

Dilemmas in Choosing and Using Growth Charts

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Abstract

Human growth is both a target seeking process regulated by genes and environment, and a highly dynamic process that even under similar social and economic circumstances varies considerably both in amplitude (being short or tall) and tempo (maturing fast or slow). This has led to vivid discussions about which growth chart is the right chart to use. In contrast to wide-spread opinions emphasizing the similarity in early childhood growth among diverse ethnic groups, it has become apparent that a single “global” reference fails to adequately mirror the diversity in human growth. In view of the raising evidence that growth is also influenced by the peer group, we refer to novel, cost-effective procedures that facilitate producing growth references “on demand”, for limited regional purposes, for ethnically, socio-economically or politically defined minorities, but also for matching geographically different groups of children and adolescents for international growth and registry studies.

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to proceed along narrow canals (canalized growth) (1) and to finally reach the individual’s full genetic potential. On the other hand, human growth has been shown to be a dynamic process that even under similar social and economic circumstances tends to produce a variety of individual patterns both in amplitude (being short or tall) and tempo (maturing fast or slow) (2). Individual growth is usually visualized by plotting measurements on so called growth charts. Growth charts are common tools in the paediatric practice (3). Growth charts are usually derived from cross-sectional surveys that are considered representative for the population of interest.

At first sight it appears reasonable to assume that an “expert approved” recent national growth chart does appropriately represent growth of the population of interest, and is a relevant tool to depict individual patterns of growth. National growth charts are available for most European, and also for many non-European populations. They usually display tables (and figures) with mean values and standard deviations for body height (for clinical purposes, the parameter height can be considered normally distributed) and percentiles for body weight and body mass index (BMI) from birth to maturity (the parameters weight and BMI are asymmetrical distributed, and thus cannot fully be described by mean values and standard deviations alone). Such charts typically use *absolute scales*. On those the individual measures of height, body weight and BMI are plotted in absolute terms (cm, kg, kg/m²), and traditionally evaluated by eye. Yet plotting measurements on conventional charts is afflicted with various limitations.

Introductory Remarks

Human growth is envisaged as a target seeking process regulated by genes, nutrition, health and the social and economic environment. Under optimum conditions growth is supposed

LMS Method

Almost 25 years ago Waterlow (4) has recommended for clinical use to convert the individual measurement from *absolute scales* into *standard deviation score (SDS)* scales. The SDS scale is a single unified format with z- or *SDS-values* (5, 6). The LMS method uses three parameters (L, M and S). M stands for mean value, S stands for a scaling parameter, and L stands for the Box-Cox power to transform skewed data to normality.

Based on the principles of transformation techniques (7), the conversion in case of $L \neq 0$ (with the $L=0$ being also available) is achieved via

$$Z = \frac{\left(\frac{y}{m}\right)^L - 1}{LS}$$

where Z denotes a standard normal distributed random variable. The equation can be rewritten yielding

$$y = M(zLS + 1)^{\frac{1}{L}}$$

The LMS method has widely been accepted, and is being used in most modern growth references. References that lack the Box-Cox power to transform skewed data to normality and instead, provide information on skewness and kurtosis such as the recent Swedish population based study can unfortunately not be converted into LMS.

Why Standard Deviation Score Scales?

Growth charts conventionally record cross-sectional (distance) information, but they can be extended to also monitor growth velocity (8). When plotting SDS against age, serial measurements of an individual's height, weight, or any other anthropometric parameter, usually appear as fairly horizontal lines. Horizontal lines can easier be analyzed, and have long been recommended as a better way to present growth data (4).

Horizontal lines of height SDS indicate average growth velocity. But not all children grow at all times at average velocity. Lower than average growth velocity results in decreasing height SDS scores, higher than average growth velocity results in increasing height SDS scores. The difference between two SDS measured at two ages, divided by the time interval between the measurements, thus reflects growth velocity. Growth velocity manifests as *the rate of change in SDS* rather than the rate of change in the measurements themselves. Serial standard deviation scores illustrate growth dynamics. **Figure 1a/b** exemplifies serial SDS of 15 male and 15 female individuals

of the First Zürich Longitudinal growth Study (9). The upper three male and female panels present fairly horizontal patterns indicating *canalized or parallel to percentile growth*. The other individuals cross percentiles; some show *downward percentile crossings* and downward peaks, other show *upward percentile crossings* and upward peaks. *Downward percentile crossings* indicate slower than average, *upward percentile crossings* faster than average height velocity. The characteristic peaks usually occur during puberty (2). There is a close association between upward/downward percentile crossings and accelerated/delayed bone age (10).

Presenting modern growth charts in the form of LMS tables for body height, body weight and BMI, from birth to maturity appears straightforward. But the clinical reality differs. A recent meta-analysis revealed that only a minority of currently used European growth charts in fact, provides full range LMS tables for height, weight and BMI at all ages (11). E.g. recently published Belgian references (12) present LMS for height, but lack BMI below the age of 3 years, recent Italian references (13) lack height and BMI below the age of 2 years. The currently used French (14), the Swiss (9) and one still widely used German reference (15) entirely lack information on BMI. The well accepted modern Swedish references (16, 17) consist of tables for mean values, skewness and kurtosis that however cannot be converted into percentiles or SD-scores.

References and Standards

In addition, disagreement exists upon whether to use *growth references* or *growth standards*. *Growth references* are "*representative*" and describe how children grow; *growth standards* are "*predictive*" and describe how children should grow (18). Meanwhile so-called international growth standards are offered around the world (http://www.who.int/childgrowth/1_what.pdf) and cause vivid discussions about which chart is the right chart to use for a particular child (19). The rationale for charts based upon global rather than local samples of children, goes back to recommendations of a Working Group on infant growth established by the World Health Organization (WHO) that emphasized the similarity in early childhood growth among diverse ethnic groups. In contrast to early childhood however, growth in later childhood and adolescence differs between the different ethnic groups and nations. **Figure 2** exemplifies the incongruence of nine currently used European growth charts by plotting the various 10th height percentiles on *WHO growth standard/references*, and illustrates the marked growth differences even among modern affluent societies. The picture becomes even more incongruent when plotting weight or BMI percentiles on *WHO growth standard/references* (11).

Using Growth Charts

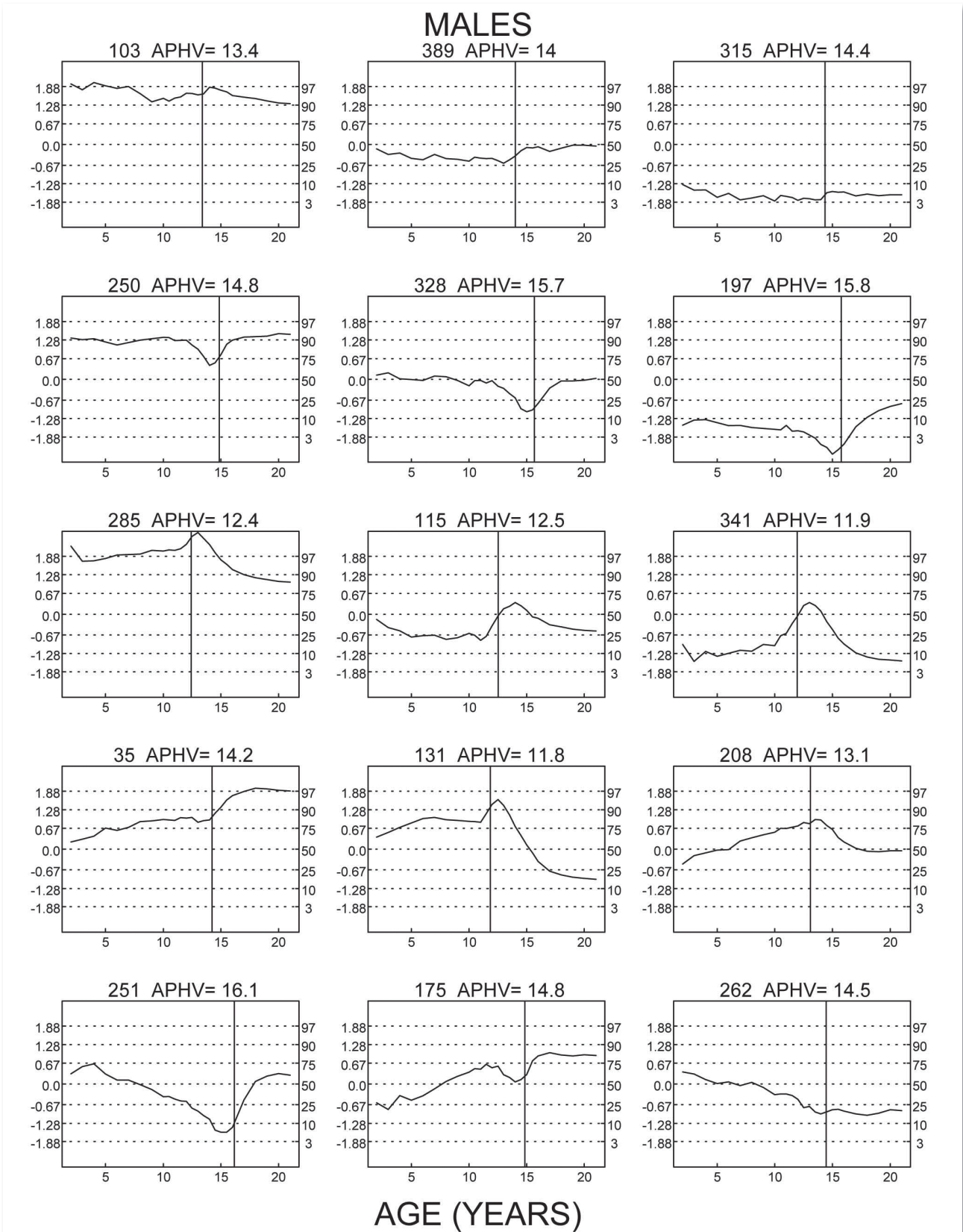


Figure 1a

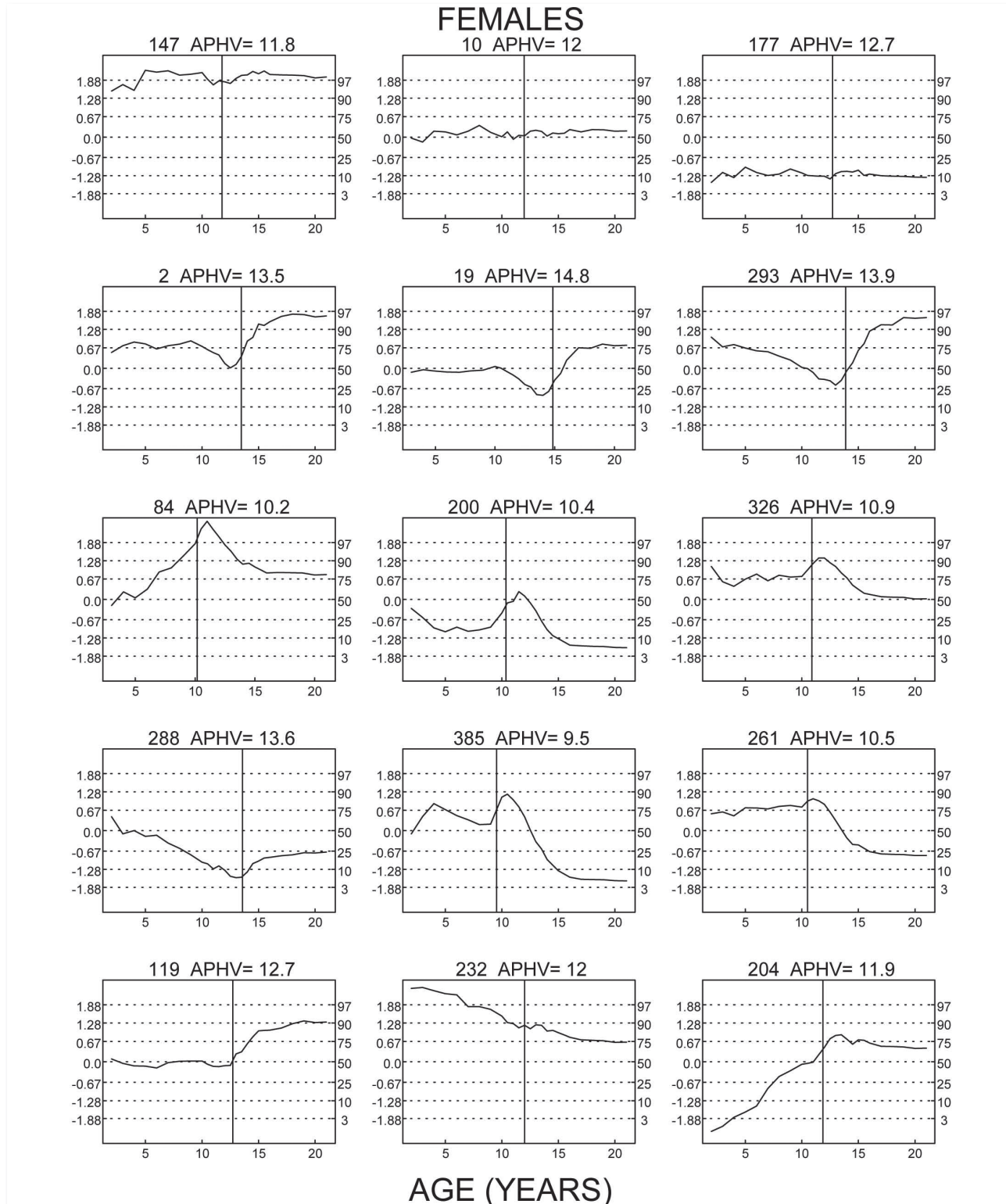


Figure 1b

Figure 1a/b: Serial height SDS (left scale) and height centiles (right scale) of a sample of 15 male and 15 female individuals of the First Zürich Longitudinal growth Study (9). The subject numbering refers to the original numbering of the study cohort. In order to relate maturational tempo and SDS peaks, height of the individuals were modelled by Preece-Baines (24) analysis. Ages at peak height velocity (APHV) are indicated by vertical bars, and given in decimal years ((1), reprint by courtesy of the publisher).

Using Growth Charts

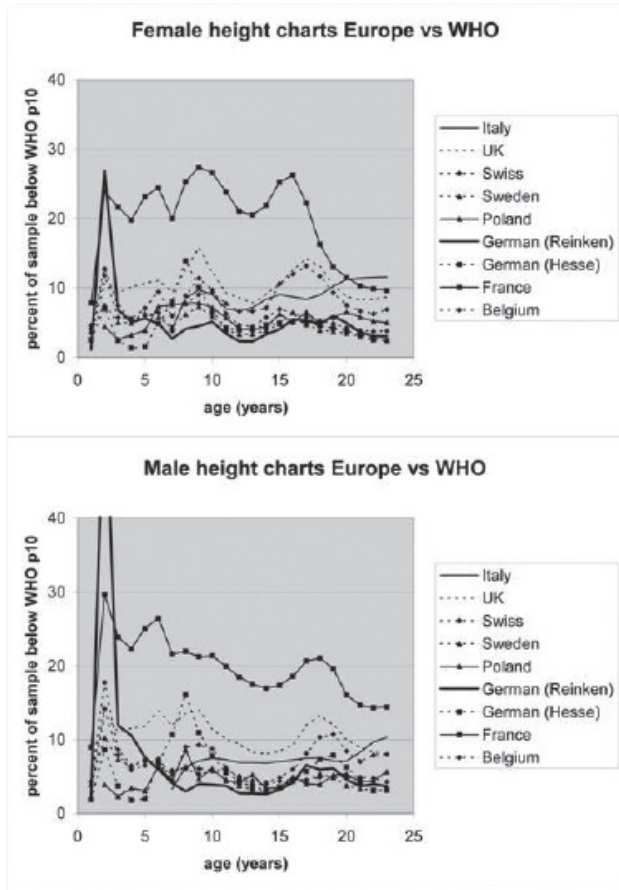


Figure 2: 10th height percentiles of 9 European growth references plotted on WHO growth standard/references. European 10th height percentiles markedly deviate from the WHO 10th height percentile. The percentiles were derived from LMS values. The figure clearly illustrates how inappropriately the European references are represented by the WHO references. The trough at 12-13 years indicates warping of the European percentiles against the WHO reference.

Who is the Population of Interest?

Which is the representative population to refer an individual's height and weight measurement to? **Figure 3** illustrates population patterns of mean height in 180 male, and 178 female growth studies published world-wide since 1830. Though the technical quality of these studies varied, and may not in all cases be considered appropriate in the modern sense, each study had once been considered representative in its time. The figure clearly illustrates how mean height differed throughout recent history. The same is true for weight. Mean weight differed between some 45 kg and more than 75 kg in young adult males, and between some 40 kg and more than 60 kg in young adult females. The figures underline that a single "global" reference fails to adequately mirror the diversity of human growth.

Figure 4 shows average Swiss conscript height 2007-2009 by place of residence at the district level at age 19. The data comprise 80-90% of the 19-year-old male Swiss population and

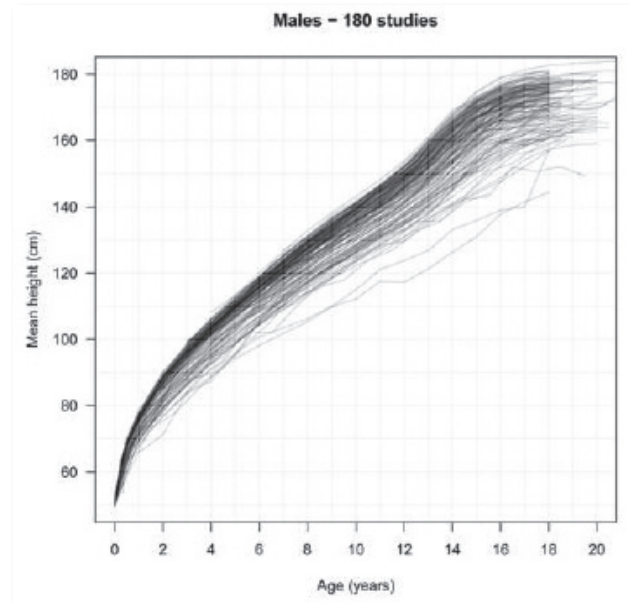


Figure 3a: Various population patterns of mean height in 180 male, and growth studies published world-wide since 1830

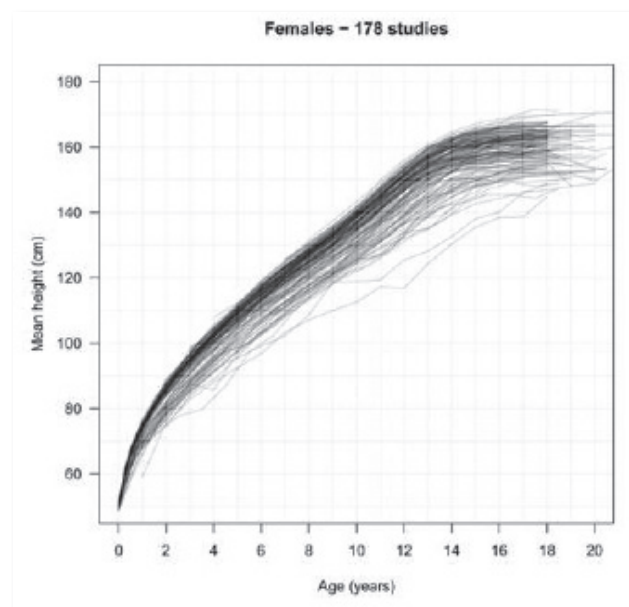


Figure 3b: Various population patterns of mean height in 178 female growth studies published world-wide since 1830

are thus, considered representative (Individual height data for the conscription years 2007-2009 was provided to Kaspar Staub by the Swiss Army (Logistikbasis der Armee, LBA San) (20)). Average height differs by up to 6 cm particularly among the various mountainous regions in the South of Switzerland. Preliminary analyses of these data failed to explain the regional differences by migration or socio-economic characteristics of these districts. Quite in contrast, there is rising evidence that it is the peer group of a young adolescent that exhibits significant influence on growth and final height.

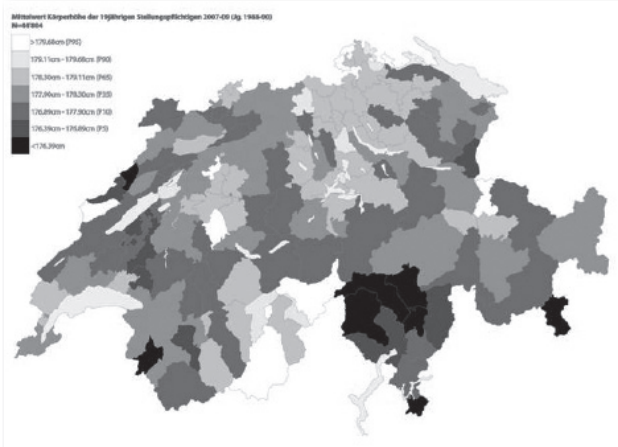


Figure 4: Swiss conscript height at the district level. Average male adult height differs by up to 6 cm among the various mountainous regions.

Requirements and New Approaches for Constructing Modern Growth Charts

In view of these data, it is reasonable to postulate some requirements for modern growth charts. Technically, growth charts should be presented in the form of smoothed LMS tables from birth to maturity. Smoothing is important. Figure 5 gives the example of smoothed percentiles in a German national reference for BMI. Smoothed references allow a particular child's SDS pattern to exhibit its characteristic personal features, whereas unsmoothed references by themselves lead to warping and will conceal the individual features.

Biologically, it appears advantageous to use references that are as close to the child as possible, and to depict local growth in order to best mirror a child's growth patterns within its immediate vicinity. There are a few countries with separate references for certain geographic regions, such as Central-North and South Italy (13), or ethnic minorities such as

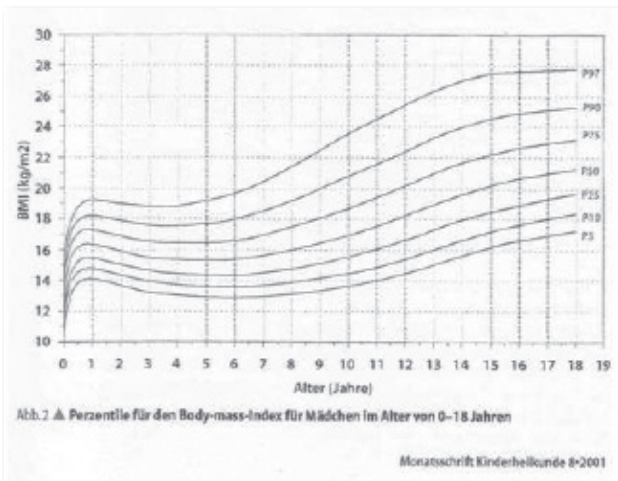


Figure 5: A good example of smoothed BMI percentiles in a German (25) national reference.

children of Turkish origin in the Netherlands (21). But most national references still lack “small scale” information. Novel, convenient and cost-effective procedures are now available for both generating de-novo (synthetic) local growth charts (22,23), and for harmonizing charts from available sets of data (11) that can be used to further optimize growth references. These techniques facilitate producing references “on demand”, for limited regional purposes, for ethnically, socio-economically or politically defined minorities, but also for matching geographically different groups of children and adolescents for international growth and registry studies. The use of growth references matched to the individual child eliminates known variation between children, thus enabling more precise and better decision for individuals. (cf. Van Buuren 2007: [www.stefvanbuuren.nl/publications/Growth%20disorders%20-%20Chapter%2011%20\(proof\).pdf](http://www.stefvanbuuren.nl/publications/Growth%20disorders%20-%20Chapter%2011%20(proof).pdf)).

It has been discussed that these techniques may raise problems in that their simplicity will encourage people to neglect the true needs for properly raised original data. It is of particular importance to note that all local growth references are only as valid as the data they are constructed from. But synthesizing growth references for the first time enables to also include large data pools such as school investigations that have not been used in most current growth references.

Irrespectively of the new possibilities for constructing local references, there still is the problem of “what is normal”. Particularly the recent world-wide increase in body mass index has fuelled the dispute on whether frequently observed - i.e. representative “normal” - BMI are desirable and predictive standards for BMI. In terms of health this is certainly to be questioned. But carefully considering these arguments, we are still convinced that if used thoughtfully, a low-budget harmonized growth reference with its simple and unified SD score format will provide significant advantages for individual growth assessments, and may strongly facilitate the investigation of world-wide variation in human growth (11).

Disclosure

The authors declared no conflict of interest.

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