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Fitness Assessment

Body Composition

KAROLINUM

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Content

Preface

The book Fitness assessment – Body composition was primarily written for researchers dealing with the issues of nutrition, proper diet and treatment of body composition as one of the components affecting sport performance, for researchers involved in selecting appropriate diagnostic methods for body composition identification in terms of monitoring changes under various factors (load, sport training periodization, pre-season weight reduction, etc.), for researchers focusing on selection and comparison of diagnostic methods for body composition on the basis of particular models of the body, for postgraduate students in the fields of medicine and sport and last but not least for coaches with the possibility of using the published data for feedback for their sport team.

The book is structured on the basis of available literature on this problem to the following sections: Body composition, Models of body composition, Body composition variation and Introduction to body composition methodology, i.e. methods identifying body composition.

The publication presents individual reference methods (dual-energy X-ray absorptiometry, hydrodensitomery) and methods most frequently used in practice (anthropometric methods, calliper measurements, bioelectrical method) in terms of description of their potential use, principles, average values of individual body composition parameters, validity and reliability; furthermore it also provides comparison and advantages and disadvantages of these methods. The last chapters of the publication consist of practical outputs of elite male and female sport teams (basketball, volleyball, judo, pentathlon, handball, softball, futsal and fencing) which may serve as a kind of standard for comparison of the level of body composition in these sport disciplines as well as feedback for sport training process.

It is our hope that book increases your understanding and appreciation of both the art and the science of body composition assessment, further develops your knowledge and skill as a body composition practitioner and helps you provide your clients and students with the most accurate information about body composition.

Chapter 1
Body composition. Models of body composition

Body composition assessment is an inseparable part of several disciplines on the bounds between biology and medicine. The issue of body composition and its relationship to body parameters is a part of sport anthropology (examining morphological and functional conditions of human motion) as well as functional anthropology (describing and assessing body construction and proportionality). Body composition assessment and estimation of parameters of individual body segments links in functional anthropology to other fields, such as nutrition, kinanthropology, sports medicine, biomechanics and other clinical disciplines (Riegerová et al., 1998). From the perspective of exercise physiology, body composition parameters are predispositions of sport performance, in other words, some sport disciplines require certain qualities of body composition parameters (Petrásek, 2002).

Body composition, most commonly perceived as the proportion of lean body mass and fat mass, represents a significant somatic characteristic that develops in relation to various factors (age, gender, genetics, level of physical activity). Body composition, especially the ratio and relationship between individual components that contribute to body composition has a number of physiological as well as pathological aspects that affect functions of the human body. From the physiological point of view, body composition is related to oxygen consumption, energy expenditure during physical activity and significantly influences levels of some indicators of lipid metabolism in the blood which brings it to a closer relationship with functions of respiratory and cardiovascular systems (Pařízková, 1962). The percentage of fat mass is often characterised as a limiting factor of maximum oxygen consumption expressed in kg per body weight presented in several studies focused on children (Goran et al., 2000; Maffeis et al., 1994), as well as on the general population –

untrained women with optimal body weight (Bunc et al., 2000). The reaction of obese individuals on physical load is determined by somatic and motoric peculiarities, namely relatively low proportion of muscle mass, high proportion of fat mass, lower values of maximum oxygen consumption and low physical fitness (Placheta et al., 1999). Higher proportion of fat mass causes a decrease of maximum oxygen consumption as a logical result of increased body weight without any contribution to increase of oxygen metabolism (Cureton et al., 1978).

Heymsfield et al. (2005) mention three interacting research areas by Wang et al. (1992) as follows: body composition rules and models, body composition methodology and body composition variation. Based on this, we divided our treatise into particular parts; moreover we also describe the system of models of body composition.

The human body has to be considered as a model consisting of individual components and can be characterised from several points of view. The most common point of view is chemical and anatomical. Chemically, the human body consists of fat, proteins, carbohydrates, minerals and water. Anatomically, it consists of fat mass, muscle mass, bones, inner organs and other tissues (Maud & Foster, 1995).

The central model in body composition research is the five-level model (Table 1, Figure 1) in which body mass is considered as the sum of all components at each of the five levels – atomic, molecular, cellular, tissue-organ, and whole body (Wang et al., 1992). The current models of body composition and an overview of methods used for measurements of individual components were also summarised by Pařízková (1998).

a) **Atomic model** is based on the elements occurring in the body. 98% of body weight is composed of six elements, i.e. C, H, N, O, P and

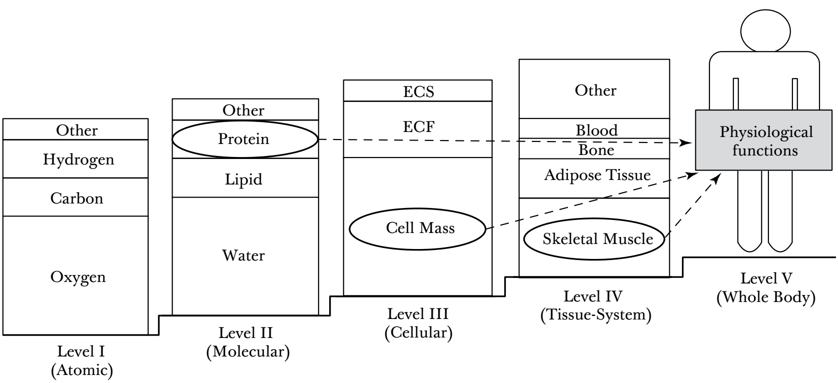

Figure 1 Five-level model of body composition (Wang et al., 1992).

Ca. The remaining 2% is covered by 44 other elements. More than 96% of body mass is accounted for by four elements (oxygen, carbon, hydrogen and nitrogen (Heymsfield et al., 2005). An example of a method based on the atomic model is a neutron activation analysis.

b) Molecular model. 11 main elements create molecules which represent more than 100 000 chemical compounds constituting the human body. The human body consists of six main components (water, proteins, lipids, carbohydrates, bone minerals, soft tissue). It is possible to measure total body water, fat free mass, fat mass (e.g. bioimpedance methods) and bone density (DEXA).

c) Cellular model. Conjunction of molecular components into cells is the next stage in the perception of the human body. Body cell mass is an active energy metabolising part of the human body related to muscle mass. Extracellular water (composed of 94% water) is a frequently observed component of body composition. The next components are extracellular organic and inorganic solids. The cellular level can be described by the following equation:

Body weight = body cell mass + extracellular water + extracellular solids
Body cell mass = muscle + tissue + epithelial + nerve cells
Extracellular water = plasma + interstitial fluid
Extracellular solids = organic + inorganic solids
Body weight = fat mass cells + body cell mass + extracellular water + extracellular solids

These descriptions form a base for a number of methodological approaches. For instance, extracellular liquid and plasma can be measured by means of isotope dilution methods (Pařízková, 1962) and extracellular solids by neutron activation analysis (Heymsfield et al., 1991).

d) Tissue-organ model. Components of the cellular model are further organised into various tissues, organs and systems. 75% of body weight is represented by three tissues, i.e. bone, muscle mass and fat mass.

From the perspective of systems, the human body is defined as follows:

Body weight = musculoskeletal + integumentary + nervous + cardiovascular + respiratory + digestive + excretory + reproductive system

For observing these components, there are only a few in-vivo methods, for instance, computed tomography (Kvist et al., 1988), magnetic resonance, determination of muscle mass by 24 hours measuring creatinin excretion (Wang, 1996).

e) **Whole-body model.** To monitor a whole body model, anthropometric measurements of individual indicators, such as body height, body weight, body mass index, circumferential measures, length and width of body segments, skinfolds and body volume which enables the calculation of human body density and indirect estimation of fat mass an fat free mass (Wang, 1996), are used. The whole human body consists of head, trunk and appendages (Heymsfield et al., 2005).

Table 1 Representative Multicomponent Models at Five Body Composition Levels (Heymsfield et al., 2005).

Level	**Body composition model**	**Number of components**
Atomic	BM = H + O + N + C + Na + K + Cl + P + Ca + Mg + S	11
Molecular	BM = FM + TBW + T + Ms + CHO	6
	BM = FM + TBW + TBPro + M	4
	BM = FM + TBW + nonfat solids	3
	BM = FM + Mo + residual	3
	BM = FM + FFM	2
Cellular	BM = cells + ECF + ECS	3
	BM = FM + BCM + ECF + ECS	4
Tissue-organ	BW = AT + SM + bone + visceral organs + other tissues	5
Whole-body	BW = head + trunk + appendages	3

Note: AT – adipose tissue, BCM – body cell mass, BM – body mass, CHO – carbohydrates, ECF – extracellular fluid, ECS – extracellular solids, FFM – fat free mass, M – mineral, Ms – soft tissue mineral, SM – skeletal muscle, TBPro – total body protein, TBW – total body water.

A different view is offered by the number of components that constitute the human body. There are more than 30 major components at the five levels of body composition (Wang et al., 1992). A typical feature of the multicomponent model is determination of directly measurable parameters (total body water, phase angle, human body density) and indirectly derived measurable parameters (fat free mass, fat mass, body cell mass). The example is a direct measurement of resistance and reactance or total body water, respectively, in bioimpedance analysis and subsequent derivation of fat free mass by means of relevant equations, presented by authors specifically for adolescents:

Fat free mass = 0.61 × (Ht^2/R) + 0.25 × Wt +1.31 (Ht in cm)
(Houtkooper et al., 1992)
Fat free mass = 0.258 × 104 × (Ht^2/R) + 0.375 × Wt + 6.3 × sex + 10.5 × Ht − 0.164 × age − 6.5

(sex: 1 – male, 2 – female; Ht in m)
Wt – body weight (kg); Ht – body height (m or cm, resp.), Fat Free Mass (kg), R – resistance (Ω)

A useful step in understanding the multicomponent methods that follow is to analyse a classic two – component hydrodensitometry approach (Heymsfield et al., 2005), which describes the human body as the sum of fat mass and fat free mass (Brožek et al., 1963; Heymsfield & Waki, 1991; Siri, 1961). This method was derived from two models at the molecular level, a body mass model and a body volume model (Heymsfield et al., 2005).

Body weight = fat mass + fat free mass
Body volume = (Wa − Ww) / Dw

$$Bodydensity = \frac{W_a}{\frac{(W_a - W_w)}{D_w}} - (RV + 0.100)$$

Wa – subject's weight in air (kg)
Ww – subject's weight in water (kg)
Dw – density of water ($kg.m^{-3}$)
RV – residual lung volume (l)

Brožek et al. (1963), Siri (1961) suggest that application of a two-component model requires the following conditions:

1. Fat mass density is 0.901 g/cm^3 at 36 °C
2. Fat free mass density is 1.10 g/cm^3 at 36 °C
3. Fat mass density and fat free mass component (water, proteins, minerals) are identical for all individuals
4. Densities of tissues forming fat free mass are constant in individuals and their ratio to the active component remains constant

5. Measured individuals differ only in the proportion of fat mass, fat free mass consists of 73.8% of water, 19.4% of protein component and 6.8% mineral component (Heyward & Stolarczyk, 1996).
   The example for calculation of fat mass is as follows:

   Fat mass = 2.057 × body volume – 0.786 × total body water – 1.286 × body mass (Siri, 1961)
   Fat mass = (4.570 – 4.142) × 100 (Brožek et al., 1963)

This model was subsequently developed into three-component and four-component models in order to eliminate the source of errors concerning different proportion of water and minerals and when measuring body volume, total body water, bone mineral and body mass, the example of calculation of indirectly measurable parameter is as follows:

Fat mass = 2.513 × body volume – 0.739 × total body water + 0.947 × bone mineral – 1.79 × body mass (Heymsfield et al., 1997)
Fat mass = 2.748 × body volume – 0.699 × total body water + 1.129 × bone mineral 2.051 × body mass (Wang et al., 2002)
Fat mass = 2.057 × body volume – 0.786 × total body water – 1.286 × bone mineral (Siri, 1961).

The measurement of total body water reduces errors in the two-component model related to individual differences in hydration. Also the three-component model has, however, its prerequisites, especially a constant ratio of protein and mineral substances (Wang et al., 2005). Multicomponent models assume constant fat mass density (Mendez et al., 1960, Wang et al., 1992), water (Diem, 1962), bone mineral (Dallemagne & Melon, 1945), protein density (Hulmes & Miller, 1979), density of soft tissue mineral and density of carbohydrates (Wang et al., 2005) and body temperature (Siri, 1961; Brožek et al., 1963).

Measurement error in the multi-component models comes from estimation of indirectly measurable parameters but also from possible error in measurement of directly measurable parameters. Measurement error can be caused by examiners, laboratories, measurement devices, not to mention biological variability of participants. One of the most common sources of errors is prediction equations for calculation of indirectly measurable parameters. Summary of measurement errors for the multicomponent hydrodensitometry models are presented by Wang et al. (2005), when, the author mentions 1.3% error in bone mineral measurement using DEXA method and 0.6% error in body fat in estimation of body volume using hydrodensitometry (Withers et al., 1998, 1999). In our treatise, we provide an overview of errors in identification of individual methods of body composition assessment. (Chapter 3).

The second area of body composition research involves body composition methodology. Different methods are available to measure the major body components of the five levels in vivo and in vitro (Heymsfield et al., 2005). The third area of body composition research is body composition variation and it involves the changes in body composition related to physiological or pathological conditions. Areas investigated include growth, development, aging, race nutrition, hormonal effects, and physical activity, as well as some diseases and medications that influence ones' body composition (Heymsfield et al., 2005). Methods for body composition identification and individual components determining the "quality" of body composition are analysed in separate chapters (Chapter 3).

Chapter 2
Body composition variation

Factors influencing body composition include age, gender, ethnicity, genetics, level of performed physical activity and others (hormonal influence, pregnancy, etc.). For each of these factors, a separate chapter could be written; however, in our treatise, we focus on age and physical activity as, in the practical part, we present profiles and comparisons of body composition of elite male and female athletes of different age categories who regularly perform controlled and planned physical activity – a factor subsequently influencing their body composition.

One of the critical factors, in the course of which body composition changes, is age. When fat mass changes under age, we can consider fat mass the most variable component. Fat mass is a major factor of inter- and intra-individual variability of body composition throughout ontogeny. Proportion of fat mass ranges between 6–60% of total body weight (Heymsfield et al., 2005). In infants, characteristic proportion of fat mass is 10–15% (Forbes, 1987), continually raising up to 30% in the first six months of life. The next period is characterised by gradual reduction of fat mass and the beginning of sexual differentiation during adolescence when annual increase of fat mass is usually lower in boys than in girls (Guo et al., 1997). Already in this period, we can speak about android and gynoid pattern of fat mass distribution (Bouchard, 1988). Maffeis et al. (2001) confirm the beginning of the relationship between obesity or being overweight, respectively, and a risk of diseases resulting from it already in the early years of an individual. The adulthood is characterised by increase of fat mass until the period of old age (Guo et al., 1997).

The necessity of optimal fat mass proportion is indicated by high health risk in the case of excessive fat mass (problems related to obesity) as well as in the case of low fat mass proportion (problems connected to reproductive abilities and ensuring vital functions). Optimal fat mass proportion in relative values (per kg of body weight or percentage, respectively) is presented by Heyward & Wagner (2004) in Standards for Adults, Children, and Physically Active Adults, data taken from Lohman et al., Houtdooper & Going (1997) (Table 2).

Table 2 Percent body fat standards for adults, children, and physically active adults (Heyward & Wagner, 2004).

Group	Age (years)	Recommended percent body fat levels for adults and children				
		NR	**Low**	**Mid**	**Upper**	**Obesity**
Males	6–17	< 5	5–10	11–25	26–31	> 31
	18–34	< 8	8	13	22	> 22
	35–55	< 10	10	18	25	> 25
	> 55	< 10	10	16	23	> 23
Females	6–17	< 12	12–15	16–30	31–36	> 36
	18–34	< 20	20	28	35	> 35
	35–55	< 25	25	32	38	> 38
	> 55	< 25	25	30	35	> 35
Group	**Age (years)**	**Recommended percent body fat for physically active adults**				
		Low	**Mid**	**Upper**		
Males	18–34	5	10	15		
	35–55	7	11	18		
	> 55	9	12	18		
Females	18–34	16	23	28		
	35–55	20	27	33		
	> 55	20	27	33		

Note: NR – not recommended, Data from Lohman, Houtkooper & Going (1997).

Generally, we can say that an appropriate range of fat mass proportion for the general population is 15–18% for males and 20–25% for females. Values higher than 25% for males and more than 29% for females are considered to be risky for health (Spirduso, 1995). Also the presented standards from Table 2 indicate that optimal values for males are 13% on average and 28% for females (the value for a healthy physically inactive adult). In individuals performing physical activity at an elite level, fat mass proportion is lower than in the non-sporting population and it typically depends on the type of physical activity performed (combat athletes, endurance runners show a lower percentage of fat mass proportion) and on gender (women has more fat mass than men).

Fat mass can be easily influenced by nutrition and physical activity (Riegerová, Přidalová & Ulbrichová, 2006), however, it is an important factor in development of a number of diseases (Doll, Petersen & Stewart-Brown, 2000; Katz et al., 2000; Pařízková, 1998). In terms of health and aesthetics in the general population, as well as from the performance point of view in the sporting population, excessive amount of fat mass is undesirable and therefore we try to minimalize it. However, fat which is a part of organs (bone marrow, heart, lungs, kidneys and brain) is essential for proper functions and storage fat plays an important role in protection of internal organs and isolation of body heat.

Malá et al. (2010a) present average values recorded in inactive and active males and females from the Czech Republic (n = 80, BIA 2000M method). The obtained values are higher than recommended standards and thus represent a higher risk for health and development of several diseases connected to overweight and obesity.

Similarly, Malá et al. (2010b) in comparison to available literature, values of fat mass approaching the upper limit of optimal proportion which indicate the need of reduction in individuals with higher percentage proportion of fat mass (18.32 ± 5.5% in males and 24.69 ± 5.88% in females; the used method was InBody 3.0). In accordance with available

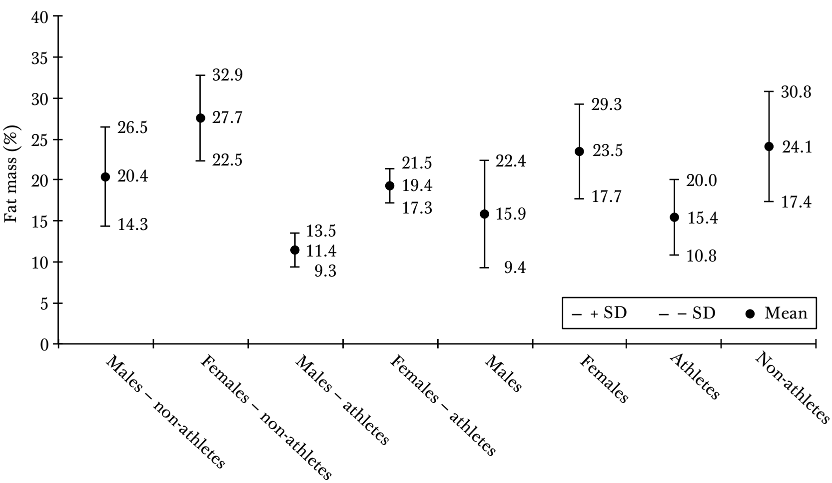

Figure 2 Percentage proportion of fat mass in selected groups of general population (Malá et al., 2010a).

literature (Heyward & Wagner, 2004; Malá et al., 2010a; Meyer et al., 2007), intersexual differences also appear when males show lower percentage of fat mass proportion than females ($p < 0.01$). Many authors have reported that obese parents have a higher risk of having obese children than lean parents (Bray, 1981). Heller et al., 1984; Pérusse et al., 1988; Tambs et al., 1991 point out the effect of genetics on BMI. Also the effect of genetics on reduction and changes in fat mass proportion was revealed (Korkeila et al., 1995; Hunt et al., 2002).

We must also take into consideration that fat free mass shows high genetic dependence (Guo et al., 1997). Changes of fat free mass are relatively stable after the period of growth until adulthood. At the age of 13 years, intersexual differences start to appear; in boys, there is a higher increase of muscle mass as a part of fat free mass as well as bone mass than in girls (Guo et al., 1997). These differences subsequently indicate higher losses of fat free mass during ageing in males than in females (Baumgartner et al., 1995; Gallagher et al. 1998), in relation to similar changes in body cell mass. Bláha (1986), Heyward & Wagner (2004) mention in their studies a gradual decrease of fat free mass caused by age. This decrease is 1.5-times greater in males than in females since it was found that males lose approximately 0.34 kg of fat free mass annually, while females only 0.22 kg. Decrease of fat free mass caused by age is also reported in a study by Visser et al. (1998), where authors mention lower absolute amount of fat free mass, namely 48.5 ± 6.0 kg in males (n = 2095, average age = 73.4 ± 5.7 years) and 32.8 ± 4.6 kg in females (n = 2714, average age = 72.4 ± 5.4 years).

Along with fat free mass, the amount of total body water also changes in the course of ontogeny. The change in the amount of total body water reflects the loss of intracellular water which corresponds to decrease of muscle mass. This process is accelerated by inactivity of an individual.

Despite ontogenetic changes reported by literary sources (decrease of fat free mass caused by age) it is stated that regular exercises of medium or higher intensity can reduce the loss of fat free mass caused by ageing by up to 25%. The faster loss of fat free mass occurs in physically inactive individuals (Heyward & Wagner, 2004). It is possible to keep the amount of fat free mass by performing adequate physical activity.

It is also demonstrated by our study (Malá et al, 2010a), which presents significant differences in relative values of fat free mass in active and inactive population ($p < 0.01$). Inactive males showed similar values of fat free mass as active females ($p > 0.56$). The effect of gender was reflected in all monitored parameters identifying body composition (Table 3).

Table 3 Significance of difference in body composition parameters (Malá et al. 2010a).

Parameter	Factor	F	Sig.	η^2_p
Body height (cm)	Gender	14.36	0.00	0.16
	Activity	0.52	0.47	0.01
	Gender * Activity	0.02	0.90	0.00
Body weight (kg)	Gender	83.36	0.00	0.52
	Activity	5.22	0.03	0.06
	Gender * Activity	0.90	0.35	0.01
Body mass index ($kg.m^{-2}$)	Gender	8.50	0.00	0.10
	Activity	18.72	0.00	0.20
	Gender * Activity	0.27	0.61	0.00
Waist to hip ratio	Gender	7.96	0.01	0.09
	Activity	32.78	0.00	0.30
	Gender * Activity	0.24	0.63	0.00
Total body water (l)	Gender	151.13	0.00	0.67
	Activity	1.22	0.27	0.02
	Gender * Activity	3.18	0.08	0.04
Intracellular water (l)	Gender	128.11	0.00	0.63
	Activity	0.72	0.40	0.01
	Gender * Activity	1.74	0.19	0.02
Extracellular water (l)	Gender	22.96	0.00	0.23
	Activity	2.55	0.11	0.03
	Gender * Activity	2.25	0.14	0.03
Fat free mass (kg)	Gender	181.39	0.00	0.70
	Activity	3.38	0.07	0.04
	Gender * Activity	4.20	0.05	0.05
Muscle mass (kg)	Gender	181.98	0.00	0.71
	Activity	3.50	0.08	0.04
	Gender * Activity	5.39	0.02	0.07
Body cell mass (kg)	Gender	197.24	0.00	0.72
	Activity	2.82	0.10	0.04
	Gender * Activity	4.69	0.03	0.06
Fat free mass / Body weight	Gender	67.81	0.00	0.47
	Activity	56.00	0.00	0.42
	Gender * Activity	1.87	0.18	0.02