Using the LMS method to calculate z-scores for the Fenton preterm growth chart

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ORIGINAL ARTICLE

Using the LMS method to calculate *z*-scores for the Fenton preterm infant growth chart

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Objectives: The use of exact percentiles and *z*-scores permit optimal assessment of infants' growth. In addition, *z*-scores allow the precise description of size outside of the 3rd and 97th percentiles of a growth reference. To calculate percentiles and *z*-scores, health professionals require the LMS parameters (Lambda for the skew, Mu for the median, and Sigma for the generalized coefficient of variation; Cole, 1990). The objective of this study was to calculate the LMS parameters for the Fenton preterm growth chart (2003).
Design: Secondary data analysis of the Fenton preterm growth chart data.
Methods: The Cole methods were used to produce the LMS parameters and to smooth the L parameter. New percentiles were generated from the smooth LMS parameters, which were then compared with the original growth chart percentiles.
Results: The maximum differences between the original percentile curves and the percentile curves generated from the LMS parameters were: for weight; a difference of 66 g (2.9%) at 32 weeks along the 90th percentile; for head circumference; some differences of 0.3 cm (0.6–1.0%); and for length; a difference of 0.5 cm (1.6%) at 22 weeks on the 97th percentile.
Conclusion: The percentile curves generated from the smoothed LMS parameters for the Fenton growth chart are similar to the original curves. These LMS parameters for the Fenton preterm growth chart facilitate the calculation of *z*-scores, which will permit the more precise assessment of growth of infants who are born preterm.
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Introduction

Although the ideal growth pattern of preterm infants remains uncertain, it has long been considered that growth at the intrauterine rate is a prudent goal (Nutrition Committee Canadian Paediatric Society, 1995; Committee on Nutrition American Academy Pediatrics, 1998). Recent work has noted an association between preterm birth and increased higher blood pressure (Johansson et al, 2005) and suggested that accelerated growth of preterm infants is associated with components of the metabolic syndrome in later life, including increased insuling resistance (Agget et al, 2006) Also worthy of consideration is the association between more optimal nutritional intakes and growth rates in the first few weeks and months of postnatal life for preterm infants with better psychomotor and mental developmental indices (Georgieff *et al*., 1985; Latal-Hajnal *et al*., 2003), higher verbal intelligence quotient among boys (Lucas *et al*., 1998) and a lower incidence of cerebral palsy (Lucas *et al*., 1998). Although controversies remain, with the critical importance of brain development for preterm infants after birth, it has been suggested that the best practice continues to be to support growth rates of preterm infants at the intrauterine rate (Lucas, 2005).

To describe an infant's size and growth rate precisely, it is useful for health professionals to obtain an infant's exact percentiles or *z*-scores. *Z*-scores are superior to percentiles for infants whose size is outside of the normal range of a growth chart, that is, beyond the 3rd and 97th percentiles. *Z*-scores refer to the number of standard deviations greater (positive value) or smaller (negative value) than the median. For

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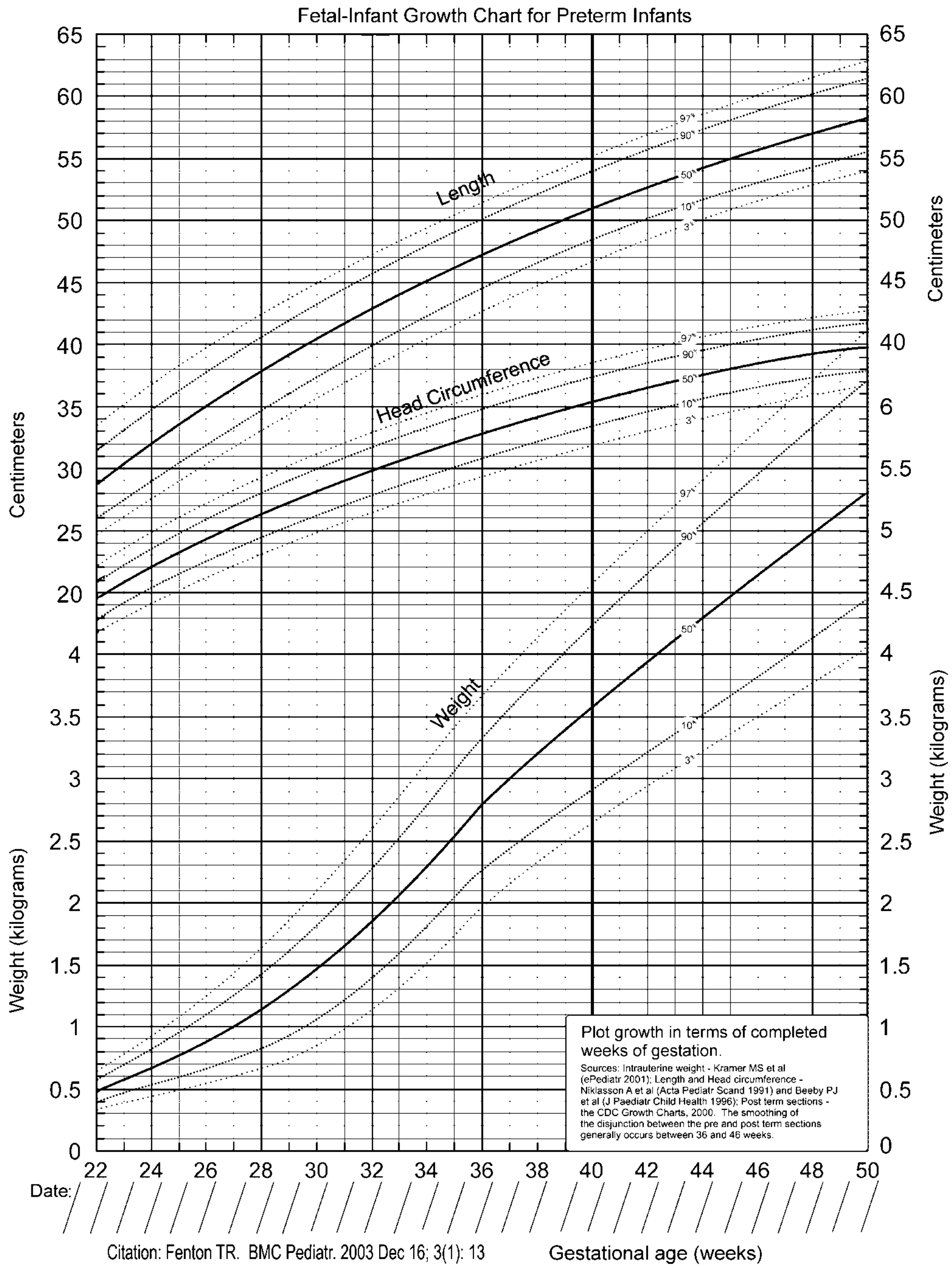

Figure 1 A growth chart for preterm infants (Fenton, 2003).

example, using percentiles, an infant would be described as weighing less than the 3rd percentile, whereas with *z*-scores, the infant could be described more precisely as having a weight *z*-score of −2.7 or −3.2. By examining serial *z*-scores it would be apparent whether the infant was maintaining growth at, or growing faster than or slower than, the intrauterine rate.

Cole developed a method to obtain exact percentiles and/or *z*-scores for children, by summarizing growth charts as LMS parameters (Lambda for the skew, Mu for the median, and Sigma for the generalized coefficient of variation (Cole, 1990). This method takes note of any departures in normality of the growth reference by inclusion of the *L* parameter (Cole, 1989).

The Fenton growth chart for preterm infants allows comparison of an infant's growth with the intrauterine growth rate and the term infant (Figure 1) (Fenton, 2003).

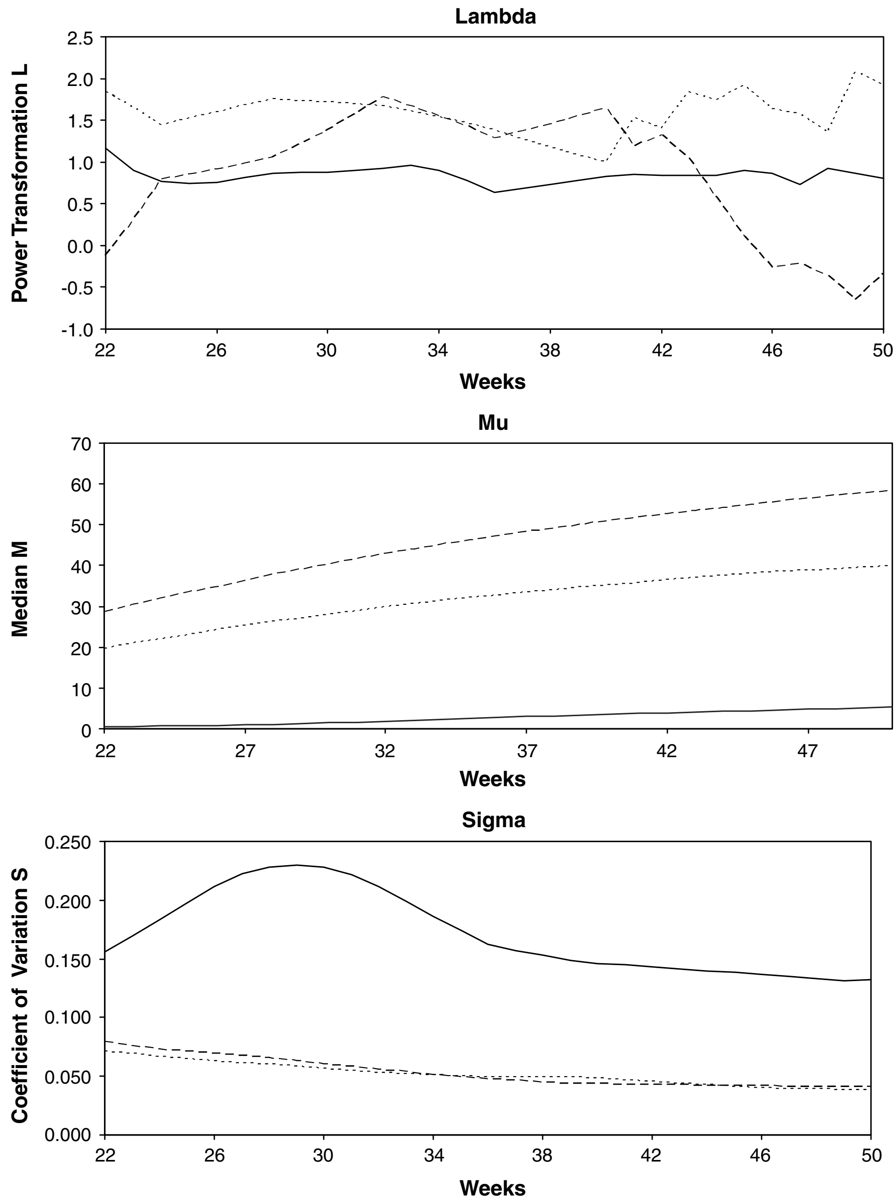

Figure 2 The L, M and S curves derived from the Fenton growth chart for weight (————), head circumference (- - - - - - -) and length (— — — —).

This growth chart is based on recent estimates of intrauterine size of infants between 22 and 36 weeks (and between 22 and 40 weeks along the 50th percentile), and the size of term infants between 46–50 weeks postconception age from the Centre for Disease Control (CDC) (http://www.cdc.gov/growthcharts/) growth reference (Fenton, 2003). The LMS parameters for the Fenton growth chart have not been previously published. The purpose of this study is to produce the LMS parameters for the calculation of *z*-scores and exact percentiles for the Fenton preterm growth chart, using the methods of Cole and co-workers (Cole, 1990; Davies *et al*., 1993).

Methods

The methods described by Cole *et al* were used to derive the LMS parameters from the weight, head circumference and length data of the Fenton preterm growth chart (Cole, 1990; Davies *et al*., 1993). These LMS parameters describe the skew (L for lambda), the median (M for mu) and the coefficient of variation (S for sigma) for each weekly measurement of the growth chart. To calculate the LMS parameters, we first calculated the natural log and the reciprocal of each of the percentiles for each week. Second, we calculated the mean,

Table 1 The weight *L*, *M* and *S* parameters of the Fenton growth chart for preterm infants

Weeks	L	M	S
22	1.0	0.481	0.156
23	1.0	0.575	0.170
24	1.0	0.670	0.183
25	1.0	0.770	0.198
26	1.0	0.877	0.212
27	1.0	0.995	0.222
28	1.0	1.128	0.228
29	1.0	1.277	0.230
30	1.0	1.446	0.228
31	1.0	1.635	0.222
32	1.0	1.846	0.211
33	1.0	2.073	0.199
34	1.0	2.309	0.186
35	1.0	2.553	0.174
36	1.0	2.796	0.162
37	1.0	2.992	0.157
38	1.0	3.188	0.153
39	1.0	3.384	0.149
40	1.0	3.581	0.146
41	1.0	3.757	0.145
42	1.0	3.927	0.144
43	1.0	4.099	0.142
44	1.0	4.271	0.140
45	1.0	4.453	0.138
46	1.0	4.618	0.137
47	1.0	4.799	0.135
48	1.0	4.976	0.133
49	1.0	5.147	0.131
50	1.0	5.305	0.132

Table 2 The head circumference *L*, *M* and *S* parameters of the Fenton growth chart for preterm infants

Weeks	L	M	S
22	1.5	19.734	0.071
23	1.5	20.875	0.069
24	1.5	22.017	0.067
25	1.5	23.094	0.065
26	1.5	24.172	0.063
27	1.5	25.249	0.061
28	1.5	26.327	0.060
29	1.5	27.200	0.058
30	1.5	28.074	0.056
31	1.5	28.947	0.055
32	1.5	29.821	0.053
33	1.5	30.569	0.052
34	1.5	31.317	0.051
35	1.5	32.065	0.050
36	1.5	32.812	0.049
37	1.5	33.421	0.049
38	1.5	34.031	0.049
39	1.5	34.640	0.049
40	1.5	35.232	0.048
41	1.5	35.842	0.047
42	1.5	36.421	0.045
43	1.5	37.023	0.044
44	1.5	37.578	0.043
45	1.5	38.027	0.041
46	1.5	38.450	0.040
47	1.5	38.833	0.039
48	1.5	39.188	0.039
49	1.5	39.547	0.039
50	1.5	39.805	0.038

standard deviation, coefficients of variation (mean/standard deviation) of all three versions of the percentiles (unaltered, log and reciprocal) for weight, length and head circumference. Since the starting data was in the form of percentiles, we calculated each mean and standard deviation by fitting a normal curve to the percentiles using a least squares best fit method. Third, we calculated the power transformation (*L*) necessary to eliminate the skew and the generalized coefficient of variation (*S*) from the calculated coefficients of variation for each weekly measurement. Fourth, the generalized mean or median (*M*) (Davies *et al*., 1993) was then calculated from the means (arithmetic, geometric and reciprocals).

The graphical presentation of the *M* and *S* parameters were found to be quite smooth; however, the *L* parameters for head circumference and length were quite jagged and variable (Figure 2). The weight and length *L*'s varied around 1.0, which is a normal distribution, so this value was used for smoothing. The average *L* for head circumference was 1.5, so this value was used to represent the *L* for the head measurement at all ages.

Finally, new percentiles were generated from these LMS parameters, which were then compared with the original growth chart percentiles.

Results

The LMS parameters as generated by the Cole methods for the Fenton growth chart are shown in Figure 2. Although the L head circumference and length curves are variable and jagged, the M and S curves are quite smooth. The M curves are the median curves of the weight, head circumference and length curves and therefore illustrate the patterns of those curves. The S curves for head circumference and length demonstrate low and relatively constant variability of those percentile curves. In contrast the S curve for weight increases until 30 weeks and remains higher than the head circumference and length S curves which reflects the rapid spreading of the percentile through these ages and the generally greater variability of weight measures.

The final LMS parameters for the weight, head circumference and length percentiles are shown in Tables 1–3. In a comparison shown in Figures 3–5, the original percentile curves of the growth chart were very similar to the curves derived from the LMS parameters.

There were some differences between the original percentile curves and the percentile curves generated from the LMS parameters. For weight, the maximum differences between the original percentiles and those newly generated occurred

Table 3 The length *L*, *M* and *S* parameters of the Fenton growth chart for preterm infants

Weeks	L	M	S
22	1.0	28.720	0.079
23	1.0	30.303	0.076
24	1.0	31.893	0.073
25	1.0	33.372	0.071
26	1.0	34.851	0.069
27	1.0	36.330	0.067
28	1.0	37.809	0.065
29	1.0	39.103	0.063
30	1.0	40.398	0.060
31	1.0	41.693	0.058
32	1.0	42.987	0.056
33	1.0	44.042	0.054
34	1.0	45.098	0.051
35	1.0	46.155	0.049
36	1.0	47.212	0.047
37	1.0	48.190	0.046
38	1.0	49.168	0.045
39	1.0	50.146	0.044
40	1.0	51.114	0.043
41	1.0	51.859	0.043
42	1.0	52.693	0.043
43	1.0	53.469	0.043
44	1.0	54.238	0.042
45	1.0	54.960	0.042
46	1.0	55.681	0.042
47	1.0	56.437	0.041
48	1.0	57.103	0.041
49	1.0	57.679	0.042
50	1.0	58.301	0.041

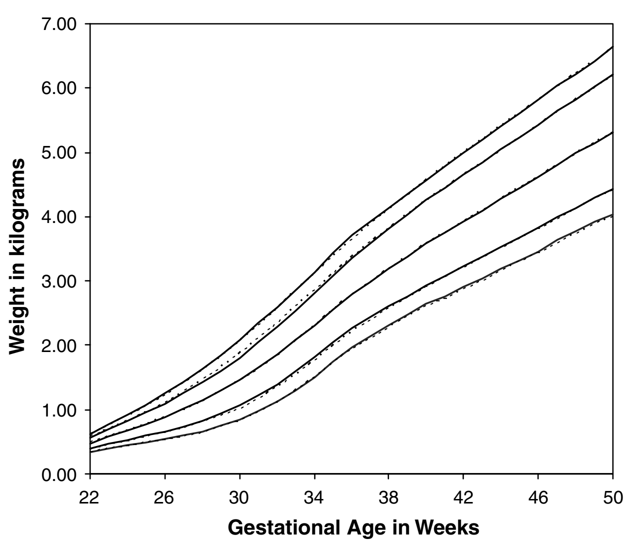

Figure 3 A comparison of the weight percentiles for the Fenton growth chart as originally published (——) with those derived using the LMS values (- - - -).

along the 90th percentile at 32 weeks, where the difference was equal to 66 g, or 2.9%. The maximum percent difference in weight occurred at 26 weeks also along the 10th percentile

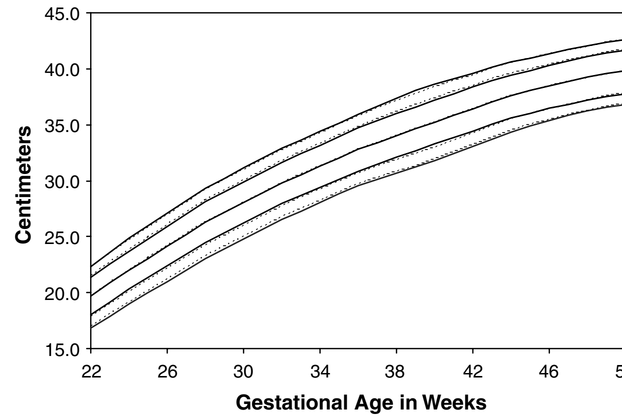

Figure 4 Comparison of the head circumference percentiles for the Fenton growth chart as originally published (——) with those derived using the LMS values (- - - -).

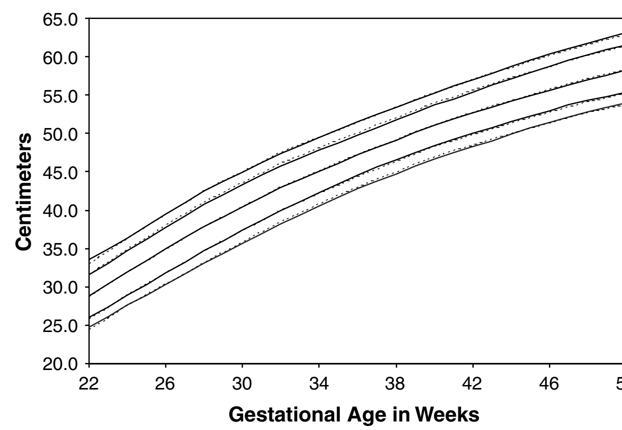

Figure 5 Comparison of the length percentiles for the Fenton growth chart as originally published (——) with those derived using the LMS values (- - - -).

where the difference was 4.0% or 27 g. Along the 3rd percentile, the largest difference between the two weight curves was 55 g at 47 weeks, which was equal to 1.5%. Along the 50th percentile, the maximum difference was 21 g at 30 weeks, which is equivalent to 1.5%.

The maximum difference in head circumference between the two sets of percentiles occurred between 28 and 32 weeks along the 10th percentile and between 39 and 40 weeks, with a difference of 0.3 cm (0.6–1.0%). The median head circumference did not differ between the two median (50th percentile) curves by more than 0.1 cm.

The maximum differences in length between the two sets of percentiles was 0.5 cm at the 10th percentile at 22 weeks (1.6%).

Discussion

When growth curves are generated from the LMS parameters, the weekly distributions are captured mathematically (Cole, 1989). The LMS parameters can then be used to generate the growth chart. This process of generating a growth reference from the LMS parameters decreases the influence of minor errors that originated during the sampling and measurement of the original subjects (Cole, 1989). The close agreement between the original percentiles and those generated from the LMS parameters of the Fenton growth chart demonstrates that the LMS method accurately replicates the nuances of these cross-sectional growth curves. The magnitude of the differences between raw data curves and LMS-derived curve is slight therefore they can be considered unimportant (Davies *et al*., 1993). A benefit of using the growth curves generated from LMS parameters is that population sampling and measurement errors have less influence on the percentiles thus generated (Healy, 1992).

When shown graphically, the LMS parameters are expected to change smoothly with age since physiological changes are gradual and continuous, and differences from smoothness are usually due to sampling errors (Cole, 1989; Cole and Green, 1992). Smoothing of the L parameters can be justified based on these concepts (Cole and Green, 1992). Additionally, changes in *L* have very little impact on the skew of the final curves when the magnitude of the *S* values are small S, as they are in this case for head circumference and length (Cole, 1989).

Z-scores can be calculated from the LMS parameters by comparing the child's measure with the median size for that age, and dividing the result by the standard deviation. Inclusion of the *L* parameter in the calculation ($z = (\text{measure}/M)^L - 1/(L/S)$) takes any skew in the growth reference into account (Cole, 1989). Alternatively, the *z*-scores or percentiles for an infant can be obtained using a file (Fenton growth chart calculations. xls) that may be downloaded from the website http://members.shaw.ca/growthchart/.

The percentile curves generated from the LMS parameters for the Fenton growth chart are similar to the original curves. The LMS parameters for the Fenton preterm growth chart facilitate the calculation of *z*-scores, which will permit the more precise growth assessment of infants who are born preterm.

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