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Technical report

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There has been much debate over the last fifty years about whether an international, prescriptive growth standard is realistic and useful.[1] Growth *standards* are meant to be prescriptive, to indicate the rate and level of growth of children 'that has been associated empirically with specified health outcomes and the minimization of long-term risks of disease'. Growth *references*, on the other hand, represent the growth of a specific population and are meant merely as a point of comparison rather than as a recommendation for growth. The general consensus in the medical profession is that young children's growth does not vary across sub-populations, so it would be possible to construct a growth standard for children at all ages by sex.[2] This has been strongly affirmed for children under the age of 5 by the WHO Multicentre Growth Reference Study (MGRS), which compared the growth of children aged 0-5 in Brazil, Ghana, India, Norway, Oman and the US.[3] However, the consensus is more disputed for children over the age of five. Eveleth and Tanner challenged this in both editions of their book *Worldwide Variation in Human Growth*, arguing that people of East Asian origin (Japanese people form the reference category) reach puberty earlier than European and African populations and end up shorter overall.[4] However, it is not clear whether the reference populations used by Eveleth and Tanner are really comparable, especially since all three populations were still experiencing a secular increase in height at the time of measurement. Haas and Campirano tried to eliminate this problem by comparing only the tallest subsample of populations around the world. They still found that East and South Asians were shorter than the 1977 NCHS reference and Northern Europeans were taller.[5] This does suggest that there may be some differences in the growth pattern and final height potential across human subpopulations. However, the children studied in this chapter are almost exclusively European or Americans of European descent, so using the WHO growth references should not pose methodological problems.

[1] Eveleth and Tanner, *Worldwide Variation*, pp. 15-16; Butte *et al.*, 'Evaluation', pp. s170-s171; Wang *et al.*, 'Limitations', pp. s180-s182; Seidell *et al.*, 'Cross-sectional Growth References', pp. s189-s191; Haas and Campirano, 'Interpopulation Variation', pp. s212-s216.
[2] Butte *et al.*, 'Evaluation', p. s171, quote p. s171.
[3] WHO MGRS, 'Assessments'; and see also Habicht *et al.*, 'Height and Weight Standards'.
[4] Eveleth and Tanner, *Worldwide Variation*, pp. 180-4.
[5] Haas and Campirano, 'Interpopulation Variation', pp. s215-8; Butte *et al.*, 'Evaluation', p. s171.

In the past, most historians have relied upon the 1977 United States National Center for Health Statistics (NCHS) reference for infant, preschool, preadolescent and adolescent children. The Center for Disease Control (CDC) normalised these NCHS charts, and these CDC adaptations were recommended by the WHO for use as an international reference for child growth in 1978.[6] These standards form the basis of Steckel's calculations of height percentiles for children in historical populations published in *Historical Methods*.[7] Steckel modified the 1977 NCHS reference for historical populations for two main reasons. First, historical populations faced greater deprivation than modern populations and were therefore clustered in the lower percentiles. He therefore provided percentiles below the 5th percentile, which was the lowest presented in the 1977 NCHS references. He also provided standard deviations for heights at specific ages so that exact percentiles could be calculated under assumptions of normality instead of using linear interpolation between percentiles, which was commonly done before. Second, Steckel adjusted the variance of the height distributions, following Healy (1962) because the ages of children in historical populations are often grouped in one-year age categories, which would naturally have greater variances than exact age estimates. These differences were more important in infancy and early childhood than in adolescence because children grow fastest early in life and the variance on their growth is smaller before the adjustment.[8]

Despite Steckel's careful work with the 1977 NCHS references, I believe it is best to incorporate the 2006/7 WHO standard/reference in future research unadjusted.[9] These references differ from the 1977 references in a number of ways. Steckel began his percentiles with children aged three, but because the samples employed in this chapter contain younger children, I will discuss the development of the infant and early child growth standards. The NCHS growth standard for infants and children aged 0-23 months developed in the late 1970s was based on the Ohio Fels Research Institute Longitudinal Study from 1929-75. The children in the study were similar in terms of socioeconomic, genetic and geographic factors and were also fed primarily on infant formula during early development.[10] These infant and early child NCHS growth standards were criticized for focusing only on Americans of European descent in one community. In addition, children in the Fels study were only measured every three months, which was not considered frequent enough to capture the state of growth in infancy. The statistical techniques used for smoothing had also become out-dated, and curves reflecting the growth of breast-fed children were preferred.[11] In order to overcome these problems, the WHO established and implemented the Multicentre Growth Reference Study (MGRS) between 1997 and 2003. The MGRS surveyed children in socioeconomic conditions favourable to growth aged 0-5 years in six countries: Brazil, Ghana, India, Norway, Oman and the US. The MGRS collected longitudinal anthropometric measures for 1,737 children at 21 points in the first 24 months and cross-sectional anthropometric data for 8,440 children aged 18-71 months.[12] In addition, the most advanced smoothing techniques

[6] Wang *et al*., 'Limitations', p. s176.
[7] Steckel, 'Percentiles'.
[8] Steckel, 'Percentiles', pp. 158-61.
[9] Steckel's variance adjustment is not required for the data presented here because the children's birthdates were included in the documents, allowing their exact age to be calculated.
[10] de Onis and Yip, 'WHO Growth Chart', pp. 75-6; de Onis *et al*., 'Time'.
[11] WHO, *WHO Child Growth Standards*, pp. 1-2; de Onis and Yip, 'WHO Growth Charts', pp. 77-82.
[12] WHO, *WHO Child Growth Standards*, pp. 3-5.

were employed to set the percentiles and Z-scores.[13] Because of the inclusion of multi-ethnic sample sites, a strict longitudinal structure for early ages, and the precision of the smoothing techniques employed, the new 2006 WHO Child Growth Standard presents a marked improvement on the earlier NCHS standard and seemed appropriate to use for comparisons with historical populations.

The growth reference for school-age children and adolescents changed less drastically between 1977 and 2007. Both references are based on the same data drawn from three separate samples of non-obese US children taken from 1960-1975.[14] Beginning in the mid 1990s, scholars had called for a school-age and adolescent reference that incorporated non-stunted, healthy samples from a number of countries rather than just relying on the US data. Although, as mentioned above, the consensus opinion confirmed by the WHO Multicentre Growth Reference Study was that subpopulations had similar growth patterns, especially before the age of five, many studies suggested that there could be differences between growth patterns across subpopulations for children over five.[15] de Onis *et al.* attempted to find additional datasets from around the world when constructing the 2007 school-age and adolescent growth references, but the heterogeneous methodologies of the studies made it impossible to combine them and still maintain consistency with the 2006 infant and preschool-age growth standards. Therefore, they continued to only use the US data. In addition, both growth references for 5-18 year olds are based on cross-sectional rather than longitudinal data. Therefore, the reference 'does not express growth as a velocity percentile – it gives no clue as to whether or not a given rate of percentile crossing is unusual; there is no adjustment for regression to the mean, whereby smaller children tend to grow faster; and the rapid changes in velocity due to puberty and variability in timing of puberty are not captured by cross-sectional data'.[16] Most scholars would have preferred that the 2007 reference combine both cross-sectional and longitudinal data, but again this was not possible given the paucity of longitudinal studies spanning the ages 5-18.[17] Although there are some problems with using only cross-sectional data to construct the growth references, most experts appear to take a more optimistic position about the references than Wang *et al*. The WHO 2006/7 references have been widely accepted around the world as a benchmark for rich, healthy children as well as poor, malnourished children and have often been used to measure catch-up growth.[18]

The new 2007 WHO references for school-age children and adolescents have three main advantages. First, although percentiles are more readily understood by the average, non-statistical historian and the public, Z-scores are a much better method for measuring anthropometric differences from modern standards. Z-scores provide a

[13] WHO, *WHO Child Growth Standards*, pp. 7-10.

[14] Wang *et al.*, 'Limitations', p. s177; de Onis *et al.*, 'Development', p. 660-1; de Onis and Yip, 'WHO Growth Chart', p. 76.

[15] Butte *et al.*, 'Evaluation', pp. s170-1; Wang *et al.*, 'Limitations', pp. s180-2; Seidell *et al.*, 'Cross-sectional Growth References', pp. s196-8; Haas and Campirano, 'Interpopulation Variation'; WHO MGRSG, 'Assessment'.

[16] Wang *et al.*, 'Limitations', pp. s177.

[17] de Onis *et al.*, 'Development', pp. 660-1.

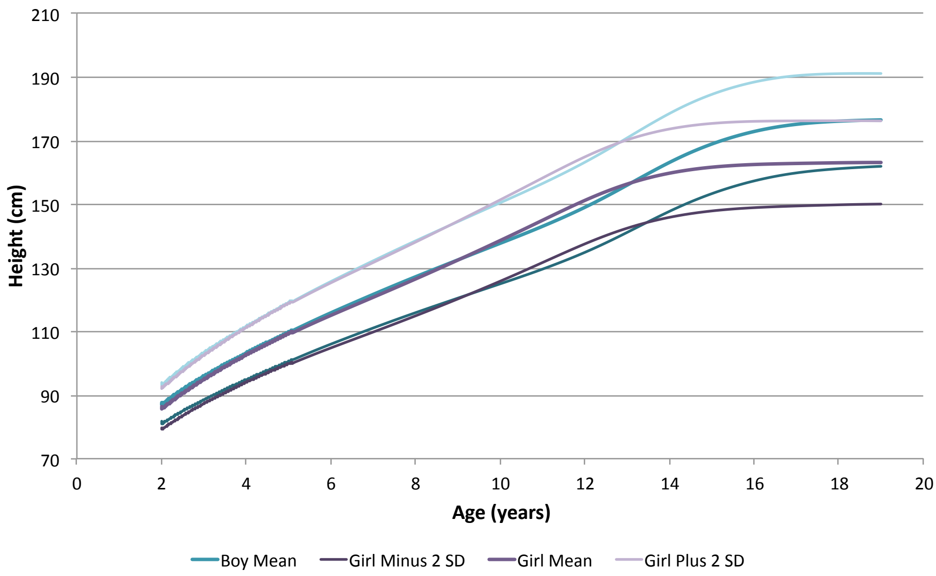
[18] The WHO 2006/7 growth references have been endorsed by the European Childhood Obesity Group, the International Pediatric Association, the UN Standing Committee on Nutrition, and the International Union of Nutrition Science. See also Butte *et al.*, 'Evaluation'; Wang *et al.*, 'Limitations'; Ulijaszek, 'International'; Eveleth and Tanner, *Worldwide*, pp.15-16; Adair, 'Filipino Children'; Dercon and Singh, 'Nutrition'; Singh *et al.*, 'School Meals'.

continuous rather than ordinal variable; as Steckel notes, they can easily capture the extremes of a distribution that would be difficult to capture using percentiles; they can be compared easily across age and sex; and finally, Z-scores are a better measure of longitudinal growth over time than percentiles. It should also be noted that a one unit increase in Z-scores reflects a constant absolute change in anthropometric indicators, while a one percentile increase has different absolute values depending on where the percentile is in the distribution.[19] Second, the cut-off points for stunting, underweight, overweight, and obese in the early NHCS references changed at different ages and were sometimes measured in percentiles and sometimes in Z-scores. This meant that children who would be considered underweight at age 9.99 might be considered within a normal range at age 10.01.[20] The new WHO growth standards were developed so that both the infant and early child standard and the school-age and adolescent reference used the same cut-off points for stunting, underweight, overweight, and obesity across all ages and so that the infant and early child growth standard would transition more or less seamlessly with the school-age and adolescent reference.[21] Finally, because the 1977 NCHS reference was based on children from the United States, the thresholds for overweight and obese were set too high for global populations. This also meant that the threshold for underweight was set too high, overestimating the number of children at risk.[22] The new WHO standard/reference adjusts for this, lowering the absolute cut-off points, and also uses BMI-for-age as the primary indicator of underweight or overweight rather than the confusing weight for height measures used in the 1977 NCHS standards.[23]

Figure 1 shows the WHO growth curve for height across the range of growing ages. It suggests that on average boys and girls have similar heights until girls begin to overtake boys during their pubertal growth spurt. The boys then overtake girls later on when they experience their own pubertal growth spurt. The timing of these growth spurts is more easily discerned when looking at a graph of height intervals over time, i.e. the growth between one-year cohorts in cross-section (Figure 2). From these figures it is clear that girls experience a pubertal growth spurt beginning around age seven, peaking around age eleven and declining swiftly thereafter. Boys have a later, more distinctive pubertal growth spurt, which begins around age ten, reaching its peak at age 13 and declining thereafter. These growth spurts tend to be delayed in malnourished populations. It is also important to note that the growth intervals in Figure 2 are measured using cross-sectional rather than longitudinal measurements of children's heights. If individual children had been measured longitudinally, there would have been a more pronounced acceleration of growth during the pubertal growth spurt. Thus, the more gradual growth spurt for girls in the cross-sectional height interval graphs reflects higher variance in the timing of the pubertal growth spurt rather than a slower, less distinct growth spurt than men.[24]

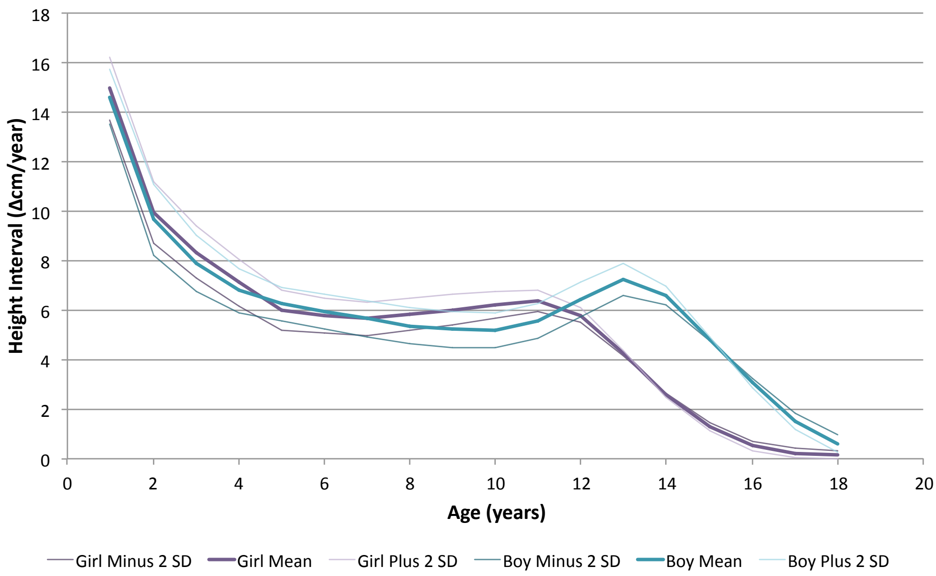
[19] Wang *et al.*, 'Limitations', p. s180; Steckel, 'Percentiles', p. 158.
[20] Wang *et al.*, 'Limitations', pp. s179-80.
[21] de Onis *et al.*, 'Development', pp. 663-664.
[22] Wang *et al.*, 'Limitations', pp. s182-s184.
[23] de Onis *et al.*, 'Development', pp. 664-665.
[24] Eveleth and Tanner, *Worldwide Variation*, p. 10; Cole, 'Statistical Considerations', p. s242.

Figure 1: WHO 2006/7 height-for-age standards for modern, healthy children. Mean heights with standard for +2 and -2 standard deviations around the mean.



Sources: de Onis *et al.*, 'Development'; WHO, *WHO Child Growth Standards*; data drawn from http://www.who.int/growthref/en/.

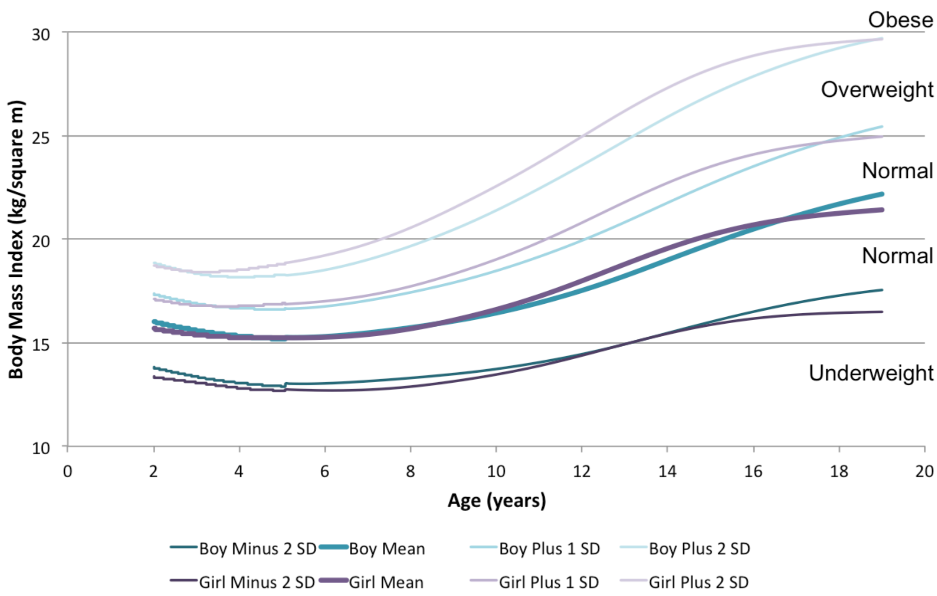
Figure 2: Growth velocity (height intervals) for modern children according to the WHO 2006/7 growth references.



Sources: de Onis *et al.*, 'Development'; WHO, *WHO Child Growth Standards*; data drawn from http://www.who.int/growthref/en/.

The WHO also defined weight-for-age standards for children up to age ten. After age ten the relationship between weight and age is no longer straightforward or useful as a measurement of deprivation. The curves generally increase over time, but otherwise have fewer problems with interpretation than the height-for-age standards. The BMI-for-age WHO growth references are more complicated. As can be seen in Figure 3, BMI-for-age standards decline until the age of 3.5 to five and then increase thereafter. The nadir of these curves is called the adiposity rebound, the point at which children begin putting on weight relative to height. The BMI standards are designed so that children with a BMI-for-age that is two standard deviations below the mean are considered underweight. Children between two standard deviations below the mean and one standard deviation above the mean are considered to have a normal BMI-for-age. Children between one standard deviation above the mean and two standard deviations above the mean are considered overweight, and children over two standard deviations above the mean are considered to be obese.

Figure 10: WHO 2006/7 BMI-for-age standards for modern, healthy children.



Sources: de Onis *et al.*, 'Development'; WHO, *WHO Child Growth Standards*; data drawn from http://www.who.int/growthref/en/.