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Relation of Lean Body Mass to Height in Children and Adolescents

GILBERT B. FORBES[25]

Departments of Pediatrics and Radiation Biology, University of Rochester School of Medicine and Dentistry, Rochester, New York, USA

Extract

Lean body mass (LBM) was estimated by ^{40}K counting in 609 normal boys and girls 7.5–20.5 years of age. This component of the body is shown to be related to stature, but the quantitative nature of the relation varies with age and sex.

Boys have a higher LBM/height ratio in adolescence than do girls, and the slope of the LBM-height regression is also greater, whereas before adolescence there is no appreciable sex difference. Age also affects LBM independently of stature. This effect is first seen during adolescence, and it is more pronounced in boys.

When the entire age span for this group of subjects is considered, the relation between LBM and height is exponential, LBM $= b \cdot e^{k \cdot \mathrm{ht}}$, b and k being constants. This means that the relative, or percentage, growth in LBM is a linear function of height growth at this time of life.

Speculation

The relations developed from these data emphasize the need to gear nutritional requirements to the speed of height growth. On the average, the adolescent boy has greater needs than does the girl, merely to satisfy the demands of the growth process.

The changing pattern of the LBM-height relation during adolescence lends support to the concept that androgens facilitate the growth of the LBM with its large component of muscle.

Introduction

In the course of evaluating our data on the growth of the lean body mass (LBM) it became evident that the LBM/height ratio showed less variability (smaller coefficient of variation) within a given age group than LBM itself. This led us to inquire into the relation between these two parameters of body size. The relation between weight and height is well established both for children [18] and adults [14]. Since body weight is more variable than its component LBM, it may be of some interest to examine the nature of the LBM-height relation.

Methods

Lean body mass was estimated by ^{40}K counting, according to methods previously described [8]. Our present technique involves corrections for adiposity and for age and sex [7, 10]. Body weight and standing height were taken with the subject clothed in cotton pajamas and paper slippers. Subjects [22] were recruited from the Boy and Girl Scouts, the suburban schools, and the families of university personnel. With the exception of those with diabetes, obvious physical handicaps, or other manifestations of ill health, all who volunteered were accepted. There were a total of 338 boys and 271 girls 7.5–20.5 years of age.

The technical error of the counting procedure, as estimated from repeated assays of single subjects over short intervals of time, yields an average coefficient of variation of 2.9%.

Results

The distribution of LBM/height ratios was roughly symmetrical for each age group of subjects in the present series. Consequently, the data shown in Figure 1 are graphed as the means ± 2 SE according to age. From ages 7.5 through 12.5 years, the mean LBM/height ratio rises rather slowly, and, although the values for boys are consistently higher than those for girls, the range of standard errors is such that the sex difference during this age period is not statistically significant. Thereafter, the male LBM/height ratio increases rapidly, to reach a maximum at 19–20 years, whereas the increase for the female is much more gradual. The female maximum, which is only about two-thirds that of the male maximum value, is less well defined, but appears to be attained about 3 years earlier, at age 16. That these values are truly maxima is shown by the data of a previous report [9] in which a gradual decline in LBM/height ratio is documented for the adult years.

The sex difference in the LBM/height ratio after age 12 years is greater than that for the weight/height ratio in this group of subjects. At age 13 years, for example, the male/female ratio for LBM/height is 0.295/0.247 or 1.20, whereas that for weight/height ratio is 0.307/0.299 or 1.03. At age 18 years the former is 0.346/0.240, or 1.44, whereas the latter is 0.402/0.347 or 1.16.

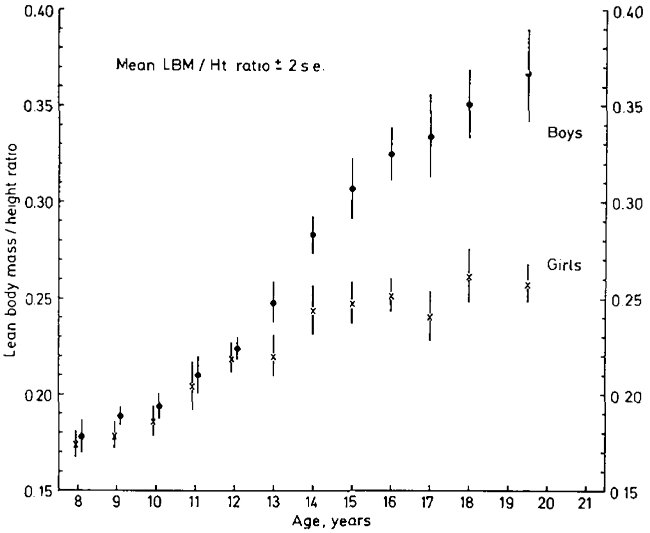

Fig. 1. Plot of lean body mass (LBM) height ratio for boys and girls as a function of age. Means ± 2 SE for each age group. The points for 8–12-year-old boys and girls are separated for clarity. Points for each age include subjects who are within 6 months of that birthday, except that the point at 19.5 years includes a 2-year span. Number of subjects is listed in *Table 1.*

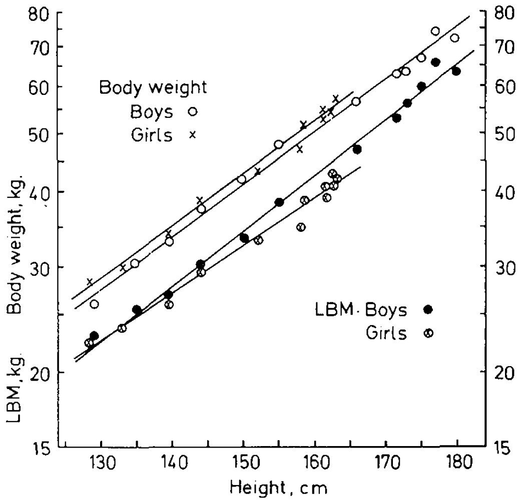

Fig. 2. Plot of logarithm of average weight against average height (*upper two lines*), and of logarithm of average LBM against average height (*lower two lines*) for the various age groups. Regression lines calculated by method of least squares.

Sargent [18] has shown that a linear relation exists between height and logarithm of weight over a fairly wide range of heights (110–160 cm in girls and 110–170 cm in boys). The upper two lines in Figure 2 is such a plot for our subjects through age 20. These appear reasonably linear. The calculated regression line for boys is

$$\mathrm{Wt} = 2.00\, e^{0.0202\ \mathrm{ht}} \tag{1a}$$

and for girls it is

$$\mathrm{Wt} = 2.10\, e^{0.0201\ \mathrm{ht}} \tag{1b}$$

in which weight is in kilograms, height is in centimeters, and e is the base of the natural system of logarithms. Sargent's equation, based on data earlier than ours, is $\mathrm{wt} = 2.6\, e^{0.018\ \mathrm{ht}}$ for the combined sexes [18]. The difference in exponents between her equation and ours may reflect differences in the source of subjects, although it is tempting to speculate that there has been a secular change in rate of gain in weight relative to height. Meredith's compilation [13] does show that modern adolescents are proportionally heavier than taller when compared with the children of several decades ago.

Figure 2 also includes plots of logarithm of LBM as a function of height. These also appear linear, but now there is a sex difference, the equation for boys being

$$\mathrm{LBM} = 1.44\, e^{0.0212\ \mathrm{ht}} \tag{2a}$$

and for girls

$$\mathrm{LBM} = 2.06\, e^{0.0184\ \mathrm{ht}} \tag{2b}$$

in which LBM is in kilograms and height is in centimeters. The standard errors of the exponents are 0.00082 and 0.00096, respectively, and, inasmuch as the exponents differ by 0.0028, the probability is high that the difference is not a chance phenomenon.

These equations imply that there is a constant percentage change in LBM and weight for each unit gain in height over this range of heights. On the average, boys gain 2.12% in LBM for each centimeter of height gain, whereas girls, under similar circumstances, have only a 1.84% increment. Comparison of *equations* (*1*) and (*2*) as well as the plots in Figure 2 shows that LBM increases at a faster relative rate than weight in boys, whereas the converse is true for girls. Hence, even if girls were to grow as tall as boys, they would still have, on the average, a smaller lean body mass, inasmuch as boys put on 0.28% more LBM for each unit of height gain. Obviously, the sex difference in LBM increases with stature.

The fact that the relation between LBM and height is an exponential one makes it possible to calculate the amount of height gain needed to double the LBM, a value which might be called the "doubling height." This turns out to be 32.7 cm for boys, and 37.6 cm for girls.

[These mathematical relations can be made clearer by differentiating *equations* (*1*) and (*2*), with respect to height, as follows:

$$\frac{d\,(\mathrm{Wt})}{\mathrm{Wt}} = k \cdot d\,(\mathrm{ht}); \qquad \frac{d\,(\mathrm{LBM})}{\mathrm{LBM}} = k \cdot d\,(\mathrm{ht}) \tag{3}$$

where k is the exponent. Hence, *equation* (*1*) says in effect that the instantaneous *change in weight per unit weight* (or, when multiplied by 100, the percentage change) is equal to $k \times$ change in height. *Equation* (*2*) says, similarly, that the *relative growth* of the LBM is a linear function of height growth. The "doubling height" is simply the natural logarithm of $2 \div k$ (or $0.693 \div k$).]

The relation between LBM and height *within* the various age groups was also examined. Plots show that these, in contradistinction to the semilog relation found *between* age groups, are reasonably linear. Table I lists the linear regression coefficients, with LBM as the dependent variable, and the respective correlation coefficients, all of which are significant at the 0.05 level except where otherwise noted. (The negative slope and r value for the 18.5–20.5-year-old boys are rather disconcerting. A possible explanation is that the range of body heights was very narrow in this particular age group.) Height accounts for an appreciable share of the LBM variation, and the trend is for the regression slopes to be distinctly steeper in boys and for the correlation coefficients to be a little higher.

Calculated regression lines for selected age groups are shown in Figure 3. Not only does the LBM/height ratio increase during late childhood and adolescence, as shown in Figure 1, but so, too, does the regression of LBM on height. Moreover, this age progression of re-

Table I. Regression of lean body mass, in kilograms, on height, in centimeters (x)

Age, yr	Boys			Girls		
	N		r	N		r
7.5– 8.5	7	$-11.7 + 0.270\,x$	0.75[1]	12	$-12.2 + 0.270\,x$	0.87
8.5– 9.5	29	$-10.2 + 0.264\,x$	0.56	25	$-9.2 + 0.248\,x$	0.52
9.5–10.5	20	$-19.7 + 0.335\,x$	0.73	24	$-28.5 + 0.390\,x$	0.73
10.5–11.5	21	$-39.3 + 0.483\,x$	0.77	18	$-50.0 + 0.553\,x$	0.78
11.5–12.5	57	$-30.3 + 0.427\,x$	0.69	36	$-35.8 + 0.455\,x$	0.57
12.5–13.5	39	$-73.6 + 0.723\,x$	0.87	24	$-26.6 + 0.391\,x$	0.70
13.5–14.5	41	$-70.9 + 0.712\,x$	0.78	15	$-14.6 + 0.337\,x$	0.50[1]
14.5–15.5	31	$-60.9 + 0.664\,x$	0.57	27	$-33.1 + 0.457\,x$	0.59
15.5–16.5	20	$-66.0 + 0.707\,x$	0.80	31	$-1.2 + 0.259\,x$	0.37
16.5–17.5	39	$-83.2 + 0.818\,x$	0.67	14	$-40.3 + 0.490\,x$	0.71
17.5–18.5	18	$-97.1 + 0.892\,x$	0.63	19	$-44.7 + 0.538\,x$	0.59
18.5–20.5	16	$+162.0 - 0.542\,x$	−0.22[2]	26	$-21.3 + 0.392\,x$	0.59

[1] $P < 0.1 > 0.05$.

[2] $P > 0.25$.

gression slopes takes place more rapidly in the boy. The preadolescent regression slope of about 0.26 kg LBM/cm height triples by age 16–18 years in boys, while merely doubling in girls.

Inspection of Figure 3 also reveals that the slope of the individual regression lines is in most instances less than would be the slopes of successive tangents to a curve which could be drawn through the 50th height percentile points. This means that age influences LBM as well as height. In Figure 4, LBM is plotted against age, with height held constant. This figure was constructed by plotting the regressions listed in Table I, each over the 3rd–97th height percentile range of the Stuart and Stevenson standards [19], and then reading off LBM values for selected heights. For example, this range of height percentiles includes a value of 130 cm for normal 8–10 year-olds, one of 140 cm for 8–12-year-old girls and 8–11-year-old boys, and so on.

Evidently age has very little effect on LBM in short children, whereas the effect is considerable for tall children. For example, the 10-year-old boy has no LBM advantage over the 8-year-old if both are 130 cm tall, whereas the 12-year-old boy who is 150 cm tall has 4 kg more LBM than the 10-year-old of the same stature. The slopes of the LBM/age lines increase with increasing height, and, once again, the trends are more pronounced in boys.

Discussion

The techniques now available for estimating lean body mass permit one to look at the phenomenon of adolescent growth unencumbered by the restrictions found in dealing with total body weight with its variable burden of fat [6].

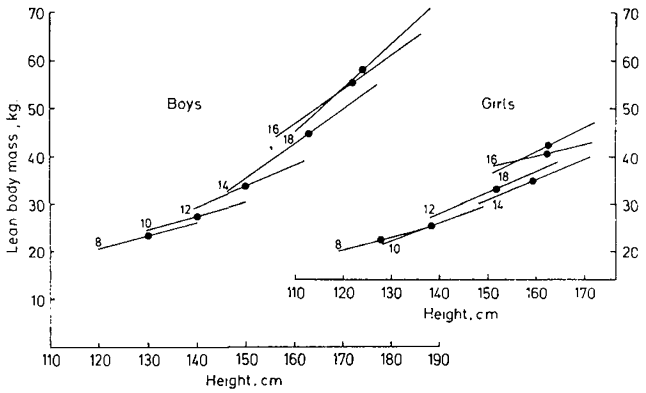

Fig. 3. Calculated regression lines for LBM as a function of height, for selected ages. Each line embraces the 3rd–97th height percentiles of the Stuart and Stevenson standards [19] and the dot is placed at the 50th percentile.

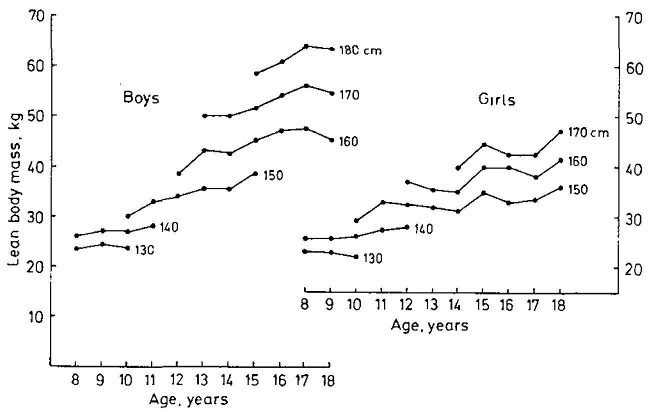

Fig. 4. Plot of LBM against age for selected body heights. For explanation, see text.

It is apparent that LBM is, among other things, a function of stature in man. The data presented here are, in this respect, supported by the findings of others. Novak *et al.* [15] found a relation between total body potassium (an index of LBM) and body length in newborn infants, and Cheek [2] found a relation between total body water (also an index of LBM) and height in children. The potassium data of Sagild [17] and of da Costa and Moorhouse [3] document a similar relation for young and old adults, respectively. Tall individuals, generally speaking, have more muscle mass.

The relations which we have assumed here, namely a linear one *within* age groups, and an exponential one *between* age groups, may well not be the only ones which could be formulated. Behnke [1], for instance, found that LBM was proportional to the square of the height in young adults. Cheek [2] presented two alternative formulations for his child subjects. The first of these involved two linear functions relating LBM to height: one for younger children, the other for older children and adolescents, with a break in the regression slope at about age 10. The second formulation was a quadratic function embracing the entire age range.

The formulations of the present study, however, do permit certain postulations to be made about the general phenomenon of adolescent growth. The disparity in LBM-height regression slopes between preadolescent and adolescent boys suggests that tallness is more advantageous for the latter than for the former. The tall preadolescent boy or, for that matter, the tall girl, shows only a modest increase in LBM over his shorter age peers, a factor which may explain the athletic awkwardness of such children. On the other hand, the older teenage male who is tall gains a handsome ad-

Table II. Average regression coefficient for lean body mass (LBM) and weight against height at selected age periods

Age, yr	Boys		Girls	
	Wt *vs.* ht	LBM *vs.* ht	Wt *vs.* ht	LBM *vs.* ht
7.5–10.5	0.577	0.290	0.698	0.303
10.5–12.5	0.884	0.455	0.514	0.504
12.5–15.5	0.878	0.700	0.634	0.395
15.5–18.5	0.917	0.806	0.528	0.429

vantage in LBM size over his shorter age peers, and a rather spectacular advantage over the teenage girl of comparative height. This disparity is reflected in sex differences in athletic ability. Khosla's compilation [12] shows that for many Olympic events the winners are taller than the average of all participants, and he concludes that for competitive athletics there is an overwhelming bias in favor of the very tall.

It may be of interest to compare regressions for LBM-height against regressions for weight-height for various age periods. This is done in Table II in which the average coefficients for age periods roughly corresponding to preadolescence, early adolescence, midadolescence, and late adolescence are listed. Several interesting phenomena emerge from such a compilation.

First, the difference in the regression slopes for LBM-height and weight-height is greater in the younger age groups. Here stature has a greater effect on body weight than on LBM. Then the difference abruptly vanishes in the 10.5–12.5-year-old girl, or at about the time her adolescent growth spurt is under way. In the boy, on the other hand, the difference becomes even greater during this age period, at a time when he is undergoing adolescent "fat spurt" and before his LBM spurt has begun [6]. Then in late adolescence the difference in LBM-height and weight-height regression slopes diminishes.

Whatever it is that determines stature in childhood and adolescence (heredity, nutrition, or endocrine function [20]) appears to affect LBM also, but the proportionate effect on LBM and height differs quantitatively with age. If it is assumed for the moment that nutrition is a prominent factor, it is possible to indulge in some interesting speculations. In the preadolescent years, a nutritionally induced increase in height would be accompanied by a much greater gain in weight than in LBM. Once the hormonal changes of adolescence are under way, a similar surfeit would produce a proportionally greater increase in LBM. Perhaps androgens exert a permissive role here, facilitating the effect of food on the growth of the LBM; with the minimal quantities produced by the preadolescent, only a slight increase in LBM is possible and excess food appears as fat, whereas the increasing androgen production during adolescence facilitates the acquisition of more lean tissue and there is less disparity between gains in weight and LBM. The sex difference in LBM/height ratio at adolescence is in keeping with this idea; Tanner [20] has shown that genital development is faster in tall boys.

A nutritional consideration of practical importance emerges from the regressions shown in Figures 2 and 3. The lean body mass comprises the bulk of the actively metabolizing tissues of the body; inasmuch as the tall boy acquires LBM at a faster rate than the short boy, his nutritional needs will be far greater during the period of his adolescent growth spurt. Furthermore, since LBM is an exponential function of height, the larger the LBM at a given height the faster it grows with each increment in height (*equation 3*). Children who undergo a rapid adolescent spurt in height will, as this equation shows, sustain a rapid increment in relative, or percentage, LBM growth. Consequently, it seems futile to define "average" nutritional requirements for this period of life which is characterized by such variability in body size and onset and intensity of the adolescent growth process.

As pointed out previously [4], the sex difference in LBM growth velocity is particularly striking during adolescence, from which one could anticipate a difference in food needs. Indeed, a compilation of recorded caloric intakes from the literature [11] shows just this: the male/female ratio for caloric consumption is close to 1 from ages 7 through 12 years, and then it rises to about 1.5 at age 16; these values are roughly similar to those for the sex ratio of the lean body mass [5].

In 1932 the participants in the White House Conference concluded that stature was a better parameter with which to relate caloric needs than either age or weight [21]. Recently, Rutenfranz and Mocellin [16] were able to plot the physical working capacity of children as a function of height for various childhood age groups; their series of regressions show the same progression with age and much the same sex differences as those which are depicted in Figure 3.

Although stature is obviously not the only determinant of lean body mass during late childhood and adolescence, the two are definitely related, and so stature assumes importance as a parameter both of body size and of those physiologic functions which are properties of the lean body mass.

Summary

The relation of lean body mass, as estimated by ^{40}K counting, to body height has been examined in 609 normal older children and adolescents. Regression analysis establishes the relation between these two parameters of body size.

The LBM/height ratio increases continuously during growth and the increase is rapid during adolescence. At this time a sex difference appears and progressively enlarges, until at age 20 the boy has 1.5 times more LBM per centimeter height than does the girl.

The quantitative nature of the LBM-height relation changes during adolescence and is influenced by sex. Age also affects LBM independently of stature. Over the entire age period under study (7.5–20.5 years), LBM appears to be an exponential function of height, which suggests that the percentage growth rate for LBM is linearly related to the speed of growth in height.

These findings provide a basis for the sex difference in both nutritional needs and athletic performance which is known to exist in adolescence; in addition, they emphasize the importance of individual growth rates in this context. The facilitative role of androgens in LBM growth during adolescence is supported by these data.

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