National Health Statistics Reports

Number 63 ■ February 11, 2013

Construction of LMS Parameters for the Centers for Disease Control and Prevention 2000 Growth Charts

by Katherine M. Flegal, Ph.D., Office of the Director, National Center for Health Statistics; and Tim J. Cole, Ph.D., MRC Centre of Epidemiology for Child Health, Institute of Child Health, University College London, UK

Abstract

Objectives—In 2000, the Centers for Disease Control and Prevention (CDC) released a new set of childhood growth charts for the United States. These charts included a set of smoothed percentiles along with LMS (lambda-mu-sigma) parameters to allow the calculation of other percentiles or standard deviation scores. These parameters resemble the LMS parameters derived using Cole's LMS method. Similarities in the terminology mask differences in the methods used. This brief commentary is intended to clarify these differences.

Discussion—The background for the creation of standard deviation scores (*z* scores) for growth charts is discussed, and the method used to create the CDC LMS parameters is compared with Cole's LMS method.

Conclusion—Using an approach similar to that used by CDC, LMS parameters could be calculated for any set of fitted percentile curves, regardless of the smoothing methods employed to create the curves. However, this is not equivalent to using the LMS method.

Keywords: National Health and Nutrition Examination Survey • smoothing • children

Introduction

Growth charts provide a graphical method to compare a child's achieved growth with that of children of the same age and sex from a suitable reference population. For clinical use, such charts show selected percentiles of anthropometric variables such as weight, height, or body mass index (BMI) plotted against age or weight plotted against height. Because of statistical variation in the reference sample, empirical percentile curves are generally irregular, and some type of smoothing over age or height is applied. As noted by Cole and Green (1), the smoothing is partly for cosmetic reasons but also partly because changes of weight or other anthropometric variables over age or height would be expected to be continuous.

In 1977, the National Center for Health Statistics (NCHS) released growth charts based on U.S. data (2). These charts, intended for clinical use, depicted a set of selected percentiles of weight, height, and head circumference for age and weight for length or stature, smoothed using restricted linear splines. Waterlow et al. (3) suggested the use of *z* scores, or standard deviation scores, to provide a quantitative measure of how far a child departs from the mean value of height or weight for age, expressed in units of standard deviations. This was of particular usefulness to describe children who fell well below or, in some cases, well above the outermost percentiles on the chart. For a reference measure that follows a normal distribution, the calculations can be done with the usual standard deviation. However, for a reference measure that follows a skewed distribution, Waterlow et al. suggested calculating standard deviations separately for the lower and upper halves of the distribution at each age. This method was applied by the Centers for Disease Control and Prevention (CDC) (4) to the 1977 NCHS growth charts.

Discussion

Cole's development of LMS method

Subsequent to release of the 1977 NCHS growth charts, Cole (1,5) developed a comprehensive method of smoothing for growth curves, known as the LMS method, that allowed for development of smoothed curves and efficient calculation of *z* scores simultaneously. The LMS method is based on the use of Box-Cox transformations to normality (6) through the calculation of a skewness parameter. The LMS parameters are the power in the Box-Cox transformation (*L*), the median (*M*), and the generalized coefficient of variation (*S*). Given these parameters, and the assumption that the residuals follow a normal distribution, any desired percentile can be calculated. The following equations, where *X* is the value of the anthropometric variable and *Z* is the desired percentile in standard deviation units, give the value of *X* at the desired percentile:

$$X = M\,(1 + LSZ)^{1/L}\ ;\ L \neq 0,$$

or

$$X = M\,\exp(SZ)\ ;\ L = 0$$

Conversely, for any given value of *X*, the corresponding *z* score (*Z*) can be calculated as:

$$Z = [(X/M)^{L} - 1]/LS\ ;\ L \neq 0,$$

or

$$Z = \ln(X/M)/S\ ;\ L = 0$$

The method of maximum penalized likelihood generates values of *L*, *M*, and *S* parameters that are smoothed over age or height. These parameters are then used to construct the desired percentiles. The LMS method has been used for a variety of growth charts (7–9) and to smooth additional types of data that vary with age (10). Although the 2000 CDC growth charts also present values of LMS parameters, these were not generated through use of the LMS method developed by Cole. Differences in the methods used are disguised by similar terminology.

Calculation of LMS parameters for CDC growth charts

The 2000 CDC growth charts are a revision of the 1977 NCHS charts. Planning for this revision began at NCHS in the early 1980s and included plans for additional data collection for children in the third National Health and Nutrition Examination Survey, which was conducted from 1988 through 1994. Throughout the process, the focus was on creating the charts with selected smoothed percentiles (3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th, 97th, and, for BMI only, 85th percentile). To achieve smooth curves with a reasonable fit to the empirical data, a variety of parametric and nonparametric smoothing methods were employed, as detailed elsewhere (11). These methods produced a set of smoothed percentiles to be depicted on the charts but did not allow for the calculation of percentiles or equivalent *z* scores for other than the selected smoothed percentiles.

After the smoothing had been performed, it was decided to create parameters that would allow for the calculation of *z* scores. Because these parameters were intended to be used with the same equations as the LMS parameters of Cole, the same terminology was used. The problem to be solved may be described as follows: Given a set of selected smoothed percentiles at a given age, what values of *L*, *M*, and *S* can be found for that age that, when used in the preceding equations, would most closely reproduce those smoothed percentiles? A simultaneous solution for the three parameters of *L*, *M*, and *S* from the group of specified equations was generated as the best solution to a system of equations and not as likelihood-based estimates from empirical data. Unlike the Cole LMS method, the CDC LMS parameters were created only from the smoothed percentiles and not from the underlying data. Also unlike the Cole LMS method, the CDC LMS parameters were not explicitly smoothed over age or height. Rather, at each interval of age or height, an independent solution for the three parameters was found. However, because the percentiles on which the parameters were based varied smoothly, the CDC LMS parameters themselves also tended to vary smoothly.

The selected CDC percentiles were evaluated graphically relative to the corresponding empirical percentiles of the CDC growth chart data set. Because the CDC LMS parameters simply reproduce the selected smoothed CDC percentiles, they were also, in effect, evaluated relative to the corresponding empirical percentiles, but not to any other percentiles. The above equations can be used with the CDC LMS parameters to calculate an estimate for any specified percentile, but that does not guarantee that the estimate will necessarily be a good fit to the empirical data. In particular, as noted in the growth charts' technical documentation (11), the CDC LMS parameters were not based on any data above the 97th percentile or below the 3rd percentile and, thus, any extrapolations should be approached cautiously. As shown elsewhere (12), the CDC LMS parameters did not provide a good fit to the empirical 99th percentile of BMI-for-age.

Summary

In the LMS method, LMS parameters are estimated from the data, smoothed, and then used to create the desired percentiles. In the method employed by CDC, the desired percentiles are estimated from the data, smoothed, and then used to create the LMS parameters. Using an approach similar to that used by CDC, LMS parameters could be calculated for any set of fitted percentile curves regardless of the smoothing methods employed to create the curves. However, this is not equivalent to using the LMS method.

References

1. Cole TJ, Green PJ. Smoothing reference centile curves: The LMS method and penalized likelihood. Stat Med 11(10):1305–19. 1992.
2. Hamill PVV, Drizd TA, Johnson CL, et al. NCHS growth curves for children: Birth–18 years, United States. National Center for Health Statistics. Vital Health Stat 11(165). 1977.
3. Waterlow JC, Buzina R, Keller W, Lane JM, Nichaman MZ, Tanner JM. The presentation and use of height and weight data for comparing the

nutritional status of groups of children under the age of 10 years. Bull World Health Organ 55(4):489–98. 1977.

4. Dibley MJ, Goldsby JB, Staehling NW, Trowbridge FL. Development of normalized curves for the international growth reference: Historical and technical considerations. Am J Clin Nutr 46(5):736–48. 1987.
5. Cole TJ. The LMS method for constructing normalized growth standards. Eur J Clin Nutr 44(1):45–60. 1990.
6. Box GEP, Cox DR. An analysis of transformations. J R Stat Soc, Ser B (Method) 26(2):211–34. 1964.
7. Inokuchi M, Hasegawa T, Anzo M, Matsuo N. Standardized centile curves of body mass index for Japanese children and adolescents based on the 1978–1981 national survey data. Ann Hum Biol 33(4):444–53. 2006.
8. Roelants M, Hauspie R, Hoppenbrouwers K. References for growth and pubertal development from birth to 21 years in Flanders, Belgium. Ann Hum Biol 36(6):680–94. 2009.
9. Silva S, Maia J, Claessens AL, Beunen G, Pan H. Growth references for Brazilian children and adolescents: Healthy growth in Cariri study. Ann Hum Biol 39(1):11–8. 2012.
10. Stanojevic S, Wade A, Cole TJ, Lum S, Custovic A, Silverman M, et al. Spirometry centile charts for young Caucasian children: The Asthma UK Collaborative Initiative. Am J Respir Crit Care Med 180(6):547–52. 2009.
11. Kuczmarski RJ, Ogden CL, Guo SS, et al. 2000 CDC growth charts for the United States: Methods and development. National Center for Health Statistics. Vital Health Stat 11(246). 2002.
12. Flegal KM, Wei R, Ogden CL, Freedman DS, Johnson CL, Curtin LR. Characterizing extreme values of body mass index-for-age by using the 2000 Centers for Disease Control and Prevention growth charts. Am J Clin Nutr 90(5):1314–20. 2009.

U.S. DEPARTMENT OF HEALTH & HUMAN SERVICES

Centers for Disease Control and Prevention
National Center for Health Statistics
3311 Toledo Road
Hyattsville, MD 20782

Suggested citation

Flegal KM, Cole TJ. Construction of LMS parameters for the Centers for Disease Control and Prevention 2000 growth charts. National health statistics reports; no 63. Hyattsville, MD: National Center for Health Statistics. 2013.

For free e-mail updates on NCHS publication releases, subscribe online at: http://www.cdc.gov/nchs/govdelivery.htm.
For questions or general information about NCHS: Tel: 1–800–232–4636 • E-mail: cdcinfo@cdc.gov • Internet: http://www.cdc.gov/nchs

DHHS Publication No. (PHS) 2013–1250 • CS237424