Somatic measurements and their use in establishing reference values

Romuald Stupnicki
The Jozef Pilsudski University of Physical Education, Warsaw, Poland

Summary

Reference values (norms) of many somatic variables are indispensable in diverse areas, e.g., medicine, sports, armed forces, etc. Such norms are usually presented as means and standard deviations or as lower/upper limits for various age categories of given sex and mostly represent population values instead of being related to body size.

The aim of this paper is to present the most common errors in the process of establishing norms, not only those related to somatic measurements. A set of rules is proposed that may greatly facilitate that process and make the resulting norms rational and reliable.

Key words Somatic variables – BMI – Allometry – Cut-off points

Introduction

Somatic variables, i.e., anthropometric measurements including body composition variables, may be used directly or as various indices for diagnostic purposes. The applications range from assessing developmental changes within or between populations to individual counselling in medicine, sports, armed forces, etc. Medical applications are of special importance since an accurate diagnosis of many growth disorders requires precise assessments of somatic traits (cf. [1,8]) but appropriate approaches and/or reference data are often missing or are improperly used.

The reference data, or norms, are indispensable for the abovementioned applications and a few general comments on norms seem necessary. First, the concept of norm has two attributes [15]: axiological and empirical. While the former refers to something ideal, desired, recommended, the latter is simply a statistical description of a group or population. As a rule, in every “norm”, whatever it pertains to, both attributes are present, albeit to a varying degree. Inasmuch the recommended values, i.e. those having a strong axiological component, regarded as the best suited to be called norms, they have to be based on solid physiologic (as in e.g. nutrition) or e.g. epidemiological (like in case of BMI) ground. No “recommendation” can be attributed to e.g. anthropometric variables but a solid biological ground is still required. In all cases, a precise statistical justification is indispensable.

The aim of this paper is to highlight the most common errors in the process of establishing norms, not only those related to somatic measurements. A set of rules is proposed that may greatly facilitate that process and make the resulting norms rational and reliable.

Reference Values of Somatic Variables

In general, somatic measurements are conducted either on cohorts representative of certain populations or on groups selected by specific criteria, e.g., ethnicity, demographic categories, engagement in sport activities, etc. In case of studying e.g. a national, unselected population, the data may serve to somatically describe that population. Since many variables deviate from normal distribution because of skewness and/or non-homogeneity, somatic (and other) data are often presented in form of the so-called percentile tables or charts [10,18,22]. Percentile charts are “photographs of the population” at the time of collecting the data, i.e., purely descriptive, and may be used to compare various populations or the same population by e.g. decades. Such graphs are not infrequently used in an assessment of individuals, i.e. as “norms”. This is acceptable for anthropometric variables like body height or body proportions but not for variables affected by external factors, e.g., for body mass or some body components.

Other forms of reference values include means ± standard deviations (SD), determined for age categories of male and female subjects separately, or simply upper and lower limits of given variable. Upper and lower limits may be based on percentile values, in which case the respective probabilities (e.g., 5 – 95%) ought to be reported, this requirement being often neglected. On the other hand, means and SDs are reliable only for variables that are normally distributed across age and should thus

Author's address Prof. Romuald Stupnicki, Stryjenskich 10/199, 02-791 Warsaw, Poland rstupnicki@gmail.com
be used with caution. The reason for caution is due to the fact that populations are, as a rule, non-homogenous with respect to many factors, other than the pure statistical randomness, affecting the variable in question. It ought to be remembered that statistical measures apply only to homogenous populations and that is rarely the case and, furthermore, it may be impossible to detect heterogeneity by applying statistical tests. Those problems may be associated to a higher degree with body composition than with anthropometric variables, therefore those two categories shall be discussed separately.

**Body height**

Body height is the only somatic measurement that can be collected in an unselected population, as except extreme conditions, it is controlled by genetic factors. This implies that no “norm” in the axiological sense can be applied to body height and the only reasonable reference values are those derived from population data in the form of means and standard deviations, percentiles, etc. It is to be remembered that body height is one of the few variables distributed normally, so that means and standard deviations of raw data provide reliable distribution parameters. Strictly speaking, the distribution of body height is only pseudo-normal, or a result of its exceedingly low coefficient of variability, usually not exceeding 5%. For that reason, arithmetic and logarithmic distributions of body height are practically non-distinguishable albeit logarithmic transformation is required for e.g. allometric analysis (see the Allometry section).

**Other anthropometric variables**

Diverse anthropometric measures are often presented as sex- and age-specific means and used as reference (cf. [7,10]). Such data are usually presented as raw yearly means ±SD and/or as smoothed percentile graphs or values, standard percentiles being 3, 10, 25, 50, 75, 90 and 97, or 5, 10, 15, 25, 50, 75, 85, 90 and 95 in Western countries and the U.S. In case of adult populations, the age intervals are much wider, e.g. 30 – 40, 60 – 80 years, etc. Means and standard deviations are usually reported as raw, untransformed values, irrespectively of the shape of the distribution and then, in case of skewness, such means may greatly differ from the 50. percentile (cf. [7]). Summing up, the axiological element may be in such approaches next to absent.

**Body composition variables**

These include, e.g., body mineral, water, and fat contents, etc. They differ from the anthropometric variables in their susceptibility to dietary and other external factors. In effect, their high variability is not directly related to body size which may make establishing “normal”, “physiological” values difficult. A good example of such variables is the body fat content that may range from very few (in starvation) to about 60% (in morbid obesity; [3]).

The percentile chart shown in Fig. 1 simply describes a representative cohort of Polish girls with respect to body fat content (%F). That illustration of the status of the population cannot serve as “norm”; the common sense would prevent us to accept body fat content of a 10-year old girl equal to nearly 25% (corresponding to Percentile 75) as normal. The same data shown against the background of proposed normal, “acceptable”, values of body fat content [19], reveal excessively high %F, especially in younger girls, reflecting the impact of factors like sedentary lifestyle, dietary habits, etc.

Inasmuch other body composition variables may behave alike, body fat content is the principal one and establishing its sex-, ethnic-, etc.-specific, acceptable ranges is of utmost importance. Establishing normal ranges of %F-dependent variables like BMI or other weight/height indices, waist-to-height ratio (WtHR), body circumferences in relation to body height (see the Allometry section), etc., ought to be based on data recorded in subjects.

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Fig. 1. Body fat content in a random cohort (n = 840) of Polish girls presented as percentile distribution (left) and vs. acceptable limits [19] defined as mean (regression line) ±2SD
having acceptable body fat content, otherwise the designed normal ranges may prove unreliable. It should be empha-
sised that the acceptable ranges of body fat content used to select subpopulations for the abovementioned purposes need not be accurately established. Approximate, accept-
able ranges are sufficient for even if the upper %F limit would be by, say, 2% higher than presented here, the effect on normal ranges of body fat-dependent variables would be only slight.

**BMI – the Most Widely Used Somatic Index**

Body mass index, a ratio of body mass and squared height (in metres), has been in use for nearly 30 years as an indicator of the risk of cardiovascular diseases. It ought to be remembered that the so-called cut-off points, which correspond to recommended normal values, were estab-
lished from epidemiological studies on that risk, not from physiologically justified findings. Originally, the BMI concept was meant to assess the risk of cardiovascular diseases in an adult population, not an individual. How-
ever, that latter use is dominating nowadays and often applied as a substitute to determining body fat content [4]. Another extension of the original idea was the ap-
plication of BMI to children and youths, for whom an epidemiologically confirmed risk of obesity-related dis-
ese remains to be demonstrated.

The concept of BMI was based on the assumption of proportionality between body mass and squared body height. Inasmuch that assumption is in many cases true for adults, it certainly is not for children and youths in whom the power of body height, to which body mass is proportional, may be as high as above 3 (see next sec-
tion). This means that in the growth period BMI is a to-
tally artificial value representing no true body propor-
tions. The same applies to adults; in a study on women differing in the engagement in physical activity, as many as 42% had excessive body fat content (above 25%), their BMI being within normal limits [14] and DiRenzo et al. [6] studied a group of normal-weight obese women (so-called NWO syndrome). In addition, the reported high correlations between BMI and %F are misleading. In pre-adolescents BMI explained up to 63% of the total %F variance [21] and only 38 – 54% in adolescents [9,21] which is by far inadequate to use BMI as a predictor of body fat content. In order to support that statement, the error in the logarithmic BMI-%F regression for the data presented in the previous section was computed. The following ranges of %F were obtained (mean ± 1SD): 15 – 22% at BMI = 18.5 and 27 – 38% at BMI = 25. This shows the “accuracy” of BMI used to predict the body fat content of an individual.

In order to overcome those difficulties and to adjust the data for children and youths to those for adults, Cole et al. [2] collected BMI values of subjects, aged 2 to over 20 years, from several countries at the time when obe-

sity was not as prevalent as nowadays. They computed the z values corresponding to BMI = 25 or 30 and applied those values to all yearly age categories. Since the subjects were not preselected with respect to body fat content, the resulting cut-off points were biased.

In WHO’s opinion [20], BMI may not correspond to the same degree of fatness in different populations due, in part, to different body proportions. The health risks associated with increasing BMI are continuous and the interpretation of BMI gradings in relation to risk may differ for different populations. That statement points to the fact that body proportions may affect BMI and that various ethnic populations may differ in body proportions. Even within the same population, the BMI subjects with e.g. short legs or broad hip and shoulders relative to body height might be overestimated.

All those reasons prompted many a scientist to question the reliability of BMI, especially applied to individ-
uals (see e.g. [11,12,13,23]). The only real advantage of that index is the simplicity of its use but this is not suffi-
cient to be a reliable tool especially during the growth period when the weight-height relations change dynam-
ically. In order to make BMI at least physiologically justified, the “norms”, i.e. recommended values, ought to be based on data collected from subjects for whom their body fat content may be considered acceptable [19]; otherwise no sound foundation of that index is feasible. Populations with acceptable body fat content ought to serve as reference not only in case of BMI but in designing “normal limits” or cut-off points of all weight-
height relationships.

**Allometry**

Allometry relates individual anthropometric measurements to the size of the body (mostly body height), in place of population averages, in the logarithmic coordinate system. Since the proportions of an organism in the growth period are under genetic control, allometry enables both determining those proportions for various body parts and to determine individual characteristics. However, various anthropometric measurements may be non-linearly related to body height. In such cases, simple ratios would not reflect the true relations. The allometric approach gives a precise insight into not only anthropometric but into other relations as well, e.g. in medicine [5].

Examples of the allometric approach to the data re-
corded in a cohort of schoolgirls are presented in Fig. 2.
Fig. 2. Examples of allometric relationships obtained for a group of girls aged 11 – 16 years. Graphs D and F pertain to girls selected for an acceptable body fat content, other graphs pertain to the entire cohort.

Graphs A, B, C and E pertain to the entire cohort, Graphs D and F – to girls having acceptable body fat content. Upper extremity length (A) proved to be directly proportional to body height as the regression slope did not differ significantly from 1.00. On the other hand, elbow width (B) was proportional not to body height but to its power equal to 2/3.

A different picture was obtained for arm girth; it might be expected that arm girth would be related rather to body mass than to body height as the accumulating adipose tissue would increase both body mass and arm girth. Indeed, the correlations with body mass were much higher than with body height. However, data from the unselected cohort markedly differed from those recorded in girls having acceptable body fat content in the exponents of body height or body mass. Thus, whenever allometric relationships found for unselected and selected (for acceptable body fat content) cohorts differ from one another, data from the selected cohort ought to be used for designing normal values.

When inspecting the allometric graph for body mass of subjects having acceptable body fat content (Fig. 3), a slight non-linearity is apparent. This can be managed either by applying linear regressions to two ranges of data, as shown in the graph, or by applying e.g. quadratic regression. That latter approach requires, however, considerable experience in selecting an appropriate polynomial regression and in interpreting it.

The right approach to computing regressions, whether linear or polynomial, consists of arranging data by the independent variable (log body height in this instance) and then computing fractional means and standard deviations for overlapping intervals of equal counts [17]. In the presented example, total number of subjects was 604 and the intervals counted 60 each: 1 to 60, 31 to 90, 61 to 120, etc. The graphs obtained in that way are presented in Fig. 4. When comparing Figs. 3 and 4, the equations differ slightly but the two-component linear regression is clearly appropriate.

Fig. 3. Allometric relationship between body mass and body height of boys, aged 6 – 20 years, with acceptable body fat content (n = 604); dotted line shows the intersection point of regression lines.
much better than all individual points reflect the course of the relationship thus enabling the selection of proper fit. It should be noted that standard deviations show a much greater variability than means which makes necessary fitting a function, in this case a two-component quadratic one. The sets of functions serve to compute the desired reference ranges.

4. Reference ranges for anthropometric and body composition variables, as well as related indices depending on body fat content, ought to be based on data recorded in subjects having acceptable body fat content. Otherwise, the established values (means, ranges, cut-off points, etc.) would be unreliable.

**Fig. 4.** Fractional means and standard deviations (n = 60 each) of log body mass vs. log body height of boys, aged 6 – 20 years, with acceptable body fat content (n = 604); dotted line shows the intersection point of regression lines

Irrespective of the approach, it is obvious that body mass, at least in the presented age range, is fairly closely proportional to the cube of body height. It is obvious that the square of body height appearing in the BMI formula is by far inadequate and artificial, thus being strongly criticised. The terms “overweight” and “obesity” applied to children and youths ought to be thus based on the allometric body mass/body height relation [19] and not on BMI.

**Suggested Guidelines on Constructing Normal Ranges**

The subjects discussed in this paper were summarised and listed below in form of the most essential guidelines. Of course, these recommendations apply not only to the anthropometric and body composition variables but may and ought to be used in most other instances after the values had been brought to a normalised form by applying e.g. logarithmic transformation.

1. Age categories should be avoided. Instead, age functions of given variable ought to be computed and used (cf. [16]). Relying on means and standard deviations computed for e.g. age categories may result in serious errors in the standardised values.

2. Among the anthropometric variables, the only one for which population means and reference values can be reliably established is body height.

3. Direct population measures for other anthropometric variables are senseless. The respective reference values or ranges ought to be computed from appropriate allometric regressions.

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Romuald Stupnicki Ph.D., D.Sc., retired professor of physiology and biostatistics, former Managing Editor of this journal and head of the Department of Biometry, is a specialist in exercise physiology, auxology, and in statistical approaches to reference ranges and to experimental sciences in general. Served in European and North American countries as invited professor.