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Estimating Child BMI Growth Curves for Canada

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Abstract

Growth curves are used by health professionals to determine whether the growth of a child or a foetus, for example, is within normal limits. The growth charts currently used in Canada for height, weight and body mass index (BMI) are based on US data. Child growth curves can now be generated from the latest available data in Canada. One way of estimating and drawing growth curves is the Lambda-Mu-Sigma (LMS) method. The method has been used in various studies by the World Health Organization, the United Kingdom and the United States to generate reference growth curves for children. In this article, the LMS method is used to estimate growth curves in BMI percentiles from weighted cross-sectional data provided by cycle 2.2 of the Canadian Community Health Survey. This article is about the child BMI, one of the anthropometric measures most commonly used to assess growth and obesity.

KEYWORDS: Growth curves; LMS method; body mass index; percentile; centile.

1. Introduction

According to the latest statistics, one out of four Canadians aged 2 to 17 is overweight or obese (Shields, 2006); that is, one quarter of Canadian children and youth have a body mass index (weight in kg/height in m^2) above World Health Organization (WHO) standards. And the proportion is increasing. In view of the evidence that excess weight in adolescence often persists into adulthood (Guo *et al*., 2002; Cole *et al*., 2002) and that excess weight is associated with a number of chronic illnesses (Freedman *et al*., 1999; CIHI, 2004), the WHO is concerned that when those children reach adulthood, there will be sharp increases in the number of cases of type 2 diabetes, coronary artery disease and various cancers such as colon cancer, prostate cancer, breast cancer and uterine cancer (see http://www.who.int/topics/obesity/en/index.html). In a number of countries, including Canada, the incidence of type 2 diabetes in children is already rising (Pinhas-Hamiel and Zeitler, 2005). Other studies show that excess weight can result in a substantial decrease in life expectancy (Peeters *et al*., 2003). Hence, the long-term economic impact of excess weight among young people may be significant.

To properly track changes and the impact on health, weight gain and child development policies, comprehensive indicators produced with standard anthropometric data are needed. Height, weight, skin fold thickness and hip and waist circumference are examples of internationally recognized standard anthropometric measurements. Body mass index (BMI), waist-to-hip circumference ratio and total skin fold thickness are examples of common indicators. The use of growth curves to study anthropometric changes over time (Chart 1) is a simple approach commonly used by health professionals to assess the general well-being of children and foetuses (Borghi *et al*., 2006).

Until very recently, the only anthropometric data available at the national level in Canada were self-reported and often biased and imprecise (Strauss, 1999; Roberts, 1995). The reference growth curves used in Canada are recognized by the WHO, however, the curves are based on US anthropometric data and may be biased because the two countries have different anthropometric distributions (Shields, 2006).

In 2004, the height and weight of a representative sample of Canadians aged 2 to 17 were directly measured in the Canadian Community Health Survey (CCHS). Descriptive growth curves for Canadian children can now be estimated and compared with those of other countries. This article describes a technique for estimating growth

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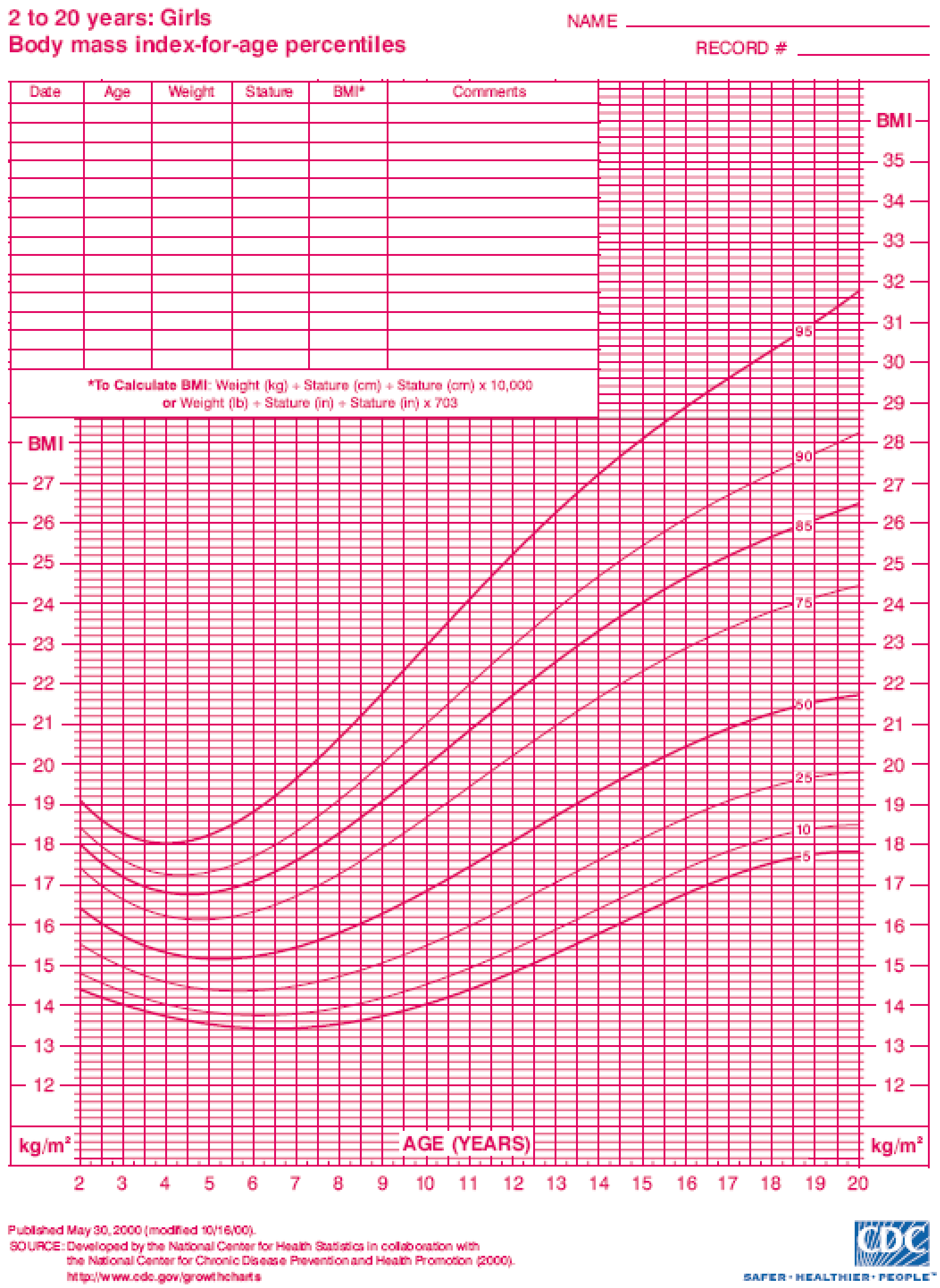
curves known as the LMS method as well as a spline smoothing function and some validation methods. It also presents applications of the LMS method using the new anthropometric data and a comparison between Canadian descriptive curves and international reference curves.

Chart 1: CDC BMI growth curves for girls aged 2 to 20



Source: Kuczmaski *et al*. (2002)

2. Methodology

2.1 LMS method

Wright and Royston (1997) reviewed the proposed statistical methods for constructing growth curves, or reference intervals. In general, parametric construction methods, based on a particular distribution, combined with a smoothing technique, are used most frequently because they can produce standardized statistics (z-scores) and estimate extreme percentiles with precision (Borghi *et al.*). One of the simplest such methods – and one that is highly accessible and understandable – is the LMS (Lambda-Mu-Sigma) method, also known as Cole's method or the Box-Cox normal method. The method has been used in various studies by the World Health Organization, the United Kingdom and the United States to generate reference growth curves for children. Proposed by Cole (1988), the method is based on the assumption that, for each level of a covariate, the data have a normal distribution, having been transformed previously by the Box-Cox method to correct any asymmetry. In other words, if the child's age is the covariate, the method assumes a three-parameter distribution – the Box-Cox λ, median μ, and a coefficient of variation σ – for each age.

Suppose we have a positive variable y with median μ, for which y^{λ}, (or, if λ=0, $\log_e(y)$), has a normal distribution. It is appropriate to consider the following transformation proposed by Box and Cox (1964):

$$x = \begin{cases} \dfrac{(y/\mu)^{\lambda} - 1}{\lambda}, & \lambda \neq 0 \\ \log_e(y/\mu), & \lambda = 0 \end{cases} \tag{1}$$

If we use σ to denote the standard deviation of x (and the CV of y), the z-score of x, and hence of y, is given by:

$$z = \begin{cases} x/\sigma = \dfrac{(y/\mu)^{\lambda} - 1}{\lambda\sigma}, & \lambda \neq 0 \\ \dfrac{\log(y/\mu)}{\sigma}, & \lambda = 0 \end{cases} \tag{2}$$

where z is assumed to have a standardized normal distribution. Now suppose that the distribution of y varies with covariate t, and that at t, the parameters λ, μ and σ take the values of the curves $L(t)$, $M(t)$ and $S(t)$. We can then rewrite the previous equation as follows:

$$z = \begin{cases} \dfrac{[y/M(t)]^{L(t)} - 1}{L(t)S(t)}, & L(t) \neq 0 \\ \dfrac{\log[y/M(t)]}{S(t)}, & L(t) = 0 \end{cases} \tag{3}$$

Rewriting the previous equation, we can estimate the centile curves of y at t with

$$C_{100\alpha}(t) = \begin{cases} M(t)[1 + L(t)S(t)Z_{\alpha}]^{1/L(t)}, & L(t) \neq 0 \\ M(t)\exp[S(t)Z_{\alpha}], & L(t) = 0 \end{cases} \tag{4}$$

where Z_{α} is the normal equivalent deviate at level α. In this article, a centile curve is defined as a boundary line between two consecutive intervals of a 100-interval distribution, each interval of which contains 1% of the population total. Percentile is set of divisions that produce exactly 100 equal parts in a series of continuous values such as blood pressure, height, weight, etc.

The centile curves will be smooth if the L, M and S curves are also smooth. Using the penalized likelihood method, Cole and Green (1992) showed that the three curves can be estimated by the cubic spline method and that the degree of smoothing depended on three parameters corresponding to L, M, and S curves. This approach uses the log-likelihood function l derived from equation (3):

$$l = l(L, M, S) = \sum_{i=1}^{n} \left(L(t_i)\log\frac{y_i}{M(t_i)} - \log S(t_i) - \tfrac{1}{2} z_i^2 \right)$$

(5)

The curves are then estimated by maximizing the log-likelihood function adjusted by three penalty functions:

$$l - \tfrac{1}{2}\alpha_{\lambda}\int\{L''(t)\}^2\,dt - \tfrac{1}{2}\alpha_{\mu}\int\{M''(t)\}^2\,dt - \tfrac{1}{2}\alpha_{\sigma}\int\{S''(t)\}^2\,dt \tag{6}$$

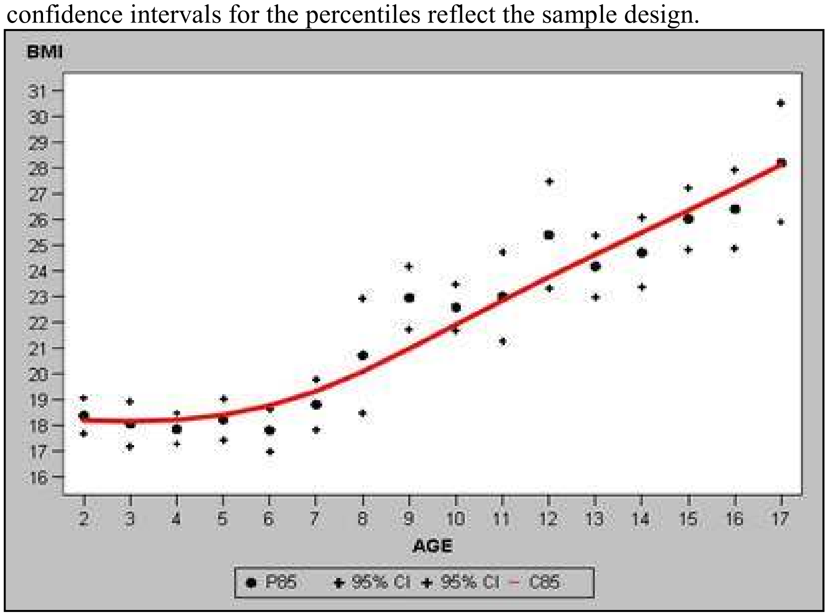
where α_λ, α_μ and α_σ are the smoothing parameters corresponding to *L*, *M* and *S*. This type of penalty leads to the smoothing technique known as cubic splines with knots at each distinct value of *t*.

2.2 Selection and validation of the model

The model can be evaluated with overall measures of fit. The two most common measures are deviance and the Akaike information criterion, which are used to produce a quantitative value for the degree of smoothing required in the model. First, to generate a reference model, we arbitrarily choose a value for each smoothing parameter. Second, we increment one of the three parameters by one smoothing unit, thereby causing a change in the overall measures of fit. Third, the amplitude of the difference between the overall measures for the new model and the overall measures for the reference model indicates whether the curve requires further smoothing or not. The same procedure is followed for the other two curves. Techniques for rescaling and transforming variables can also be used (Cole *et al*., 1998). Velocity and acceleration charts can be used to identify finer behaviour of the M curve.

A quick way of checking the selected model's fit is to plot on the same chart the centile curves of interest from (4) and, for each age group, the corresponding empirical percentiles together with their confidence intervals based on the sample design (Chart 2). If there is a large proportion of percentiles whose confidence interval does not overlap the centile curve of interest, or if there is a systematic tendency across a number of age groups, there may be a bias in the estimate of the centile curves. Another non-parametric method of validating the model is to compute the proportion of children under the estimated centile curve. Substantial variation in those proportions across age groups may also point to a weakness in the estimate.

Chart 2: Comparison between the estimated 85th centile growth curve based on the BMI of Canadian girls aged 2 to 17 and the 85th percentile estimated empirically for each age. The confidence intervals for the percentiles reflect the sample design.



Source: Canadian Community Health Survey – Nutrition, 2004.

In addition to graph validation (detrended QQ plot, worm plot), a number of local or global tests (Q, asymmetry, kurtosis) can be performed on the z-scores or the model's residuals to validate the assumption of normality (Van Buuren and Fredriks, 2001; D'Agastino *et al*., 1990).

It is worth noting that software such as lmsChartMaker and GAMLSS and various S+ and SAS functions for selecting and validating the three estimated curves are fairly accessible to analysts.

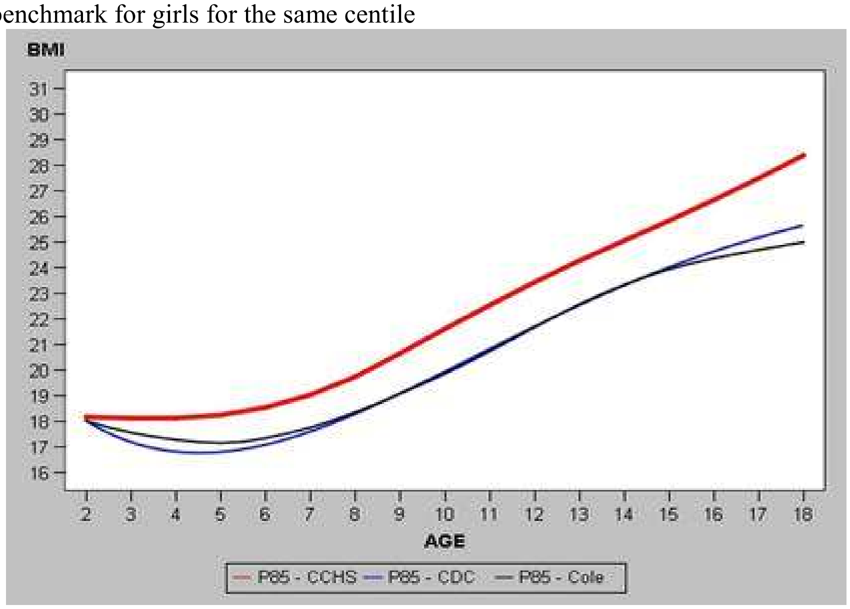
3. Applications

The data set used in this section is composed of 8,661 Canadian children, including 4,325 girls aged 2 to 17 whose height and weight were measured directly. They made up 65% of the respondents aged 2 to 17 who took part in the 2004 CCHS on nutrition (see http://www.statcan.ca/english/concepts/hs/index.htm and Béland, 2002). Standardized survey weights and lmsChartMaker Pro 2.2 were used to generate the BMI growth curves by age for the two applications described below. Age is calculated in days, and each sex is processed separately.

3.1 International comparison

In practice, a child is identified as overweight when his or her BMI is higher than the BMI of the 85th percentile of a reference population of children the same age, in other words, when 85% of the reference population has a lower BMI. The identification can be made quickly and easily with a growth curve. One need only plot the intersection of the child's BMI and his/her age on a growth curve chart (Chart 1) and read off his/her position relative to the reference growth curve of the 85th centile/percentile. The area above the curve is the overweight zone. The two sets of growth curves currently used in Canada as BMI reference curves were estimated by Cole (Cole *et al*., 2000) and the CDC (Kuczmaski *et al*., 2002) using the LMS method. Cole's growth curves are a compilation of anthropometric measurements collected from nearly 200,000 children in representative cross-sectional surveys of the population of six countries, while the CDC's curves were compiled from a number of representative data sets for the US population between 1963 and 1994. Chart 3 shows the estimated growth curve of the 85th centile of Canadian girls from the CCHS 2004 compared with the Cole and CDC curves for girls for the same centile.

Chart 3: Comparison between the estimated 85th centile growth curve based on the BMI of Canadian girls aged 2 to 17 and the Cole and CDC growth curves traditionally used as a benchmark for girls for the same centile



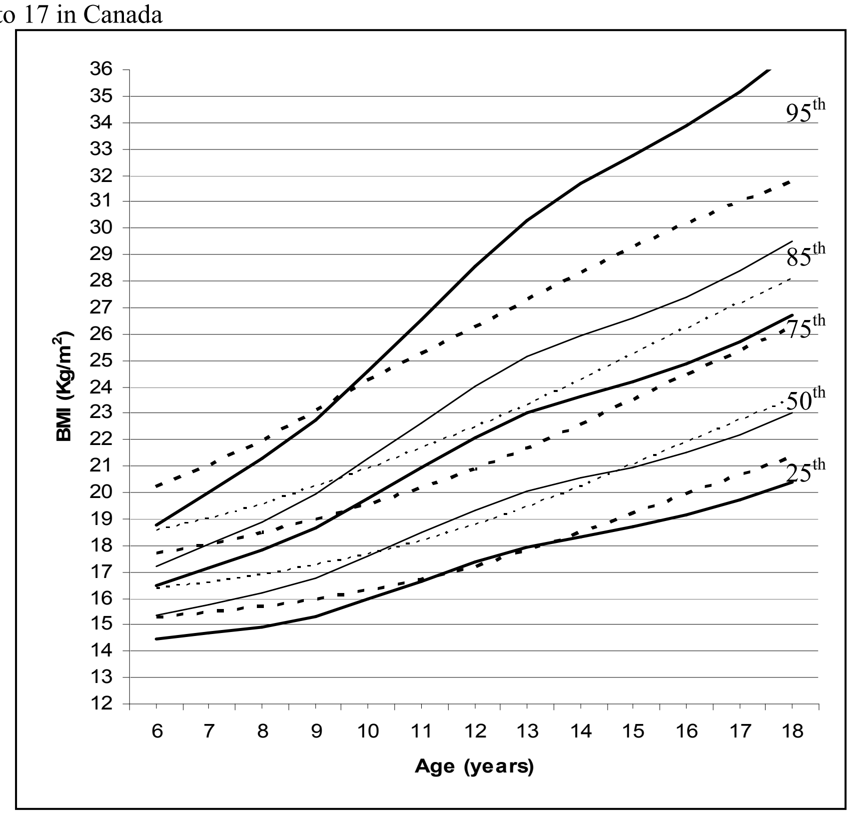
Source: Canadian Community Health Survey – Nutrition, 2004, for the Canadian curve, Cole *et al*. (2000) for the Cole curve, and Kuczmaski *et al*. (2002) for the CDC curve.

In addition to the discrepancy between the Canadian growth curve and the two reference curves, there are several important differences. First there is the behaviour of the curves at the end points. No data were available for children aged 0 to 2, and people 18 and over were excluded from the Canadian growth curves. The Canadian curves do not appear to bend as sharply at the ends as the reference curves, probably because of the lack of observations in those age groups (0-2 and 18+). Cole's reference curve is more rounded because a BMI of 25 at age 18 was built into it. The other difference is the growth curves' degree of concavity between 2 and 7 years of age. There are a few possible reasons for the lack of concavity in the Canadian curve. It may be due to a lingering effect of the lack of children under age 2, to excessive smoothing of the curve, to a sample size problem or to a kurtosis problem in the BMI for that age group. This point will be discussed in the last section. It is also possible that the differences are typical of the Canadian population. It is worth noting that the growth curves for boys have similar characteristics.

3.2 Physical activity and the BMI

The next application is drawn from Katzmarzyk *et al*. (2007), who studied the effect that physical activity has on pediatric obesity reference data for Canada. The approach used was to plot the BMI growth curves for both active and inactive children aged 6 to 17 on the same chart (see Chart 4). The children assessed their own physical activity levels through a questionnaire administered by an interview. They were then divided into two groups based on quartiles of physical activity; the first quartile consisted of inactive children and the last quartile of active children. For both girls and boys, the lower-centile growth curves (25th and 50th, the median) show many similarities. However, the upper centiles (85th and 95th) suggest that from the age of 10 on, inactive boys have a higher BMI than active boys and that the difference increases with age. In conclusion, the findings of this article indicate that an assessment of physical activity may be important in the development of national reference data for obesity in young people.

Chart 4: Comparison of BMI growth curves for physically active and inactive boys aged 2 to 17 in Canada



Source: Katzmarzyk *et al*. (2007)

4. Discussion

These initial studies on constructing and using growth curves are the first steps in the construction of Canadian reference growth curves. In the near future additional Canadian surveys will expand the current sample of direct measures. In the 2005 CCHS, height and weight measurements were taken for a subsample of respondents, and the new Canadian Health Measures Survey (see http://www.statcan.ca/chms) scheduled for the spring of 2007 will collect direct measures of a number of anthropometric variables, including height and weight.

The use and methodology of growth curves are not confined to health professionals who want to assess how well a child or a foetus is doing. Growth curves can also be used to identify physiological changes (e.g., blood pressure), analyze blood composition (e.g., lead levels) and evaluate physical performance. In agriculture, for example, they are used to study the effects that certain fertilizers or genetically modified organisms have on crop or livestock growth. In economics, they are used to gauge the financial health of small and medium-sized businesses. More generally, growth curves can be employed in comparative studies of populations, to study trajectories in longitudinal data or to show correlation to various independent variables.

As mentioned in section 2, the LMS method of constructing growth curves has many advantages over other methods. Yet it is far from perfect. The anthropometric data used in the applications presented in this article are from a complex multi-stage cross-sectional survey (CCHS 2.2). The design effect associated with the BMI may have a significant impact on the final *S* curve, even if normalized survey weights are used. The *S* curve has a major effect on the estimation of extreme centiles. In addition to assuming that the reference distribution at a given age is normal after a Box-Cox transformation, the LMS method does not correct for kurtosis in the tails of the distribution. D'Agastino *et al*. (1990) suggests statistical tests for analyzing the distribution and the kurtosis.

As discussed in section 3.1, the curvature of growth curves, especially at their end points, requires special attention in the estimation process. Supplementary data or auxiliary data from the same target population will enhance the precision of the smoothing process and thus the areas where growth curves bend more sharply. Curvature at the end points can be ameliorated simply by estimating the growth curves over a longer period of time. For example, if we wanted to estimate growth curves for a target population between 4 and 12 years of age, we could, if the sample allows, estimate the curves with children aged 3 to 13 and then truncate the curves at ages 4 and 12.

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