 20 and 50, the proportion of muscle mass in lean mass is between 40 and 60%.
As far as the densities of the other components of the above-mentioned lean are concerned, the variability of the bone mass is the one that causes most problems as it can vary - in relation to lean mass - between 12.5 and 18.7% (X = 15.6%).
It is clear to see that *it will be the variation of the bone component that will have the greatest repercussions on the value of lean mass density*. However, the percentage of muscle mass (density =1.07g/ml) in relation to lean mass is not particularly important in the likely variability of the density of the latter.
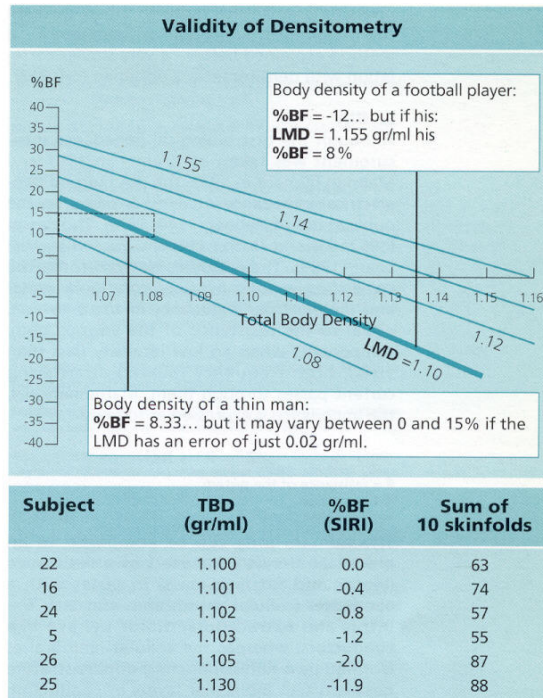*There are some population groups, though, in which the variability of lean mass density does indeed stand out.* In children it is lower as the lean mass contains much more water and less minerals. This means that if the normal reference values for adults are used ($d_{LM}$ = 1.1g/ml), the percentage of fat will be overestimated. In this sense, Lohman's equation (1984) to calculate the percent body fat assumes a $d_{LM}$ = 1.084g/ml.
In black adults, Shutte et al. (1983) - quoted by Martin (1984) - found values of 1.113g/ml for the mentioned $d_{LM}$.
Basing our arguments on the above-mentioned data, *it is clear to see that the density of lean mass as a constant should no longer be assumed in the scientific evaluation of body composition.* Thus, the question we must ask ourselves is as follows: *How will such variability affect the evaluation of the percentage of fat?*
The error that may result from using a constant value for all population types in general may be quite large. Thus an individual whose total body density is D = 1.08g/ml and for whom we take a $d_{LM}$ = 1.1g/ml; applying the Siri formula (as we can see in figure 7), his percent body fat will be equal to 8.33%.
*However, if we take a $d_{LM}$ value of 1.12g/ml, that is a difference of just 0.02g/ml, his BF percentage will be 15%. And if the $d_{LM}$ = 1.08g/ml, the percent body fat will be 0%. In other words, a difference of 47.9% in his percentage of fat!* (Martin, 1984).
Finally, yet no less importantly, it must be



**Validity of Densitometry**

Body density of a football player:
**%BF** = -12… but if his:
**LMD** = 1.155 gr/ml his
**%BF** = 8 %

Body density of a thin man:
**%BF** = 8.33… but it may vary between 0 and 15% if the LMD has an error of just 0.02 gr/ml.

| Subject | TBD (gr/ml) | %BF (SIRI) | Sum of 10 skinfolds |
|---------|-------------|------------|---------------------|
| 22 | 1.100 | 0.0 | 63 |
| 16 | 1.101 | -0.4 | 74 |
| 24 | 1.102 | -0.8 | 57 |
| 5 | 1.103 | -1.2 | 55 |
| 26 | 1.105 | -2.0 | 87 |
| 25 | 1.130 | -11.9 | 88 |

Negative predictions of body fat in football players (Adams et al., 1992).

borne in mind that the densitometric method used for the evaluation of the percent body fat may be affected by the individual's degree of hydration.
*To conclude*, we can affirm that, although the densitometry protocols have constantly been improved since the Behnke proposed them almost fifty years ago now, they are considered to be the reference method for the evaluation of body composition, *the variability in the relative proportions and densities of the fat components may produce substantial errors.*

**DOUBLE INDIRECT METHODS**

**1.- TOBEC**
The TOBEC method (*Total Body Electrical Conductivity*), also based on the 2-*component* model, attempts to measure the amount of water present in the organism *taking into account that lean mass has a greater electrolyte content than fat.*
The correlation of this method with densitometry is very high, r=0.962 (Segal et al., 1985), though the complex infrastructure required

*Figure 7*
*Curve graph to fin out the percent body fat according to different lean body mass densities by the Siri formula. (Taken from Martin, 1984 -modified-).*

limits its use. All the more so when through the measurement of electrical impedance - a method explained below - a very similar correlation with densitometry is obtained (r=0.912).

## 2.- BIA

Although the first biological impedance measurement was taken by Cremer in 1907 and Mann in humans in 1937, the BIA method (Bioelectrical Impedance Analysis) is based on the publications of Nyboer (1940, 1970), Thomasset (1962, 63) and Hoffer (1969) - quoted by Van Loan (1990). These studies *demonstrated the correlation existing between total body water and the electrical impedance of the organism*, equal to the resistance of the various body components when an low intensity (less than 1mA), high frequency (50kHz) alternating current passes through them. Mathematically, the impedance is expressed as follows:

$$Z^2 = R^2 + Xc^2$$

R = resistance of the system
X = reactance

The human body can be compared to an electrical circuit composed of a resistance (water and fat-free mass) in series with a condenser (cellular membranes and fat). The intra- and extracellular fluids behave like conductors, whereas the cellular membranes (formed by a non-conducting double stratum between two molecular layers of conducting protein material) behave like capacitating or condensing elements.

Thus, by measuring the electrical impedance or some if its parameters, *it is possible to determine the amount of water in the organism and, indirectly, the percentages of the fat and lean components given that the latter contains practically the body's water (73.2%).*

The measurement is based on the physical observation that for a frequency and a volume of the specific conductor:

Z = pL/A. Multiplying by L/L, gives:
$Z = pL^2/AL$ (P = resistance [Ohms], L = conductor length [cm], A = conductor area [cm²]). AL = volume:

$$V = pL^2/Z$$

Although today there are several authors who have validated the BIA method (Presta et al., 1985; Lukasky et al., 1986; Ross et al., 1989), affirming that this method constitutes a good system for evaluating the total amount of water and fat in our organisms through the measurement of the electrical impedance components (resistance and reactance or capacitance), the reality of the matter is that those studies used the 2-component reference model (Body Fat and Lean Body Mass or Fat-Free Mass) which automatically implies the assumption that the density of FFM is constant (in one or different subjects). This aspect, as we have seen already in the analysis of the densitometric method, is very variable.

To obtain reliable data with this method, it is essential to follow a protocol that is affected by many variables. Thus, the degree of body hydration may vary in the same individual depending on the time of day when the measurement is taken or on forced dietary regimens. Furthermore, in high level competition, these aspects can be even more determining, being affected to a large extent by the type of training and competition.

It is clear to see, therefore, that if we bear in mind that although the resistance to a low intensity, high frequency electrical current is directly related to the volume of the conductor (fat and lean masses), *the factor that will really limit the conducting capacity of our organisms is the number of electrolytes in the water.* In other words, the hydration or dehydration index.

Furthermore, *the validity of the measurement of body fat or lean body mass will depend on the type of equations (double indirect) included in the software programme of the equipment used.*

## 3.- NIR

NIR (*Near Infrared Reactance*) is a technique used since 1965 in the United States (Department of Agriculture) to evaluate the chemical composition of food, and it is *based on the specific absorption features that certain materials have under a light source.* This absorption capacity determines the greater or lesser reflection as compared to standard sample (Conway et al., 1984).

Knowing that pure fat "absorbs" waves whose length is 930nm, that water does the same with waves whose length is 970nm, and that the logarithmic coefficients of absorption vary linearly in relation to the concentration of a specific component, equations of regression can be developed taking into account weight, stature, sex and race, providing evaluations of fatty and lean mass which are sufficiently valid.

In this sense, very few validation studies have been carried out (Conway et al., 1984) and even though the two done in the United States (Human Nutrition Research Center - Beltsville, MD) proved that the body fat evaluation using NIR is technically possible and scientifically valid (r = 0.91 with densitometry and skinfolds), its commercial adaption still has a few important question marks.

Basically, the main question is knowing up to what point the use of a much less sensitive spectrometer (50nm instead of 5nm as used in the pilot studies) can validate the system. ▰

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