

Critical Appraisal of Human Body Composition Techniques

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Abstract: A pubmed hit search teaches us that Human Body Composition (BC) is a frequently used issue in nutrition publications. Body composition is a branch of human biology and is subject to variable interpretation by its users. Quantifying human BC plays an important role in monitoring health and disease but inaccurate interpretation of terms and techniques plays a key role in a series of classical errors. The purpose of this study is to make an overall review of general and specific errors that occur in BC e.g. in medicine and nutrition in particular. It was found that the transfer from morphological BC to chemical BC interpretations is the major origin of error. It all started with hydrodensitometry that for too long was “the” reference method, but being itself erroneous. This has caused different outcomes of methods assumed to measure the same variable producing the same outcome. More specific, it was found that the Body Mass Index as used in BC is a violation of biological evidence, while the new reference criterion DXA does make good predictions but is not accurate for individual patient evaluation or diagnosis.

Keywords: Adipose Tissue; Body Composition; BMI; DXA; Fat; Hydro densitometry

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Introduction

The study of human Body Composition (BC) can be defined as a branch of human biology which focuses on the *in vivo* quantification of body components and the quantitative changes in these components related to various influencing factors. The use of BC in medicine is based on its relationship with morbidity and mortality [1]. In the 80's it was recognized that many chronic and acute illnesses involved alterations in BC, and that these changes might be linked with morbidity and mortality. The vast majority of these associations relate to obesity, a medical condition characterized by the accumulation of excess Adipose Tissue (AT) or fat [2]. The main impact of these associations tend to be on the cardiovascular system, although the effects on an individual can be modified or compounded by environmental or genetic factors [3]. Meta-analysis reports show that obesity is a risk factor for cardiovascular disease, type 2 diabetes, hypertension, some forms of cancer and all-cause mortality in adults [4,7]. Consequently, accurate measurements of BC may lead to better

diagnosis, understanding of disease mechanisms and treatment [8].

Body composition research is organized based on theoretical models that describe the body as the sum of its components. These models are named after the number of compartments included: two, three, four, five or multi-compartment models. Each of these compartment models stand on their own, but the interchangeable use of terms and faulty assumptions lacking biological evidence often lead to confusion among researchers and health professionals [9,10].

The inaccurate interpretation of chemical and anatomical terms, the arbitrary use of models and the difference in reliability of the clinical user and

the manufacturer for a number of techniques undoubtedly play a key role in a series of errors that often are ignored or simply not known by the health professional or even the researchers. The major problem of BC is the dispersion of its fundamental research publications in too many different journals combined with a low criticism profile of its user resulting in a marketing dominating sales technique of clinical instrumentation [11]. Although BC analysis is popular, reference data and criterion techniques are sparse, e.g. dissection, are not readily available, too expensive or have different application priorities, e.g. Magnetic Resonance Instrumentations (MRI).

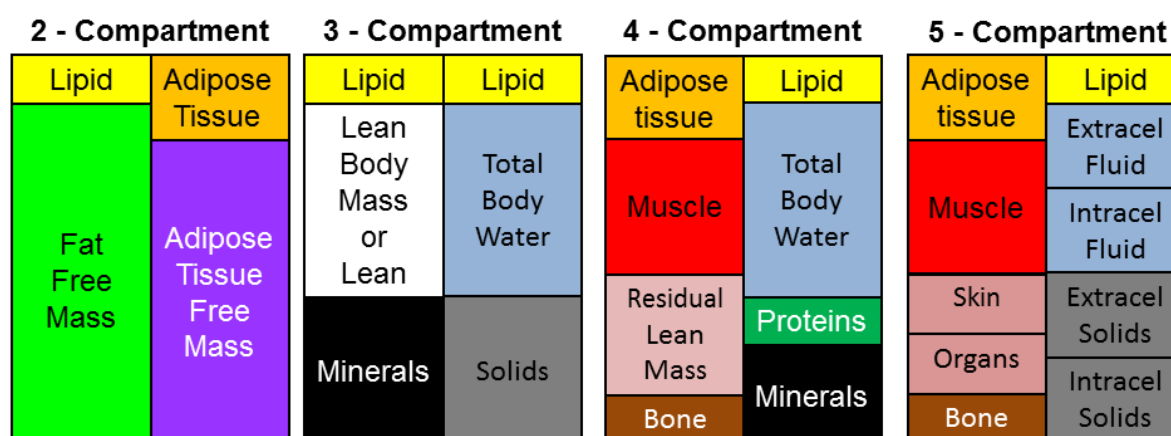


Figure 1. Compartment models and associated components used in body composition research.

All classical errors in traditional BC have been confirmed via direct data acquisition, e.g. Brussels cadaver analysis study data bank of 32 human cadavers (age range 16-94 years) and additional carcass research. [11, 12]

Purpose

This synoptic review of BC errors will deal with the following issues: 1. Fat versus adipose tissue ... a

language or biological problem. 2. The use of the BMI, a conspiracy of ignorance. 3. The diagnosis of one patient with different systems ... what to believe? 4. Hydrodensitometry in the 21st century ... a surprise. 5. DXA ... golden standard or good marketing.

1. Fat versus Adipose Tissue ... a language or biological problem ?

The inaccurate translation of 'chemical' terms into 'anatomical' terms and vice versa within or between BC compartments and models undoubtedly plays a key

role in this confusion. The term ‘fat’ can be used in a biochemical or in a morphological sense. In the first case ‘fat’ refers to the extractable lipids (triglycerides, free fatty acids, phospholipids, blood and muscle lipids etc. in the body. In the second situation ‘fat’ refers to anatomically separable tissues (adipose tissue including connective tissue, micro-vessels, etc.). Although there is a significant relationship between chemical ‘lipid’ and anatomical ‘adipose tissue’ both are clearly distinct

entities. Lipid fraction in AT may vary from 0.5 in the lean persons to 0.9 in obese individuals [9]. **Figure 2** is for that matter self-explanatory [14]. This ambiguity has resulted from the fact that ‘FAT’ is a colloquial Anglo-Saxon term, not per se used for what it should be e.g. lipids. Simple errors can be avoided by using AT under all morphological - anatomical circumstances

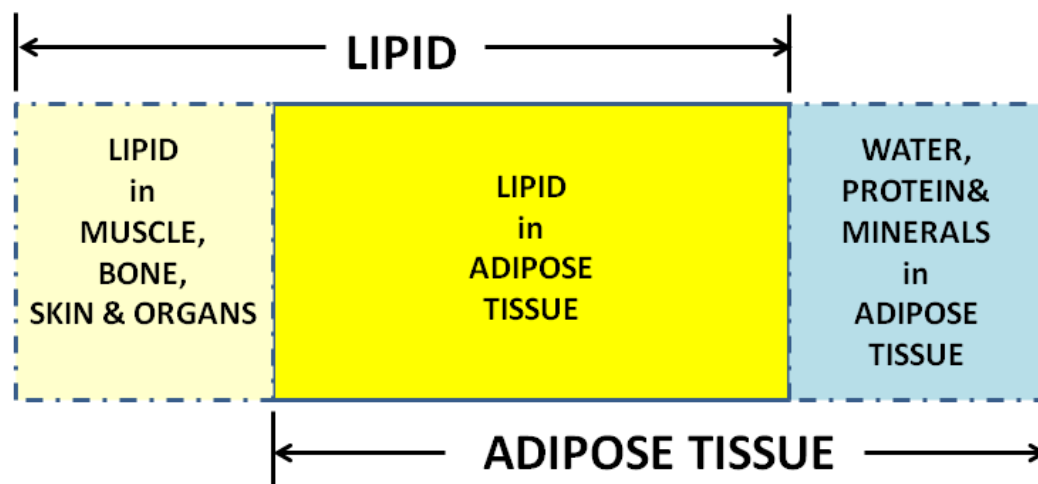


Figure 2. The relationship between fat and adipose tissue [9, 14]

2. The use of the BMI ... a conspiracy of ignorance

Let there be no doubt, the BMI as projected by the World Health Organization (WHO) and the global data base on Body Mass Index is no more, no less (misleading) popular science. No other BC index ever has received an outspoken interest of the media and popular literature. No other BC index has been subject of mega and meta-analysis studies. [6, 7, 15]

The index of Quetelet described in 1832, calculated as a person’s weight (in kilograms) divided by the square of his height (in meters), was described for classification purposes, but was re-introduced in epidemiological health related studies after the

Second World War [16]. Although various other indices of relative weight were studied until the eighties, the term “Body Mass Index” (BMI) was suggested for the first time in 1972 [17]. Since the introduction of BMI as an index of relative weight, adiposity and obesity, a number of studies have emerged determining its relationship with Body Composition (BC). Relationships, however, are based on indirect estimations of adiposity [10, 18]. The validation of the BMI is principally based on comparisons against two-compartment and three-compartment models e.g. hydrodensitometry, bioelectrical impedance or Dual energy X-ray Absorptiometry (DXA). All these methods are based on assumptions of constancy and/or

homogeneity of body compartments (or issues) ignoring the ad hoc human biological and ethnical variations, as well as the inter- and intra-individual tissue distribution variance [18].

An adiposity index equal for men, women, elderly, athletes, ethnicities etc. is a violation of biological evidence.

Because of the lack of directly measured fundamentals, the relationship of BMI with total body Adipose tissue and other whole body and segmental tissues (e.g. muscle, skin, viscera and

bone) was determined by external anthropometry followed by direct dissection of 29 white Caucasian cadavers (17 females and 12 males) [12]. The relationships are shown in (Table 1) and clearly suggest that the BMI is not an appropriate adiposity index, confirming and enhancing the findings of the prospective mega studies [6, 7, 15]. All direct obtained data considered, the BMI can stay as an acronym but with a different application namely the Bone Mass Index [18].

Table 1. Relationship between body mass index and body composition tissue constituents

Gender	N	AT%	TAT%	SAT%	IAT%	TSAT%	Mm%	Bm%	Vm%
Mixed	29	.52**	.55**	.48**	.48**	.52**	-.23	-.80***	-.52**
Females	17	.61**	.57*	.42	.63**	.63**	-.31	-.91***	-.54*
Males	12	.57	.63*	.61*	.33	.70*	.19	-.64*	-.45

Values represent Spearman's Rho correlation coefficients. AT% = total body AT percentage, TAT% = trunk AT percentage, SAT% = trunk subcutaneous AT percentage, IAT% = internal AT percentage, TSAT% = total body subcutaneous AT percentage, Mm% = Muscle mass percentage, Bm% = Bone mass percentage, Vm% = Visceral mass percentage, *p<0.05, **p<0.01, ***p<0.001.

3. The diagnosis of one patient, ... what to believe ?

Measuring the adiposity of one subject has no statistical value but belongs to daily medical routine. Verifying a result with the result of another technique

or device that is assumed to produce a similar value is clinically evident but is certainly not daily practice. One assumes that different techniques or systems that measure the same variable should have an identical outcome (Table 2).

Table 2. Predicted whole body adiposity percentage measured on the same day, on the same patient/subject using 5 different techniques or devices [9]

Method (N = 1)	Whole body adiposity (%)
Hydrodensitometry	26.8%
Anthropometric formula	25.1%
Bio-electrical Impedance Analysis (BIA)	21.5%
Dual Energy X-ray Absorptiometry (DXA)	17.0%

Skinfold formula

12.1%

4. Hydrodensitometry in the 21st century ... a surprise

Hydrodensitometry has served as a ‘direct reference method’ for many (if not most) BC techniques and methods, e.g. in chemical and anatomical studies alike. It is based on the assumption of a density constancy of 0.90 g/ml for fat and of 1.10 g/ml for Fat Free Mass (FFM) and this constancy was projected to all tissues that compose FFM. This knowledge has been extensively discussed in the past, suggesting its lack of reliability. Indeed “direct” in this context refers only to the directly obtained values of the hydrostatic weight, volume and density. With the formulae of SIRI [19] or Brozek [20] the follow-up approach to obtain kg or

percent of Fat becomes fully indirect based on an erroneous non-anatomical foundation of Fat (AT?) and FFM (ATFM?) constancies. The listing of errors provoking issues has become so important that the accumulated errors takes unrealistic dimensions e.g. all tissues have a variable density, no constancy! All tissues have an extreme variable hydration, ranging from 10 to 84%, no constancy! The 2-component model depends entirely on a (graphical) determination of Fat – but in reality AT - from the hydrostatic weight and density. It is not exceptional that densities higher than 1.100 are registered resulting in negative amounts of Fat/AT (**Figure 3**).

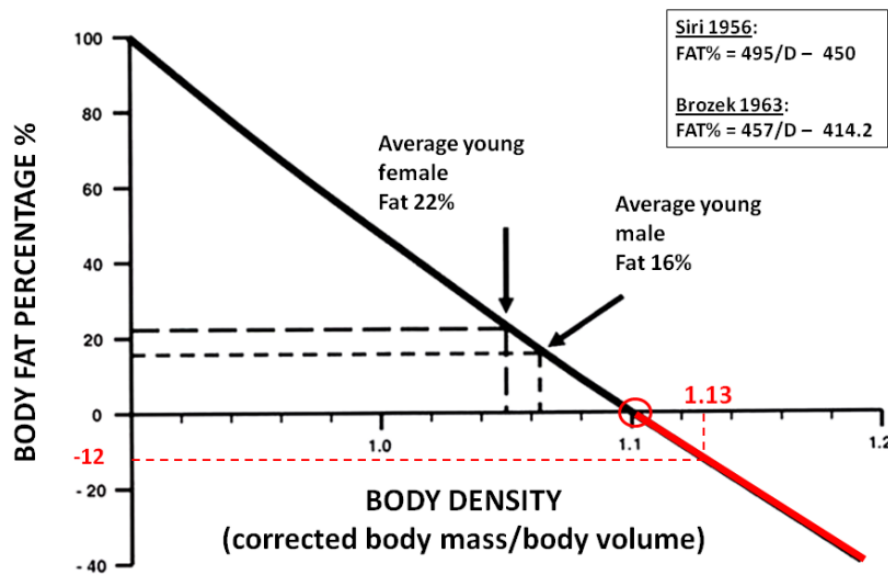


Figure 3. The hydrodensitometric determination of body adiposity in a 2 component model

The most extravagant result known is “MINUS 12%” of Fat/AT, obtained via hydrodensitometry, while the sum of 10 skinfolds of the same athlete equaled 88mm [21]. Averaging a double layer of skin (measured with a skinfold caliper) being + 5mm summated over 10 skinfolds equals + 50mm of skin leaving us with 38 mm of (subcutaneous) AT. Projecting this value on

direct data of the Brussels CAS data bank and considering the relation between the total amount of subcutaneous AT and the whole body AT mass (**Figure 4**) [22] one can make a safe prediction of a whole body AT ranging between 5% and 10% for that same athlete with minus 12% WBA. A negative

amount of AT therefore is ludicrous and a violation of biological evidence.

Despite a series of well known limitations, enhanced by recent findings that confirm additional and serious shortcomings, hydrodensitometry has not been

abandoned yet and is used still in various sport medical centers, nutrition laboratories and educational facilities around the world, although studies quantifying the inaccuracy of the method are readily available [9].

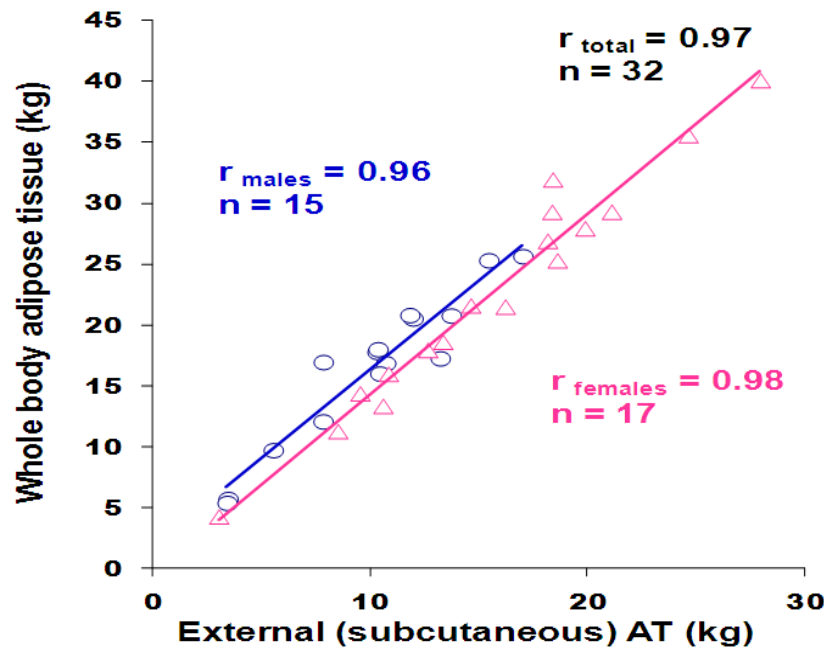


Figure 4. Direct cadaver evidence of the relation between subcutaneous and whole body adipose tissue

5. DXA: gold standard or good marketing ?

Dual energy X-ray Absorptiometry (DXA) equipment is designed for human and animal research and clinical diagnosis originally for osteoporosis, later for BC data acquisition. Controversial impression concerning its use is dictated by various critical appraisals and clinical reports. Assumption is made that a different reliability approach of the manufacturer against that of the clinical user could be at the origin of this controversy. A cross-validation study [23] compared DXA fan beam scans with direct dissection and Computed Tomography (CT) scanning data. Carcasses were measured with DXA and CT before dissection into its major five components e.g. skin, AT, muscle, bone and viscera. Tissue samples were chemically analyzed and hydration of all tissues was determined. The complete skeleton was ashed. This users–quality evaluation

confirms that part of the existing problem results from erroneous terminology suggested by the manufacturer [24]. The predictive values of DXA for BC purposes are good to perfect ranging from $r=0.62$ to $r=1.00$ but with one variable only that is found to be not significantly different e.g. ashed skeleton versus Bone Mineral Content (BMC). Unfortunately this has no diagnostic value. The precision capacity of DXA variables on the other hand resulted into significant differences indicating that: a) DXA (and CT) are based on models and algorithms with a tissue constancy of its variables resulting in b) a lack of clinical precision essential for the individual patient who is at risk, e.g. for bone data in particular [25]. Its bone measurements, e.g. BMC and Bone Mass Density (BMD) are therefore very important for both reliability and accuracy. But with BMD expressed in a weight/surface density

(g/cm²) instead of a classical weight/volume density (g/cm³), it is not surprising that DXA provides 65% only of the true density. If the radiology staff is not familiar with this reasoning, realizing the majority of osteoporosis studies refer to a g/m³ density, the diagnosis of osteoporosis will certainly not be correct. In the literature in general it is rather seldom that one can read a full conclusion in an articles title. Bolotin and Sievanen [26] did, (Quote) “Inaccuracies inherent in dual-energy X-ray absorptiometry in vivo bone mineral density can seriously mislead diagnostic/prognostic interpretation of patient-specific bone fragility” (end of quote). A better conclusion for DXA cannot be given.

Conclusion

Almost one third of diet and nutrition literature uses BC methodology that is based on multi-compartment models both chemical and morphological e.g. macro-anatomical. The disparity of BC literature and the interchangeable use of terms between models is a major source of error. All in-vivo BC techniques have been validated with indirect methods creating another source of error. BMI, hydrodensitometry and DXA combine these error sources. BMI and hydrodensitometry cannot be used for diagnostic purposes at all. DXA on the other hand provides good predictions but lacks clinical precision.

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