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— Review —

Total Body Composition in Children

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Abstract

The study of body composition involves quantifying the primary tissue components of body mass- i.e, the lean body mass (LBM) and fat mass (FM). The human body composition changes as the body develops, matures, and ages. Regardless of the area of interest, some basic information about LBM and FM is usually needed by researchers, practitioners, clinicians, and others in health- and fitness-related professions. This review attempts to provide the requisite information regarding the LBM and FM that constitute total body composition in children and, when data are available, to discuss the effects of age and gender on body composition. The focus will be on the major components of the body — LBM, FM, and percent body fat (%BF) — and on changes observed from infancy to puberty. However, the limited use of densitometry and hydrometry in body composition studies of children may be attributed to the difficulty in accessing appropriate instruments, the cost, and the time required to make such measurements. Major changes in body composition occur during childhood. With growth and maturation, the absolute values of LBM and TBW increase, whereas the relative contribution of water to LBM declines. As a result, this review considers methods used for studying body composition, the applicability of the methods to growing children, and changes in body composition during growth.

Key words: body composition, children, measurement method, lean body mass, fat mass

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Introduction

The human body is a complex organism composed of a variety of tissues that change as the body develops, matures, and ages. It is important to recognize how these body parts may be affected by age and gender, while remembering that they are also influenced by a variety of environmental agents and the lifestyle of the individual.

The human body is composed of primarily five

increasingly complex levels: atomic, molecular, cellular, tissue-system, and whole-body¹⁾. At each level, the sum of all components is equivalent to body mass. Body mass is a gross measure of the mass of the body; it is a composite of measures of different tissues, the primary ones being bone, muscle, fat, and viscera. However, knowing the body mass does not provide one with adequate information on tissue distribution or quantity of different tissues within an individual. At present,

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most body composition research is performed using the classic two-component model, which partitions body mass into its lean and fat components.

The lean aspect of the body is referred to as lean body mass (LBM), or fat-free mass (FFM), and the other portion of this model is the fat mass (FM). The FFM consists of total body water, bone, muscle, connective tissue, and vital organs. The LBM contains the FFM plus essential lipid substances present in the bone marrow, spinal cord, brain, and certain organs. The LBM is a theoretical *in vivo* entity, while the FFM is a *in vitro* entity based on carcass analysis²⁾. However, these small essential lipid components are usually ignored in body composition research or grouped into a miscellaneous or residual mass component. Therefore, this review uses the terms LBM and FM.

The quantification of body composition into its FM and LBM components is important if one wishes to describe excesses or deficiencies of FM and LBM that have significant associations with the risk or onset of disease. FM is readily influenced by, for example, habits of diet and physical activity, and thus FM is the most labile component of body composition. In particular, obesity has a negative influence on physical performance and is associated with several diseases (e.g., non-insulin-dependent diabetes and heart disease).

On the other hand, there is increasing interest in LBM because of its relationships to caloric balance and physical performance. Therefore, an understanding or basic knowledge of body composition in children is relevant to many disciplines, including health and medicine, nutrition, and other biological sciences. The study of human body composition includes the quantification and distribution of FM and LBM and their variation as a function of age and gender.

This review attempts to provide the requisite information regarding the LBM and FM of the body that constitute total body composition in children and, when data are available, to discuss the effects of age and gender on body composition. The focus will be on the major components of the body — LBM, FM, and percent body fat (% BF) —

and on the changes observed from infancy to puberty. This review defines childhood as “the period from infancy to puberty” (it is commonly agreed that infancy ends at one year of age) according to Webster’s dictionary.

Applications of measurement methods to children

Commonly used methods for estimating body composition *in vivo* are indirect. Thus, $FM = \text{body mass} - LBM$ or $LBM = \text{body mass} - FM$. Of the available methods for estimating body composition within the two-component model, two are widely used and have been applied quite regularly with children: measurements of body density and body water. Of special importance to studies of growing children is the fact that the methods have been developed on adults. The formulas for estimating LBM or FM, and the assumptions underlying the procedures, are based primarily upon measuring young adult males.

Long considered the “gold standard,” hydrodensitometry often has been used as the criterion method in validation studies of new body composition assessment methods. The findings from recent studies, however, have emphasized the limitations of densitometry, especially when applied across a wide age range without adjustments for the changes that occur with growth and maturation³⁾. Furthermore, the densitometric method is somewhat slow and often requires training subjects to become comfortable with the procedure. The lower age limit for its use with children is about 7 or 8 years.

Total body water (TBW) can be used to estimate body composition¹⁾. The two-component model is based on the knowledge that lipids are hydrophobic and thus free of water, which is therefore restricted to the LBM component. TBW can be measured using the dilution principle. Application of the dilution principle *in vivo*, however, is more complex than it is *in vitro*. This complexity arises because the tracers used in the *in vivo* dilution do not behave in an ideal manner. Labeled water for the measurement of TBW can be assayed using one of

several methods. The choice of method is often one of convenience and depends on the local availability of instruments and expertise. Deuterium oxide (D_2O) was the first tracer available to investigators for the measurement of TBW, especially for studies involving children. If tritiated water is used, there is the problem of exposure to a radioactive isotope. The calculation of LBM from TBW depends on an assumption of constant hydration of LBM – i.e., that the ratio of water to solids in the LBM is the same in all subjects. The most commonly used hydration constant is 0.732, which was first recommended by Pace and Rathbun⁴⁾. An exception to constancy of hydration occurs in children when the hydration of LBM is elevated relative to adult values in humans. Fomon et al.⁵⁾ have estimated the hydration constant for ages ranging from birth to 10 years. As a percentage of LBM, TBW declines slowly from the value observed at one year to five years of age. However, they assumed that D_2O overestimated TBW by only 1.3%.

The limited use of densitometry and hydrometry in body composition studies of children may be attributed to the difficulty of access to the appropriate instruments, the cost, and the time required to make such measurements.

The development of additional methods of measuring TBW, such as bioelectric impedance analysis (BIA), have provided investigators with the means to estimate the hydration constant *in vivo*. The use of BIA to estimate body composition is based on the different conductive and dielectric properties of various biological tissues at various frequencies of current. Tissues that contain a lot of water and electrolytes such as LBM are highly conductive, whereas FM is highly resistive. For a cylindrical, isotropic conductor such as a wire, resistance (R) is directly proportional to the conductor's length (L , cm) and inversely proportional to its cross-sectional area (A , cm^2), or $R = \rho L/A$. Since volume (V) equals $L \times A$, algebraic rearrangement shows that $V = \rho L^2/R$. Hence, the volume of a conductor can be deduced from measurements of its length and resistance. The BIA method is applicable technically to all subjects, regardless of age and

gender.

In healthy young men the mean TBW/LBM has been shown to be close to the expected value with a narrow range of variation resulting in only a small increase in the error of prediction of LBM compared to TBW. Indeed, the bioelectric impedance method of estimating body composition is best suited to epidemiological studies. This situation, however, cannot be assumed to hold for samples including children, who may have different mean levels as well as greater variability for TBW/LBM. In four surface-electrode techniques, the current is applied with one pair of electrodes located distally while a second pair located proximally measures the electrical potential across a segment of the conductor. When using this technique, the paired source and receiving electrodes must be separated by at least 5 cm to avoid interaction. Barillas-Mury et al.⁶⁾ were able to separate the electrodes sufficiently to stabilize the measurement of resistance on the feet but not the hands of children aged 3 to 10 years. In particular, the main limitation to the general applicability of BIA is the availability of appropriately calibrated, cross-validated predictive equations. It is most important to make a careful selection of equations that were developed from a sample that is similar in age and gender to the subjects under study^{7), 8), 9)}.

The important issue in growing children is to determine when adult density and water concentration of lean tissue are achieved. One limitation to the general availability of a useful technique of assessing body composition in children is the relative lack of direct data on anatomical body compartments (i.e., LBM and FM). In any case, their application, or perhaps more appropriately, misapplication, to growing children may thus result in spuriously high or low estimates of body composition.

Estimated LBM in children

LBM consists of water, bone, muscle, connective tissue, and vital organs. However, LBM does not distinguish among bone, muscle, and the viscera.

The increase in LBM and TBW from birth to 8 years is clear. Although there is a gender difference in LBM throughout infancy and childhood, it is not of great magnitude. In contrast, as a percentage of LBM, TBW declines slowly from the value observed at one year (79.0% in boys and 78.8% in girls) to about 76% by 8 years of age (Table 1). Thus, with growth and maturation, the absolute values of LBM and TBW increase, whereas the relative contribution of water to LBM declines. Gender differences in the relative composition of LBM are negligible during infancy and become apparent in early childhood. After about 3 years of age, the estimated relative composition of LBM

indicates less water in boys and water comprises a slightly greater percentage of LBM in girls (75.7% in boys vs. 77.2% in girls at 8 years of age). Thus, the estimated water content of LBM does not approach the 73.2% suggested in studies of adults until late childhood.

Estimates of LBM, TBW, and hydration of LBM in Japanese children 3 to 8 years of age are summarized in Table 2. Clearly, major changes in body composition occur during childhood. These changes include a decrease in the water fraction of the LBM; adult levels are reached at 8 years in Japanese boys but not until about 8 years in Japanese girls. Thus, use of the adult constant of

Table 1 Lean body mass (LBM), total body water (TBW) and hydration of LBM (%LBM) in children

Age	Boys				Girls			
	BM, kg	LBM, kg	TBW, ℓ	%LBM	BM, kg	LBM, kg	TBW, ℓ	%LBM
Birth	3.54	3.06	2.47	80.6	3.33	2.83	2.28	80.6
1 mo	4.45	3.78	3.04	80.5	4.13	3.46	2.79	80.5
2 mo	5.51	4.41	3.54	80.3	4.99	3.94	3.16	80.2
3 mo	6.44	4.94	3.95	80.0	5.74	4.38	3.50	79.9
4 mo	7.06	5.32	4.25	79.9	6.30	4.72	3.76	79.7
5 mo	7.58	5.66	4.51	79.7	6.80	5.03	4.00	79.5
6 mo	8.03	5.99	4.77	79.6	7.25	5.34	4.24	79.4
9 mo	9.18	6.98	5.54	79.3	8.27	6.20	4.90	79.0
1 yr	10.15	7.86	6.21	79.0	9.18	7.01	5.52	78.8
2 yr	12.59	10.13	7.91	78.1	11.91	9.48	7.41	78.2
3 yr	14.68	12.10	9.38	77.5	14.10	11.49	8.95	77.9
4 yr	16.69	14.03	10.81	77.0	15.96	13.20	10.26	77.7
5 yr	18.67	15.95	12.22	76.6	17.66	14.71	11.42	77.6
6 yr	20.69	17.90	13.65	76.3	19.52	16.31	12.64	77.5
7 yr	22.85	19.92	15.12	75.9	21.84	18.18	14.05	77.3
8 yr	25.30	22.01	16.66	75.7	24.84	20.52	15.84	77.2

Adapted from "Body Composition of Reference Children From Birth to Age 10 Years," by S.J. Fomon et al., 1982, *American Journal of Clinical Nutrition*, 35, pp. 1169-1175.

Table 2 Lean body mass (LBM), total body water (TBW) and hydration of LBM (%LBM) in Japanese children

Age	Boys				Girls			
	BM, kg	LBM, kg	TBW, ℓ	%LBM	BM, kg	LBM, kg	TBW, ℓ	%LBM
3 yr	14.83	12.46	9.28	74.1	47.74	11.81	8.97	76.0
4 yr	16.18	13.67	10.10	73.9	16.28	13.20	10.00	75.8
5 yr	18.32	15.25	11.23	73.7	18.01	14.37	10.86	75.5
6 yr	20.37	17.21	12.64	73.4	19.65	15.79	11.90	75.4
7 yr	22.11	18.37	13.50	73.5	21.97	17.17	12.95	75.4
8 yr	25.97	21.33	15.62	73.2	26.74	20.35	15.29	75.2

S.Komiya, unpublished data.

0.732 to estimate LBM from TBW in early childhood results in overestimation of LBM and underestimation of FM. Between the ages of 3 and 8, the average increment in LBM is 8.75 kg in boys and 8.54 kg in girls. The mean increments did not differ significantly between the genders for LBM. At 3 years of age, the boy/girl ratio in LBM is 1.06:1, and at 8 years of age it is 1.05:1. Figure 1 shows the calculated regression lines for LBM against stature in Japanese children 3 to 9 years old. The correlation coefficients of LBM with stature are 0.916 ($p < 0.001$) for boys and 0.922 ($p < 0.001$) for girls. This points up the fact that LBM is indeed related to stature. The slope for boys (0.34 kg/cm) is somewhat steeper than that for girls (0.32 kg/cm). Thus, gender differences in LBM per unit stature are small in childhood.

Estimated FM in children

Lipids can be classified physiologically as essential or non-essential. Non-essential lipids, mainly in the form of triglycerides, provide thermal insulation and a storage depot of available fuel. The non-essential component is synonymous with the term *fat*, as it consists almost entirely of triglycerides. The essential lipid components are usually ignored in body composition research. Therefore, storage fat mass has become virtually synonymous with total body fat mass, also called FM (i.e., FM = body mass - LBM). The storage fat consists of non-essential lipids that accumulate

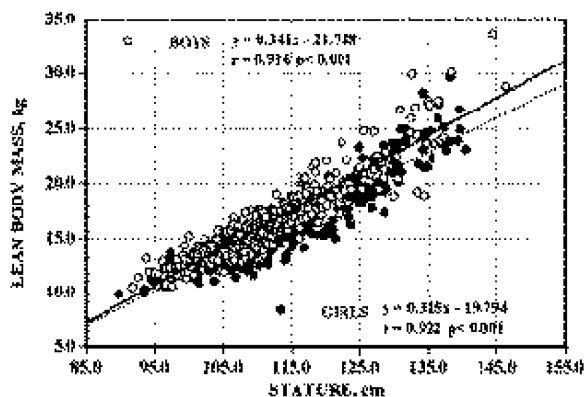


Fig. 1 Lean body mass as a function of height

in adipose tissue. Adipose tissue can be differentiated into that which is visceral (internal or deep) and that which is subcutaneous (external or outer). However, information on the contribution of visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT) to FM during growth is limited.

Total body fat mass (FM) and percent body fat (%BF)

The estimates of FM and %BF should provide an adequate indication of the growth pattern of FM and %BF as indicators of body composition. The full-term infant is born with a store of body fat (14-15% of body mass) greater, relatively speaking, than that of other mammals. Fat accumulation begins promptly after birth, and calculations by Fomon et al.⁵⁾ show a remarkable increase during the first year of life, followed by only small changes through 5 to 6 years of age (Fig. 2). Subsequently, FM increases more rapidly in girls than in boys. Increases in the gender differences between boys and girls are observed in FM, which continues to increase to almost 2.0 kg by the age of 10 years.

Relative fatness (%BF) increases rapidly in both

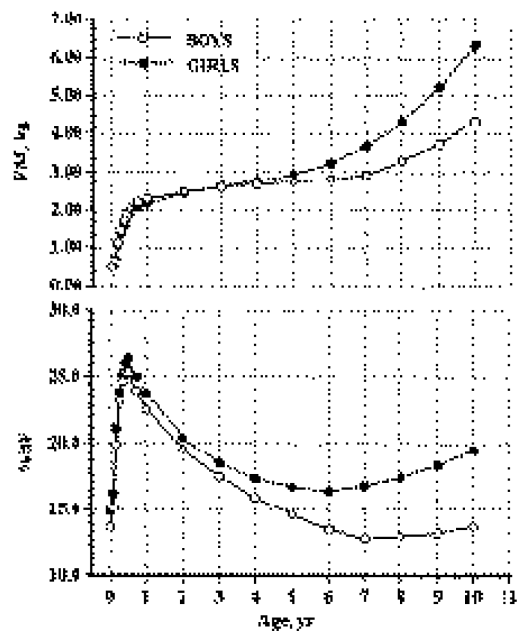


Fig. 2 Growth curves for FM and %BF

Drawn from data reported by Fomon et al. (1982).

sexes during infancy: at 6 months old infant body fat is estimated at 25 to 26 percent. Thereafter there is a decline in %BF, to a low level in the mid-childhood years (6 years of age for boys and 7 years of age for girls), and then an increase in the late-childhood girls, while it appears to reach a plateau in boys. Namely, girls tend to average a slightly greater %BF than boys during infancy and early childhood, but from age 6 to 10 years, girls consistently have a greater %BF than do boys. Figure 3 shows the relationship between FM and body mass. The correlation coefficients of FM with body mass are 0.815 and 0.555 in boys and girls, respectively. On average the regression slopes are about 0.31 kg and 0.24 kg of FM/kg in boys and girls, respectively.

Subcutaneous fat mass (SFM) and internal fat mass (IFM)

There is no consensus as to which methods best define and describe adipose tissue distribution. Computerized tomography (CT) is the primary tool in the study of VAT and SAT, most often in the abdominal region. Since it requires a radiation dose, application of CT procedures to large samples and to clinically normal children is unlikely. Most of the literature on age and sex variation in adipose tissue distribution is based upon skinfold thickness measurements, usually in terms of the relative size of trunk (central) versus extremity (peripheral) skinfold thickness. Ratios of skinfold thicknesses

at various trunk (T; sums of the subscapular and suprailiac) and extremity (E; sums of the triceps and biceps) sites also describe relative adipose tissue distribution. Changes in the ratio of T to E skinfold thicknesses (T/E ratio) from one month old to 10 years of age are summarized in Fig. 4¹⁰⁾. Shortly after birth, infants have almost equal thicknesses of SAT in the T and E sites. Subsequently, the ratio decreases through early childhood, reaching a low point at about 5 years of age. This suggests a proportionally greater accumulation of SAT on the extremities than on the trunk. After 5 years of age, the ratio increases gradually to 10 years in each sex. The gender difference in the ratio is negligible.

We have attempted to partition FM into its subcutaneous and internal components using anthropometric procedures^{11), 12)}. Subcutaneous fat mass (SFM) was derived from 14 skinfold measurements, body surface area, skin weight, and the density of adipose tissue in Japanese children. Total FM was derived from bioelectric impedance analysis (BIA). Internal fat mass (IFM) was derived by subtraction. Estimates of FM, %BF, SFM, and IFM in Japanese children 3 to 8 years of age are summarized in Table 3 and Fig. 5. After 3 years of age, the FM, SFM, and IFM increases gradually to 6 years of age in each sex, and the difference between the sexes is small. Subsequently, FM, SFM, and IFM increase rapidly in both sexes to 8 years of age, except for IFM in boys.

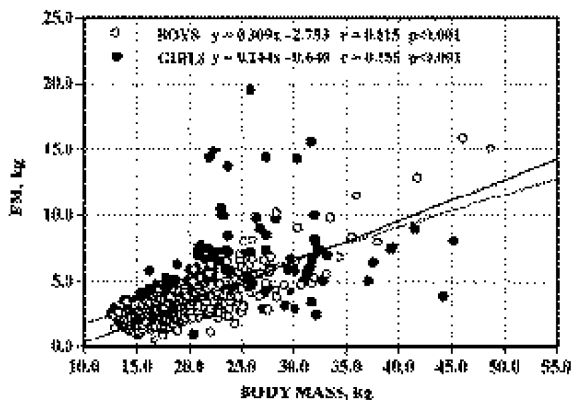


Fig. 3 Total body fat mass (FM) as a function of body mass

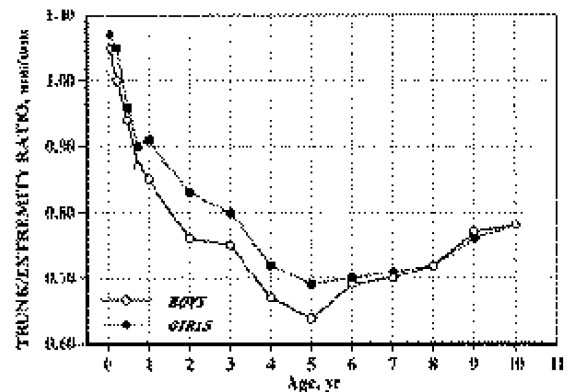


Fig. 4 Subscapular + suprailiac / triceps + biceps skinfold thicknesses in children

Drawn from data reported by Rolland-Cachera et al. (1990)

At the same time, the sex difference becomes significant. Though not differentiating between SAT and VAT, estimates of SFM and IFM distributions of adipose tissue (AT) indicate the sex difference and change in relative AT distribution associated with age (Fig. 6). The proportion of IFM is greater than that of SFM in each sex. As a percentage of FM, IFM declines slowly from the value observed at 3 years of age (56%) to about 51% by 8 years of age in boys, but not in girls.

Estimated total body composition in Japanese children

Data on the stability of estimates of LBM, FM, and %BF in Japanese children are not presently available. The availability of age-specific reference data would permit estimation of the increments in specific body components associated with growth at various ages. We have therefore attempted to describe the body composition of reference children applicable to selected ages from 3 to 6 years of age. Figure 7 shows the growth curve for BMI and the

Table 3 Total body fat (FM), percent body fat (%BF), subcutaneous fat mass (SFM) and internal fat mass (IFM) in Japanese children

Age	Boys				Girls			
	FM, kg	%BF	SFM, kg	IFM, kg	FM, kg	%BF	SFM, kg	IFM, kg
3 yr	2.4	15.9	1.1	1.3	2.9	19.8	1.3	1.6
4 yr	2.5	15.3	1.2	1.3	3.1	18.7	1.5	1.6
5 yr	3.2	16.8	1.5	1.7	3.6	19.9	1.7	1.9
6 yr	3.4	12.0	1.7	1.7	3.9	14.0	1.8	2.1
7 yr	4.0	16.8	2.0	2.0	5.4	22.4	2.5	2.9
8 yr	5.4	17.5	3.2	2.2	7.4	24.7	3.8	3.7

S.Komiya, unpublished data.

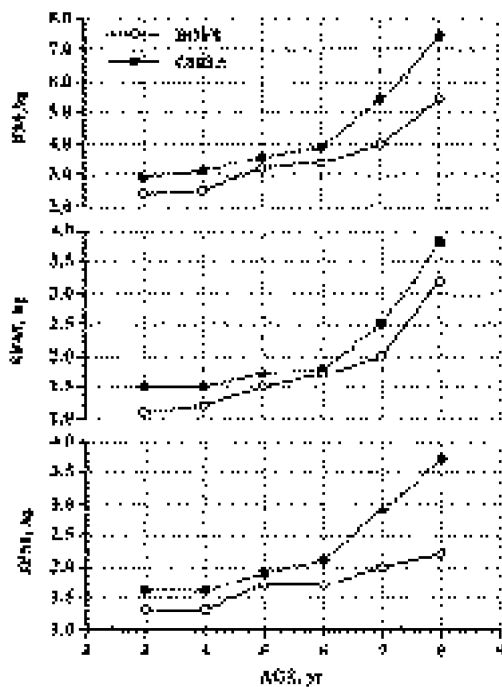


Fig. 5 Growth curves for FM, SFM, and IFM in Japanese children

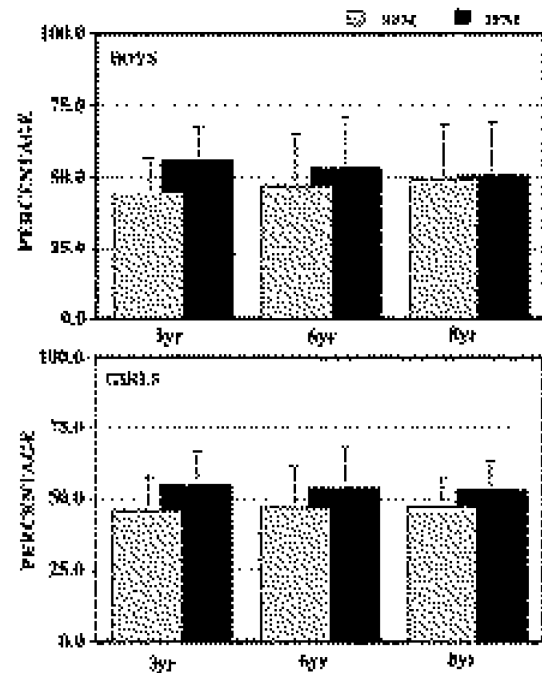


Fig. 6 Proportion of SFM and IFM in Japanese children

relationship between FM and BMI. Similar trends are apparent in BMI and FM (see Fig. 5). Furthermore, the correlation coefficients between BMI and FM were significant ($p < 0.001$). We used the BMI of reference children whose measurements fell between the 25th and 75th percentile values from the data of 141 boys and 139 girls¹³. The body composition estimates for the reference children at each age are given in Fig. 8. In reference boys, fat comprised 18.1% of body mass at age 3 years and 17.3% of body mass at age 6 years. Corresponding values for girls were 20.7% and 19.2%. LBM was found to be 11.8 kg in the 3-yr-old reference boys and 17.4 kg in the 6-yr-old reference boys. Corresponding values for girls were 11.4 kg and 16.2 kg. The body composition estimates for the low- and high-body-mass children are given in Fig. 9¹². The low-body-mass children are defined as those children having a BMI below the 25th percentile, and the high-body-mass children were those with a BMI above the 75th percentile. The low-body-mass girls had more SFM than the low-body-mass boys; expressed as a percentage of body mass, and SFM estimated by the two-component model was significantly higher in the low-body-mass girls (7.0%

versus 5.1%; $p < 0.05$). However, the LBM and IFM did not differ significantly between low-body-mass boys and girls. The high-body-mass girls had higher %BF than the high-body-mass boys (24.0% versus 20.8%; $p < 0.05$); girls tend to average slightly greater percentages of SFM and IFM than those of boys.

Summary

The study of body composition attempts to quantify the primary tissue components of body mass (i.e., the LBM and FM). The human body composition changes as the body develops, matures, and ages. Regardless of the area of interest, some

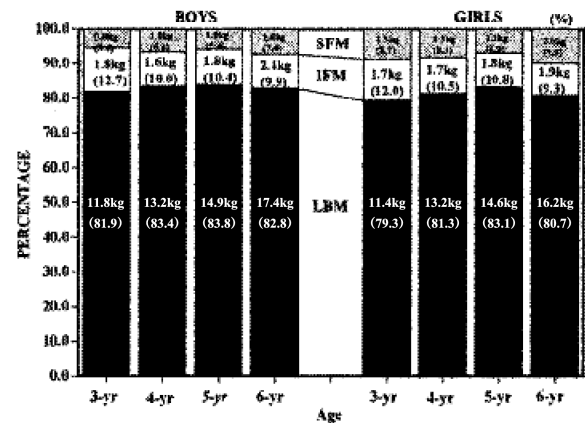


Fig. 8 Changes in total body composition as a percentage of body mass with age of reference children (3-to 6-years of age)

Drawn from data reported by Otaki et al. (1999)

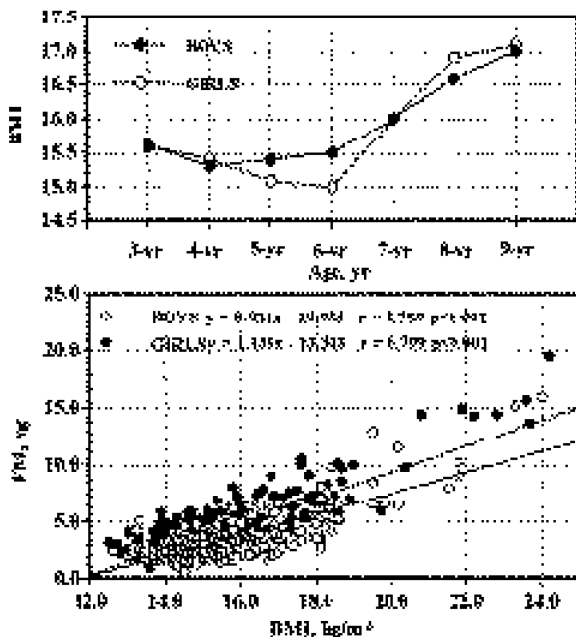


Fig. 7 Growth curves for BMI and total body fat mass (FM) as a function of BMI

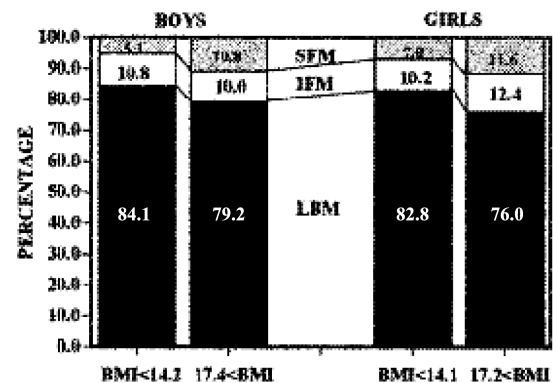


Fig. 9 Total body composition in low- and high-body-mass children

Adapted from Komiya et al., 2000.

basic information about LBM and FM is usually needed by researchers, practitioners, clinicians, and others in health- and fitness-related professions. This review considers methods used for studying body composition, the applicability of the methods to growing children, and changes in body composition during growth.

The limited use of densitometry and hydrometry in body composition studies of children may be attributed to the difficulty of access to the appropriate instruments, the cost, and the time required to make such measurements. The formulas for the estimation LBM or FM, and the assumptions underlying the procedures, are based primarily upon measurements made of young adult males. The important issue in growing children is to determine when adult density and water concentration of lean tissue are achieved. It is most important to make a careful selection of equations that were developed from a sample that is similar in age and gender to the subjects under study. In any case, the equations' application, or perhaps more appropriately, misapplication, to growing children may thus result in spuriously high or low estimates of body composition.

Clearly, major changes in body composition occur during childhood. With growth and maturation, the absolute values of LBM and TBW increase, whereas the relative contribution of water to LBM declines. Between the ages of 3 and 8, the average increment in LBM is 8.75 kg in boys and 8.54 kg in girls. The mean increments did not differ significantly between the genders for LBM. At 3 years of age, the boy/girl ratio in LBM is 1.06:1, and at 8 years of age it is 1.05:1.

Increases in the gender differences between boys and girls are observed in FM, which continues to increase to almost 2.0 kg by the age of 10 years. Relative fatness (%BF) increases rapidly in both sexes during infancy. Thereafter there is a decline in %BF, to a low level in the mid-childhood years (6 years of age for boys and 7 years of age for girls), followed by an increase in late childhood in girls, while it appears to reach a plateau in boys. Shortly after birth, infants have almost equal thicknesses

of SAT in the T and E sites. Subsequently, the ratio decreases through early childhood, reaching a low point at about 5 years of age. After 5 years of age, the ratio increases gradually to 10 years in each sex. After 3 years of age, the FM, SFM, and IFM increases gradually to 6 years of age in each sex, and the difference between the sexes is small. Subsequently, FM, SFM, and IFM increase rapidly in both sexes to 8 years of age, except for IFM in boys. The correlation coefficients between BMI and FM from 3 to 6 years of age were significant. We used the BMI of reference children whose measurements fell between the 25th and 75th percentile values. In reference boys, fat comprised 18.1% of body mass at age 3 years and 17.3% of body mass at age 6 years. Corresponding values for girls were 20.7% and 19.2%. LBM was found to be 11.8 kg in the 3-year-old reference boys and 17.4 kg in the 6-year-old reference boys. Corresponding values for girls were 11.4 kg and 16.2 kg.

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