BODY COMPOSITION AS A DETERMINING FACTOR IN THE AEROBIC FITNESS AND PHYSICAL PERFORMANCE OF CZECH CHILDREN

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Body composition (BC) may be used as a criterion of the actual biological state of children, in other words, their physical state of development. The aim of our study was to determine the interdependence of some body composition variables and aerobic fitness ($VO_2max.kg^{-1}$) and parameters of physical performance, ie. calculated total work (CTW) and maximal power output (MPO) on the treadmill in a group of Czech children and youth. The interdependence between frequently used indicators of aerobic fitness ($VO_2max.kg^{-1}$, CTW, and MPO), and BC (% BF, FFM, BCM and ECM/BCM) were studied in a group of 1235 Czech children (756 boys and 479 girls) aged from 6 to 14 years. Both aerobic fitness and physical performance variables were assessed by means of an incremental treadmill test with a constant slope of 5%. The age dependent initial speed was increased by 1 $km.h^{-1}$ till subjective exhaustion. Body composition was determined by whole body bioimpedance measurements using a modified prediction equation for children. The percentage of BF was negatively correlated with $VO_2max.kg^{-1}$, and CTW. Both FFM and BCM were positively related to CTW, MPO, and $VO_2max.kg^{-1}$. The ECM/BCM relationship was negatively related to $VO_2max.kg^{-1}$ and CTW. In conclusion, BC is an important determinant of physical performance in the laboratory (treadmill exercise tests) and in the field (running and/or walking tests). The BC parameters significantly influence the variables that could be used for characterisation of aerobic fitness. The results further demonstrate that when oxygen consumption is not feasible, physical performance characteristics together with parameters of BC seem to be a good predictor of aerobic fitness. This may be very helpful in large population studies.

Keywords: Body composition, oxygen consumption/uptake, aerobic fitness, physical performance, laboratory and field testing, children.

INTRODUCTION

An accurate assessment of body composition (BC) is necessary in order to properly identify a client's health risk as associated with an excessively low or high amount of related body fat (BF). This assessment can then be used to estimate a subject's ideal body mass and formulate an exercise and diet regimen. Periodic BC evaluation can be used to assess the effectiveness of exercise and diet interventions or monitor changes in BC associated with growth and maturation or states of disease (Bouchard et al., 1994). Thus there is a clinical need to measure not only the % of BF, but fat distribution, muscle mass, total body water content (TBW), body-water compartments (extracellular – ECW, and intracellular water – ICW), body-water volume changes, and bone mass as well (Roche, Heymsfield, & Lohman 1996; Segal et al., 1991).

At the present time, the above can be used together with classical parameters of BC which have already been in use for a long time such as BF content and free fat mass and also other variables which may characterise BC, such as body cell mass (BCM) and extracellular mass (ECM) (Wang et al., 2000). At the cellular level, FFM consists of BCM, extracellular fluids (ECF) and extracellular solids (ECS).

Numerous tools and methodologies have been developed to measure various BC parameters. Bioelectrical impedance analysis (BIA) seems to be one of the most used methods under field conditions. This method is based on the principle that lean tissue, which contains large amounts of water and electrolytes, is a good electrical conductor, and fat, which is anhydrous, is a poor conductor (Lukaski et al., 1985).

Regardless of which instrument is chosen to assess BC, the method is only as good as the measurement technique and prediction or conversion formula applied. The conversion formulas and prediction equations, the use of which are selected, must be restricted to the populations from which they were derived to remain valid (Bunc et al., 2001; Roche, Heymsfield, & Lohman, 1996).

Aerobic fitness (AF) is frequently considered the most important aspect of physical fitness (Shephard, 1994; Shephard & Bouchard, 1994). The generally accepted physiological criterion of AF – maximal oxygen uptake (VO_2max), is only a predisposition for physical performance (PP) (Astrand & Rodahl, 1986; Bunc, 1994). A high VO_2max does not guarantee good PP, since technique of motion and psychological factors may have an influence either positively or negatively. In work and exercise where the body is lifted, oxygen uptake should be related to the subject's body mass. In this case, the individual's VO_2max provides a measure of the "motor effect" (Astrand & Rodahl, 1986; Bunc, 1994). With this parameter the subject's ability to move her or his body can be evaluated. In practice this means that if we wish to characterise fitness level, we must evaluate VO_2max and physical performance at the same time.

The parameters which may characterise PP in the laboratory as calculated total work (CTW) and maximal power output (MPO) are highly associated with absolute values of VO_2max. Relative values of VO_2max (related to kg of body mass) are strongly related to the size and quality of the free fat component of body mass, which is logical because VO_2 during exercise depends on the oxygen demands of the exercising muscles (Astrand & Rodahl, 1986; Bunc, 2001).

The fact that differences in body size and BC influence the predisposition and interpretation of parameters such as absolute and relative maximal oxygen consumption and/or physical performance is well known (Astrand & Rodahl, 1986). Less well studied are the effects of differences of BC on performance predispositions like VO_2max, CTW and MPO in young subjects.

The aim of our study was to determine the interdependence of some body composition variables and aerobic fitness ($VO_2max.kg^{-1}$) and parameters of PP – calculated total work (CTW) and maximal power output (MPO) on the treadmill in a group of Czech children and youth.

SUBJECTS AND METHODS

In this study, a group of 1235 Czech children (756 boys and 479 girls) ranging in age from 6 to 14 years and differing in level of aerobic fitness (their maximal oxygen uptake was in the range of 32–65 $ml.kg^{-1}.min^{-1}$ in boys and from 30 to 60 $ml.kg^{-1}.min^{-1}$ in girls) was evaluated.

The BC variables were determined by the whole body's impedance multifrequency measurements using modified prediction equations which were verified for Czech children (Bunc, 2001).

Resistance and reactance were measured at four frequencies – 1, 5, 50 and 100 kHz (B. I. A. 2000 M, Data input, Germany) on the right side of the body by tetrapolar electrode configuration (four electrodes, two on the hands and two on the feet in accordance with the manufacturer's specification).

Maximal oxygen uptake was evaluated by means of an incremental exercise test to subjective exhaustion on a treadmill at 5% inclination. The respiratory variables and gas exchange were measured using an open system with the help of TEEM 100 diagnostics equipment.

The CTW was calculated as the sum of the workloads of all completed stages plus the workload of the last incomplete stage. The MPO was calculated by linear interpolation from power output during the previously completed stage and power increment between the last stage and the previously completed stage.

Values are presented as the mean of $\pm s_D$. Simple regression analysis was performed to describe the relationships among various parameters. Cross correlation and calculation of standard error of estimation were used to validate the regression equations. The 0.05 level of significance was used for all data analyses.

RESULTS

The selected variables of BC for each year of age are presented in TABLES 1, 2 and 3. Similarly, values of maximal oxygen uptake that were determined with the help of an incremental exercise on the treadmill are presented in TABLE 4. The mean values of the followed variables of BC are collected in TABLE 5.

The mean values of total body-water (in relative terms as a part of total body mass) was slightly higher in boys than in girls and these values were significantly higher in children (the mean in boys was 65.3 ± 3.8%, and in girls 62.6 ± 4.2%) than in adults of the same physical fitness status who were assessed by the same analyser (the mean in men ranging in age from 40 to 60 was 61.3 ± 4.8%, and in women it was 57.2 ± 5.0%). In children we found a negative significant interdependence of these values with regard to age ($r = -0.586$, $p < 0.0001$ in boys, and $r = -0.612$, $p < 0.0001$, $S_{EE} = 3.4\%$ in girls).

The mean values of BF were 19.7 ± 5.3% of the total body mass in boys, and 21.7 ± 5.0% in girls. In both sexes a positive significant gender interdependence was found ($r = -0.698$, $p < 0.0005$ in boys, and $r = -0.681$, $p < 0.005$ in girls).

The mean values of selected maximal functional variables, CTW and MPO are collected in TABLE 6. We found significant negative relationships between % BF and $VO_2max.kg^{-1}$ ($r = -0.511$, $p < 0.0001$ in boys; $r = -0.584$, $p < 0.0001$ in girls), MPO ($r = -0.471$, $p < 0.0005$; $r = -0.435$, $p < 0.0005$), and CTW ($r = -0.531$, $p < 0.0001$; $r = -0.495$, $p < 0.0001$).

Significant positive relationships were found between FFM and CTW ($r = 0.311$, $p < 0.0005$; $r = 0.421$, $p < 0.0005$), MPO ($r = 0.401$, $p < 0.0005$; $r = 0.456$, $p < 0.0005$), and $VO_2max.kg^{-1}$ ($r = 0.371$, $p < 0.0005$; $r = 0.332$, $p < 0.0005$).

Also we found significant relationships between BCM and CTW ($r = 0.583$, $p < 0.0001$; $r = 0.598$,

$p < 0.0005$), MPO ($r = 0.535$, $p < 0.0001$; $r = 0.578$, $p < 0.0005$), and $VO_2max.kg^{-1}$ ($r = 0.612$, $p < 0.0001$; $r = 0.751$, $p < 0.0005$).

The ECM/BCM relationship was significantly negatively correlated with CTW ($r = -0.671$, $p < 0.0001$; $r = -0.634$, $p < 0.0001$), MPO ($r = -0.683$, $p < 0.0001$; $r = -0.687$, $p < 0.0001$), and $VO_2max.kg^{-1}$ ($r = -0.787$; $p < 0.0001$; $r = -0.766$, $p < 0.0001$).

TABLE 1
Mean values ($\pm s_D$) of body fat in the percentages of body weight (% BF) that were determined by the whole body bioimpedance method

	N_{Boys}	Boys	N_{Girls}	Girls
Age (years)		% BF (%)		% BF (%)
6	80	22.4 ± 4.1	53	24.5 ± 4.0
7	78	21.4 ± 3.8	54	23.1 ± 3.8
8	86	20.4 ± 4.4	51	22.8 ± 3.9
9	82	20.1 ± 3.6	56	22.3 ± 3.6
10	85	19.9 ± 3.2	50	21.9 ± 3.3
11	88	19.5 ± 3.0	52	21.3 ± 3.1
12	84	18.2 ± 3.1	56	20.3 ± 3.0
13	86	17.9 ± 2.9	54	20.9 ± 2.6
14	87	18.0 ± 2.8	53	21.4 ± 3.0

TABLE 2
Mean values ($\pm s_D$) of the percentages of total body water (% TBW) determined by the whole body bioimpedance method

	Boys	Girls
Age (years)	% TBW (%)	% TBW (%)
6	69.2 ± 5.1	67.2 ± 4.8
7	68.4 ± 4.1	66.5 ± 4.3
8	67.3 ± 3.6	65.1 ± 4.6
9	66.6 ± 3.4	64.1 ± 4.0
10	65.3 ± 3.1	62.9 ± 4.2
11	64.3 ± 3.0	61.5 ± 3.6
12	63.7 ± 3.2	60.2 ± 3.4
13	62.4 ± 3.6	58.9 ± 3.8
14	60.7 ± 3.7	57.2 ± 3.6

TABLE 3
Mean values ($\pm s_D$) of the ECM/BCM relationship that were determined by the whole body bioimpedance method

	Boys	Girls
Age (years)	ECM/BCM	ECM/BCM
6	0.92 ± 0.08	0.95 ± 0.09
7	0.90 ± 0.09	0.92 ± 0.09
8	0.88 ± 0.08	0.91 ± 0.08
9	0.85 ± 0.07	0.88 ± 0.08
10	0.83 ± 0.09	0.87 ± 0.08
11	0.82 ± 0.07	0.84 ± 0.09
12	0.80 ± 0.07	0.82 ± 0.08
13	0.78 ± 0.06	0.81 ± 0.07
14	0.75 ± 0.06	0.78 ± 0.06

TABLE 4
Mean values ($\pm s_D$) of the maximal oxygen uptake ($VO_2max.kg^{-1}$) that was determined by an incremental test on the treadmill

	Boys	Girls
Age (years)	$VO_2max.kg^{-1}$ ($ml.min^{-1}.kg^{-1}$)	$VO_2max.kg^{-1}$ ($ml.min^{-1}.kg^{-1}$)
6	30.9 ± 4.3	30.0 ± 3.8
7	36.4 ± 5.1	33.6 ± 4.0
8	40.1 ± 4.8	35.9 ± 4.2
9	42.7 ± 5.2	37.9 ± 3.7
10	44.6 ± 5.3	39.7 ± 4.0
11	46.9 ± 4.6	40.4 ± 4.3
12	48.2 ± 4.5	41.9 ± 4.4
13	50.8 ± 4.9	42.1 ± 4.3
14	52.9 ± 4.4	42.3 ± 4.5

TABLE 5
Mean values ($\pm s_D$) of selected anthropometrical variables that were determined by the whole body bioimpedance method

	Boys	Girls
Age (years)	10.1 ± 2.8	10.1 ± 2.9
Body Mass (kg)	34.5 ± 3.4	35.1 ± 4.8
Height (cm)	147.5 ± 4.3	145.8 ± 4.7
% Body Fat (%)	19.8 ± 2.4	21.9 ± 3.1
TBW (l)	22.5 ± 3.4	22.1 ± 3.6
TBW/body mass (%)	65.3 ± 3.8	62.6 ± 4.2
BCM (kg)	14.9 ± 3.5	14.6 ± 3.6
ECM/BCM	0.84 ± 0.09	0.87 ± 0.10

TABLE 6
Mean values (± s_D) of selected functional variables and calculated total work (CTW) and maximal power output (MPO) that were determined on a treadmill with a slope of 5%

	Boys	Girls
$VO_2max.kg^{-1}$ ($ml.kg^{-1}.min^{-1}$)	43.7 ± 6.4	38.2 ± 4.2
CTW (kJ)	44.2 ± 6.2	36.2 ± 4.8
MPO (W)	140.9 ± 11.2	121.3 ± 10.2
v_{max} ($km.h^{-1}$) 5%	13.1 ± 2.3	12.0 ± 2.6

DISCUSSION

Body composition during prepuberty and mainly during puberty is a marker of metabolic changes that occur during this period of growth and maturation, and, thus, holds key information regarding current and future health. During puberty, the main components of body composition (total body fat, lean body mass, bone mineral content) all increase, but considerable sexual dimorphism exists (Okely, Booth, & Chey, 2004). Components of body composition show age to age correlations (i. e. "tracking"), especially from adolescence onwards. Furthermore, adipose tissue is endocrinologically active and is centrally involved in the interaction between adipocytokines, insulin and sex-steroid hormones, and thus influences cardiovascular and metabolic disease processes.

Age showed a significant effect for most body composition variables. Total body water is by far the most abundant of the constituents of the body. As a percentage of body mass, TBW decreases significantly with increasing age – it varies from 70 to 75% at birth to less than 40% in obese adults (Roche, Heymsfield, & Lohman, 1996). Our slightly lower data in Czech children are probably caused by the use of a different method of % TBW determination that in the above mentioned paper. Total body water is essential for life, serving as a solvent for biochemical reactions and as a transport media. Despite being the most abundant constituent of the body, it is often neglected because the volume of TBW is well regulated in normal healthy conditions. Indeed, a 15% decrease in body water due to dehydration is life threatening (Roche, Heymsfield, & Lohman, 1996). Even a small change in TBW however, can produce a measurable change in body mass and thus determination of TBW is central to measuring body composition.

Fat free mass rises throughout childhood similarly in boys and girls until puberty (Malina & Bouchard, 1991). The acceleration in FFM at this time in males reflects their augmented muscle mass at the time of the adolescent growth spurt. The absence of an increase in FFM at puberty in females means that girls reach adult levels approximately 5 years before males, whose FFM matures at the age of 19–20 years (Malina & Bouchard, 1991).

Average fat mass in females is greater than in males from mid-childhood on. These differences become more obvious in the pubertal years as girls accumulate greater adipose tissue. The percentage of body fat slowly declines during early childhood in both sexes after an early jump in infancy (Malina & Bouchard, 1991). As puberty approaches, females demonstrate a progressive rise that continues throughout adolescence. Males, on the other hand, show a slight increase in relative fatness in the late prepubertal age; their percentage of body fat then slowly declines, reflecting the development of FFM at puberty. Consequently, females have a greater percentage of body fat than males throughout childhood after the age of 3–4 years. In the late teen years, the average female has an about 50% higher percentage of body fat than the relative fatness of her counterpart.

The value of ECM/BCM may be used as a complementary criterion for the assessing of predispositions for exercise. The lower the ECM/BCM is, the better is the predisposition for physical exercise. In highly trained adult athletes, these values were at about 0.7. In our children, the mean values were 0.87 ± 0.12 in boys, and 0.96 ± 0.14 in girls. Both these values are similar to those in adults.

The ratio of ECM/BCM is a decisive parameter for sports events which require a big power output, like endurance running, cross country skiing, etc. The determination of the ECM/BCM ratio is mainly a problem of the selection of suitable types for every kind of sport.

The whole body impedance measurement at different frequencies is an attractive method of body composition assessment because it is quick, does not require a high degree of technician skill, and does not intrude on the client's privacy. Because it is difficult to obtain accurate measurements by using other methods for the determination of body composition (e. g. dual-energy x-ray absorptiometry, isotope dilution, etc.) on children, the impedance method is the preferred field and laboratory method for estimating body composition in these populations. Generally the impedance methods have limited accuracy because:

- we cannot measure the whole body (including the head, feet, and hands),
- the shape of the body deviates from the ideal cylinder,
- the conductive material is unequally distributed throughout the body, and
- the methods were not evaluated in large sample sizes.

In the present study, boys performed a bigger workload and achieved higher maximal work rates than girls, which corresponded with previously published observations of young athletes (e. g. Astrand & Rodahl, 1986).

The initial concern with the development of a youth fitness test must be definitional. The definition of physical fitness has evolved over the last 50 years but remains largely operationally defined by the tests used to measure it (Astrand & Rodahl, 1986; Franks et al., 1988). The tests used to measure physical fitness have, in turn, frequently been selected by the criteria of convenience (e. g. no equipment, little time involvement, ease of scoring) and tradition (e. g. familiar) rather than by physiological soundness representing specific components of fitness.

Physical fitness, and thus aerobic fitness, is not understood solely in terms of a potential for tolerating physical stress. Often it is viewed as one of the dimensions of health.

Aerobic fitness is not synonymous with health related fitness, though this has sometimes been supposed. Nevertheless, a large degree of cardiovascular fitness – maximal oxygen uptake – is one of the most important physiological indicators of good physical condition. It is necessary in many forms of strenuous occupational activity, and its maintenance makes a major contribution to quality of life in childhood and mainly in older age (Shephard, 1994).

The presented standards of maximal oxygen uptake and thus of AF do not significantly differ from the data of European population samples (e. g. Armstrong & Welsman, 1994; Lange Andersen et al., 1985; Seliger & Bartůněk, 1977; Welsman & Armstrong, 2000). Physical performance in younger groups (younger than 12 years) is similar to the data from other European countries but performance for older subjects is slightly lower than in other European studies. These differences increase with an increase in age. The reason for this is probably connected with the amount of physical activity, which significantly decreases with increasing age – from 4.7 hours of physical activity per week in young subjects (younger than 12 years) to 2.1 hours per week in older groups.

The mean speed during the motor tests can characterise the level of physical performance, and may be used for indirect determination of aerobic fitness under field conditions. The accuracy of VO_2max assessment and thus the determination of aerobic fitness from the mean speed of motion was altered at around 15%.

These differences may seem to be large, but one should note that the errors of cardiorespiratory measurements during exercise testing are at about the level of 5%. From this point of view it is legitimate to assume that the TABLE presented for the assessment of aerobic fitness in the field conditions is valid. Motivation has a similar influence on the results of this test as in other methods which use maximal parameters.

The primary determinant of success in physical activity like sport is the ability to sustain a high rate of energy expenditure for prolonged periods of time. Exercise training – induced physiological adaptations in virtually all systems of the body allow the subject to accomplish this. Aerobic capacity as described with the help of VO_2max, economy of motion and fractional utilisation of maximal capacity reflect the integrated responses of these physiological adaptations (Astrand & Rodahl, 1986).

The physiological adaptations to physical exercise that correspond to and facilitate improved VO_2max occur centrally in the cardiovascular system, centred on increased maximal cardiac output, and peripherally in the metabolic system, centred an increased arterio-venous O_2 difference.

In summary, based on the significant relationships between selected variables of the BC and aerobic fitness and physical performance in children, it could be concluded that the BC is an important determinant of functional and physical performance that often is overlooked. Pubertal and pre-pubertal body composition is important, not only for the assessment of contemporaneous nutritional status, but also for being linked directly to the possible onset of chronic disease later in life and is, therefore, useful for disease risk assessment and intervention early in life.

The results demonstrate that by evaluating training state and/or sports predisposition, it is necessary to assess both BC and functional characteristics. Calculated CTW and MPO and VO_2max are dependent on FFM and mainly on BCM. Therefore, we conclude that:

- determination of BC is necessary to interpret laboratory exercise testing,
- calculated performance variables together with laboratory PP characteristics such as CTW and MPO could us help with an assessment of predisposition for success in physical exercise.

The results demonstrate that when VO_2 is not feasible, physical performance characteristics together with parameters of body composition seem to be a good predictor of aerobic fitness; this may be very helpful in large population studies.

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TĚLESNÉ SLOŽENÍ JAKO URČUJÍCÍ FAKTOR AEROBNÍ ZDATNOSTI A TĚLESNÉ VÝKONNOSTI ČESKÝCH DĚTÍ

(Souhrn anglického textu)

Tělesné složení (TS) je možné použít jako kritérium aktuálního biologického stavu dětí – stavu rozvoje. Cílem naší studie bylo stanovit závislost parametrů tělesného složení a aerobní zdatnosti ($VO_2max.kg^{-1}$) a proměnných tělesné výkonnosti – počítaná celková práce (CTW) a maximální výkon (MPO) stanovené na běhátku u skupiny českých dětí.

Závislost mezi běžně užívanými parametry aerobní zdatnosti ($VO_2max.kg^{-1}$, CTW a MPO) a TS (% BF, FFM, BCM a ECM/BCM) byla stanovena u 1235 dětí (756 chlapců a 479 děvčat) ve věku 6 až 14 let. Aerobní zdatnost a tělesná výkonnost byly hodnoceny pomocí stupňovaného zatížení na běhacím koberci o stálém sklonu 5 %. Počáteční na věku závislá rychlost běhu byla zvyšována o 1 $km.h^{-1}$ až do okamžiku subjektivního vyčerpání. Tělesné složení bylo hodnoceno pomocí celotělové bioimpedanční metody s využitím predikčních rovnic pro děti. Procento BF vykazovalo zápornou signifikantní korelaci s $VO_2max.kg^{-1}$ a CTW. Obojí jak FFM tak BCM pozitivně korelovalo s CTW, MPO a $VO_2max.kg^{-1}$. Koeficient ECM/BCM byl v negativním vztahu s $VO_2max.kg^{-1}$ a CTW. Závěrem lze konstatovat, že TS je významným funkčním determinantem v laboratorních podmínkách (zátěžový test na běhátku) a v terénu (běžecký nebo chodecký test). Sledované proměnné, charakterizující TS, významně ovlivňují proměnné, které mohou definovat aerobní zdatnost. Výsledky dokládají, že jestliže není možné přímo měřit spotřebu kyslíku, lze k odhadu těchto proměnných využít parametrů tělesné výkonnosti a tělesného složení; toto může být velmi užitečné v případě velkých populačních studií.

Klíčová slova: tělesné složení, spotřeba kyslíku, aerobní zdatnost, tělesná výkonnost, děti, laboratorní testování.

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Scientific orientation

Application of mathematical methods and models in PE and sport, the use of biocybernetics in the evaluation of physical fitness, exercise physiology, functional and physical testing in laboratory and field, body composition, BIA methods, moving regimes for prevention in cardiac patients.

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