Body composition assessment. Critical and methodological analysis*

Part II

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4. Anthropometry

As the name indicates, *anthropometric methods derive from the use of body measurements or parameters*. They can be divided into two groups depending on whether or not they allow a theoretically direct evaluation of body fat.

4.1. Indirect adiposity indices

These indices, constitute one of the most simple proposals for the evaluation of body composition. With very clear antecedents in the normative-descriptive theories of Quetelet (1833), and more specifically of his well-known index:

$$\text{Q.I.} = \text{Weight/Stature}^2\ (\text{kg/m}^2)$$

...and later, since 1953, known as the Body Mass Index (BMI) (Keys and Brozek, 1953), it has had a great influence in the public health setting (figure 8).

In reality, the BMI is nothing more than a statistical-mathematical manipulation of weight and height. Its fundamental limitation lies in the assumption on which it is based: *Any weight that exceeds the values determined by the "stature-weight" tables is body fat...*, is not absolutely true.

It is clear to see that this excess of weight may also be due to an increase in muscle or bone mass. Thus, its use or interpretation as an adiposity or health status index (morbidity) is not much more valid than the well-known existing "ideal weight" tables (Crawford, 1991) (table 3).

Another highly-used index in the epidemiological field (figure 9) is the one resulting from dividing the girth of the waist by the girth of the gluteal (hip) (*I = Waist Girth/Gluteal[hip] Girth*), which is related to the amount of visceral fat (Ross et al., 1991).

The ponderal index: $PI = W/S^{1/3}$, used by Carter to evaluate the ectomorphic component of the somatotype (Carter and Heath, 1975), was based on the consideration that the weight of an individual is proportional to his volume and that the latter varies as a cube function of its linear dimensions. However, now it has been proved that weight in men varies more as a function of the square of stature.

Finally, *the index determined by the sum of the various skinfolds* is probably the one that has a more objective evaluation to better estimate and control the adiposity index in that its increase or decrease is fundamentally determined by the greater or lesser amount of subcutaneous adipose tissue.

4.2. Formulae deriving from the use of weight, stature, skinfolds, girths and body breadths.

These formulae are the most commonly used ones because they theoretically allow the various components to be quantified, particularly muscle mass and fat or adipose tissue mass in a relatively easy and functional manner.

The first person who proposed a rational and scientific method to evaluate one or another of the body components was J. Matiegka who, in 1921, developed a series of formulae to estimate the weight of the skin and the subcutaneous cellular tissue, the skeletal muscular mass, the bones and a so-called residual component that included the various organs, viscera and fluids.

This *4-component* model was based on the use of anthropometric measurements directly related to the tissues being evaluated and to some limited data gathered from the dissection of cadavers by Vierord, 1890-1906 (quoted by Matiegka, 1921).

However, due to the lack of samples or data relating the dissected bodies that could validate his results and the increase in popularity of the chemical methods, his proposal gradually stopped being used.

Between 1932 and 1935, as explained in the sections about chemical methods and densitometry, the *2-component* concept or model came into being.

In 1951, Brozek and Keys published the first equations of regression to evaluate body fat using skinfolds.

In 1956, Von Döbeln (1964) developed an equation to calculate bone weight, modified in 1974 by Rocha (1975), giving rise to the *3-component* model.

$$\textbf{Bone Weight}\ (kg) = 3.02 \times (s^2 \times w.w. \times e.f.w. \times 400)^{0.712}$$

s = stature (m)
w.w. = wrist width (m)
e.f.w. = epicondylar femur width (m)

The first method of evaluating body composition in relation to a reference model is attributable to Behnke who, in 1959, proposed the representation of the human body as a cylinder whose length "H" was equal to the height of the individual and whose radius was equal to the mean radius deriving from a series of perimetric body measurements (Behnke and Wilmore, 1974).

Using this model, Behnke could estimate the weight of the subject and, assuming that body density was uniform (1g/ml) the mass or

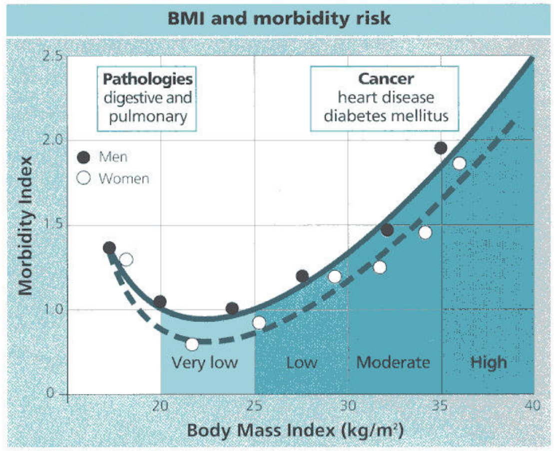


Figure 8
As the BMI increases, so does morbidity from heart disease, cancer and diabetes.(Bray, G.A.; Gray, D.S., 1978).

Ideal weight and Body Mass Index

	Height (cm) (without shoes)	Min. weight	BMI Min. weight (kg)	Max. weight	BMI Max. weight (kg)	BMI Dispersion (màx-min)
Men	155.5	58.3	24.1	68.3	28.2	4.1
	160.5	60.0	23.3	71.1	27.6	4.3
	165.5	61.8	22.6	74.7	27.3	4.7
	170.5	63.6	21.9	78.2	26.9	5.0
	175.5	65.4	21.2	81.8	26.6	5.3
	180.5	67.7	20.8	85.4	26.2	5.4
	185.5	70.3	20.4	89.4	26.0	5.6
	190.5	73.5	20.3	93.9	25.9	5.6
	Mean		21.8		26.8	5.0
Women	145.5	46.4	21.9	59.8	28.2	6.3
	150.5	47.4	20.9	62.4	27.5	6.6
	155.5	49.3	20.4	65.3	27.0	6.6
	160.5	51.9	20.1	68.8	26.7	6.6
	165.5	54.6	19.9	72.4	26.4	6.5
	170.5	57.3	19.7	75.9	26.1	6.4
	175.5	60.0	19.5	78.6	25.5	6.0
	180.5	62.6	19.2	81.2	24.9	5.7
	Mean		20.2		26.6	6.4

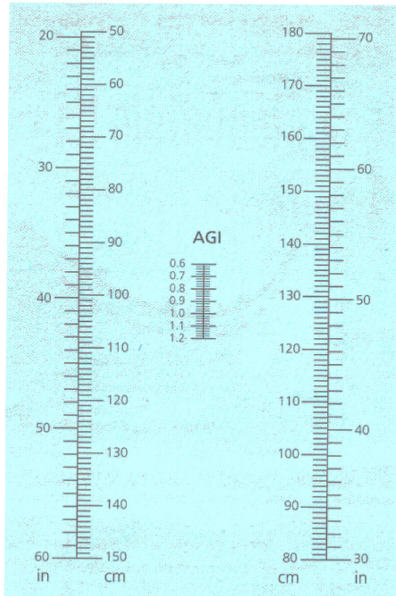
Table 3
The "stature-weight" table of Metropolitan Life Insurance with the maximum and minimum values and their respective BMIs (Crawford, 1991).

weight could be equalled to a volume. To estimate lean mass, he used the following anthropometric equations:

$$LBW^{*}\ (♂) = D^{2**} \times H^{0.7} \times 0.263$$
$$LBW^{*}\ (♀) = D^{2**} \times H^{0.7} \times 0.255$$

*LBW (Lean Body Weight) is equal to fat-free mass plus

Figure 9
The abdominal or waist/gluteal or hip index (AGI). To arrive at the index, a ruler is placed between the abdominal and gluteal values and the result is read of the central scale. For a women between the ages of 40 and 49, a value of 0.8 would signify a high morbidity risk, whereas for a man, the value would be around 0.95. Bray, G.A. and Gray, D.S. (1978).



essential fat (the latter being equivalent to approximately 3% of total body weight).
**D is the sum of the four body breadths (biacromial, biiliocristal, wrist and ankle) divided by the sum of their respective K values (D = 4d/K).

The concept of the *"K" value* used by Behnke in his somatograms is equal to the mean of each one of the 11 girth measurements of a population group, divided by the radius the mean body radius (R_{body}) of that sample. In turn, that radius is individually obtained using the following formula:

$$R_{body} = (Weight / 3.1416 \times Stature)^{0.05}$$

At the beginning of the 60s, Sloan et al. and Young et al. (quoted by Shephard, 1991) published equations of regression for specific age groups of women, though it was from the 70s onwards that the advent of personal computers aided the development of equations of multiple regression which were more valid.
The problem was that *all these equations were linear or specific*. In other words, they did not take into account the potential changes that age could have on bone density, regional distribution of adipose tissue and fat, and the relationship between subcutaneous or visceral fat deposits. This meant that the equations could only be applied to a population group identical or similar to th sample for which they had been developed. So, for example, *if a linear equation develo ped for one sex is applied to the opposite sex there is a routine error of approximatel 0.025g/ml in the evaluation of body density o 11% in body fat.*
In the same sex, if the equations derive from an adolescent group are applied to a group of high-level middle-to-long distanc runners, the percentage of fat in the latte would obviously be overestimated; wherea if they are applied to a group of middle aged adults, the percentage of fat would be underestimated.
As usual in the public health setting, it is logi cal to think that if we deal with heteroge nous populations, more general equation should be used. The first people to develop general equations of multiple regressior were Durnin and Womersley in 1974. These equations are still quite often used ever though several authors have demonstratec that they excessively overestimate the percentage of fat (Sinning et al., 1984).
The equations proposed by Yuhasz in the *Physical Fitness and Sports Appraisal Laboratory Manual* of the University of Westerr Ontario (London, Canada, 1977) for young adults aged between 18 and 30 have also been widely employed.

$$\%BF (♂) = 3.64 + (0.097 \times 6 \text{ skinfolds*})$$
$$\%BF (♀) = -4.294 + (0.221 \times 6 \text{ skinfolds**})$$

* Sum in mm of pectoral, triceps, subscapular, suprailiac, abdominal, and front thigh skinfolds
** Sum in mm of triceps, subscapular, suprailiac, abdominal, front and back thigh skinfolds
Regarding the suprailiac fold, it is important to mention that there is some discrepancy concerning its exact location. This skinfold corresponds to the iliocristal skinfold located just above the midaxillary iliac crista and it is measured forwards and downwards forming a 45° angle on a horizontal plane. However, several authors take this skinfold measurement vertically (Wilmore and Behnke, 1969; Sloan and Weir, 1970). Finally, they should not be confused with the anterior suprailiac skinfold or the supraspinal skinfold which is located along an imaginary line that runs from the anterosuperior iliac spine (EIAS) to the axillary. The latter skinfold is measured between 5 and 7 cm above the EIAS one, following the skin tension lines downwards forming a 45° angle on a horizontal plane.

For the MOGAP project (Montreal Olympic Games Anthropological Project, 1976), and due to the lack of specific formulae for athletes, Carter developed some new equations based on the data contained in the above-mentioned manual. These equations are based on the relationship between the skinfolds of Yuhasz's study's subjects (Physical Education teachers of both sexes) and the body density obtained by densitometry. The resulting linear equations were mathematically corrected to be able to convert the density into a percent body fat using Siri's formula (Carter, 1986):

$$\%BF\ (♂) = 2.585 + (0.1051 \times 6\ skinfolds^*)$$
$$\%BF\ (♀) = 3.580 + (0.1548 \times 6\ skinfolds^*)$$

* Sum in mm of triceps, subscapular, supraspinale (front suprailiac), abdominal, front thigh and medial calf skinfolds

It is logical to think that the mentioned formulae are well-suited to their use on athletes. For more heterogenous population groups, the general equations having a greater correlation to and lower standard error in the value obtained by densitometry are the ones proposed by Jackson and Pollock (1978) and Jackson, Pollock and Ward (1980). These equations are suitable for young athletes, both men and women.

$$BD\ (♂) = 1.097 - 0.00046971\ (X_1) + 0.00000056\ (X_1)^2 - 0.00012828\ (X_2)$$

$$BD\ (♀) = 1.1120 - 0.00043499\ (X_1) + 0.00000055\ (X_1)^2 - 0.00028826\ (X_2)$$

BD = Total body density (g/ml)
X_1 = Sum in mm of seven skinfolds: pectoral, midaxillary, triceps, subscapular, suprailiac, abdominal, and front thigh
X_2 = Age in years

At the beginning of the 80s, coinciding with the advent of modern Spanish Kinanthropometry, two new proposals were developed based on the Matiegka's *4-component* model: the one by De Rose and Guimaraes (1980) (De Rose and Aragonés, 1984) and the one by Drinkwater and Ross (1980). *The first one is of major importance in the Spanish setting because in general it has been the only used up to the present* to calculate the different body components. It uses the following formulae:

A.- For total body fat, the equation of Faulkner (1968), derived from Yuhasz (1962).

$$\%\ BODY\ FAT = 5.783 + (0.153 \times 4\ skinfolds^*)$$

* Sum in mm of triceps, subscapular, suprailiac, and abdominal skinfolds

B.- For bone mass, the equation of Von Döbeln as modified by Rocha.

$$BONE\ weight\ (kg) = 3.02 \times (stature^2 \times wrist\ width \times epicondylar\ femur\ width \times 400)^{0.712}$$

Body composition of a group of decathletas

	Subject	Mass (kg)			%			
		Musc.	Fat	Bone	Musc.	Fat	Bone	Resid.
Women	A.P.	31.5	6.8	9.8	51.76	11.16	16.16	20.90
	I.A.	33.5	6.4	9.8	53.30	10.21	15.59	20.90
	M.G.	29.8	6.9	12.2	50.15	11.68	17.26	20.90
	P.G.	28.5	6.0	8.9	51.89	10.98	16.22	20.90
	M.M.	33.3	7.8	9.8	51.72	12.11	15.26	20.90
	M.F.	27.6	5.4	8.4	52.59	10.40	16.10	20.90
	I.C.	31.3	6.4	12.8	50.96	11.01	17.12	20.90
Men	R.Z.	33.8	7.9	11.3	48.42	11.28	16.18	24.10
	J.G.	31.0	6.5	12.0	47.47	10.03	18.39	24.10
	F.B.	37.0	10.2	13.3	46.36	12.84	16.69	24.10
	A.B.	39.0	8.9	14.5	47.39	10.82	17.68	24.10
	A.B.	39.9	6.7	11.3	49.62	9.78	16.49	24.10
	J.A.	37.3	8.4	12.7	48.45	10.95	16.49	24.10
	A.P.	42.3	9.5	15.7	47.52	10.67	17.69	24.10

***Table 4** Body composition of a group of decathletes (Porta, 1988).*

C.- For muscle mass, Matiegka's basic proposal.

$$MUSCLE\ weight\ (kg) = W_{Total} - (BF + BW + RW)$$

D.- For residual mass (organs, fluids, etc.), the constants proposed by Würch in 1974.

$$RESIDUAL\ weight\ (kg)\ (♂) = W_{Total} \times 24.1/100$$
$$RESIDUAL\ weight\ (kg)\ (♀) = W_{Total} \times 20.9/100$$

The problem arising from the proposal put forward by De Rose and Guimaraes is that it has been badly interpreted by many people. This has occurred because the Yuhasz-Faulkner formula for the estimation of body fat is specific to a population group; to young men.
Léger and Cloutier also point this out in their "Notes de Cours" d'Evaluation de l'Aptitude Physique de l'Université de Montréal (1981), when they mention that having read Yuhasz's 1962 doctoral thesis, so often quoted by many authors, they did not find any reference to that formula. The data contained in Table 4 show just how incongruent the indiscriminate use of that proposal can be in mixed athlete populations. No only for comparative purposes between the sexes, but also in terms of the abnormally high values of the muscle mass percentage deriving in women, higher even than in men. An assumption which is anatomically and physiologically unfounded.

Based on the original data of the Belgian cadaver study, Dr. Galiano (personal communication) propose a new correction formulae for the assessment of percent body fat in adults men:

%BF (♂) = value as per FAULKNER 6.036 / 0.272

The second proposal, based on Matiegka's basic *4-component* model is the one by *Drinkwater and Ross (1980) which, in a second version (Drinkwater, 1984) adds a "5th" component, the skin*, offering the peculiarity of using anthropometric measurements previously adjusted to the asexualised reference model or "Phantom" (Ross and Wilson, 1974) (figure 10). Thus, for the calculation of each anthropometric variable or parameter used, the following formula is employed:

$$Z = 1/s \times (V/170.18/h)^d - P)$$

Z = Proportional value of the "Phantom"
s = Standard deviation of variable V
d = Dimensional constant: 1 for lengths, breadths and girths; 2 for areas and 3 for weights
h = The subject's real height in cm
V = Anthropometric variable or parameter
P = Value of the variable V in the "Phantom"

To calculate the masses of the 4 or 5 different components:

$$M = (Z \times s + P)/(170.18/h)^3$$

M = One of the models components
Z = Mean values proportional to the "Phantom" in the variables associated to the analyzed component
P = Value of the component analyzed in the "Phantom"
s = Standard deviation of the "Phantom" for each component
h = The subject's real height in cm

It is clear to see that the fractionated method of Drinkwater and Ross (1980) is a combination of Matiegka's proposals (1921), as it uses the mean of several girth and length measurements and a coefficient to estimate the weight of the different tissues, and Behnke's proposals (1961), as it uses the deviations of a particular subject in relation to a reference model to estimate the weight of lean mass.
However, this method presents two problems. The first is the lack of sensitivity for taking into account the differences between the different body regions, thus making its application difficult in children. The second depends on the internal consistency of the "Phantom" itself, developed by Ross and Wilson in 1974, particularly with reference to the correlation between the linear anthropometric measurements and the assigned tissue weight values, as it assumes some constant values for their densities (Shephard, 1991).
The likely solution to this problem, from a functional point of view at least, may lie in the already known yet currently rarely used "O-SCALE" (Ward, Ross, Leyland and Selbie, 1989) that Porta introduced into Spain after his stay with Ross at the Simon Frazer University in Vancouver, Canada.
Developed on a wide-ranging database of information on the 24,000 subjects included in the Canadian programme "YMCA-LIFE" (Bailey et al., 1982), it has the following fundamental features:

1. There are 44 age and sex groups. 17-18 years; 18-19 years and, from the 20-24 age group, there are 5 year increments up to the age of 70.

2. It uses a geometric comparative evaluation in the context of a wide-ranging database.

3. It does not depend on the theoretical biological constant of a determined proportion or density of the tissues.

4. It provides a detailed description of the physique and body composition in both absolute values and relative values or proportionately to the reference height (170.18cm). Likewise, a comparison of the percent body fat values is made according to the equations of Yuhasz, Sloan, and Durnin and Womersley, mentioned above.

5. There are two versions that make it easier to use: the complete version and the short version. The latter, in addition to weight and height, only requires the measurement of 6 skinfolds and three girths. The complete version requires 8 skinfolds, 10 girths and 2 body breadths.

Finally, and as a colophon to this review of the most significant anthropometric formulae, we believe that it is important to refer to the proposals of Martin et al. (1990) and Martin (1984), as they are the only valid equations with a direct method (Belgian study of cadavers) and, furthermore, their results coincide with other known ones gleaned from anatomical dissection. However, we should bear in mind that the equations given below estimate muscle and bone mass in relation to total adipose tissue-free mass.

$$M.M.(♂) = STAT\ (0.0553\ Gdd^2 + 0.0987\ Ga^2 + 0.0331\ Gbb^2) - 2445$$
$$(r^2 = 0.97;\ SE = 1.53\ kg)$$

* For the evaluation of muscle mass in women, the formula used is still the one proposed by Martin (1984):

$$M.M.(♀) = 32.71\ Gaa^2 + 4.155\ Gdd^2 + 4.090\ Gbb^2 - 2149$$
$$(r^2 = 0.93;\ SE = 1.43\ kg)$$

STAT = Stature (cm)
M.M. = Muscle mass (g)
Ga = Forearm girth
Gaa = Forearm girth corrected*
Gbb = Calf girth corrected*
Gdd = Thigh girth corrected*

* Corrected girth = Girth - 3.1416 x skinfold (cm)

For the evaluation of bone mass, the formulae used are the ones proposed in 1984:

$$B.M.(♂) = 28.0 \times Z1 + 0.4815 \times Z2 + 1.377 \times Z3 + 4265$$
$$(r^2 = 0.98;\ SE = 222\ g)$$

$$B.M.(♀) = 0.1822 \times Z4 - 6.415 \times Z5 + 1.145 \times Z6 + 787$$
$$(r^2 = 0.79;\ SE = 479\ g)$$

B.M.= Bone mass (g)
Z1 = Wrist width² x ankle width
Z2 = Head girth x epicondylar humerus width x biacromial breadth
Z3 = Head girth x epiconylar humerus width x epicondylar femur width
Z4 = Head girth x wrist width x stature
Z5 = Epicondylar femur width² x wrist width
Z6 = Epicondylar humerus width² x ankle width

Conceptual considerations in relation to the validity of body composition assessment methods

When it comes to making a choice between one method or another, or one equation or another, the following aspects should be borne in mind:

A.- *Knowing exactly* what it is that we are attempting to quantify or, more precisely, *estimate.*

B.- *Its intrinsic or extrinsic value.*

C.- *Its accuracy.*

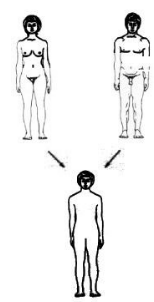
Regarding point "A", there is some confusion about he definition and nomenclature of some components, terms and even concepts concerning body composition. This confusion normally arises when considering *fat*, a component which is often mistakenly used as a synonym for adipose tissue.
Technically and biochemically, fat can be defined as: *the lipids that can be extracted using*

Values (P) and standard deviation (SD) of the "Phantom" (Ross, W.D. & Wilson, N.)

		P	SD
Heights	Stature Total	170.18 cm	6.29
	Sitting	90.78 cm	4.54
	Acromial	139.78 cm	5.45
	Radial	107.25 cm	5.37
	Stylion	82.68 cm	4.13
	Spinale	96.32 cm	4.81
	Trochanterion	87.90 cm	4.40
	Tibial	46.98 cm	2.68
	Malleolar	8.01 cm	0.96
Derived lenght	Upper extremity	75.95 cm	3.64
	Arm	32.53 cm	1.77
	Forearm	24.57 cm	1.37
	Hand	18.85 cm	0.85
	Lower extremity	79.40 cm	3.97
	Thigh	32.42 cm	1.66
	Leg	38.97 cm	2.22
	Foot	25.50 cm	1.16
Body comp.	Total weight	64.58 kg	8.60
	Fat mass	12.13 kg	3.25
	Bone mass	10.49 kg	1.57
	Muscle mass	25.55 kg	2.99
	Residusl body mass	16.41 kg	1.90

		P	SD
Breadths	Acromial	38.04 cm	1.92
	Bideltoid	43.50 cm	2.40
	Side Transv. chest	27.52 cm	1.74
	Anter-post. chest	17.50 cm	1.38
	Biiliocristal	28.84 cm	1.75
	Bitrochanterion	32.66 cm	1.80
	Epicondylar humerus	6.48 cm	0.35
	Wirst	5.21 cm	0.28
	Epicondylar femur	9.52 cm	0.48
	Malleolar	6.68 cm	0.37
Girth	Chest	87.86 cm	5.18
	Arm relaxed	24.88 cm	3.67
	Arm flexed and tensed	29.41 cm	2.37
	Forearm	25.13 cm	1.41
	Fist	16.35 cm	0.72
	Thigh	55.82 cm	4.23
	Ankle	21.71 cm	1.33
Skinfolds	Triceps	15.40 mm	4.47
	Subscapular	17.20 mm	5.07
	Suprailiac	15.20 mm	4.47
	Abdominal	25.40 mm	7.78
	Front thigh	27.00 mm	8.33
	Medial calf	16.00 mm	4.67

***Figure 10** The "Phantom" reference model with its values (P) and standard deviations (SD) (Ross and Wilson, 1974).*



Phantom

Estimation of different fat deposits				
Specificity		Fat deposit		
		Adipose tissue		Esential fat
		Subcutaneous	Visceral	
Anthrop.	Skinfolds	XXX		
Anthrop.	Girths and Breadths	X	X	
Imaging	Ultrasound	XXX		
Imaging	CT	XXX	XXX	
Imaging	NMR	XXX	XXX	
Densitometry		XX	XX	XX
BIA H_2O and K		X	X	X
Chemical-Physical		X	X	X

Figure 11
Specificity of the methods for evaluating body composition in terms of the different fat deposits. The rectangles indicate simultaneous prediction of the different fatty deposits. The number of "X"s indicates the method's efficacy (Léger, 1992 - modified).

an ether solution. Thus, the terms lipids and fat can be used synonymously. Fat is formed by: *deposited lipids* (triglycerides and free fatty acids), *essential lipids* (phospholipids, cholesterol), *lipoproteins and waxes.*

Adipose tissue, *the dissectionable mass*, includes subcutaneous and visceral adipose tissue, as well as a limited amount of intramuscular adipose tissue. It is formed by: *Fat or lipids*, with a variability between 42.4 and 94.1% of total adipose tissue (Martin, 1984), or between 60 and 85% (Shephard, 1991), *water*, with a variability between 4.4 and 53% (Martin, 1984) and *vascular and nerve tissue.*

Taking these considerations into account, it is clear to see that *the use of the terms fat or adipose tissue will depend on the method used.* To be more precise, when anthropometric methods are used, it would be more congruent to speak of "adipose tissue", whereas when densitometric methods are used, it would be more correct to refer to "fat" (figure 11).

Regarding point "B", intrinsic validity will be determined by the conceptual limitations and extrinsic validity will be determined by the correct application of the protocols and statistical procedures.

An example of *limited intrinsic validity would be the case of applying equations of linear regression to heterogenous populations*, or claiming to evaluate the percentage of fat through adiposity indices and *"stature-weight"* tables (table 3).

Extrinsic validity is usually very constrained in all the complex protocol methods, whether because of the size of the studies or because they require the measurement of many anthropometric parameters,

B.2. Wrongly using the constant values independently of age, sex and physical training for:

- **2.1.** The densities of the fat and lean mas ses (0.9 and 1.1g/ml, respectively).
- **2.2.** Amount of fat in the subcutaneous adipose tissue.
- **2.3.** Relationship between the subcutaneous and visceral adipose tissue, and essential fat.
- **2.4.** Thickness and compressibility of the skin.
- **2.5.** Regional distribution of the adipose tissue and fat.

In reality, whatever the method employed is, when an anthropometric formula is used to estimate body density and the percentage of fat, we must be aware of the fact that the their accuracy is relative as they always carry some implicit error.

So, regarding the level of accuracy required, as mentioned in point "C", the most important statistical parameter when it comes to evaluating the accuracy of an equation of estimation is the so-called Standard Estimation Error (SEE) which can be defined as follows:

The SEE value should be between 0.007 and 0.008g/ml which, as a percentage and in relation to body fat estimation, assumes an Standard Error between 3.1 and 3.6%. This error does not include the one generated in

the estimation of the percentage of body fat with the densitometric method using any of the existing formulae (Siri, Brozek, etc.). The error is due to the variability of the lean mass density and may vary between 2.5% according to Lohman and 3.5% according to Siri (quoted by Jackson, 1984).
Thus, these errors are independent and must be added together. Taking into account the formula for finding out the SE of the percentage of fat:

$$SEE = \sqrt{\text{Error variance estimation of the \% Body Fat by Densitometry} + \text{Error variance estimation of the \% Body Fat by an equation of regression}}$$

Where the total SEE is 4.6%.

General Conclusions

1a.- Knowledge and evaluation of body composition is becoming more and more important and necessary in the field of physical activity and sports medicine in that the individual's health and functional capacity depend on the amount and proportion of fundamental tissues.

2a.- For the moment, awaiting the most conclusive results on the quantification of the various components of the human organism, especially by means of NMR imaging techniques, we must accept that all the existing methods and formulas can only offer is a relative evaluation of body composition. In Katch and Behnke's (1984) own words, "...an estimation rather than a quantification of the various components".

3a.- Although fat is one of the main components of adipose tissue, they are not synonymous terms or concepts. The use of the terms basically depends on the evaluation method used.

4a.- The Standard Estimation Error (SEE) in general equations of 3.5% in men and 4% in women (an error similar to linear or specific equations) does not include the biological error associated to the estimation of the percentage of fat (up to 3.6% according to Siri) by the densitometric method using the equations of Siri and Brozek (Lohman, 1984).

5a.- Although it can continue to be taken as a reference method, Densitometry should not be considered as the "standard" method and less still as an absolutely valid one, as a variation in the density of lean mass of just 0.02g/ml on the adopted constant value of 1.1g/ml may produce a difference of 47.9% in the evaluation of body fat.

6a.- The choice of the best-suited method or equation for the evaluation of body composition should be based on the following considerations:

6.1.- Use of formulae with intrinsic and extrinsic validity.

6.1.1. Choice of equation best suited to each population group. If the latter is heterogeneous, general equations should be used.

6.1.2. Use of those equations that contain significant anthropometric parameters (preferably validated with direct methods) to estimate each one of the body components in all body regions. Thus, for example:

- **Total body fat:** Front thigh and medial calf skinfolds (r = 0.867 and r = 0.84 in men and women, respectively, according to Martin, 1984); and the sum of the triceps, suprailiac and thigh (r = 0.89 in men) or pectoral, abdominal and thigh (r = 0.84 in women) according to Jackson, Pollock and Ward (1980).

- **Muscle mass:** Corrected forearm girth (r = 0.998 and 0.915) in men and women, respectively, according to Martin (1984).

Table 5
Linear correlations between body density and different anthropometric variables in adults (Jackson and Pollock, 1978; Jackson, Pollock and Ward, 1980).

	Variables	Men n=402	Women n=283
General measurements	Stature	-0.03	-0.03
	Weight	-0.63	-0.63
	BMI (weight/stature ^{2})	-0.70	-0.70
Skinfolds	Pectoral	-0.85	-0.64
	Midaxillary	-0.82	-0.73
	Triceps	-0.72	-0.77
	Subscapular	-0.77	-0.67
	Abdominal	-0.83	-0.75
	Suprailiac	-0.76	-0.76
	Thigh	-0.74	-0.74
Skinfolds	Sum of three Women: Triceps, suprailiac, thigh Men: Pectoral, abdominal, thigh	-0.89	-0.84
	Sum of seven	-0.88	-0.83
Girths	Waist	-0.80	-0.71
	Gluteals	-0.69	-0.70
	Thigh	-0.64	-0.68
	Biceps	-0.51	-0.63
	Forearm	-0.35	-0.41

Table 6
Classification by ideal percentage of fat in different population groups (Wilmore, 1983 and Lohman, 1981).

Ideal percentage of fat		
Clasification by percentage		
Clasification	**Men**	**Women**
Thin	< 8%	< 15%
Optimum	8-15%	13-20%
Slightly overweight	16-20%	21-25%
Overweight	21-24%	25-32%
Obese	≥ 25%	≥ 32%
Long-distance runners	4-9%	6-15%
Wrestlers	4-10%	——
Gymnasts	4-10%	10-17%
Body builders (elite)	6-10%	10-17%
Swimmers	5-11%	14-24%
Basketball players	7-11%	18-27%
Rowers	11-15%	18-24%
Tennis players	14-17%	19-22%

- **Bone mass:** Wrist width for men (r = 0.875) and epicondylar humerus width (r = 0.599) in women, according to Martin (1984).

6.1.3. Control of the reliability and reproducibility of the measurements.

6.2. When using anthropometric formulae of regression, the SEE obtained is more important than the correlation with the densitometric reference method.

6.3. Choice of methods or equations which, satisfying the above considerations, are more functional in terms of both the necessary infrastructure (financial cost of the necessary material) and the method. In this sense and as shown in Table 5, using 3 skinfolds is as significant as using 7 to estimate body density and the percentage of fat.

7a. To establish the Ideal Weight, we should not base our estimations on the adiposity and body mass indices or on the "stature-weight" tables. A more rational evaluation would, for example, be the one proposed by De Rose (1984):

$$\textit{IDEAL WEIGHT} = \frac{LM}{1 - \%\ \textit{IDEAL BF*}/100}$$

LM = Lean body mass (kg)
BF = Body fat (kg)
(*) See Table 6

As a colophon to this analysis of the methods for evaluating body composition, Table 7 sums up everything discussed in this study.

Table 7
Comparative features of the methods used to predict body composition. The value "5" represents the best option for each particular feature (Porta, Galiano, Tejedo, González de Suso, 1992; modified from: Lukaski, 1987; Preuss and Bolin, 1988).

Evaluation of body composition									
Methods			Subject's safety	Subject's adaptation	Materials required	Method	Financial cost	Functionality	Validity
Direct (Anat. dissection)			-	-	2	5	1	0	5
Indirect	Physical-Chemical	Pletis. and Abs. G.N.	4	1	1	3	1	1	3
		Isotopic dilution	2	3	2	2	2	2	3
		Photon spectro.	2	3	2	3	2	2	3
		Neutron activation	3	2	1	2	1	1	3
		Creat. excretion	4	3	3	3	3	3	2
	Imaging	Radiology	1	3	2	2	2	1	2
		Ultrasound	4	4	2	3	2	3	2
		CT	1	3	1	2	1	2	4
		NMR	4	3	0	2	0	2	4
		Densitometry	4	2	2	2	2	2	4
Double indirect		TOBEC	3	4	1	3	1	1	4
		NIR	5	5	4	4	3	4	2
		BIA	5	4	4	4	3	4	3
	Anthrop.	Mass and/or adip. index	5	5	5	5	5	5	1
		Equa. regression	5	4	4	3	4	4	4

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