In 1993 the World Health Organization (WHO) undertook a comprehensive review of the uses and interpretation of anthropometric references. The review concluded that the NCHS/WHO growth reference, which had been recommended for international use since the late 1970s, did not adequately represent early childhood growth and that new growth curves were necessary. The World Health Assembly endorsed this recommendation in 1994. The WHO Multicentre Growth Reference Study (MGRS) was undertaken in response to that endorsement and implemented between 1997 and 2003 to generate new curves for assessing the growth and development of children the world over. The MGRS collected primary growth data and related information from 8440 healthy breastfed infants and young children from diverse ethnic backgrounds and cultural settings (Brazil, Ghana, India, Norway, Oman and USA). The growth standards developed based on these data and presented in this report provide a technically robust tool that represents the best description of physiological growth for children under five years of age. The standards depict normal early childhood growth under optimal environmental conditions and can be used to assess children everywhere, regardless of ethnicity, socioeconomic status and type of feeding.

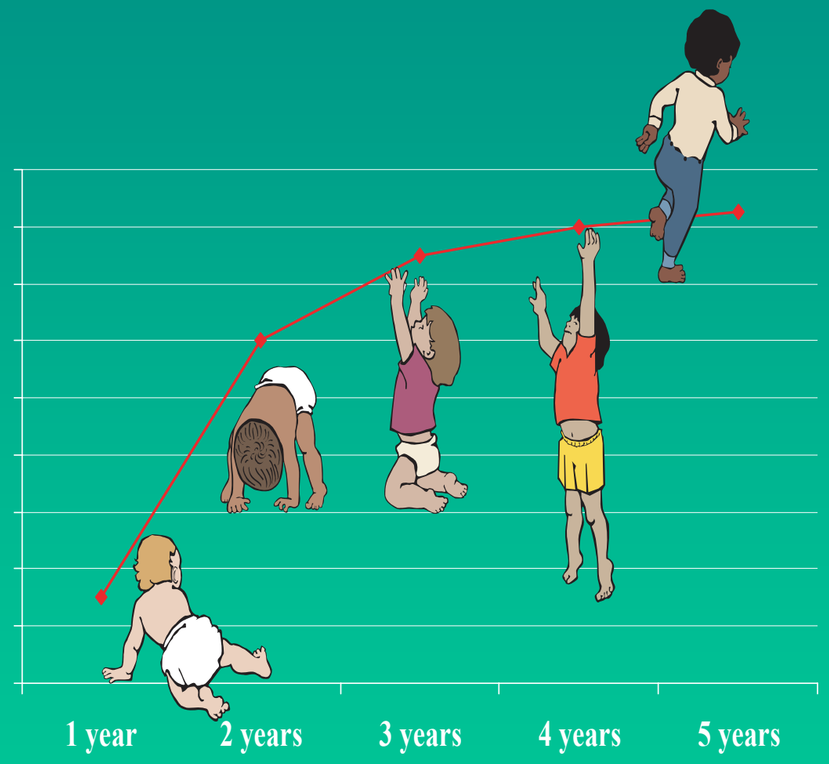
ISBN 9789241547185

WHO Child Growth Standards - Methods and development

WHO Child Growth Standards

Head circumference-for-age, arm circumference-for-age, triceps skinfold-for-age and subscapular skinfold-for-age

Methods and development



World Health Organization

WHO Child Growth Standards

Head circumference-for-age, arm circumference-for-age, triceps skinfold-for-age and subscapular skinfold-for-age

Methods and development

World Health Organization

Department of Nutrition for Health and Development

WHO Library Cataloguing-in-Publication Data

WHO child growth standards : head circumference-for-age, arm circumference-for-age, triceps skinfold-for-age and subscapular skinfold-for-age : methods and development.

Coordinating team: Mercedes de Onis ... [et al.].

1.Anthropometry. 2.Anthropometry - methods. 3.Body size - standards. 4.Child development. 5.Growth. 6.Reference standards. 7.Nutrition assessment. I.de Onis, Mercedes. II.World Health Organization. III.Title: World Health Organization child growth standards.

ISBN 978 92 4 154718 5 (NLM classification: WS 103)

Printed in China, Hong Kong Special Administrative Region.

Members of the WHO Multicentre Growth Reference Study Group

Coordinating Team

Mercedes de Onis [Study Coordinator], Adelheid Onyango, Elaine Borghi, Amani Siyam, Alain Pinol (Department of Nutrition for Health and Development, World Health Organization).

Executive Committee

Cutberto Garza [Chair], Mercedes de Onis, Jose Martines, Reynaldo Martorell, Cesar G. Victora (up to October 2002), Maharaj K. Bhan (from November 2002).

Steering Committee

Coordinating Centre (WHO, Geneva): Mercedes de Onis, Jose Martines, Adelheid Onyango, Alain Pinol.

Investigators (by country): Cesar G. Victora and Cora Luiza Araújo (Brazil), Anna Lartey and William B. Owusu (Ghana), Maharaj K. Bhan and Nita Bhandari (India), Kaare R. Norum and Gunn-Elin Aa. Bjoerneboe (Norway), Ali Jaffer Mohamed (Oman), Kathryn G. Dewey (USA).

United Nations Agency Representatives: Cutberto Garza (UNU), Krishna Belbase (UNICEF).

Advisory Group

Maureen Black, Wm. Cameron Chumlea, Tim Cole, Edward Frongillo, Laurence Grummer-Strawn, Reynaldo Martorell, Roger Shrimpton, Jan Van den Broeck. For the work presented in this document, Huiqi Pan, Robert Rigby, Mikis Stasinopoulos and Stef van Buuren, participated in an advisory capacity.

Participating countries and investigators

Brazil: Cora Luiza Araújo, Cesar G. Victora, Elaine Albernaz, Elaine Tomasi, Rita de Cássia Fossati da Silveira, Gisele Nader (Departamento de Nutrição and Departamento de Medicina Social, Universidade Federal de Pelotas; and Núcleo de Pediatria and Escola de Psicologia, Universidade Católica de Pelotas).

Ghana: Anna Lartey, William B. Owusu, Isabella Sagoe-Moses, Veronica Gomez, Charles Sagoe-Moses (Department of Nutrition and Food Science, University of Ghana; and Ghana Health Service).

India: Nita Bhandari, Maharaj K. Bhan, Sunita Taneja, Temsunaro Rongsen, Jyotsna Chetia, Pooja Sharma, Rajiv Bahl (All India Institute of Medical Sciences).

Norway: Gunn-Elin Aa. Bjoerneboe, Anne Baerug, Elisabeth Tufte, Kaare R. Norum, Karin Rudvin, Hilde Nysaether (Directorate of Health and Social Affairs; National Breastfeeding Centre, Rikshospitalet University Hospital; and Institute for Nutrition Research, University of Oslo).

Oman: Ali Jaffer Mohamed, Deena Alasfoor, Nitya S. Prakash, Ruth M. Mabry, Hanadi Jamaan Al Rajab, Sahar Abdou Helmi (Ministry of Health).

USA: Kathryn G. Dewey, Laurie A. Nommsen-Rivers, Roberta J. Cohen, M. Jane Heinig (University of California, Davis).

Acknowledgements

The WHO Child Growth Standards were constructed by the Coordinating Team in the Department of Nutrition for Health and Development of the World Health Organization.

The Study Group is indebted to the parents, children and more than 200 field staff that participated in the WHO Multicentre Growth Reference Study. The generous contribution of many individuals that provided expertise and advice was also crucial to the development of the growth standards.

The project has received funding from the Bill & Melinda Gates Foundation, the Netherlands Minister for Development Cooperation, the Norwegian Royal Ministry of Foreign Affairs, and the United States Department of Agriculture (USDA). Financial support was also provided by the Ministry of Health of Oman, the United States National Institutes of Health, the Brazilian Ministry of Health and Ministry of Science and Technology, the Canadian International Development Agency, the United Nations University, the Arab Gulf Fund for United Nations Development, the Office of the WHO Representative to India, and the Department of Child and Adolescent Health and Development.

Contents

Figures

Tables

Glossary

BCPE	The Box-Cox power exponential distribution.
μ	The median of the Box-Cox power exponential distribution.
σ	The approximate coefficient of variation of the Box-Cox power exponential distribution — related to the variance.
ν	The power of the Box-Cox transformation (to the normal distribution) of the Box-Cox power exponential distribution — related to the skewness.
τ	The power exponential parameter of the Box-Cox power exponential distribution — related to the kurtosis.
λ	The power of the age (or length/height) transformation.
Body mass index (BMI)	The ratio weight (in kg) / recumbent length or standing height (in m^2).
Box-Cox transformation	A power transformation to the normal distribution.
Coefficient of variation	The ratio of the standard deviation to the mean.
Cubic spline	A piecewise third-order polynomial function that passes through a set of *m* (or degrees of freedom) control points; it can have a very simple form locally, yet be globally flexible and smooth.
Cut-off	A designated limit beyond which a subject or observation is classified according to a pre-set condition.
Degrees of freedom (df)	The number of control points used to fit the cubic splines.
Kurtosis	An attribute of a distribution describing "peakedness". A high kurtosis portrays a distribution with fat tails in contrast to a low kurtosis, which portrays a distribution with skinny tails.
P-value	The probability of falsely rejecting the hypothesis being tested. In this report all p-values were compared to a level of significance set to 0.05.
Q-test	A statistical test which combines overall and local tests assessing departures from the normal distribution with respect to median, variance, skewness and kurtosis.
Skewness	A statistical term used to describe a distribution's asymmetry in relation to a normal distribution.
Standard deviation score (SD)	See z-score.
Worm plots	A set of detrended Q-Q plots — plots that compare the distribution of a given set of observations to the normal distribution.
Z-score	The deviation of an individual's value from the median value of a reference population, divided by the standard deviation of the reference population (or transformed to normal distribution).

Executive summary

In 1993 the World Health Organization (WHO) undertook a comprehensive review of the uses and interpretation of anthropometric references. The review concluded that the NCHS/WHO growth reference, which had been recommended for international use since the late 1970s, did not adequately represent early childhood growth and that new growth curves were necessary. The World Health Assembly endorsed this recommendation in 1994. In response WHO undertook the Multicentre Growth Reference Study (MGRS) between 1997 and 2003 to generate new curves for assessing the growth and development of children the world over.

The MGRS combined a longitudinal follow-up from birth to 24 months and a cross-sectional survey of children aged 18 to 71 months. Primary growth data and related information were gathered from 8440 healthy breastfed infants and young children from widely diverse ethnic backgrounds and cultural settings (Brazil, Ghana, India, Norway, Oman and USA). The MGRS is unique in that it was purposely designed to produce a standard by selecting healthy children living under conditions likely to favour the achievement of their full genetic growth potential. Furthermore, the mothers of the children selected for the construction of the standards engaged in fundamental health-promoting practices, namely breastfeeding and not smoking.

This report presents the second set of WHO Child Growth Standards (i.e. head circumference-for-age, arm circumference-for-age, triceps skinfold-for-age and subscapular skinfold-for-age) and describes the methodical process followed in their development. The first step in this process was a consultative expert review of some 30 growth curve construction methods, including types of distributions and smoothing techniques to identify the best approach to constructing the standards. Next was the selection of a software package flexible enough to allow the comparative testing of the alternative methods used to generate the growth curves. Then the selected approach was applied systematically to search for the best models to fit the data for each indicator.

The Box-Cox-power-exponential (BCPE) method, with curve smoothing by cubic splines was selected for constructing the WHO child growth curves. The BCPE accommodates various kinds of distributions, from normal to skewed or kurtotic. The age-based indicators originating at birth required a power-transformation to stretch the age scale (x-axis) as a preliminary step to fitting the curves. For each set of curves, the search for the best model specification began by examining various combinations of degrees of freedom to fit the median and variance estimator curves. When data had a non-normal distribution, degrees of freedom for parameters to model skewness and kurtosis were added to the initial model and adequacy of fit evaluated. Apart from head circumference-for-age, which followed a normal distribution, the other standards in the second set required the modelling of skewness, but not kurtosis. The diagnostic tools used iteratively to detect possible model misfits and biases in the fitted curves included various tests of local and global goodness of fit, worm plots and residual plots. Patterns of differences between empirical and fitted percentiles were also examined, as were proportions of observed versus expected percentages of children with measurements below selected percentiles.

The sample used for the construction of the second set of growth standards was the same one used for the construction of the first set of standards. The methodology described above was followed to generate ─ for boys and girls ─ percentile and z-score curves for head circumference-for-age (0 to 60 months), arm circumference-for-age (3 to 60 months), triceps skinfold-for-age (3 to 60 months) and subscapular skinfold-for-age (3 to 60 months).

The data of the longitudinal and cross-sectional samples were merged without any adjustments and a single model was fitted to generate one continuous set of curves constituting each sex-specific standard.

Head circumference followed a normal distribution. The data for arm circumference and skinfold thicknesses were skewed, so in specifying the model, the parameter related to skewness was fitted in addition to the median and the coefficient of variation. Results from the final model for girls' subscapular skinfold suggested the need to investigate potential improvements in the curves by modelling kurtosis. Adjustment for kurtosis, however had a negligible impact on the final centiles. Therefore, considering that modelling the fourth parameter would increase complexity in application of the standards and create inconsistency between the sexes, the final curves were generated without adjusting for kurtosis.

The power transformation of age was applied to stretch the age scale for each of the sexes before fitting cubic splines to generate the growth curves. The same power transformation of age was applied to both boys' and girls' head and arm circumferences. For the skinfold thicknesses, boys required a higher power transformation than did girls.

Cubic spline fitting was achieved with variable degrees of freedom for each indicator and sex. For the median curves, different degrees of freedom were required for boys and girls for arm circumference and subscapular skinfold. For the coefficient of variation curves, the degrees of freedom varied between sexes for head circumference and subscapular skinfold. For the indicators that required fitting skewness, all but the subscapular skinfold required different degrees of freedom for the parameter modelling skewness.

Overall, concordance between smoothed curves and empirical centiles was free of bias in both the median range and the tails, indicating that the resulting curves provide an adequate description of the true growth of healthy children.

The method used to construct the WHO standards generally relied on the Box-Cox power exponential distribution and the final selected models simplified to the LMS model. As a result, the computation of percentiles and z-scores for these standards uses formulae based on the LMS method. However, as was done for the construction of the first set of growth standards, a restriction was imposed on all indicators to enable the derivation of percentiles only within the interval corresponding to z-scores between -3 and 3. The underlying reasoning is that percentiles beyond ±3 SD are invariant to changes in equivalent z-scores. The loss accruing to this restriction is small since the inclusion range corresponds to the 0.135th to 99.865th percentiles.

The arm circumference and skinfold thicknesses presented right-skewed distributions. When modelled correctly, right skewness has the effect of making distances between positive z-scores increase progressively the farther away they are from the median, while distances between negative z-scores decrease progressively. The LMS method fits skewed data adequately by using a Box-Cox normal distribution, which follows the empirical data closely. The drawback, however, is that the outer tails of the distribution are highly affected by extreme data points even if only very few. A restricted application of the LMS method was thus used for the construction of the indicators with skewed distributions, limiting the Box-Cox normal distribution to the interval corresponding to z-scores where empirical data were available (i.e. between -3 SD and 3 SD). Beyond these limits, the standard deviation at each age was fixed to the distance between ±2 SD and ±3 SD, respectively. This approach avoids making assumptions about the distribution of data beyond the limits of the observed values.

All four indicators presented in this report are a new addition to the previously available set of indicators in the NCHS/WHO reference. Head circumference-for-age is often used in clinical settings as part of health screening for potential developmental or neurological disabilities in infants and young children. Very small and very large circumferences are both indicative of health or developmental risk. Arm circumference-for-age is used as an alternative indicator of nutritional status when the collection of length/height and weight measurements is difficult, as happens in emergency humanitarian situations due to famine or refugee crises. Triceps and subscapular skinfold measurements assess the

thickness of subcutaneous tissue and reflect fatness primarily. The skinfold indicators are thus a useful addition to the battery of growth standards for assessing childhood obesity.

The WHO Child Growth Standards provide a technically robust set of tool that represents the best description of physiological growth for children under five years of age. The standards depict normal early childhood growth under optimal environmental conditions and can be used to assess children everywhere, regardless of ethnicity, socioeconomic status and type of feeding.

1. INTRODUCTION

Growth charts are an essential component of the paediatric toolkit. Their value resides in helping to determine the degree to which physiological needs for growth and development are met during the important childhood period. Beyond their usefulness in assessing children's nutritional status, many governmental and United Nations agencies rely on growth charts to measure the general well-being of populations, formulate health and related policies, and plan interventions and monitor their effectiveness.

The origin of the WHO Child Growth Standards dates back to the early 1990s when a group of experts was appointed to conduct a meticulous evaluation of the National Center for Health Statistics/World Health Organization (NCHS/WHO) growth reference that had been recommended for international use since the late 1970s (WHO, 1995). The limitations of the NCHS/WHO reference have been documented (WHO Working Group on Infant Growth, 1994; de Onis and Habicht, 1996; de Onis and Yip, 1996). The data used to construct the reference covering birth to three years of age came from a longitudinal study of children of European ancestry from a single community in the USA. These children were measured every three months, which is inadequate to describe the rapid and changing rate of growth in early infancy. Also, the statistical methods available at the time the NCHS/WHO growth curves were constructed were too limited to correctly model the pattern and variability of growth. As a result, the NCHS/WHO curves do not adequately represent early childhood growth.

The initial phase of the expert group's work documented the deficiencies of the reference and led to a plan for developing new growth charts that would show how children *should* grow in all countries rather than merely describing *how* they grew at a particular time and place. The experts underscored the importance of ensuring that the new growth charts were consistent with "best" health practices (Garza and de Onis, 2004).

A logical outcome of this plan was the WHO Multicentre Growth Reference Study (MGRS), which was implemented between 1997 and 2003 (de Onis et al., 2004a). The MGRS is unique in that it was purposely designed to produce a standard rather than a reference. Although standards and references both serve as a basis for comparison, each enables a different interpretation. Since a standard defines how children should grow, deviations from the pattern it describes are evidence of abnormal growth. A reference, on the other hand, does not provide as sound a basis for such value judgments, although in practice references often are mistakenly used as standards.

The MGRS data provide a solid foundation for developing a standard because they are based on healthy children living under conditions likely to favour achievement of their full genetic growth potential. Furthermore, the mothers of the children selected for the construction of the standards engaged in fundamental health-promoting practices, namely breastfeeding and not smoking (de Onis et al., 2004b).

A second feature of the study that makes it attractive as a basis for an internationally applicable standard is that it included children from a diverse set of countries: Brazil, Ghana, India, Norway, Oman and the USA. By selecting privileged, healthy populations the study reduced the impact of environmental variation (WHO Multicentre Growth Reference Study Group, 2006a). Another key characteristic of the new standards is that they explicitly identify breastfeeding as the biological norm and establish the breastfed child as the normative model for growth and development (WHO Multicentre Growth Reference Study Group, 2006b). In addition, the new standards include windows of achievement for six gross motor developmental milestones which are presented elsewhere (WHO Multicentre Growth Reference Study Group, 2006c). Although WHO in the past issued recommendations concerning attained physical growth, it had not previously made any recommendations for assessing motor development.

This report presents the second set of WHO Child Growth Standards and describes the methods used to construct the standards for head circumference-for-age, arm circumference-for-age, triceps skinfold-for-age and subscapular skinfold-for-age. The standards based on length or height, weight and age are presented in an earlier publication (WHO Multicentre Growth Reference Study Group, 2006d; Web site www.who.int/childgrowth/publications/technical_report_pub/en/index.html). Electronic copies of the WHO growth charts and tables together with tools developed to facilitate their use are available on the Web: www.who.int/childgrowth/en.

2. METHODOLOGY

2.1 Design of the WHO Multicentre Growth Reference Study

The Multicentre Growth Reference Study (MGRS) (July 1997–December 2003) was a population-based study that took place in the cities of Davis, California, USA; Muscat, Oman; Oslo, Norway; and Pelotas, Brazil; and in selected affluent neighbourhoods of Accra, Ghana and South Delhi, India. The MGRS protocol and its implementation in the six sites are described in detail elsewhere (de Onis et al., 2004a). Briefly, the MGRS combined a longitudinal component from birth to 24 months with a cross-sectional component of children aged 18–71 months. In the longitudinal component, mothers and newborns were screened and enrolled at birth and visited at home a total of 21 times on weeks 1, 2, 4 and 6; monthly from 2–12 months; and bimonthly in the second year. In the cross-sectional component, children aged 18–71 months were measured once, except in the two sites (Brazil and USA) that used a mixed-longitudinal design in which some children were measured two or three times at three-month intervals. Both recumbent length and standing height were measured for all children aged 18–30 months. Data were collected on anthropometry, motor development, feeding practices, child morbidity, perinatal factors, and socioeconomic, demographic and environmental characteristics (de Onis et al., 2004b).

The study populations lived in socioeconomic conditions favourable to growth and where mobility was low, ≥20% of mothers followed WHO feeding recommendations and breastfeeding support was available (de Onis et al., 2004b). Individual inclusion criteria were: no known health or environmental constraints to growth, mothers willing to follow MGRS feeding recommendations (i.e. exclusive or predominant breastfeeding for at least 4 months, introduction of complementary foods by the age of 6 months, and continued partial breastfeeding up to at least 12 months), no maternal smoking before and after delivery, single term birth, and absence of significant morbidity (de Onis et al., 2004b).

As part of the site-selection process in Ghana, India and Oman, surveys were conducted to identify socioeconomic characteristics that could be used to select groups whose growth was not environmentally constrained (Owusu et al., 2004; Bhandari et al., 2002; Mohamed et al., 2004). Local criteria for screening newborns, based on parental education and/or income levels, were developed from those surveys. Pre-existing survey data for this purpose were available from Brazil, Norway and the USA. Of the 13 741 mother-infant pairs screened for the longitudinal component, about 83% were ineligible (WHO Multicentre Growth Reference Study Group, 2006e). Families' low socioeconomic status was the most common reason for ineligibility in Brazil, Ghana, India and Oman, whereas parental refusal was the main reason for non-participation in Norway and the USA (WHO Multicentre Growth Reference Study Group, 2006e). For the cross-sectional component, 69% of the 21 510 subjects screened were excluded for reasons similar to those observed in the longitudinal component.

Term low-birth-weight (<2500 g) infants (2.3%) were *not* excluded. Since it is likely that in well-off populations such infants represent small but normal children, their exclusion would have artificially distorted the standards' lower percentiles. Eligibility criteria for the cross-sectional component were the same as those for the longitudinal component with the exception of infant feeding practices. A minimum of three months of any breastfeeding was required for participants in the study's cross-sectional component.

2.2 Anthropometry methods

Data collection teams were trained at each site during the study's preparatory phase, at which time measurement techniques were standardized against one of two MGRS anthropometry experts. During the study, bimonthly standardization sessions were conducted at each site. Once a year the anthropometry expert visited each site to participate in these sessions (de Onis et al., 2004c). Results from the anthropometry standardization sessions have been reported elsewhere (WHO Multicentre

Growth Reference Study Group, 2006f). For the longitudinal component of the study, screening teams measured newborns within 24 hours of delivery, and follow-up teams conducted home visits until 24 months of age. The follow-up teams were also responsible for taking measurements in the cross-sectional component involving children aged 18–71 months (de Onis et al., 2004b). The MGRS data included weight and head circumference at all ages, recumbent length (longitudinal component), height (cross-sectional component), and arm circumference, triceps and subscapular skinfolds (all children aged ≥3 months). This report presents only the standards based on head circumference, arm circumference and skinfolds. The standards based on length or height and weight are presented in an earlier publication (WHO Multicentre Growth Reference Study Group, 2006d; web site http://www.who.int/childgrowth/publications/technical_report_pub/en/index.html).

Observers working in pairs collected anthropometric data. Each observer independently measured and recorded a complete set of measurements, after which the two compared their readings. If any pair of readings exceeded the maximum allowable difference for a given variable (e.g. head circumference, 5 mm; arm circumference, 5 mm; skinfold thickness, 2 mm), both observers once again independently measured and recorded a second and, if necessary, a third set of readings for the variable(s) in question (de Onis et al., 2004c).

All study sites used identical measuring equipment. Instruments needed to be highly accurate and precise. A self-retracting, 0.7 cm-wide, flat metal tape with blank lead-in strip (range, 0–200 cm, calibrated to 1 mm), was used to measure circumferences. Metal tapes were chosen because they are more robust and accurate, and stay in a single plane around the head. They were replaced on a regular basis when the grading marks faded. The Holtain/Tanner-Whitehouse skinfold caliper (jaw face area, 35 mm^2; pressure between the jaws, 10 ± 2 g/mm^2; range, 0–40 mm; calibrated to 0.2 mm) was used to measure skinfolds. The skinfold calipers, being particularly fragile, were checked before each use with calibration blocks of various widths for accuracy and to ensure that the needle moved smoothly and continuously with the opening of the caliper jaws. Full details of the instruments used and how measurements were taken are provided elsewhere (de Onis et al., 2004c).

2.3 Sample description

The total sample size for the longitudinal and cross-sectional components from all six sites was 8440 children. A total of 1743 children were enrolled in the longitudinal sample, six of whom were excluded for morbidities affecting growth (4 cases of repeated episodes of diarrhoea, 1 case of repeated episodes of malaria, and 1 case of protein-energy malnutrition) leaving a sample of 1737 children (894 boys and 843 girls). Of these, the mothers of 882 children (428 boys and 454 girls) complied fully with the MGRS infant-feeding and no-smoking criteria and completed the follow-up period of 24 months (96% of compliant children completed the 24-month follow-up). The other 855 either failed to comply with the study's infant-feeding and no-smoking criteria or dropped out before 24 months. These children, whose size at birth was similar to that of the compliant sample, contributed only birth measurements. The increased sample size at birth served to minimize the left-edge effect in the head circumference-for-age curves. For arm circumference and the skinfolds, which were measured starting at age 3 months, the data did not allow for this correction in the corresponding standards. The total number of records for the longitudinal component was 19 900.

The cross-sectional sample comprised 6697 children. Of these, 28 were excluded for medical conditions affecting growth (20 cases of protein-energy malnutrition, five cases of haemolytic anaemia G6PD deficiency, two cases of renal tubulo-interstitial disease, and one case of Crohn disease) leaving a final sample of 6669 children (3450 boys and 3219 girls). The total number of records in the cross-sectional component was 8306 as some children in Brazil and the USA were measured two or three times at three-month intervals. A full description of the MGRS sample with regard to screening,

recruitment, sample attrition and compliance, as well as the baseline characteristics of the study sample is provided elsewhere (WHO Multicentre Growth Reference Study Group, 2006e).

2.4 Data cleaning procedures and exclusions

Data cleaning

The MGRS data management protocol (Onyango et al., 2004) was designed to create and manage a large databank of information collected from multiple sites over a period of several years. Data collection and processing instruments were prepared centrally and used in a standardized fashion across sites. The data management system contained internal validation features for timely detection of data errors and its standard operating procedures stipulated a method of master file updating and correction that maintained a clear trail for data-auditing purposes. Each site was responsible for collecting, entering, verifying and validating data, and for creating site-level master files. Data from the sites were sent to WHO/HQ every month for master file consolidation and more extensive quality control checking. All errors identified were communicated to the site for correction at source.

After data collection was completed at a given site, a period of about 6 months was dedicated to in-depth data quality checking and master file cleaning. Detailed validation reports, descriptive statistics and plots were produced from the site's master files. For the longitudinal component, each anthropometric measurement was plotted for every child from birth to the end of his/her participation. These plots were examined individually for any questionable patterns. Query lists from these analyses were sent to the site for investigation and correction, or confirmation, as required. As with the data collection process, the site data manager prepared correction batches to update the master files. The updated master files were then sent to WHO/HQ and this iterative quality assurance process continued until all identifiable problems had been detected and corrected. The rigorous implementation of what was a highly demanding protocol yielded very high-quality data.

Data exclusions

In addition to exclusions of data based on weight-for-height (WHO Multicentre Growth Reference Study Group, 2006d), a few influential observations outside ±4 SD were excluded when constructing the individual standards included in this report. These were, for head circumference-for-age: boys, all 21 observations belonging to one boy in the longitudinal sample (0.15%) and one single observation (0.01%) among girls; for triceps skinfold-for-age: boys, 7 (0.06%) and girls, 9 (0.08%); for subscapular skinfold-for-age: boys, 17 (0.16%) and girls, 19 (0.17%) observations. These observations were set to missing in the final data set and therefore did not contribute to the construction of the corresponding standards. The final number of observations used in the construction of the WHO child growth standards is shown in Table 1.

Table 1 Number of observations used in the construction of the WHO child growth standards by sex and anthropometric indicator

Indicator	Girls	Boys	Total
Head circumference-for-age	13 798	13 541	27 339
Arm circumference-for-age	10 970	10 770	21 740
Triceps skinfold-for-age	10 943	10 762	21 705
Subscapular skinfold-for-age	10 934	10 757	21 691

2.5 Statistical methods for constructing the growth curves

The underlying methodology used for constructing the head circumference-for-age, arm circumference -for-age, triceps skinfold-for-age and subscapular skinfold-for-age standards was the same used to construct the standards for length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age. The growth curve fitting method and diagnostic tools used to select the best models for each of the indicators are described in detail in the report of the first set of standards (WHO Multicentre Growth Reference Study Group, 2006d, 2006g).

The Box-Cox-power-exponential (BCPE) method (Rigby and Stasinopoulos, 2004), with curve smoothing by cubic splines was selected for constructing the WHO child growth curves. The BCPE accommodates various kinds of distributions, from normal to skewed or kurtotic. All the indicators in this second set standards required a power-transformation to stretch the age scale (x-axis) as a preliminary step to fitting the curves. For each set of curves, the search for the best model specification began by examining various combinations of degrees of freedom to fit the median and variance estimator curves. When data had a non-normal distribution, degrees of freedom for parameters to model skewness and kurtosis were added to the initial model and adequacy of fit was evaluated. Apart from head circumference-for-age, which followed a normal distribution, the other standards required the modelling of skewness, but not kurtosis. The diagnostic tools used iteratively to detect possible model misfits and biases in the fitted curves included various tests of local and global goodness of fit, like Q-tests (Royston and Wright, 2000), worm plots (van Buuren and Fredriks, 2001) and residual plots. Patterns of differences between empirical and fitted percentiles were also examined, as were proportions of observed versus expected percentages of children with measurements below selected percentiles. The curves were constructed using all available data (i.e. from birth to 71 months) but the final standards were truncated at 60 completed months to avoid the right-edge effect (Borghi et al., 2006).

The GAMLSS package (Stasinopoulos et al., 2004) was used for the construction of the growth curves.

3. CONSTRUCTION OF THE HEAD CIRCUMFERENCE-FOR-AGE STANDARDS

3.1 Indicator-specific methodology

The same approach as that described to select the best model for the length/height-for-age growth curves (WHO Multicentre Growth Reference Study Group, 2006d) was followed to select the best model to construct the head circumference-for-age growth standards. The BCPE method was used and, starting from the simplest model (i.e. with the normal distribution), the best model was sought and its goodness of fit evaluated. The diagnostic tools applied to evaluate and compare candidate models were the same as those used for constructing the first set of indicators. All data up to 71 months were used for modelling the head circumference-for-age growth curves and the standards afterwards truncated at 60 completed months to correct for the right-edge effect (Borghi et al., 2006).

3.2 Head circumference-for-age for boys

3.2.1 Sample size

There were 13 541 head circumference observations for boys. The longitudinal and cross-sectional sample sizes by visit and age are shown in Tables 2 and 3.

Table 2 Longitudinal sample sizes for head circumference-for-age for boys

Visit	**Birth**	**1**	**2**	**3**	**4**	**5**	**6**
Age	**0**	**2 wk**	**4 wk**	**6 wk**	**2 mo**	**3 mo**	**4 mo**
N	893	424	423	423	422	418	417
Visit	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Age	**5 mo**	**6 mo**	**7 mo**	**8 mo**	**9 mo**	**10 mo**	**11 mo**
N	419	422	418	418	413	409	420
Visit	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Age	**12 mo**	**14 mo**	**16 mo**	**18 mo**	**20 mo**	**22 mo**	**24 mo**
N	420	418	417	416	422	416	421

Table 3 Cross-sectional sample sizes for head circumference-for-age for boys

Age (mo)	**<18**	**18–20**	**21–23**	**24–26**	**27–29**	**30–32**	**33–35**
N	3	184	191	244	267	229	261
Age (mo)	**36–38**	**39–41**	**42–44**	**45–47**	**48–50**	**51–53**	**54–56**
N	274	254	263	244	245	229	233
Age (mo)	**57–59**	**60–62**	**63–65**	**66–68**	**69–71**	**>71**	
N	245	236	221	224	221	4	

3.2.2 Model selection and results

The model BCPE($x=age^{\lambda}$, df(μ)=9, df(σ)=4, ν=1, τ=2) served as a starting point to construct the head circumference-for-age growth curves. Improvement of the model's fit was investigated by studying changes in global deviance at varying levels of the age-transformation power λ. Table 4 shows the global deviance for a grid of λ values. The smallest global deviance corresponded to age-transformation power λ=0.20.

Table 4 Global deviance (GD) for models within the class BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, ν=1, τ=2) for head circumference-for-age for boys

λ	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
GD[a]	735.7	735.9	735.8	735.5	735.9	738.6	744.9	755.6	769.6	783.6
λ	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
GD[a]	793.4	795.7	791.3	786.9	795.4	835.5	929.0	NA	NA	NA

[a] In excess of 45 000; NA: not available (method did not converge with this power).

Having chosen the age-transformation power λ=0.20, the search for the best df(μ) and df(σ) followed, comparing models in which the parameters ν and τ had the fixed values 1 and 2, respectively, i.e. adjusting neither for skewness nor for kurtosis. For this, all possible combinations of df(μ) ranging from 5 to 15 and df(σ) from 2 to 10 were considered. Partial results are presented in Table 5.

Table 5 Goodness-of-fit summary for models using the BCPE distribution with fixed ν=1 and τ=2 for head circumference-for-age for boys

df(μ)	df(σ)	GD[a]	AIC[a]	GAIC(3)[a]	Total df
	3	758.7	778.7	788.7	10
	4	747.4	769.4	780.4	11
7	**5**	743.6	767.6	779.6	12
	6	741.9	767.9	780.9	13
	7	741.1	769.1	783.1	14
	3	750.3	772.3	783.3	11
	4	739.0	763.0	775.0	12
8	**5**	735.2	761.2	774.2	13
	6	733.6	761.6	775.6	14
	7	732.7	762.7	777.7	15
	3	746.9	770.9	782.9	12
	4	735.5	761.5	774.5	13
9	**5**	731.8	759.8	773.8	14
	6	730.1	760.1	775.1	15
	7	729.3	761.3	777.3	16
	3	745.2	771.2	784.2	13
	4	733.8	761.8	775.8	14
10	**5**	730.1	760.1	775.1	15
	6	728.5	760.5	776.5	16
	7	727.7	761.7	778.7	17
	3	744.2	772.2	786.2	14
	4	732.9	762.9	777.9	15
11	**5**	729.2	761.2	777.2	16
	6	727.6	761.6	778.6	17
	7	726.7	762.7	780.7	18

GD, Global Deviance; AIC, Akaike Information Criterion;
GAIC(3), Generalized AIC with penalty equal to 3;
[a] In excess of 45 000.

The best combination of *AIC* and *GAIC(3)* corresponds to df(μ)=9 and df(σ)=5. Further evaluations of this model were carried out by examining the fit of the μ and σ curves and the patterns of the centile residuals (the empirical minus the fitted centiles) across age.

Model 1: BCPE(x=age$^{0.20}$, df(μ)=9, df(σ)=5, ν=1, τ=2)

The fitted parameter curves showed adequate smoothing despite an erratic coefficient of variation in the cross-sectional sample (Figure 1). The residual plots of the fitted centiles for the period 0 to 24 months (Figure 2) showed some bias at the upper centiles (90th, 95th and 97th), but the underestimation represents only 1 mm on average, which was considered negligible in practical terms. The lower centiles (3rd, 5th, 10th) showed no biased pattern. For the age range 24 to 71 months, residuals of the fitted centiles showed a non-random pattern only for the 3rd centile, the average bias was about 2 mm (Figure 3).

Table 6 shows the proportions of children with head circumference below the fitted centiles. Age group labels correspond to the same age intervals provided in Table 7. There was indication of underestimation at the upper percentiles (90th and above) as well as the 1st percentile for some age groups. For the other percentiles, no biases were observed.

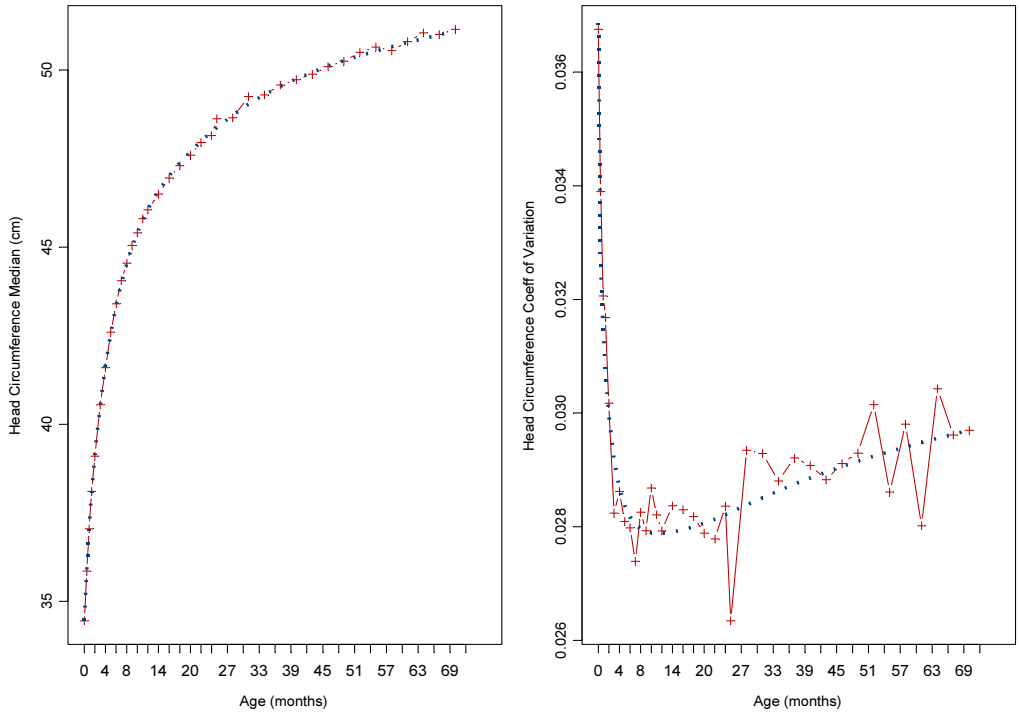


Figure 1 Fitting of μ and σ curves of Model 1 for head circumference-for-age for boys (dotted line) and their respective sample estimates (points with solid line)

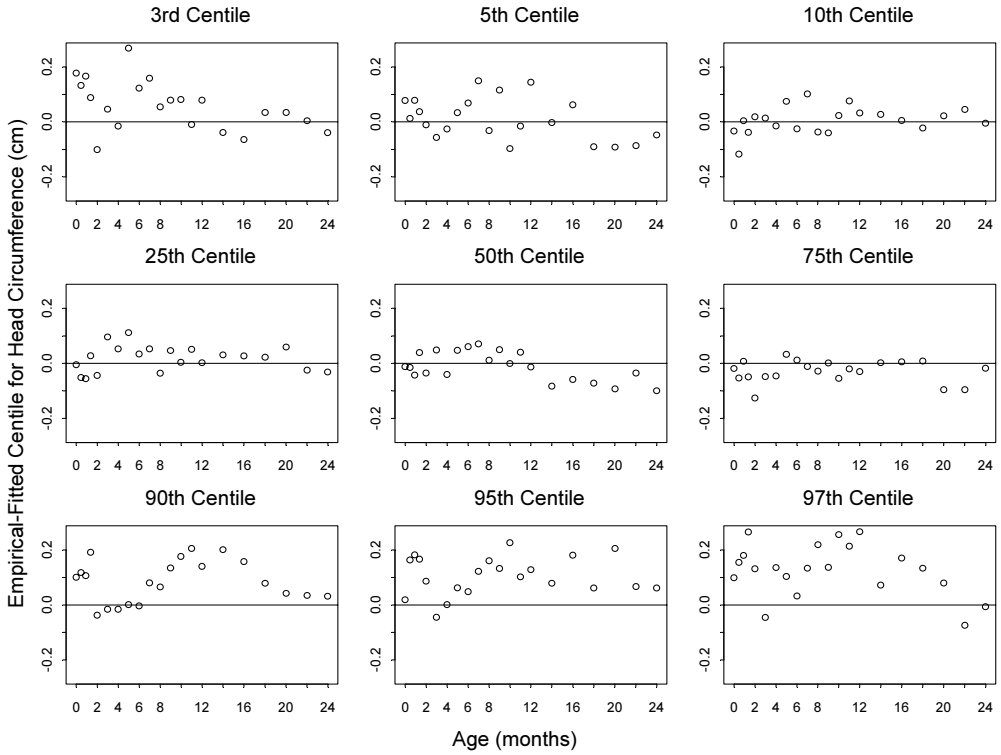


Figure 2 Centile residuals from fitting Model 1 for head circumference-for-age from 0 to 24 months for boys

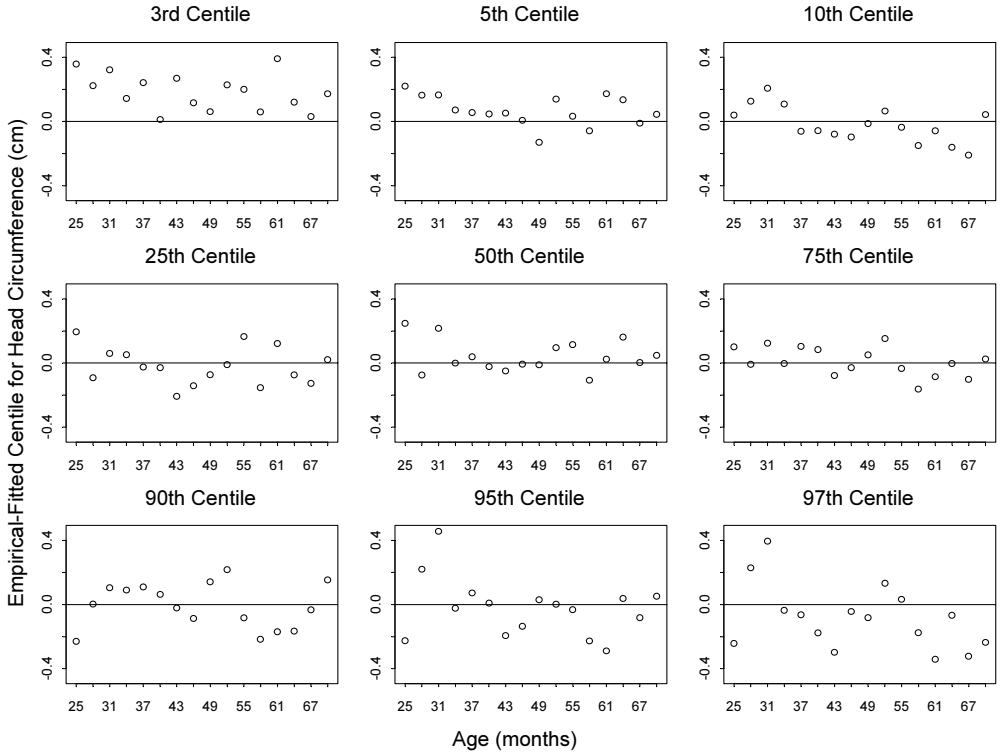


Figure 3 Centile residuals from fitting Model 1 for head circumference-for-age from 24 to 71 months for boys

The worm plots for Model 1 are shown in Figure 4. There are only three groups for which worms present slight upward or downward shifts (40 mo, 52 mo and 58 mo), but overall, the fit of the median is adequate. Groups at birth and 42 d present U-shaped worms, indicating residual skewness to the left. There are no worms with a slope, which would indicate misfit in the variance curve. S-shaped worms indicate a misfit in the curve of the parameter related to kurtosis as is the case in the 40 mo age group only. Despite the slight deviances present in a few groups, overall, the worms fitted to the points (solid red line) are all contained within the 95% confidence interval (dotted curves).

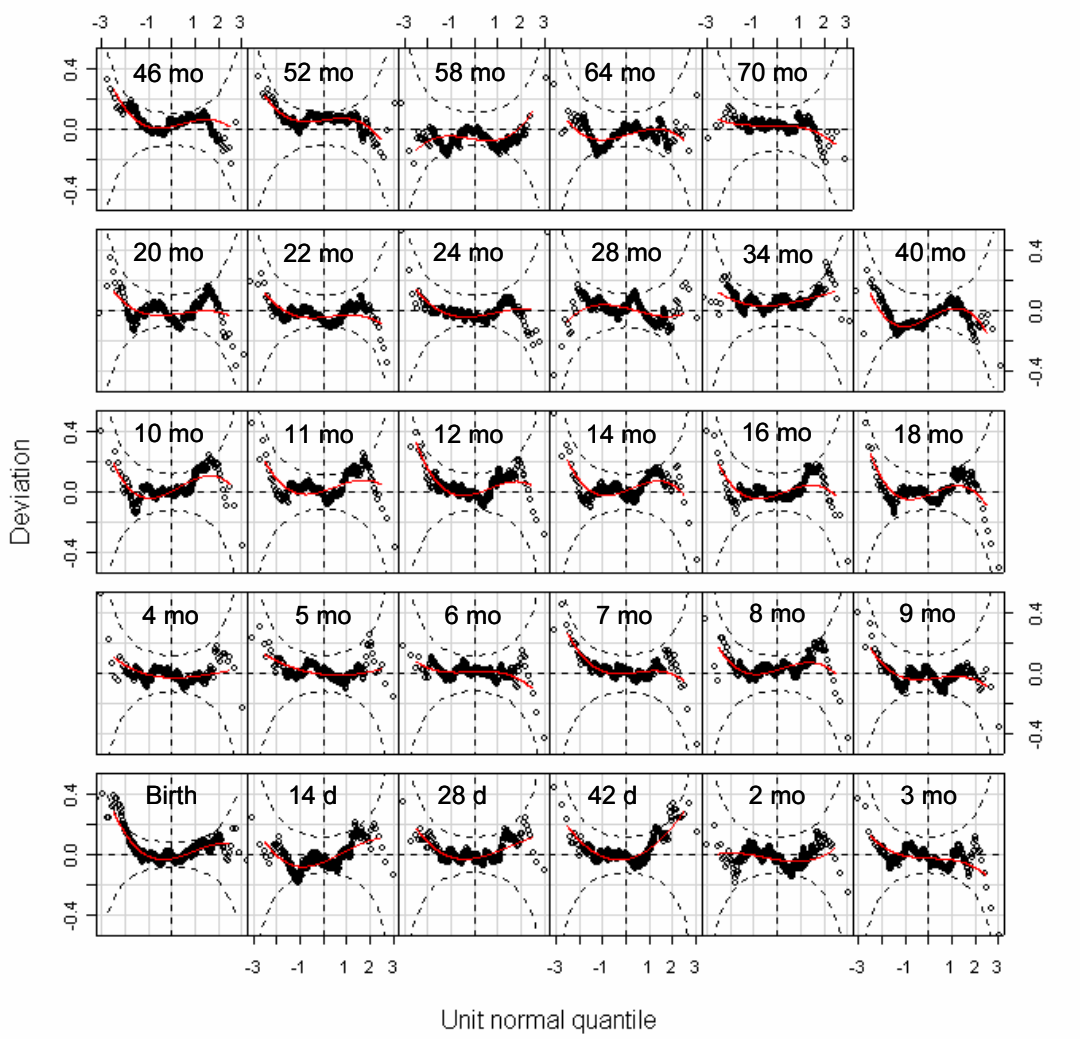


Figure 4 Worm plots of z-scores for Model 1 for head circumference-for-age for boys

Table 6 Observed proportions of children with measurements below the fitted centiles from Model 1, head circumference-for-age for boys

Expected	Birth	14 d	28 d	42 d	2 mo	3 mo	4 mo	5 mo	6 mo	7 mo
1	0.4	1.2	0.7	0.5	1.2	0.7	1.2	0.5	0.7	0.2
3	1.5	2.6	2.6	2.6	4.0	2.9	3.1	2.7	2.6	2.2
5	4.4	5.0	4.7	4.7	5.7	5.7	5.3	4.3	4.6	4.4
10	10.5	12.9	9.9	10.9	9.5	10.5	10.6	9.6	10.8	9.0
25	26.3	26.8	26.3	25.1	25.1	23.4	24.4	23.1	24.0	24.0
50	51.3	51.7	50.7	50.5	50.7	51.2	50.5	49.9	49.4	49.9
75	75.1	76.3	75.4	76.5	77.5	77.5	76.1	76.6	74.8	75.6
90	88.6	89.0	89.2	88.2	90.5	89.7	90.8	90.4	90.4	89.5
95	95.0	93.1	93.7	93.1	94.8	96.2	94.9	94.7	94.7	95.1
97	96.5	96.2	96.5	96.0	95.7	97.1	96.6	96.6	96.6	95.8
99	99.1	98.3	98.4	97.9	98.8	99.5	98.6	99.0	99.3	99.3
Expected	**8 mo**	**9 mo**	**10 mo**	**11 mo**	**12 mo**	**14 mo**	**16 mo**	**18 mo**	**20 mo**	**22 mo**
1	0.7	0.5	0.7	0.4	0.5	0.5	0.2	0.2	0.4	0.5
3	2.6	2.8	2.5	3.0	2.4	3.6	3.4	2.7	3.0	2.9
5	5.0	4.3	6.5	5.4	4.1	5.2	5.1	5.4	6.1	5.6
10	10.4	11.4	10.2	9.3	9.4	9.8	10.1	10.4	10.4	10.0
25	25.1	24.0	26.2	23.8	25.3	24.8	25.1	24.6	24.1	25.2
50	49.6	48.7	50.1	50.5	50.8	52.4	51.3	52.4	52.6	52.6
75	74.2	76.8	75.3	75.4	75.4	74.8	75.4	75.2	77.0	76.6
90	88.9	89.1	87.0	87.3	88.9	87.6	88.7	87.8	89.6	89.7
95	94.1	94.9	93.3	93.7	93.7	93.6	93.5	93.7	93.5	94.6
97	95.5	97.0	95.3	95.5	96.1	96.2	95.4	96.2	96.6	96.9
99	99.1	99.0	99.5	99.1	99.0	98.6	99.3	99.5	99.4	99.5

Table 6 Observed proportions of children with measurements below the fitted centiles from Model 1, head circumference-for-age for boys (continued)

Expected	24 mo	28 mo	34 mo	40 mo	46 mo	52 mo	58 mo	64 mo	70 mo	Overall
1	0.8	1.2	0.9	0.6	0.6	0.6	1.2	0.6	1.0	0.7
3	3.0	2.0	2.1	2.7	2.1	2.0	3.0	2.7	2.0	2.6
5	5.2	4.1	3.6	5.7	3.6	4.2	6.1	4.2	4.7	4.9
10	10.4	9.4	9.4	12.6	9.4	9.3	13.6	12.4	9.2	10.4
25	26.3	25.8	24.3	28.2	25.2	23.7	27.1	27.6	24.4	25.2
50	51.9	49.9	46.9	51.5	48.2	47.8	50.6	48.9	48.8	50.4
75	76.0	74.2	74.0	75.8	73.2	72.5	78.5	75.7	75.6	75.6
90	89.4	91.2	88.9	89.3	88.9	88.3	92.1	91.1	89.2	89.3
95	94.1	95.3	94.0	95.4	94.5	95.8	95.7	95.8	94.9	94.5
97	97.0	97.8	95.9	98.1	97.5	96.6	97.4	97.7	98.3	96.6
99	99.5	99.0	98.1	99.2	99.2	99.4	99.0	99.2	99.3	99.0

Note: Group labels correspond to the age intervals in Table 7.

The Q-test was performed to assess the overall significance of deviations that were noted based on the worm plots (Table 7). Absolute values of z3 larger than 2 were observed only in the age groups birth and 42 d, and for z4 in 40 mo. The overall tests (p-values shown for each statistic in the last row of the table) did not suggest any significant departures of the fitted model z-scores from normality at the 5% level of significance.

Table 7 Q-test for z-scores from Model 1 [BCPE(x=age$^{0.20}$, df(μ)=9, df(σ)=5, ν=1, τ=2)] for head circumference-for-age for boys

Age (days)	Group	N	z1	z2	z3	z4
0	**Birth**	893	0.2	-0.1	2.3	-1.4
1 to 16	**14 d**	418	-0.6	1.0	1.1	-0.7
17 to 34	**28 d**	426	0.1	0.2	1.3	-0.4
35 to 49	**42 d**	422	0.2	0.7	2.1	0.2
50 to 69	**2 mo**	422	-0.5	-0.2	0.5	0.5
70 to 99	**3 mo**	418	-0.4	-0.8	0.1	-0.6
100 to 129	**4 mo**	414	-0.3	-0.2	0.7	-0.1
130 to 159	**5 mo**	415	0.2	-0.6	0.7	0.1
160 to 189	**6 mo**	417	0.1	-0.3	-0.2	-0.6
190 to 219	**7 mo**	409	0.2	-0.8	0.9	-0.8
220 to 249	**8 mo**	423	0.7	0.4	0.6	-1.2
250 to 279	**9 mo**	396	-0.4	-0.5	0.6	-0.7
280 to 309	**10 mo**	401	0.5	0.8	0.7	-1.6
310 to 349	**11 mo**	463	0.5	0.4	1.0	-1.0
350 to 379	**12 mo**	415	0.3	-0.1	1.5	-1.3
380 to 439	**14 mo**	420	0.4	0.4	0.7	-1.4
440 to 499	**16 mo**	415	-0.1	0.3	0.8	-1.2
500 to 559	**18 mo**	443	-0.1	0.1	0.8	-1.8
560 to 619	**20 mo**	527	-0.6	-0.2	0.7	-0.6
620 to 679	**22 mo**	551	-0.8	-0.3	0.5	-0.8
680 to 749	**24 mo**	597	-0.6	-0.1	1.1	-0.4
750 to 929	**28 mo**	489	0.2	-0.5	-0.6	0.9
930 to 1119	**34 mo**	531	1.3	0.3	0.8	-0.2
1120 to 1309	**40 mo**	524	-1.1	0.6	0.3	-2.5
1310 to 1499	**46 mo**	523	0.8	-0.1	1.1	-0.9
1500 to 1689	**52 mo**	506	1.4	-0.5	0.1	-1.4
1690 to 1879	**58 mo**	494	-1.3	0.5	0.6	1.5
1880 to 2069	**64 mo**	474	-0.7	0.3	0.2	-1.1
2070 to 2249	**70 mo**	295	0.3	-0.4	-0.3	-0.4
Overall Q stats		**13 541**	**11.6**	**6.7**	**25.6**	**32.4**
degrees of freedom			**20.0**	**26.0**	**29.0**	**29.0**
p-value			**0.9301**	**>0.99**	**0.6447**	**0.3015**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

Considering local goodness of fit, the Q-test and worm plots based on Model 1 indicated minor departures from normality in very few age groups, but overall deviations were not significant. Thus, there was no reason to fit a more complex model, since there was neither remaining skewness nor kurtosis.

Model 1 was selected and a new iteration was done using the values df(μ)=9 and df(σ)=5 to re-search for the best age-transformation power λ. The smallest global deviance in this case was for λ=0.05 (GD=45 731.0), but with only a very minor difference from the model using λ=0.20 (GD=45 731.8). There was thus no need to update λ, and the selected model for constructing the head circumference-for-age growth curves for boys remained BCPE(x= age$^{0.20}$, df(μ)=9, df(σ)=5, ν=1, τ=2). Figures 5 to 8 show the fitted centile curves derived from the selected model against empirical head circumference-for-age values.

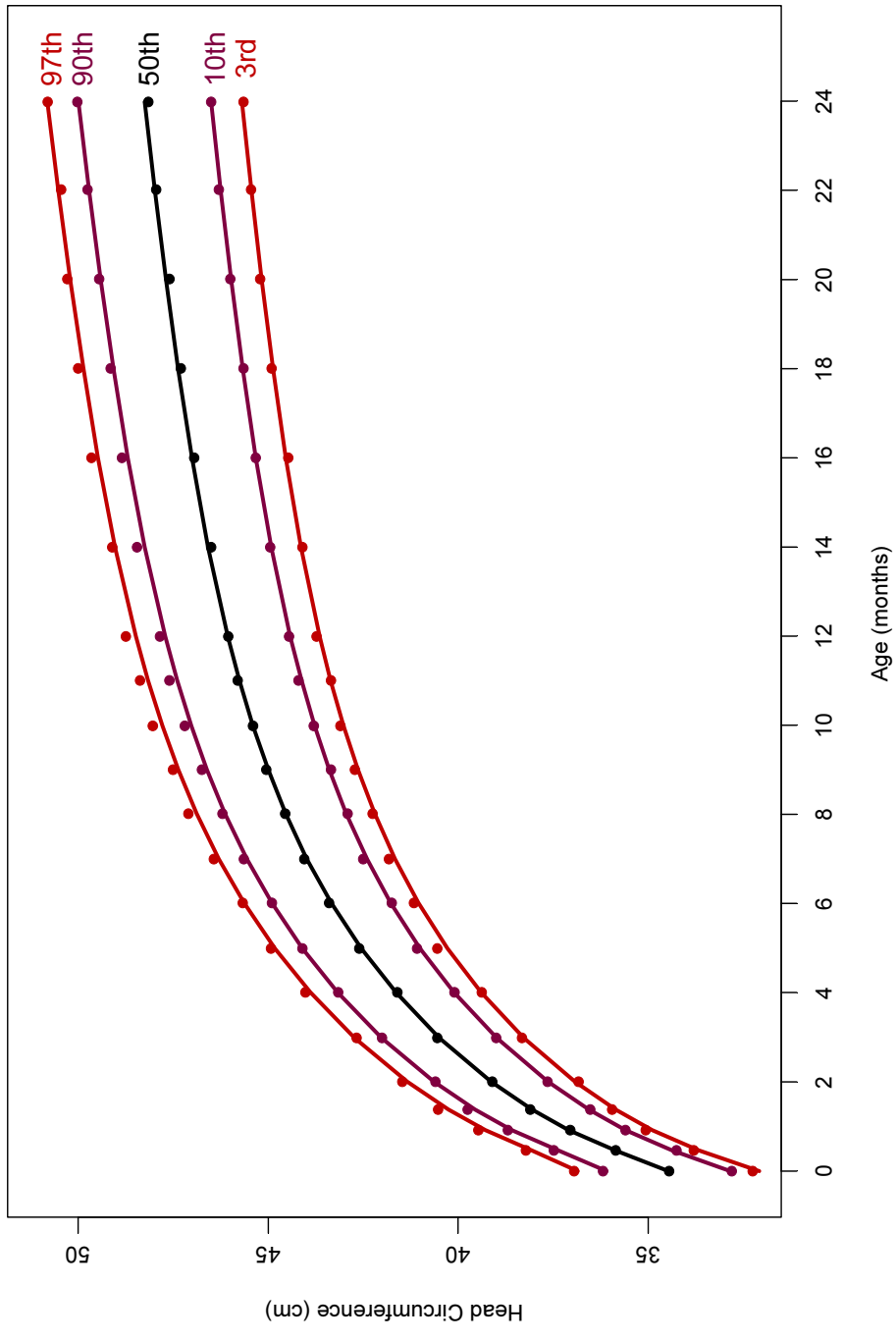


Figure 5 **3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: head circumference-for-age for boys from birth to 24 months**

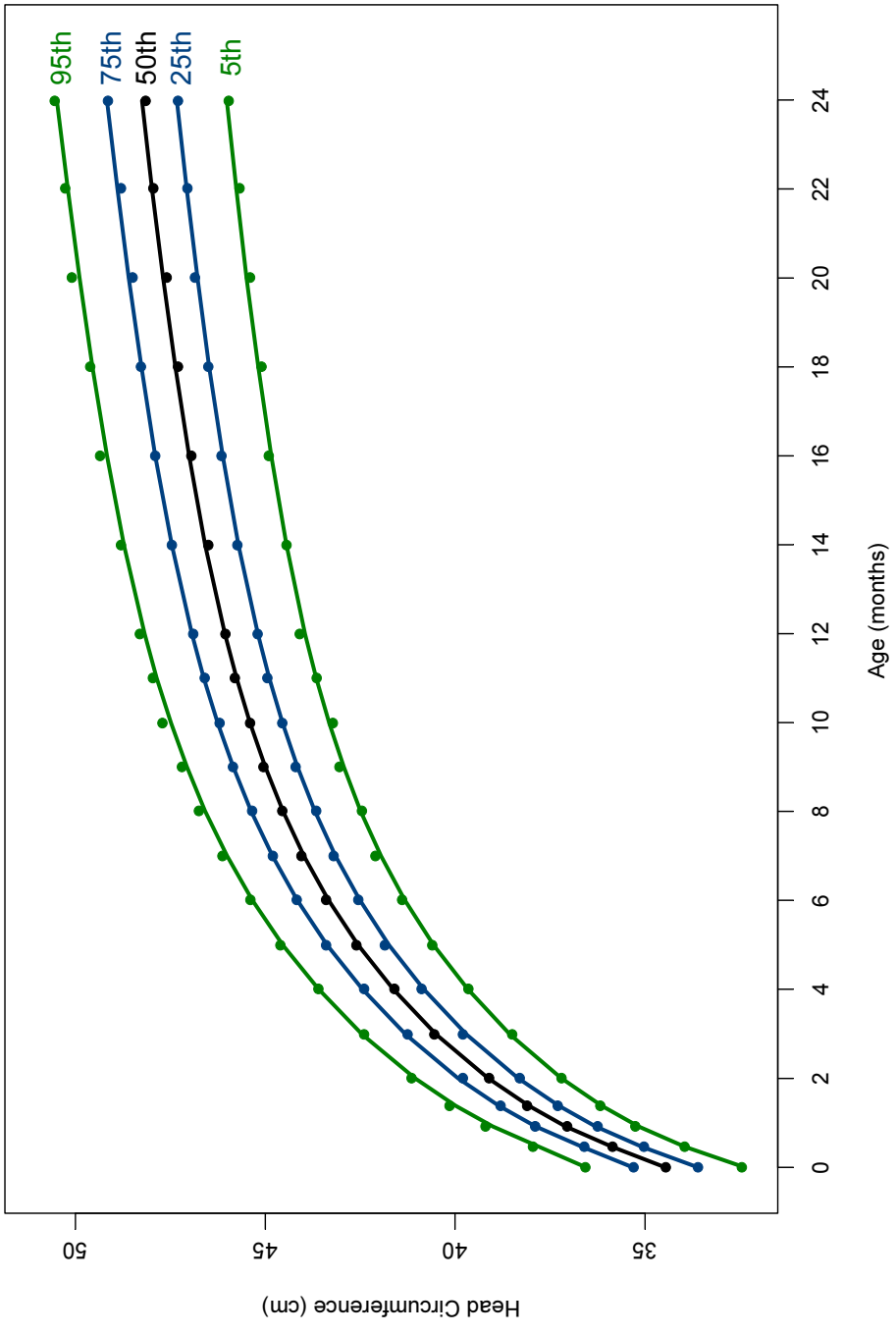


Figure 6 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: head circumference-for-age for boys from birth to 24 months

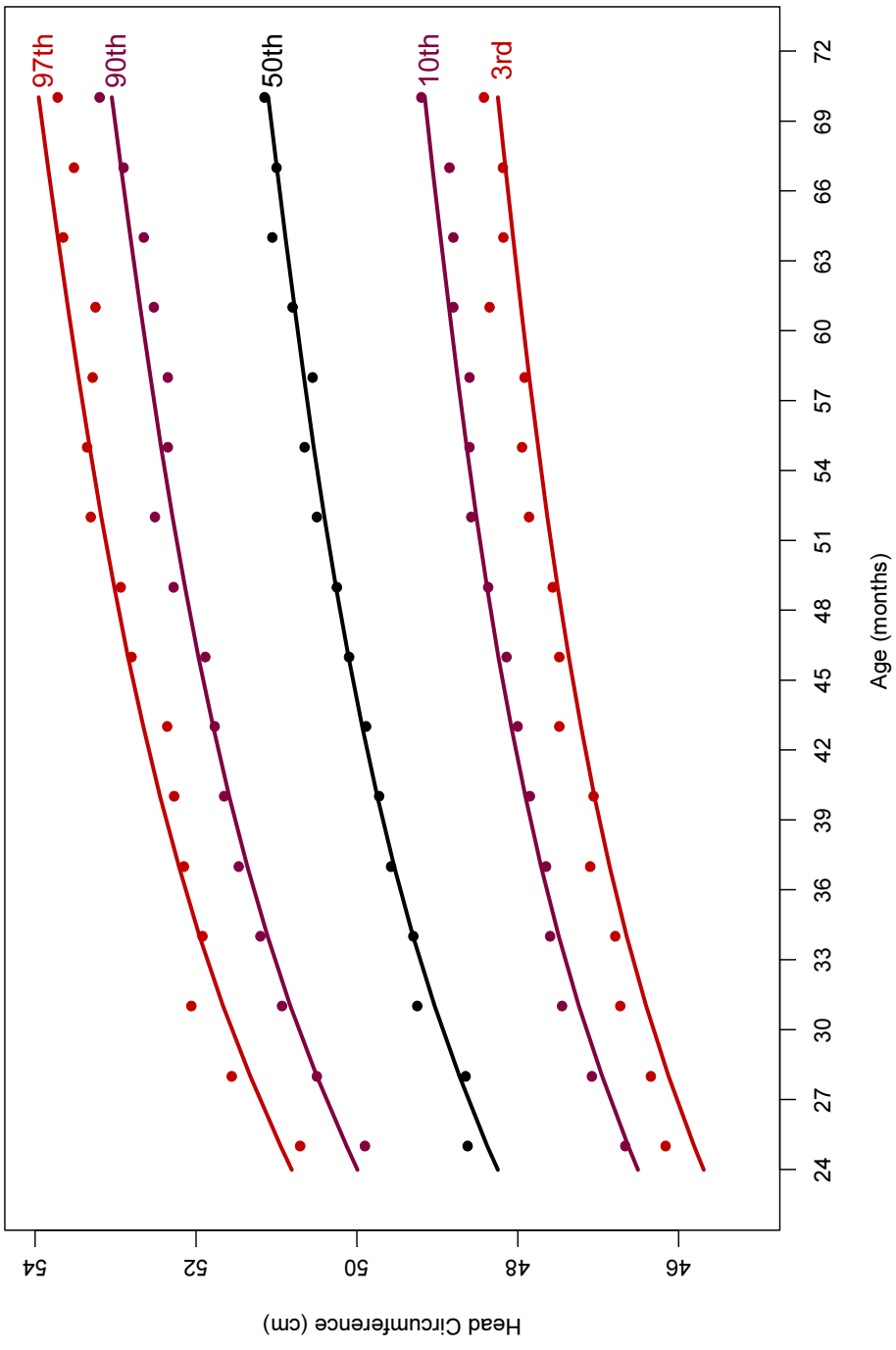


Figure 7 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: head circumference-for-age for boys from 24 to 71 months

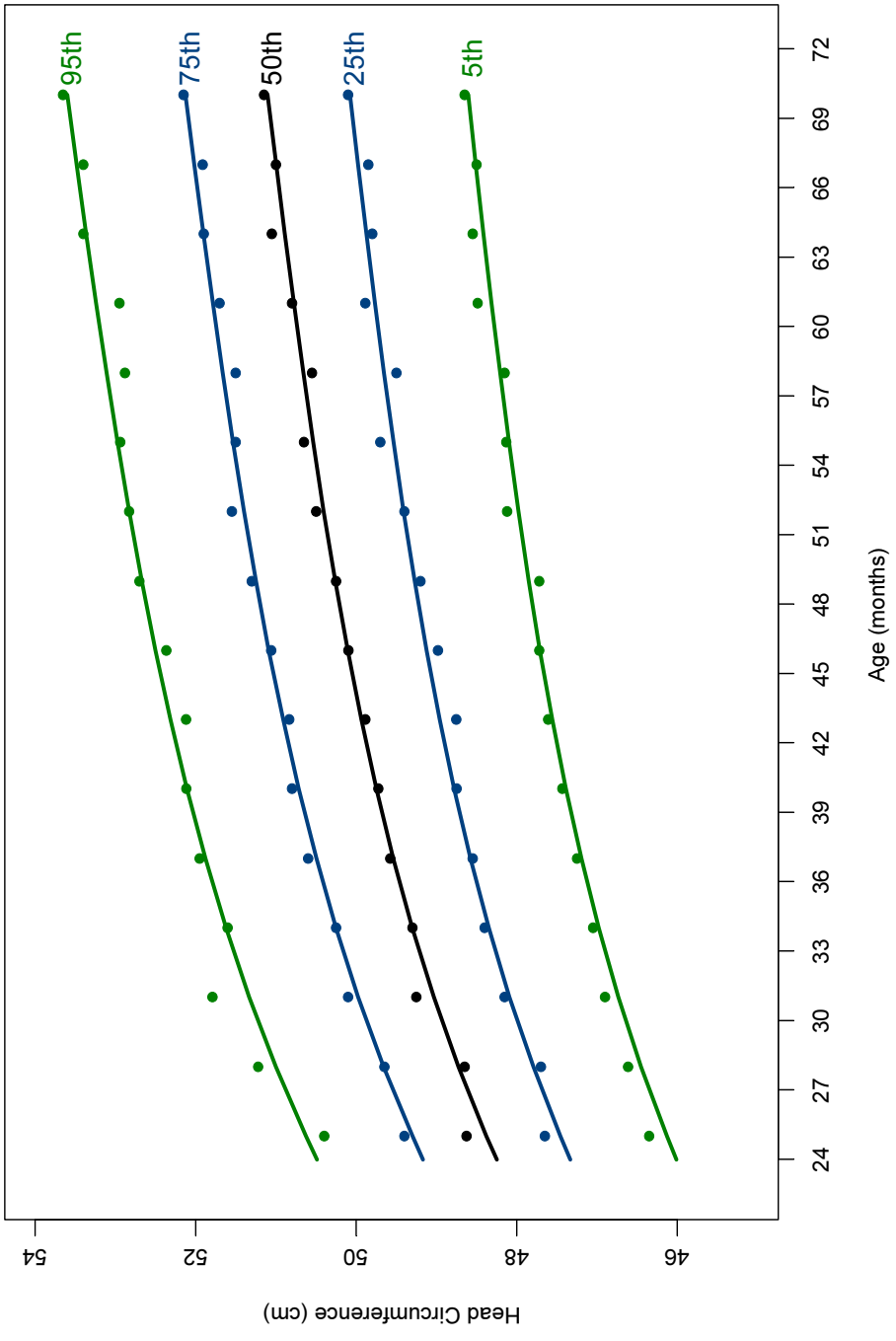


Figure 8 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: head circumference-for-age for boys from 24 to 71 months

3.2.3 WHO standards

This section presents the final WHO head circumference-for-age z-score and percentile charts (Figures 9 and 10) and tables (Tables 8 and 9) for boys.

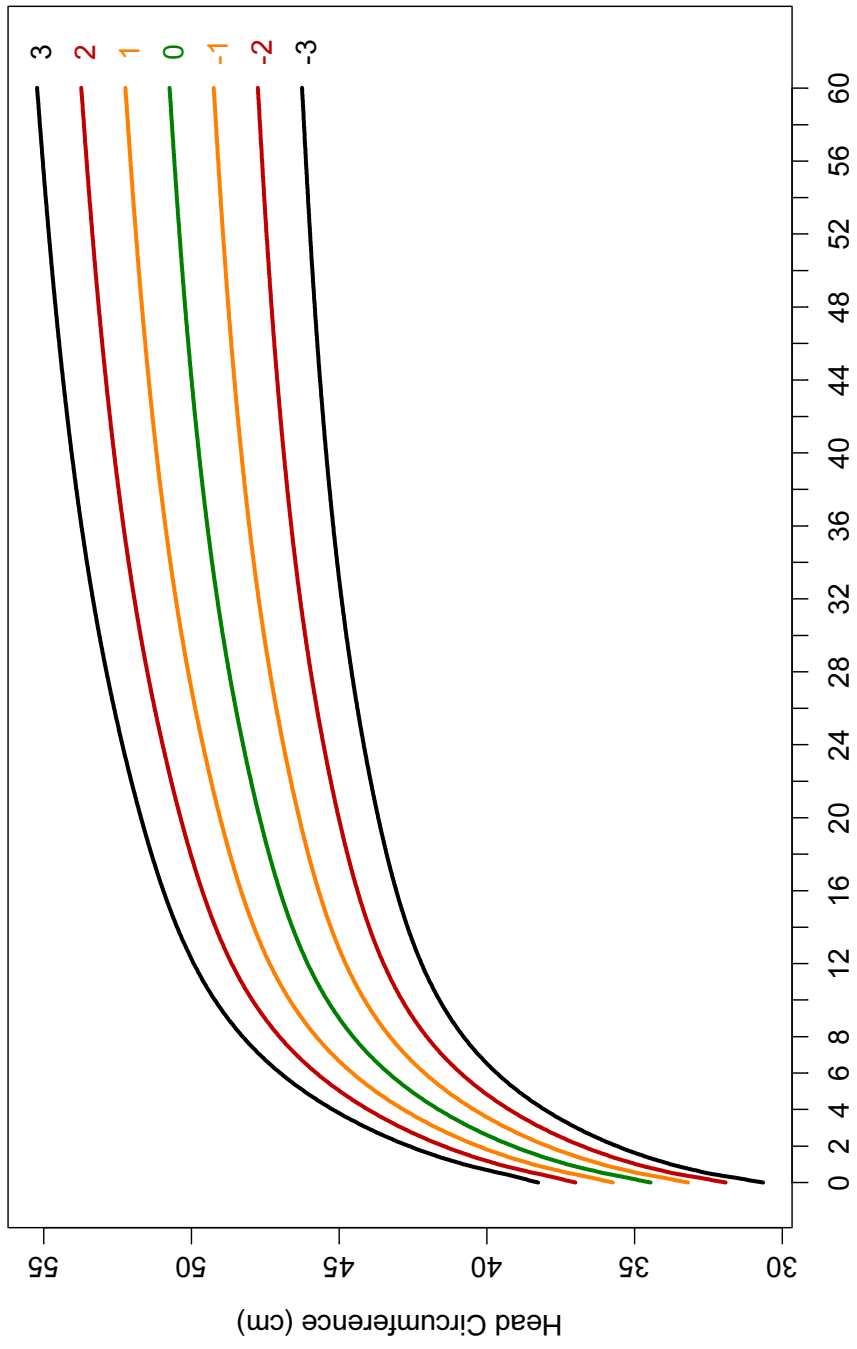


Figure 9 WHO head circumference-for-age z-scores for boys from birth to 60 months

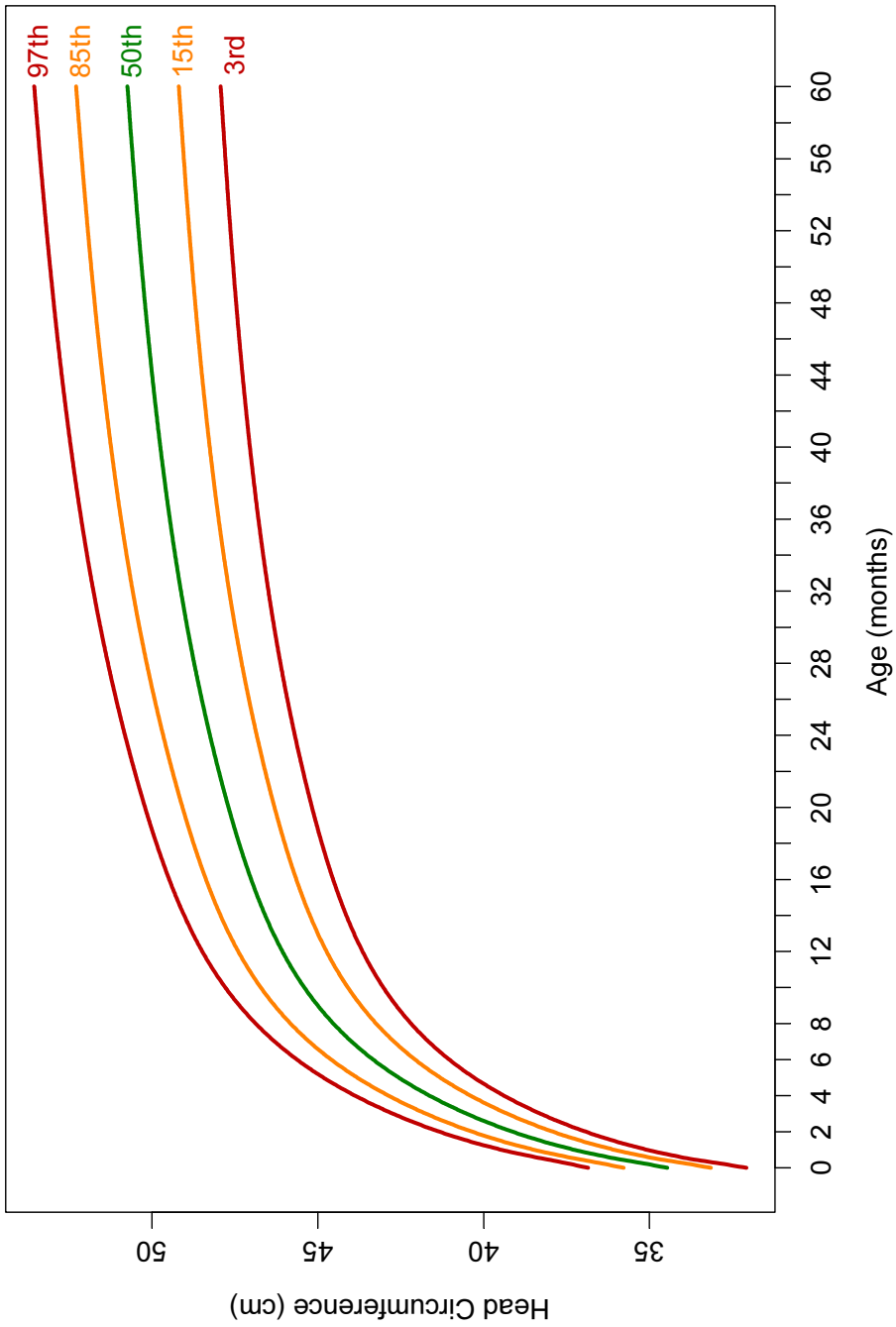


Figure 10 WHO head circumference -for-age percentiles for boys from birth to 60 months

Table 8 Head circumference-for-age for boys, age in weeks

					Percentiles (head circumference in cm)										
Week	**L**	**M**	**S**	**SD**	**1st**	**3rd**	**5th**	**15th**	**25th**	**50th**	**75th**	**85th**	**95th**	**97th**	**99th**
0	1	34.4618	0.03686	1.2703	31.5	32.1	32.4	33.1	33.6	34.5	35.3	35.8	36.6	36.9	37.4
1	1	35.1634	0.03472	1.2209	32.3	32.9	33.2	33.9	34.3	35.2	36.0	36.4	37.2	37.5	38.0
2	1	35.8649	0.03258	1.1685	33.1	33.7	33.9	34.7	35.1	35.9	36.7	37.1	37.8	38.1	38.6
3	1	36.5216	0.03197	1.1676	33.8	34.3	34.6	35.3	35.7	36.5	37.3	37.7	38.4	38.7	39.2
4	1	37.0926	0.03148	1.1677	34.4	34.9	35.2	35.9	36.3	37.1	37.9	38.3	39.0	39.3	39.8
5	1	37.6010	0.03107	1.1683	34.9	35.4	35.7	36.4	36.8	37.6	38.4	38.8	39.5	39.8	40.3
6	1	38.0609	0.03072	1.1692	35.3	35.9	36.1	36.8	37.3	38.1	38.8	39.3	40.0	40.3	40.8
7	1	38.4824	0.03041	1.1703	35.8	36.3	36.6	37.3	37.7	38.5	39.3	39.7	40.4	40.7	41.2
8	1	38.8724	0.03014	1.1716	36.1	36.7	36.9	37.7	38.1	38.9	39.7	40.1	40.8	41.1	41.6
9	1	39.2368	0.02990	1.1732	36.5	37.0	37.3	38.0	38.4	39.2	40.0	40.5	41.2	41.4	42.0
10	1	39.5797	0.02969	1.1751	36.8	37.4	37.6	38.4	38.8	39.6	40.4	40.8	41.5	41.8	42.3
11	1	39.9033	0.02950	1.1772	37.2	37.7	38.0	38.7	39.1	39.9	40.7	41.1	41.8	42.1	42.6
12	1	40.2096	0.02933	1.1794	37.5	38.0	38.3	39.0	39.4	40.2	41.0	41.4	42.1	42.4	43.0
13	1	40.5008	0.02918	1.1818	37.8	38.3	38.6	39.3	39.7	40.5	41.3	41.7	42.4	42.7	43.3

Table 8 Head circumference-for-age for boys, age in weeks (continued)

					Z-scores (head circumference in cm)						
Week	**L**	**M**	**S**	**SD**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
0	1	34.4618	0.03686	1.2703	30.7	31.9	33.2	34.5	35.7	37.0	38.3
1	1	35.1634	0.03472	1.2209	31.5	32.7	33.9	35.2	36.4	37.6	38.8
2	1	35.8649	0.03258	1.1685	32.4	33.5	34.7	35.9	37.0	38.2	39.4
3	1	36.5216	0.03197	1.1676	33.0	34.2	35.4	36.5	37.7	38.9	40.0
4	1	37.0926	0.03148	1.1677	33.6	34.8	35.9	37.1	38.3	39.4	40.6
5	1	37.6010	0.03107	1.1683	34.1	35.3	36.4	37.6	38.8	39.9	41.1
6	1	38.0609	0.03072	1.1692	34.6	35.7	36.9	38.1	39.2	40.4	41.6
7	1	38.4824	0.03041	1.1703	35.0	36.1	37.3	38.5	39.7	40.8	42.0
8	1	38.8724	0.03014	1.1716	35.4	36.5	37.7	38.9	40.0	41.2	42.4
9	1	39.2368	0.02990	1.1732	35.7	36.9	38.1	39.2	40.4	41.6	42.8
10	1	39.5797	0.02969	1.1751	36.1	37.2	38.4	39.6	40.8	41.9	43.1
11	1	39.9033	0.02950	1.1772	36.4	37.5	38.7	39.9	41.1	42.3	43.4
12	1	40.2096	0.02933	1.1794	36.7	37.9	39.0	40.2	41.4	42.6	43.7
13	1	40.5008	0.02918	1.1818	37.0	38.1	39.3	40.5	41.7	42.9	44.0

Table 9 Head circumference-for-age for boys, age in years and months

Year: Month	Month	L	M	S	SD	Percentiles (head circumference in cm)										
						1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
0: 0	**0**	1	34.4618	0.03686	1.2703	31.5	32.1	32.4	33.1	33.6	34.5	35.3	35.8	36.6	36.9	37.4
0: 1	**1**	1	37.2759	0.03133	1.1679	34.6	35.1	35.4	36.1	36.5	37.3	38.1	38.5	39.2	39.5	40.0
0: 2	**2**	1	39.1285	0.02997	1.1727	36.4	36.9	37.2	37.9	38.3	39.1	39.9	40.3	41.1	41.3	41.9
0: 3	**3**	1	40.5135	0.02918	1.1822	37.8	38.3	38.6	39.3	39.7	40.5	41.3	41.7	42.5	42.7	43.3
0: 4	**4**	1	41.6317	0.02868	1.1940	38.9	39.4	39.7	40.4	40.8	41.6	42.4	42.9	43.6	43.9	44.4
0: 5	**5**	1	42.5576	0.02837	1.2074	39.7	40.3	40.6	41.3	41.7	42.6	43.4	43.8	44.5	44.8	45.4
0: 6	**6**	1	43.3306	0.02817	1.2206	40.5	41.0	41.3	42.1	42.5	43.3	44.2	44.6	45.3	45.6	46.2
0: 7	**7**	1	43.9803	0.02804	1.2332	41.1	41.7	42.0	42.7	43.1	44.0	44.8	45.3	46.0	46.3	46.8
0: 8	**8**	1	44.5300	0.02796	1.2451	41.6	42.2	42.5	43.2	43.7	44.5	45.4	45.8	46.6	46.9	47.4
0: 9	**9**	1	44.9998	0.02792	1.2564	42.1	42.6	42.9	43.7	44.2	45.0	45.8	46.3	47.1	47.4	47.9
0:10	**10**	1	45.4051	0.02790	1.2668	42.5	43.0	43.3	44.1	44.6	45.4	46.3	46.7	47.5	47.8	48.4
0:11	**11**	1	45.7573	0.02789	1.2762	42.8	43.4	43.7	44.4	44.9	45.8	46.6	47.1	47.9	48.2	48.7
1: 0	**12**	1	46.0661	0.02789	1.2848	43.1	43.6	44.0	44.7	45.2	46.1	46.9	47.4	48.2	48.5	49.1
1: 1	**13**	1	46.3395	0.02789	1.2924	43.3	43.9	44.2	45.0	45.5	46.3	47.2	47.7	48.5	48.8	49.3
1: 2	**14**	1	46.5844	0.02791	1.3002	43.6	44.1	44.4	45.2	45.7	46.6	47.5	47.9	48.7	49.0	49.6
1: 3	**15**	1	46.8060	0.02792	1.3068	43.8	44.3	44.7	45.5	45.9	46.8	47.7	48.2	49.0	49.3	49.8
1: 4	**16**	1	47.0088	0.02795	1.3139	44.0	44.5	44.8	45.6	46.1	47.0	47.9	48.4	49.2	49.5	50.1
1: 5	**17**	1	47.1962	0.02797	1.3201	44.1	44.7	45.0	45.8	46.3	47.2	48.1	48.6	49.4	49.7	50.3
1: 6	**18**	1	47.3711	0.02800	1.3264	44.3	44.9	45.2	46.0	46.5	47.4	48.3	48.7	49.6	49.9	50.5
1: 7	**19**	1	47.5357	0.02803	1.3324	44.4	45.0	45.3	46.2	46.6	47.5	48.4	48.9	49.7	50.0	50.6
1: 8	**20**	1	47.6919	0.02806	1.3382	44.6	45.2	45.5	46.3	46.8	47.7	48.6	49.1	49.9	50.2	50.8
1: 9	**21**	1	47.8408	0.02810	1.3443	44.7	45.3	45.6	46.4	46.9	47.8	48.7	49.2	50.1	50.4	51.0
1:10	**22**	1	47.9833	0.02813	1.3498	44.8	45.4	45.8	46.6	47.1	48.0	48.9	49.4	50.2	50.5	51.1
1:11	**23**	1	48.1201	0.02817	1.3555	45.0	45.6	45.9	46.7	47.2	48.1	49.0	49.5	50.3	50.7	51.3
2: 0	**24**	1	48.2515	0.02821	1.3612	45.1	45.7	46.0	46.8	47.3	48.3	49.2	49.7	50.5	50.8	51.4

Table 9 Head circumference-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	SD	Percentiles (head circumference in cm)										
						1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
2: 1	**25**	1	48.3777	0.02825	1.3667	45.2	45.8	46.1	47.0	47.5	48.4	49.3	49.8	50.6	50.9	51.6
2: 2	**26**	1	48.4989	0.02830	1.3725	45.3	45.9	46.2	47.1	47.6	48.5	49.4	49.9	50.8	51.1	51.7
2: 3	**27**	1	48.6151	0.02834	1.3778	45.4	46.0	46.3	47.2	47.7	48.6	49.5	50.0	50.9	51.2	51.8
2: 4	**28**	1	48.7264	0.02838	1.3829	45.5	46.1	46.5	47.3	47.8	48.7	49.7	50.2	51.0	51.3	51.9
2: 5	**29**	1	48.8331	0.02842	1.3878	45.6	46.2	46.6	47.4	47.9	48.8	49.8	50.3	51.1	51.4	52.1
2: 6	**30**	1	48.9351	0.02847	1.3932	45.7	46.3	46.6	47.5	48.0	48.9	49.9	50.4	51.2	51.6	52.2
2: 7	**31**	1	49.0327	0.02851	1.3979	45.8	46.4	46.7	47.6	48.1	49.0	50.0	50.5	51.3	51.7	52.3
2: 8	**32**	1	49.1260	0.02855	1.4026	45.9	46.5	46.8	47.7	48.2	49.1	50.1	50.6	51.4	51.8	52.4
2: 9	**33**	1	49.2153	0.02859	1.4071	45.9	46.6	46.9	47.8	48.3	49.2	50.2	50.7	51.5	51.9	52.5
2:10	**34**	1	49.3007	0.02863	1.4115	46.0	46.6	47.0	47.8	48.3	49.3	50.3	50.8	51.6	52.0	52.6
2:11	**35**	1	49.3826	0.02867	1.4158	46.1	46.7	47.1	47.9	48.4	49.4	50.3	50.8	51.7	52.0	52.7
3: 0	**36**	1	49.4612	0.02871	1.4200	46.2	46.8	47.1	48.0	48.5	49.5	50.4	50.9	51.8	52.1	52.8
3: 1	**37**	1	49.5367	0.02875	1.4242	46.2	46.9	47.2	48.1	48.6	49.5	50.5	51.0	51.9	52.2	52.8
3: 2	**38**	1	49.6093	0.02878	1.4278	46.3	46.9	47.3	48.1	48.6	49.6	50.6	51.1	52.0	52.3	52.9
3: 3	**39**	1	49.6791	0.02882	1.4318	46.3	47.0	47.3	48.2	48.7	49.7	50.6	51.2	52.0	52.4	53.0
3: 4	**40**	1	49.7465	0.02886	1.4357	46.4	47.0	47.4	48.3	48.8	49.7	50.7	51.2	52.1	52.4	53.1
3: 5	**41**	1	49.8116	0.02889	1.4391	46.5	47.1	47.4	48.3	48.8	49.8	50.8	51.3	52.2	52.5	53.2
3: 6	**42**	1	49.8745	0.02893	1.4429	46.5	47.2	47.5	48.4	48.9	49.9	50.8	51.4	52.2	52.6	53.2
3: 7	**43**	1	49.9354	0.02896	1.4461	46.6	47.2	47.6	48.4	49.0	49.9	50.9	51.4	52.3	52.7	53.3
3: 8	**44**	1	49.9942	0.02899	1.4493	46.6	47.3	47.6	48.5	49.0	50.0	51.0	51.5	52.4	52.7	53.4
3: 9	**45**	1	50.0512	0.02903	1.4530	46.7	47.3	47.7	48.5	49.1	50.1	51.0	51.6	52.4	52.8	53.4
3:10	**46**	1	50.1064	0.02906	1.4561	46.7	47.4	47.7	48.6	49.1	50.1	51.1	51.6	52.5	52.8	53.5
3:11	**47**	1	50.1598	0.02909	1.4592	46.8	47.4	47.8	48.6	49.2	50.2	51.1	51.7	52.6	52.9	53.6
4: 0	**48**	1	50.2115	0.02912	1.4622	46.8	47.5	47.8	48.7	49.2	50.2	51.2	51.7	52.6	53.0	53.6

Table 9 Head circumference-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	SD	Percentiles (head circumference in cm)										
						1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
4: 1	**49**	1	50.2617	0.02915	1.4651	46.9	47.5	47.9	48.7	49.3	50.3	51.2	51.8	52.7	53.0	53.7
4: 2	**50**	1	50.3105	0.02918	1.4681	46.9	47.5	47.9	48.8	49.3	50.3	51.3	51.8	52.7	53.1	53.7
4: 3	**51**	1	50.3578	0.02921	1.4710	46.9	47.6	47.9	48.8	49.4	50.4	51.3	51.9	52.8	53.1	53.8
4: 4	**52**	1	50.4039	0.02924	1.4738	47.0	47.6	48.0	48.9	49.4	50.4	51.4	51.9	52.8	53.2	53.8
4: 5	**53**	1	50.4488	0.02927	1.4766	47.0	47.7	48.0	48.9	49.5	50.4	51.4	52.0	52.9	53.2	53.9
4: 6	**54**	1	50.4926	0.02929	1.4789	47.1	47.7	48.1	49.0	49.5	50.5	51.5	52.0	52.9	53.3	53.9
4: 7	**55**	1	50.5354	0.02932	1.4817	47.1	47.7	48.1	49.0	49.5	50.5	51.5	52.1	53.0	53.3	54.0
4: 8	**56**	1	50.5772	0.02935	1.4844	47.1	47.8	48.1	49.0	49.6	50.6	51.6	52.1	53.0	53.4	54.0
4: 9	**57**	1	50.6183	0.02938	1.4872	47.2	47.8	48.2	49.1	49.6	50.6	51.6	52.2	53.1	53.4	54.1
4:10	**58**	1	50.6587	0.02940	1.4894	47.2	47.9	48.2	49.1	49.7	50.7	51.7	52.2	53.1	53.5	54.1
4:11	**59**	1	50.6984	0.02943	1.4921	47.2	47.9	48.2	49.2	49.7	50.7	51.7	52.2	53.2	53.5	54.2
5: 0	**60**	1	50.7375	0.02946	1.4947	47.3	47.9	48.3	49.2	49.7	50.7	51.7	52.3	53.2	53.5	54.2

Table 9 Head circumference-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	SD	Z-scores (head circumference in cm)						
						-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 0	**0**	1	34.4618	0.03686	1.2703	30.7	31.9	33.2	34.5	35.7	37.0	38.3
0: 1	**1**	1	37.2759	0.03133	1.1679	33.8	34.9	36.1	37.3	38.4	39.6	40.8
0: 2	**2**	1	39.1285	0.02997	1.1727	35.6	36.8	38.0	39.1	40.3	41.5	42.6
0: 3	**3**	1	40.5135	0.02918	1.1822	37.0	38.1	39.3	40.5	41.7	42.9	44.1
0: 4	**4**	1	41.6317	0.02868	1.1940	38.0	39.2	40.4	41.6	42.8	44.0	45.2
0: 5	**5**	1	42.5576	0.02837	1.2074	38.9	40.1	41.4	42.6	43.8	45.0	46.2
0: 6	**6**	1	43.3306	0.02817	1.2206	39.7	40.9	42.1	43.3	44.6	45.8	47.0
0: 7	**7**	1	43.9803	0.02804	1.2332	40.3	41.5	42.7	44.0	45.2	46.4	47.7
0: 8	**8**	1	44.5300	0.02796	1.2451	40.8	42.0	43.3	44.5	45.8	47.0	48.3
0: 9	**9**	1	44.9998	0.02792	1.2564	41.2	42.5	43.7	45.0	46.3	47.5	48.8
0:10	**10**	1	45.4051	0.02790	1.2668	41.6	42.9	44.1	45.4	46.7	47.9	49.2
0:11	**11**	1	45.7573	0.02789	1.2762	41.9	43.2	44.5	45.8	47.0	48.3	49.6
1: 0	**12**	1	46.0661	0.02789	1.2848	42.2	43.5	44.8	46.1	47.4	48.6	49.9
1: 1	**13**	1	46.3395	0.02789	1.2924	42.5	43.8	45.0	46.3	47.6	48.9	50.2
1: 2	**14**	1	46.5844	0.02791	1.3002	42.7	44.0	45.3	46.6	47.9	49.2	50.5
1: 3	**15**	1	46.8060	0.02792	1.3068	42.9	44.2	45.5	46.8	48.1	49.4	50.7
1: 4	**16**	1	47.0088	0.02795	1.3139	43.1	44.4	45.7	47.0	48.3	49.6	51.0
1: 5	**17**	1	47.1962	0.02797	1.3201	43.2	44.6	45.9	47.2	48.5	49.8	51.2
1: 6	**18**	1	47.3711	0.02800	1.3264	43.4	44.7	46.0	47.4	48.7	50.0	51.4
1: 7	**19**	1	47.5357	0.02803	1.3324	43.5	44.9	46.2	47.5	48.9	50.2	51.5
1: 8	**20**	1	47.6919	0.02806	1.3382	43.7	45.0	46.4	47.7	49.0	50.4	51.7
1: 9	**21**	1	47.8408	0.02810	1.3443	43.8	45.2	46.5	47.8	49.2	50.5	51.9
1:10	**22**	1	47.9833	0.02813	1.3498	43.9	45.3	46.6	48.0	49.3	50.7	52.0
1:11	**23**	1	48.1201	0.02817	1.3555	44.1	45.4	46.8	48.1	49.5	50.8	52.2
2: 0	**24**	1	48.2515	0.02821	1.3612	44.2	45.5	46.9	48.3	49.6	51.0	52.3

Table 9 Head circumference-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	SD	Z-scores (head circumference in cm)						
						-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
2: 1	**25**	1	48.3777	0.02825	1.3667	44.3	45.6	47.0	48.4	49.7	51.1	52.5
2: 2	**26**	1	48.4989	0.02830	1.3725	44.4	45.8	47.1	48.5	49.9	51.2	52.6
2: 3	**27**	1	48.6151	0.02834	1.3778	44.5	45.9	47.2	48.6	50.0	51.4	52.7
2: 4	**28**	1	48.7264	0.02838	1.3829	44.6	46.0	47.3	48.7	50.1	51.5	52.9
2: 5	**29**	1	48.8331	0.02842	1.3878	44.7	46.1	47.4	48.8	50.2	51.6	53.0
2: 6	**30**	1	48.9351	0.02847	1.3932	44.8	46.1	47.5	48.9	50.3	51.7	53.1
2: 7	**31**	1	49.0327	0.02851	1.3979	44.8	46.2	47.6	49.0	50.4	51.8	53.2
2: 8	**32**	1	49.1260	0.02855	1.4026	44.9	46.3	47.7	49.1	50.5	51.9	53.3
2: 9	**33**	1	49.2153	0.02859	1.4071	45.0	46.4	47.8	49.2	50.6	52.0	53.4
2:10	**34**	1	49.3007	0.02863	1.4115	45.1	46.5	47.9	49.3	50.7	52.1	53.5
2:11	**35**	1	49.3826	0.02867	1.4158	45.1	46.6	48.0	49.4	50.8	52.2	53.6
3: 0	**36**	1	49.4612	0.02871	1.4200	45.2	46.6	48.0	49.5	50.9	52.3	53.7
3: 1	**37**	1	49.5367	0.02875	1.4242	45.3	46.7	48.1	49.5	51.0	52.4	53.8
3: 2	**38**	1	49.6093	0.02878	1.4278	45.3	46.8	48.2	49.6	51.0	52.5	53.9
3: 3	**39**	1	49.6791	0.02882	1.4318	45.4	46.8	48.2	49.7	51.1	52.5	54.0
3: 4	**40**	1	49.7465	0.02886	1.4357	45.4	46.9	48.3	49.7	51.2	52.6	54.1
3: 5	**41**	1	49.8116	0.02889	1.4391	45.5	46.9	48.4	49.8	51.3	52.7	54.1
3: 6	**42**	1	49.8745	0.02893	1.4429	45.5	47.0	48.4	49.9	51.3	52.8	54.2
3: 7	**43**	1	49.9354	0.02896	1.4461	45.6	47.0	48.5	49.9	51.4	52.8	54.3
3: 8	**44**	1	49.9942	0.02899	1.4493	45.6	47.1	48.5	50.0	51.4	52.9	54.3
3: 9	**45**	1	50.0512	0.02903	1.4530	45.7	47.1	48.6	50.1	51.5	53.0	54.4
3:10	**46**	1	50.1064	0.02906	1.4561	45.7	47.2	48.7	50.1	51.6	53.0	54.5
3:11	**47**	1	50.1598	0.02909	1.4592	45.8	47.2	48.7	50.2	51.6	53.1	54.5
4: 0	**48**	1	50.2115	0.02912	1.4622	45.8	47.3	48.7	50.2	51.7	53.1	54.6

Table 9 Head circumference-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	SD	Z-scores (head circumference in cm)						
						-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	**49**	1	50.2617	0.02915	1.4651	45.9	47.3	48.8	50.3	51.7	53.2	54.7
4: 2	**50**	1	50.3105	0.02918	1.4681	45.9	47.4	48.8	50.3	51.8	53.2	54.7
4: 3	**51**	1	50.3578	0.02921	1.4710	45.9	47.4	48.9	50.4	51.8	53.3	54.8
4: 4	**52**	1	50.4039	0.02924	1.4738	46.0	47.5	48.9	50.4	51.9	53.4	54.8
4: 5	**53**	1	50.4488	0.02927	1.4766	46.0	47.5	49.0	50.4	51.9	53.4	54.9
4: 6	**54**	1	50.4926	0.02929	1.4789	46.1	47.5	49.0	50.5	52.0	53.5	54.9
4: 7	**55**	1	50.5354	0.02932	1.4817	46.1	47.6	49.1	50.5	52.0	53.5	55.0
4: 8	**56**	1	50.5772	0.02935	1.4844	46.1	47.6	49.1	50.6	52.1	53.5	55.0
4: 9	**57**	1	50.6183	0.02938	1.4872	46.2	47.6	49.1	50.6	52.1	53.6	55.1
4:10	**58**	1	50.6587	0.02940	1.4894	46.2	47.7	49.2	50.7	52.1	53.6	55.1
4:11	**59**	1	50.6984	0.02943	1.4921	46.2	47.7	49.2	50.7	52.2	53.7	55.2
5: 0	**60**	1	50.7375	0.02946	1.4947	46.3	47.7	49.2	50.7	52.2	53.7	55.2

3.3 Head circumference-for-age for girls

The choice of the model to construct the head circumference-for-age standard for girls followed the steps described for the corresponding standard for boys. In principle, unless a clear inadequacy is detected, models used for constructing the standards for both sexes should belong to the same class.

3.3.1 Sample size

There were 13 798 head circumference observations for girls. The longitudinal and cross-sectional sample sizes by visit and age are presented in Tables 10 and 11.

Table 10 Longitudinal sample sizes for head circumference-for-age for girls

Visit	**Birth**	**1**	**2**	**3**	**4**	**5**	**6**
Age	**0**	**2 wk**	**4 wk**	**6 wk**	**2 mo**	**3 mo**	**4 mo**
N	841	449	449	447	447	448	447
Visit	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Age	**5 mo**	**6 mo**	**7 mo**	**8 mo**	**9 mo**	**10 mo**	**11 mo**
N	450	448	448	445	449	446	446
Visit	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Age	**12 mo**	**14 mo**	**16 mo**	**18 mo**	**20 mo**	**22 mo**	**24 mo**
N	452	452	445	449	445	439	449

Table 11 Cross-sectional sample sizes for head circumference-for-age for girls

Age (mo)	**<18**	**18–20**	**21–23**	**24–26**	**27–29**	**30–32**	**33–35**
N	2	164	177	249	220	237	230
Age (mo)	**36–38**	**39–41**	**42–44**	**45–47**	**48–50**	**51–53**	**54–56**
N	226	242	254	218	232	208	239
Age (mo)	**57–59**	**60–62**	**63–65**	**66–68**	**69–71**	**>71**	
N	241	223	205	230	210	0	

3.3.2 Model selection and results

Using the model BCPE($x=age^{\lambda}$, df(μ)=9, df(σ)=4, ν=1, τ=2) as the starting point, the best age-transformation power (λ) was sought. As for boys, the same value λ=0.20 corresponded to the smallest value of global deviance and was selected as the age-transformation power (Table 12). A search followed for the best combination of degrees of freedom for the cubic splines to fit the BCPE distribution parameter curves.

Table 12 Global deviance (GD) for models within the class BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, ν=1, τ=2) for head circumference-for-age for girls

λ	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
GD[a]	989.1	988.7	988.3	988.1	988.9	991.7	997.4	1006.3	1017.3	1027.3
λ	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
GD[a]	1033.0	1031.8	1024.8	1018.4	1024.3	1058.8	1140.1	NA	NA	NA

[a] In excess of 46 000; NA: not available (method did not converge with this power).

The search for the best combination of degrees of freedom for the cubic splines to fit the μ and σ parameter curves started from the simplest class of models using the BCPE distribution and fixing ν=1, τ=2, and λ=0.20. Table 13 shows various combinations that were considered. The best combination of *AIC* and *GAIC(3)* supported the model with df(μ)=9 and df(σ)=2. The properties of this model were evaluated using the same set of diagnostic tools as those used for boys' head circumference-for-age.

Table 13 Goodness-of-fit summary for models using the BCPE distribution with fixed ν=1 and τ=2 for head circumference-for-age for girls

df(μ)	df(σ)	GD[a]	AIC[a]	GAIC(3)[a]	Total df
	1	1077.7	1093.7	1101.7	8
	2	1002.9	1020.9	1029.9	9
7	**3**	1000.9	1020.9	1030.9	10
	4	1000.2	1022.2	1033.2	11
	5	998.9	1022.9	1034.9	12
	1	1069.9	1087.9	1096.9	9
	2	994.8	1014.8	1024.8	10
8	**3**	992.9	1014.9	1025.9	11
	4	992.1	1016.1	1028.1	12
	5	990.8	1016.8	1029.8	13
	1	1066.0	1086.0	1096.0	10
	2	990.9	1012.9	1023.9	11
9	**3**	988.9	1012.9	1024.9	12
	4	988.1	1014.1	1027.1	13
	5	986.8	1014.8	1028.8	14
	1	1063.8	1085.8	1096.8	11
	2	988.7	1012.7	1024.7	12
10	**3**	986.6	1012.6	1025.6	13
	4	985.9	1013.9	1027.9	14
	5	984.6	1014.6	1029.6	15
	1	1062.4	1086.4	1098.4	12
	2	987.2	1013.2	1026.2	13
11	**3**	985.2	1013.2	1027.2	14
	4	984.4	1014.4	1029.4	15
	5	983.1	1015.1	1031.1	16

GD, Global Deviance; AIC, Akaike Information Criterion;
GAIC(3), Generalized AIC with penalty equal to 3;
[a] In excess of 46 000.

Model 1: BCPE(x=age$^{0.20}$, df(μ)=9, df(σ)=2, ν=1, τ=2)

The two fitted parameter curves, i.e. the median and coefficient of variation appeared to be adequately smoothed, considering the substantial variation observed in the empirical coefficient of variation pattern in the cross-sectional sample (Figure 11). With respect to the differences between empirical values and fitted centiles (Figures 12 and 13), there was some evidence of bias for a few of the considered percentiles. There seemed to be underestimation around the 3rd centile and overestimation around the 10th centile between birth and 24 months. The average bias was approximately 1 mm. Fitted centile residuals for the age interval 24 to 71 months showed a mild systematic underestimation, only for the 25th centile curve, of less than 2 mm on average (Figure 13). These biases were very small when compared to the SD values that varied from 1.2 cm to 1.4 cm in the entire age range. Examining Table 14, the proportions of children in the sample that were below the 1st and 3rd fitted centiles confirmed some underestimation in the lower tail. For the other centiles, the distribution of the proportions below each of the fitted centiles did not indicate any systematic bias.

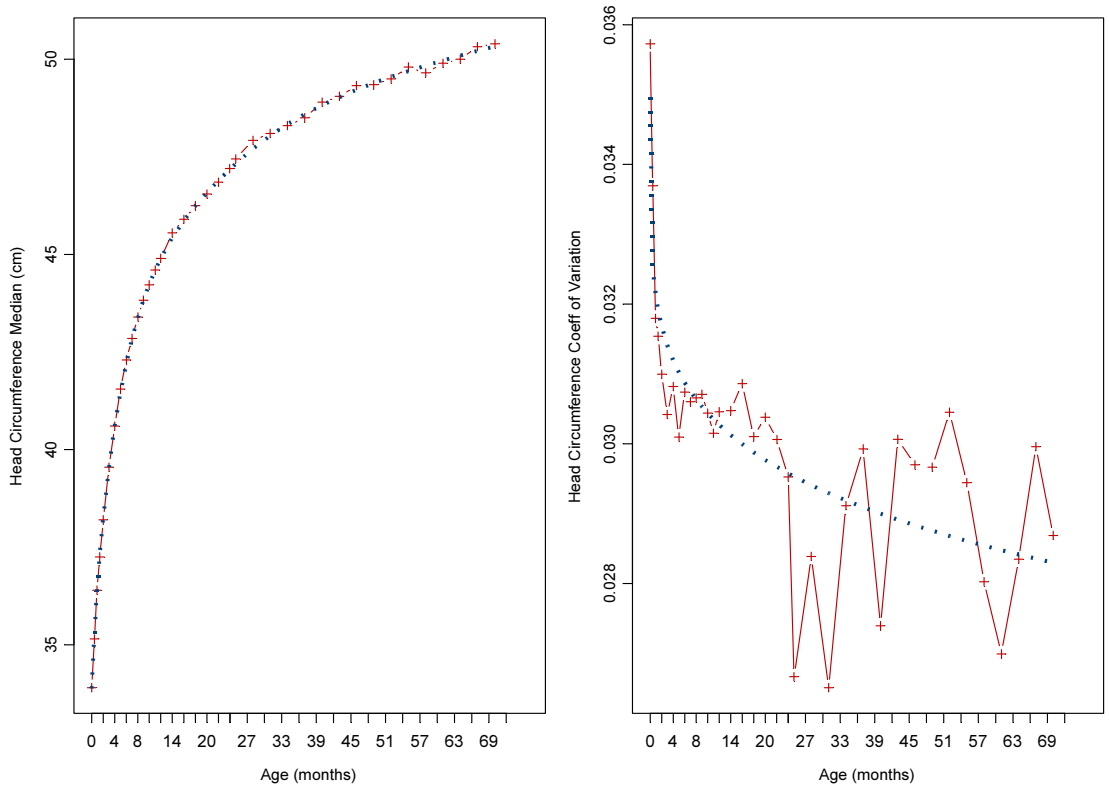


Figure 11 Fitting of the μ and σ curves of Model 1 for head circumference-for-age for girls (dotted line) and their respective sample estimates (points with solid line)

Figure 14 showed the worm plots for Model 1. For only two age groups, the shapes of the worms departed from the flat shape. The group 28 mo presented a slope, indicating misfit of the variance, and the worm corresponding to group 52 mo was slightly S-shaped, suggesting remaining kurtosis. Group 70 mo presented a worm that was U-shaped which would indicate skewness, yet the worm lay within the 95% confidence interval.

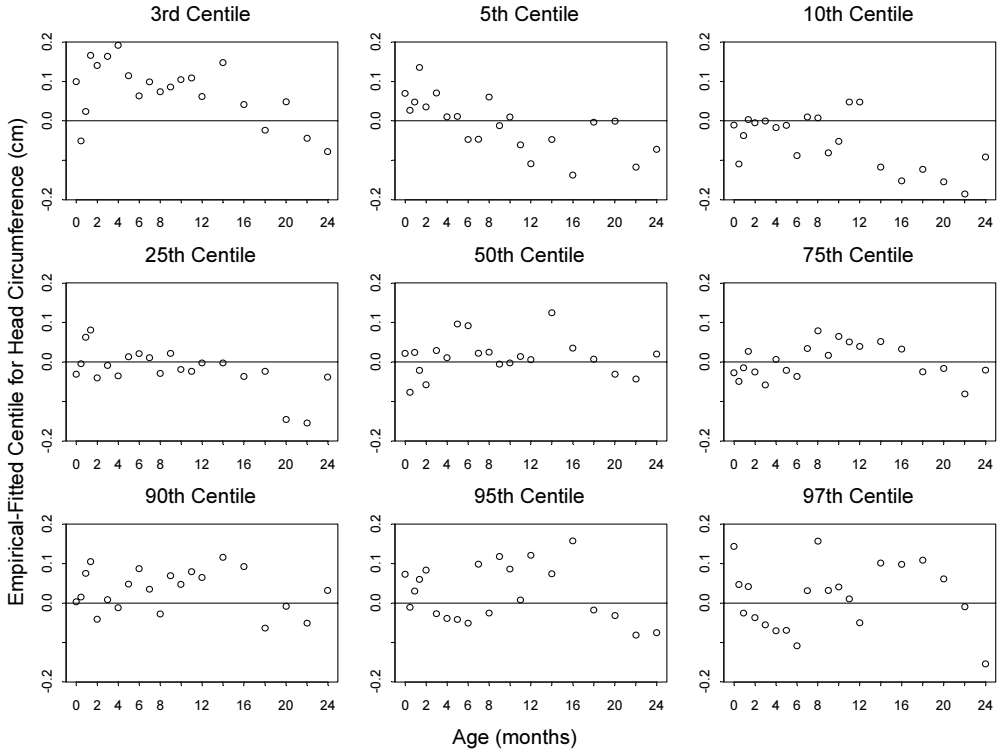


Figure 12 Centile residuals from fitting Model 1 for head circumference-for-age from 0 to 24 months for girls

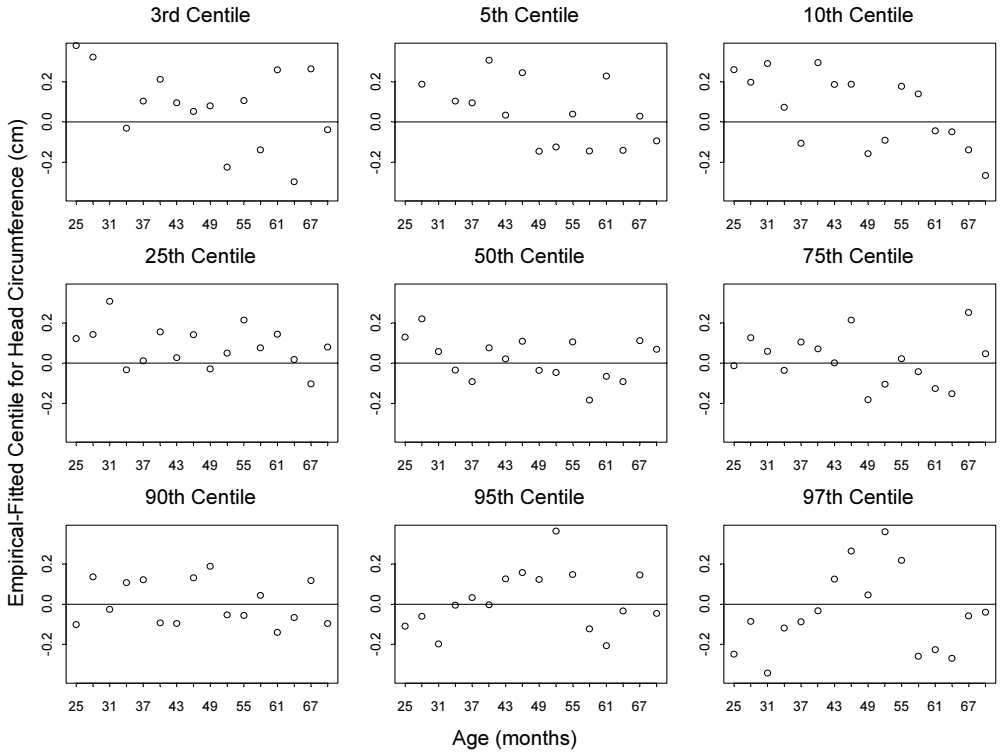


Figure 13 Centile residuals from fitting Model 1 for head circumference-for-age from 24 to 71 months for girls

Table 14 Observed proportions of children with measurements below the fitted centiles from Model 1, head circumference-for-age for girls

Expected	Birth	14 d	28 d	42 d	2 mo	3 mo	4 mo	5 mo	6 mo	7 mo
1	0.7	1.6	0.2	0.7	0.2	0.4	0.7	0.2	0.0	0.0
3	2.5	3.4	2.7	1.8	1.8	1.6	2.2	2.3	2.7	2.3
5	4.0	5.1	4.4	4.3	4.5	4.3	4.9	4.7	5.2	5.3
10	10.5	11.9	10.4	9.9	9.9	11.4	11.0	11.0	11.9	10.6
25	26.2	25.7	23.7	22.7	25.4	25.1	25.5	25.5	26.1	25.9
50	49.0	51.7	49.7	50.5	52.8	51.1	50.6	48.2	48.9	49.3
75	75.0	76.5	74.9	74.8	76.0	76.2	75.4	76.6	75.7	74.1
90	89.3	89.7	88.9	89.2	90.6	90.6	91.1	89.4	89.6	89.4
95	94.6	96.0	94.9	94.1	95.5	95.5	95.3	95.5	95.5	94.5
97	96.0	96.4	97.6	96.6	96.9	97.5	97.8	97.3	97.5	97.0
99	98.6	98.7	98.7	98.9	99.1	99.1	99.1	99.3	99.1	99.1
Expected	**8 mo**	**9 mo**	**10 mo**	**11 mo**	**12 mo**	**14 mo**	**16 mo**	**18 mo**	**20 mo**	**22 mo**
1	0.2	0.5	0.2	0.2	0.4	0.2	0.2	0.4	0.5	0.4
3	2.5	2.5	2.0	1.7	2.2	1.6	3.1	3.4	2.9	2.7
5	4.5	5.4	5.8	6.4	6.2	6.0	5.8	5.5	4.9	5.7
10	10.5	10.2	11.0	9.3	9.9	11.8	11.6	11.7	11.3	13.1
25	25.9	24.4	26.0	25.5	25.8	25.6	26.4	26.1	27.0	29.0
50	50.7	49.8	50.7	49.8	50.0	48.8	49.4	49.6	50.5	50.9
75	74.1	74.4	74.2	73.7	74.9	74.2	73.4	75.6	76.3	77.0
90	90.2	89.4	89.0	90.0	89.0	89.3	88.8	90.0	90.0	90.3
95	95.0	94.6	93.7	95.2	94.5	94.2	94.2	94.5	95.6	96.0
97	96.1	96.4	96.9	97.1	97.1	96.2	96.0	96.4	96.2	96.9
99	98.4	98.9	98.9	99.2	98.9	99.3	98.4	99.2	99.1	98.9

Table 14 Observed proportions of children with measurements below the fitted centiles from Model 1, head circumference-for-age for girls (cont)

Expected	24 mo	28 mo	34 mo	40 mo	46 mo	52 mo	58 mo	64 mo	70 mo	Overall
1	0.3	0.0	0.4	0.6	1.5	1.1	1.0	1.2	1.3	0.5
3	3.3	1.1	2.3	2.2	3.0	4.1	3.0	2.8	3.9	2.5
5	5.5	3.0	3.3	4.3	5.5	5.6	5.2	4.7	6.8	5.0
10	11.8	8.4	8.5	9.0	10.8	10.5	9.9	10.1	14.0	10.7
25	25.6	23.4	24.3	24.1	25.6	24.1	22.1	22.6	26.4	25.3
50	50.7	46.4	48.7	50.5	51.3	51.3	50.5	49.5	49.2	50.0
75	76.2	74.7	74.8	75.9	75.0	77.4	77.3	74.8	74.3	75.3
90	89.9	89.9	88.7	90.6	90.5	89.1	90.3	89.9	89.9	89.7
95	96.2	95.8	95.5	93.9	94.3	93.2	95.4	94.8	95.4	95.0
97	97.8	97.9	97.1	96.7	96.6	95.1	96.6	97.6	97.7	96.8
99	99.3	99.4	98.8	99.0	98.7	98.3	98.8	98.8	99.7	98.9

Note: Group labels correspond to the age intervals in Table 15.

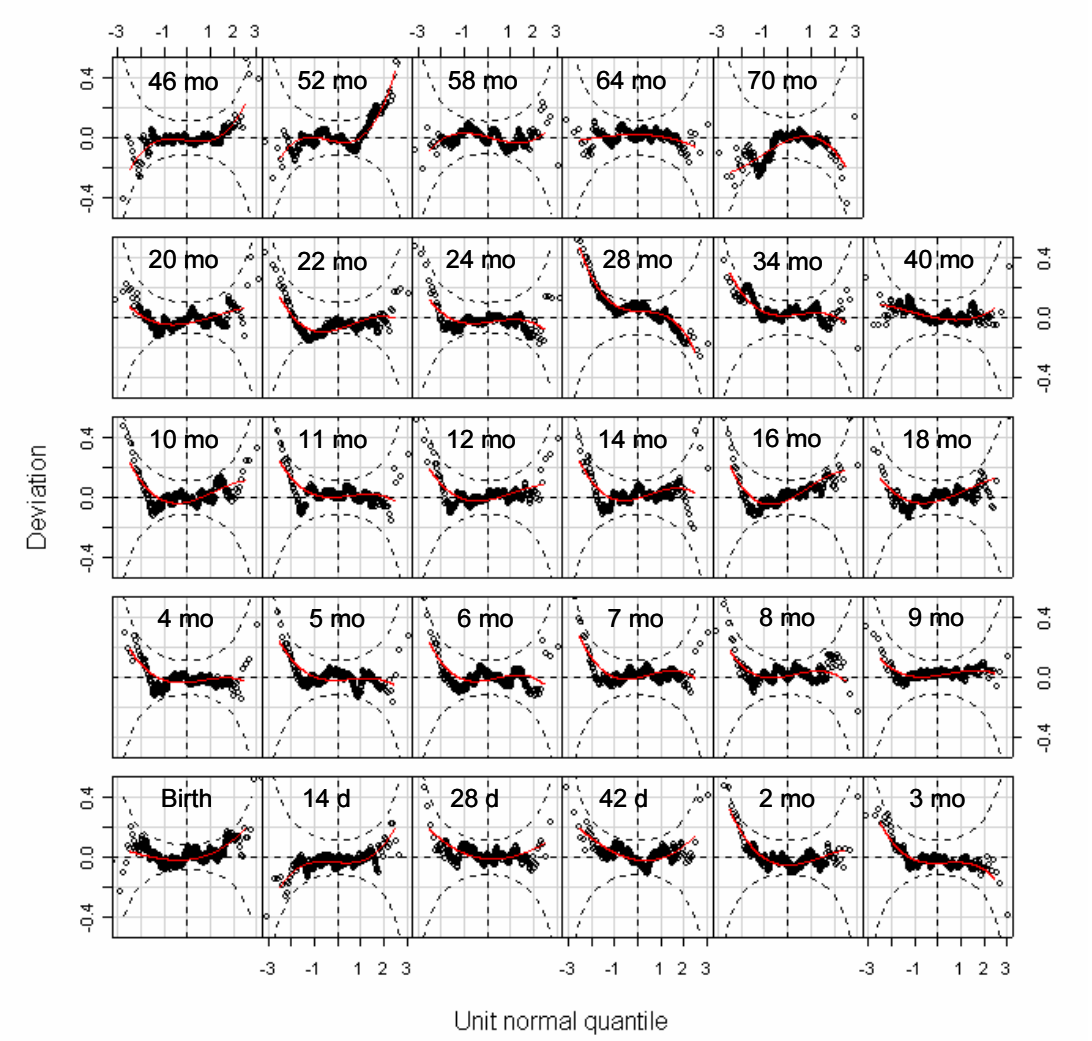


Figure 14 Worm plots of z-scores for Model 1 for head circumference-for-age for girls

Results of the Q-test presented in Table 15 showed that only the misfit of the variance (group 28 mo) was significant, i.e. the corresponding z2 absolute value was above 2. For the same age group, the Q-test suggested remaining kurtosis (z4 absolute value greater than 2), likely a consequence of the misfit of the variance. However, Q-test results for the z-scores derived from the selected model when applied across all age groups bore evidence of the model's overall adequacy (p-values corresponding to overall statistics are all greater than 0.30). More complex modelling (e.g. fitting parameter ν) was therefore not pursued.

A new iteration was done to re-search for the best λ with df(μ)=9 and df(σ)=2. This exercise did not result in any notable changes to the previous findings. The model BCPE(x= age$^{0.20}$, df(μ)=9, df(σ)=2, ν=1, τ=2) was thus chosen to construct the head circumference-for-age growth curves for girls. Figures 15 to 18 show the empirical and fitted centiles derived from the selected model for the head circumference-for-age (0 to 60 months) growth standard.

Table 15 Q-test for z-scores from Model 1 [BCPE(x=age$^{0.20}$, df(μ)=9, df(σ)=2, ν=1, τ=2)] for head circumference-for-age for girls

Age (days)	Group	N	z1	z2	z3	z4
0	**Birth**	841	0.1	0.9	1.4	0.5
1 to 16	**14 d**	447	-0.7	1.0	0.3	1.4
17 to 34	**28 d**	451	0.3	-0.4	1.3	0.4
35 to 49	**42 d**	444	0.3	-0.5	1.6	0.5
50 to 69	**2 mo**	445	-0.4	-0.7	1.9	-0.4
70 to 99	**3 mo**	446	-0.5	-1.0	0.6	-1.3
100 to 129	**4 mo**	447	-0.4	-0.3	0.9	-0.5
130 to 159	**5 mo**	444	0.1	-0.7	0.7	-0.6
160 to 189	**6 mo**	444	0.1	-0.2	0.6	-1.0
190 to 219	**7 mo**	436	0.4	-0.1	1.0	-1.0
220 to 249	**8 mo**	440	0.3	0.0	0.6	-0.9
250 to 279	**9 mo**	442	0.5	0.1	0.6	-0.6
280 to 309	**10 mo**	446	-0.1	0.2	1.7	-0.4
310 to 349	**11 mo**	482	0.4	-0.5	0.7	-0.7
350 to 379	**12 mo**	454	0.1	0.2	1.2	-0.4
380 to 439	**14 mo**	449	0.3	0.1	1.0	-0.8
440 to 499	**16 mo**	447	0.3	1.1	1.5	-0.6
500 to 559	**18 mo**	472	0.0	0.7	1.3	-0.1
560 to 619	**20 mo**	549	-0.4	0.5	0.9	-0.3
620 to 679	**22 mo**	548	-1.3	0.4	1.3	-1.1
680 to 749	**24 mo**	602	-0.7	-0.2	0.4	-0.9
750 to 929	**28 mo**	474	1.2	-2.2	0.5	-2.3
930 to 1119	**34 mo**	485	0.8	-0.9	0.9	-1.1
1120 to 1309	**40 mo**	489	0.1	-0.4	0.8	0.4
1310 to 1499	**46 mo**	472	-0.4	1.0	0.2	1.6
1500 to 1689	**52 mo**	468	0.0	1.5	1.6	2.0
1690 to 1879	**58 mo**	503	0.1	-0.4	-0.3	1.1
1880 to 2069	**64 mo**	424	0.2	-0.2	-0.5	-0.1
2070 to 2191	**70 mo**	307	-0.9	1.0	-1.2	-0.6
Overall Q stats		**13 798**	**7.5**	**16.8**	**32.3**	**27.3**
degrees of freedom			**20.0**	**27.5**	**29.0**	**29.0**
p-value			**0.9947**	**0.9440**	**0.3074**	**0.5551**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

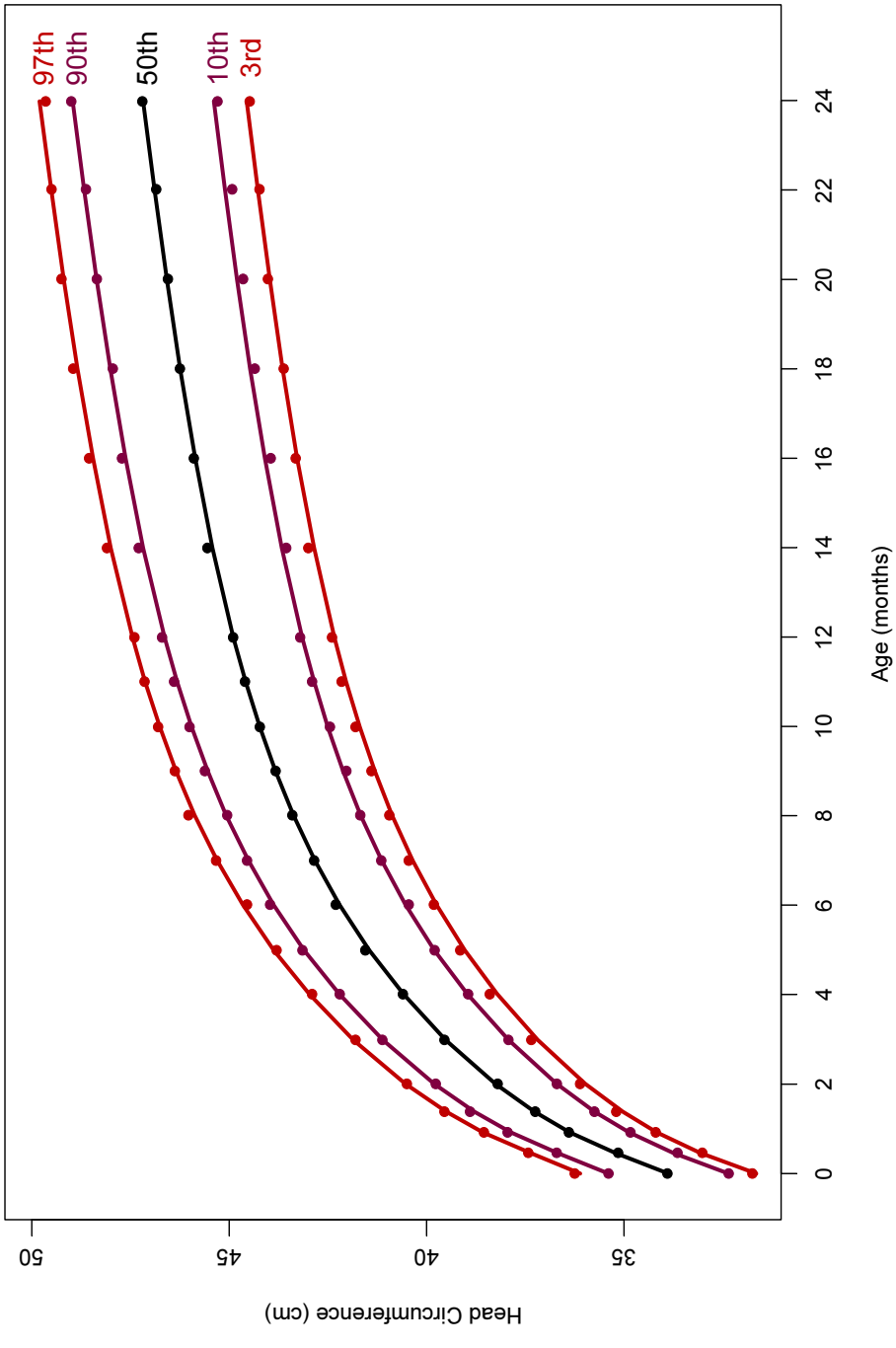


Figure 15 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: head circumference-for-age for girls from birth to 24 months

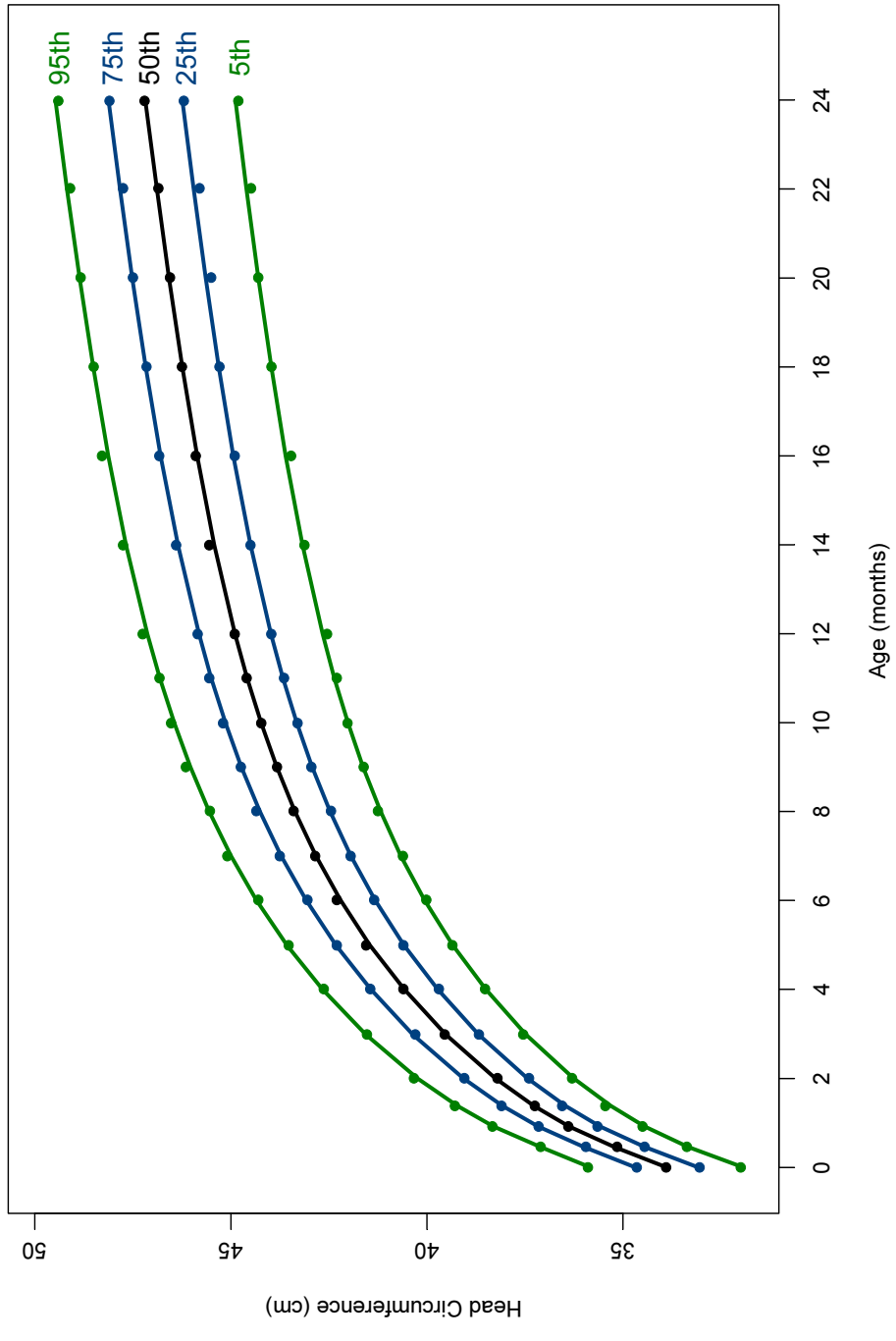


Figure 16 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: head circumference-for-age for girls from birth to 24 months

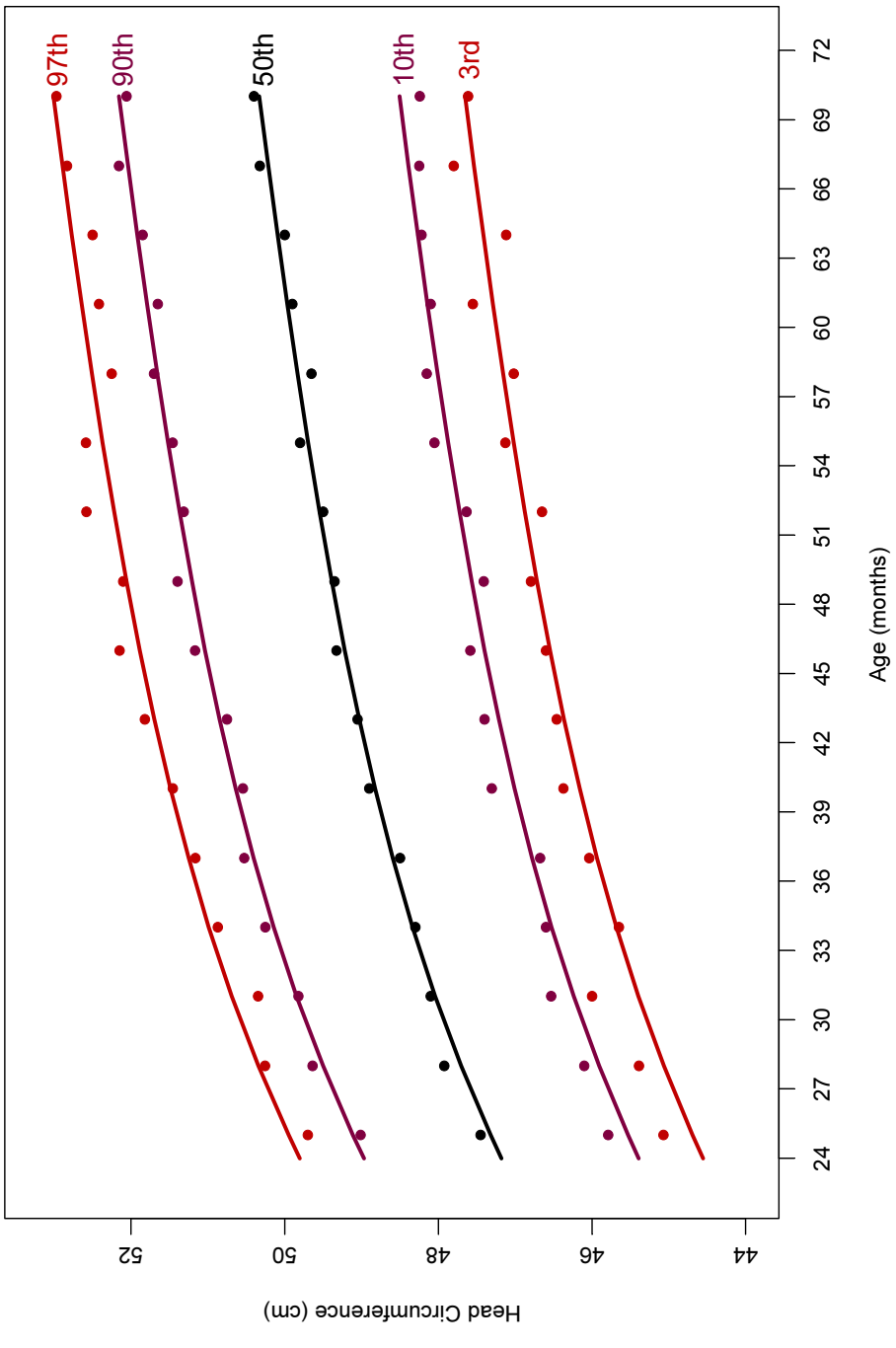


Figure 17 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: head circumference-for-age for girls from 24 to 71 months

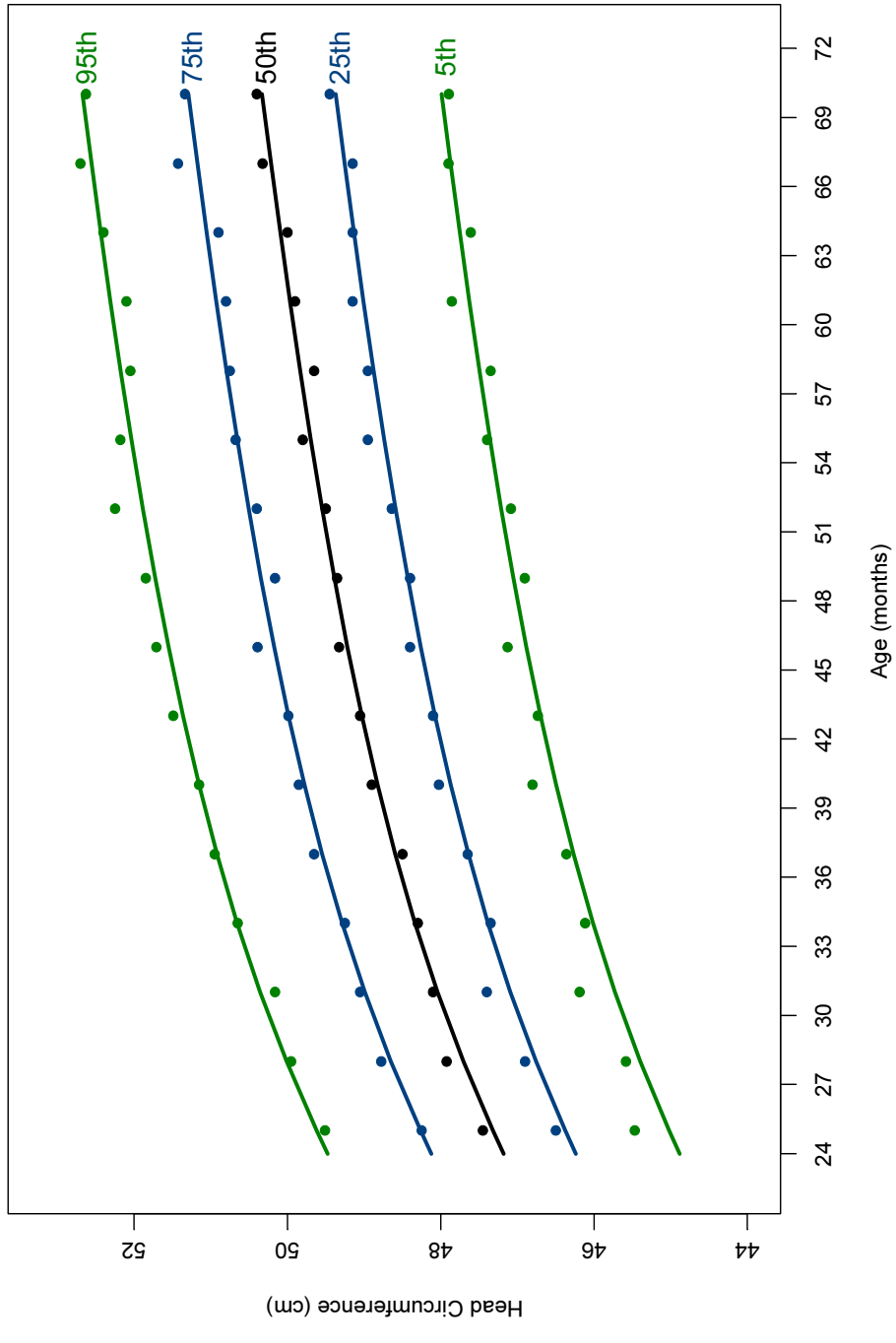


Figure 18 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: head circumference-for-age for girls from 24 to 71 months

3.3.3 WHO standards

This section presents the final WHO head circumference-for-age z-score and percentile charts (Figures 19 and 20) and tables (Tables 16 and 17) for girls.

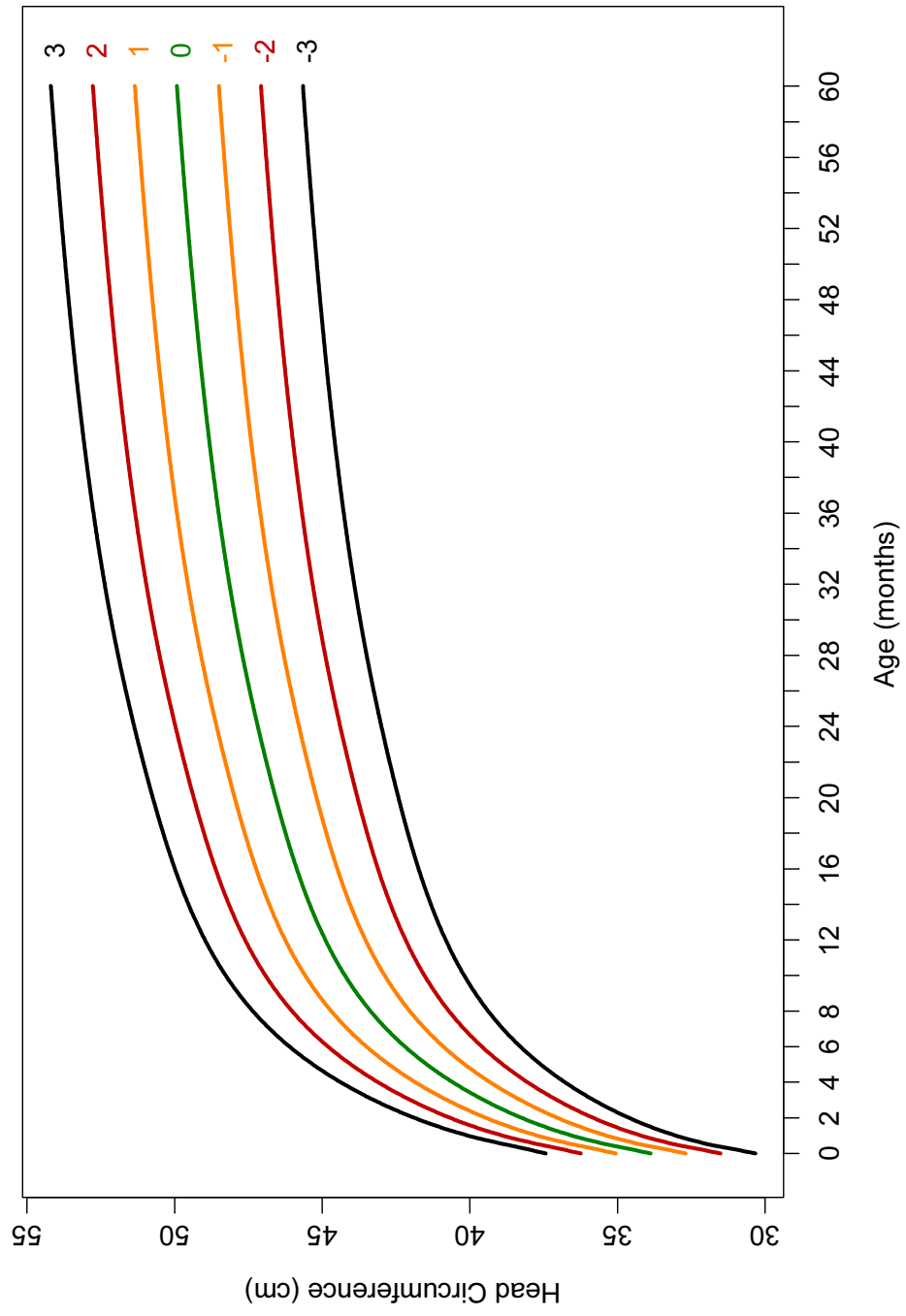


Figure 19 WHO head circumference-for-age z-scores for girls from birth to 60 months

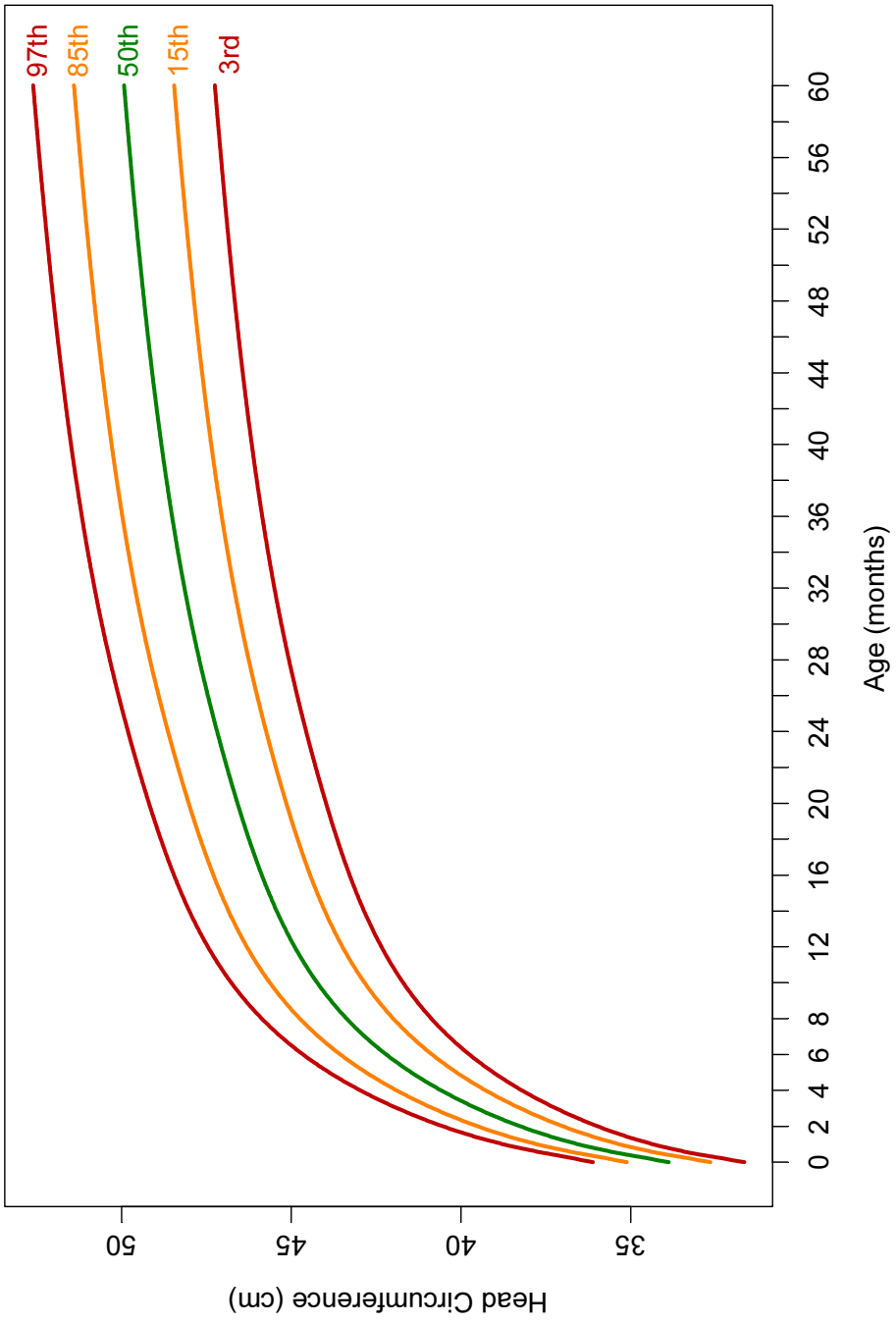


Figure 20 WHO head circumference-for-age percentiles for girls from birth to 60 months

Table 16 Head circumference-for-age for girls, age in weeks

					Percentiles (head circumference in cm)										
Week	**L**	**M**	**S**	**SD**	**1st**	**3rd**	**5th**	**15th**	**25th**	**50th**	**75th**	**85th**	**95th**	**97th**	**99th**
0	1	33.8787	0.03496	1.1844	31.1	31.7	31.9	32.7	33.1	33.9	34.7	35.1	35.8	36.1	36.6
1	1	34.5529	0.03374	1.1658	31.8	32.4	32.6	33.3	33.8	34.6	35.3	35.8	36.5	36.7	37.3
2	1	35.2272	0.03251	1.1452	32.6	33.1	33.3	34.0	34.5	35.2	36.0	36.4	37.1	37.4	37.9
3	1	35.8430	0.03231	1.1581	33.1	33.7	33.9	34.6	35.1	35.8	36.6	37.0	37.7	38.0	38.5
4	1	36.3761	0.03215	1.1695	33.7	34.2	34.5	35.2	35.6	36.4	37.2	37.6	38.3	38.6	39.1
5	1	36.8472	0.03202	1.1799	34.1	34.6	34.9	35.6	36.1	36.8	37.6	38.1	38.8	39.1	39.6
6	1	37.2711	0.03191	1.1893	34.5	35.0	35.3	36.0	36.5	37.3	38.1	38.5	39.2	39.5	40.0
7	1	37.6584	0.03182	1.1983	34.9	35.4	35.7	36.4	36.9	37.7	38.5	38.9	39.6	39.9	40.4
8	1	38.0167	0.03173	1.2063	35.2	35.7	36.0	36.8	37.2	38.0	38.8	39.3	40.0	40.3	40.8
9	1	38.3516	0.03166	1.2142	35.5	36.1	36.4	37.1	37.5	38.4	39.2	39.6	40.3	40.6	41.2
10	1	38.6673	0.03158	1.2211	35.8	36.4	36.7	37.4	37.8	38.7	39.5	39.9	40.7	41.0	41.5
11	1	38.9661	0.03152	1.2282	36.1	36.7	36.9	37.7	38.1	39.0	39.8	40.2	41.0	41.3	41.8
12	1	39.2501	0.03146	1.2348	36.4	36.9	37.2	38.0	38.4	39.3	40.1	40.5	41.3	41.6	42.1
13	1	39.5210	0.03140	1.2410	36.6	37.2	37.5	38.2	38.7	39.5	40.4	40.8	41.6	41.9	42.4

Table 16 Head circumference-for-age for girls, age in weeks (continued)

					Z-scores (head circumference in cm)						
Week	**L**	**M**	**S**	**SD**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
0	1	33.8787	0.03496	1.1844	30.3	31.5	32.7	33.9	35.1	36.2	37.4
1	1	34.5529	0.03374	1.1658	31.1	32.2	33.4	34.6	35.7	36.9	38.1
2	1	35.2272	0.03251	1.1452	31.8	32.9	34.1	35.2	36.4	37.5	38.7
3	1	35.8430	0.03231	1.1581	32.4	33.5	34.7	35.8	37.0	38.2	39.3
4	1	36.3761	0.03215	1.1695	32.9	34.0	35.2	36.4	37.5	38.7	39.9
5	1	36.8472	0.03202	1.1799	33.3	34.5	35.7	36.8	38.0	39.2	40.4
6	1	37.2711	0.03191	1.1893	33.7	34.9	36.1	37.3	38.5	39.6	40.8
7	1	37.6584	0.03182	1.1983	34.1	35.3	36.5	37.7	38.9	40.1	41.3
8	1	38.0167	0.03173	1.2063	34.4	35.6	36.8	38.0	39.2	40.4	41.6
9	1	38.3516	0.03166	1.2142	34.7	35.9	37.1	38.4	39.6	40.8	42.0
10	1	38.6673	0.03158	1.2211	35.0	36.2	37.4	38.7	39.9	41.1	42.3
11	1	38.9661	0.03152	1.2282	35.3	36.5	37.7	39.0	40.2	41.4	42.7
12	1	39.2501	0.03146	1.2348	35.5	36.8	38.0	39.3	40.5	41.7	43.0
13	1	39.5210	0.03140	1.2410	35.8	37.0	38.3	39.5	40.8	42.0	43.2

Table 17 Head circumference-for-age for girls, age in years and months

Year: Month	Month	L	M	S	SD	Percentiles (head circumference in cm)										
						1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
0: 0	**0**	1	33.8787	0.03496	1.1844	31.1	31.7	31.9	32.7	33.1	33.9	34.7	35.1	35.8	36.1	36.6
0: 1	**1**	1	36.5463	0.03210	1.1731	33.8	34.3	34.6	35.3	35.8	36.5	37.3	37.8	38.5	38.8	39.3
0: 2	**2**	1	38.2521	0.03168	1.2118	35.4	36.0	36.3	37.0	37.4	38.3	39.1	39.5	40.2	40.5	41.1
0: 3	**3**	1	39.5328	0.03140	1.2413	36.6	37.2	37.5	38.2	38.7	39.5	40.4	40.8	41.6	41.9	42.4
0: 4	**4**	1	40.5817	0.03119	1.2657	37.6	38.2	38.5	39.3	39.7	40.6	41.4	41.9	42.7	43.0	43.5
0: 5	**5**	1	41.4590	0.03102	1.2861	38.5	39.0	39.3	40.1	40.6	41.5	42.3	42.8	43.6	43.9	44.5
0: 6	**6**	1	42.1995	0.03087	1.3027	39.2	39.7	40.1	40.8	41.3	42.2	43.1	43.5	44.3	44.6	45.2
0: 7	**7**	1	42.8290	0.03075	1.3170	39.8	40.4	40.7	41.5	41.9	42.8	43.7	44.2	45.0	45.3	45.9
0: 8	**8**	1	43.3671	0.03063	1.3283	40.3	40.9	41.2	42.0	42.5	43.4	44.3	44.7	45.6	45.9	46.5
0: 9	**9**	1	43.8300	0.03053	1.3381	40.7	41.3	41.6	42.4	42.9	43.8	44.7	45.2	46.0	46.3	46.9
0:10	**10**	1	44.2319	0.03044	1.3464	41.1	41.7	42.0	42.8	43.3	44.2	45.1	45.6	46.4	46.8	47.4
0:11	**11**	1	44.5844	0.03035	1.3531	41.4	42.0	42.4	43.2	43.7	44.6	45.5	46.0	46.8	47.1	47.7
1: 0	**12**	1	44.8965	0.03027	1.3590	41.7	42.3	42.7	43.5	44.0	44.9	45.8	46.3	47.1	47.5	48.1
1: 1	**13**	1	45.1752	0.03019	1.3638	42.0	42.6	42.9	43.8	44.3	45.2	46.1	46.6	47.4	47.7	48.3
1: 2	**14**	1	45.4265	0.03012	1.3683	42.2	42.9	43.2	44.0	44.5	45.4	46.3	46.8	47.7	48.0	48.6
1: 3	**15**	1	45.6551	0.03006	1.3724	42.5	43.1	43.4	44.2	44.7	45.7	46.6	47.1	47.9	48.2	48.8
1: 4	**16**	1	45.8650	0.02999	1.3755	42.7	43.3	43.6	44.4	44.9	45.9	46.8	47.3	48.1	48.5	49.1
1: 5	**17**	1	46.0598	0.02993	1.3786	42.9	43.5	43.8	44.6	45.1	46.1	47.0	47.5	48.3	48.7	49.3
1: 6	**18**	1	46.2424	0.02987	1.3813	43.0	43.6	44.0	44.8	45.3	46.2	47.2	47.7	48.5	48.8	49.5
1: 7	**19**	1	46.4152	0.02982	1.3841	43.2	43.8	44.1	45.0	45.5	46.4	47.3	47.8	48.7	49.0	49.6
1: 8	**20**	1	46.5801	0.02977	1.3867	43.4	44.0	44.3	45.1	45.6	46.6	47.5	48.0	48.9	49.2	49.8
1: 9	**21**	1	46.7384	0.02972	1.3891	43.5	44.1	44.5	45.3	45.8	46.7	47.7	48.2	49.0	49.4	50.0
1:10	**22**	1	46.8913	0.02967	1.3913	43.7	44.3	44.6	45.4	46.0	46.9	47.8	48.3	49.2	49.5	50.1
1:11	**23**	1	47.0391	0.02962	1.3933	43.8	44.4	44.7	45.6	46.1	47.0	48.0	48.5	49.3	49.7	50.3
2: 0	**24**	1	47.1822	0.02957	1.3952	43.9	44.6	44.9	45.7	46.2	47.2	48.1	48.6	49.5	49.8	50.4

Table 17 Head circumference-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	SD	Percentiles (head circumference in cm)										
						1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
2: 1	**25**	1	47.3204	0.02953	1.3974	44.1	44.7	45.0	45.9	46.4	47.3	48.3	48.8	49.6	49.9	50.6
2: 2	**26**	1	47.4536	0.02949	1.3994	44.2	44.8	45.2	46.0	46.5	47.5	48.4	48.9	49.8	50.1	50.7
2: 3	**27**	1	47.5817	0.02945	1.4013	44.3	44.9	45.3	46.1	46.6	47.6	48.5	49.0	49.9	50.2	50.8
2: 4	**28**	1	47.7045	0.02941	1.4030	44.4	45.1	45.4	46.3	46.8	47.7	48.7	49.2	50.0	50.3	51.0
2: 5	**29**	1	47.8219	0.02937	1.4045	44.6	45.2	45.5	46.4	46.9	47.8	48.8	49.3	50.1	50.5	51.1
2: 6	**30**	1	47.9340	0.02933	1.4059	44.7	45.3	45.6	46.5	47.0	47.9	48.9	49.4	50.2	50.6	51.2
2: 7	**31**	1	48.0410	0.02929	1.4071	44.8	45.4	45.7	46.6	47.1	48.0	49.0	49.5	50.4	50.7	51.3
2: 8	**32**	1	48.1432	0.02926	1.4087	44.9	45.5	45.8	46.7	47.2	48.1	49.1	49.6	50.5	50.8	51.4
2: 9	**33**	1	48.2408	0.02922	1.4096	45.0	45.6	45.9	46.8	47.3	48.2	49.2	49.7	50.6	50.9	51.5
2:10	**34**	1	48.3343	0.02919	1.4109	45.1	45.7	46.0	46.9	47.4	48.3	49.3	49.8	50.7	51.0	51.6
2:11	**35**	1	48.4239	0.02915	1.4116	45.1	45.8	46.1	47.0	47.5	48.4	49.4	49.9	50.7	51.1	51.7
3: 0	**36**	1	48.5099	0.02912	1.4126	45.2	45.9	46.2	47.0	47.6	48.5	49.5	50.0	50.8	51.2	51.8
3: 1	**37**	1	48.5926	0.02909	1.4136	45.3	45.9	46.3	47.1	47.6	48.6	49.5	50.1	50.9	51.3	51.9
3: 2	**38**	1	48.6722	0.02906	1.4144	45.4	46.0	46.3	47.2	47.7	48.7	49.6	50.1	51.0	51.3	52.0
3: 3	**39**	1	48.7489	0.02903	1.4152	45.5	46.1	46.4	47.3	47.8	48.7	49.7	50.2	51.1	51.4	52.0
3: 4	**40**	1	48.8228	0.02900	1.4159	45.5	46.2	46.5	47.4	47.9	48.8	49.8	50.3	51.2	51.5	52.1
3: 5	**41**	1	48.8941	0.02897	1.4165	45.6	46.2	46.6	47.4	47.9	48.9	49.8	50.4	51.2	51.6	52.2
3: 6	**42**	1	48.9629	0.02894	1.4170	45.7	46.3	46.6	47.5	48.0	49.0	49.9	50.4	51.3	51.6	52.3
3: 7	**43**	1	49.0294	0.02891	1.4174	45.7	46.4	46.7	47.6	48.1	49.0	50.0	50.5	51.4	51.7	52.3
3: 8	**44**	1	49.0937	0.02888	1.4178	45.8	46.4	46.8	47.6	48.1	49.1	50.1	50.6	51.4	51.8	52.4
3: 9	**45**	1	49.1560	0.02886	1.4186	45.9	46.5	46.8	47.7	48.2	49.2	50.1	50.6	51.5	51.8	52.5
3:10	**46**	1	49.2164	0.02883	1.4189	45.9	46.5	46.9	47.7	48.3	49.2	50.2	50.7	51.6	51.9	52.5
3:11	**47**	1	49.2751	0.02880	1.4191	46.0	46.6	46.9	47.8	48.3	49.3	50.2	50.7	51.6	51.9	52.6
4: 0	**48**	1	49.3321	0.02878	1.4198	46.0	46.7	47.0	47.9	48.4	49.3	50.3	50.8	51.7	52.0	52.6

Table 17 Head circumference-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	SD	Percentiles (head circumference in cm)										
						1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
4: 1	**49**	1	49.3877	0.02875	1.4199	46.1	46.7	47.1	47.9	48.4	49.4	50.3	50.9	51.7	52.1	52.7
4: 2	**50**	1	49.4419	0.02873	1.4205	46.1	46.8	47.1	48.0	48.5	49.4	50.4	50.9	51.8	52.1	52.7
4: 3	**51**	1	49.4947	0.02870	1.4205	46.2	46.8	47.2	48.0	48.5	49.5	50.5	51.0	51.8	52.2	52.8
4: 4	**52**	1	49.5464	0.02868	1.4210	46.2	46.9	47.2	48.1	48.6	49.5	50.5	51.0	51.9	52.2	52.9
4: 5	**53**	1	49.5969	0.02865	1.4210	46.3	46.9	47.3	48.1	48.6	49.6	50.6	51.1	51.9	52.3	52.9
4: 6	**54**	1	49.6464	0.02863	1.4214	46.3	47.0	47.3	48.2	48.7	49.6	50.6	51.1	52.0	52.3	53.0
4: 7	**55**	1	49.6947	0.02861	1.4218	46.4	47.0	47.4	48.2	48.7	49.7	50.7	51.2	52.0	52.4	53.0
4: 8	**56**	1	49.7421	0.02859	1.4221	46.4	47.1	47.4	48.3	48.8	49.7	50.7	51.2	52.1	52.4	53.1
4: 9	**57**	1	49.7885	0.02856	1.4220	46.5	47.1	47.4	48.3	48.8	49.8	50.7	51.3	52.1	52.5	53.1
4:10	**58**	1	49.8341	0.02854	1.4223	46.5	47.2	47.5	48.4	48.9	49.8	50.8	51.3	52.2	52.5	53.1
4:11	**59**	1	49.8789	0.02852	1.4226	46.6	47.2	47.5	48.4	48.9	49.9	50.8	51.4	52.2	52.6	53.2
5: 0	**60**	1	49.9229	0.02850	1.4228	46.6	47.2	47.6	48.4	49.0	49.9	50.9	51.4	52.3	52.6	53.2

Table 17 Head circumference-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	SD	Z-scores (head circumference in cm)						
						-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 0	**0**	1	33.8787	0.03496	1.1844	30.3	31.5	32.7	33.9	35.1	36.2	37.4
0: 1	**1**	1	36.5463	0.03210	1.1731	33.0	34.2	35.4	36.5	37.7	38.9	40.1
0: 2	**2**	1	38.2521	0.03168	1.2118	34.6	35.8	37.0	38.3	39.5	40.7	41.9
0: 3	**3**	1	39.5328	0.03140	1.2413	35.8	37.1	38.3	39.5	40.8	42.0	43.3
0: 4	**4**	1	40.5817	0.03119	1.2657	36.8	38.1	39.3	40.6	41.8	43.1	44.4
0: 5	**5**	1	41.4590	0.03102	1.2861	37.6	38.9	40.2	41.5	42.7	44.0	45.3
0: 6	**6**	1	42.1995	0.03087	1.3027	38.3	39.6	40.9	42.2	43.5	44.8	46.1
0: 7	**7**	1	42.8290	0.03075	1.3170	38.9	40.2	41.5	42.8	44.1	45.5	46.8
0: 8	**8**	1	43.3671	0.03063	1.3283	39.4	40.7	42.0	43.4	44.7	46.0	47.4
0: 9	**9**	1	43.8300	0.03053	1.3381	39.8	41.2	42.5	43.8	45.2	46.5	47.8
0:10	**10**	1	44.2319	0.03044	1.3464	40.2	41.5	42.9	44.2	45.6	46.9	48.3
0:11	**11**	1	44.5844	0.03035	1.3531	40.5	41.9	43.2	44.6	45.9	47.3	48.6
1: 0	**12**	1	44.8965	0.03027	1.3590	40.8	42.2	43.5	44.9	46.3	47.6	49.0
1: 1	**13**	1	45.1752	0.03019	1.3638	41.1	42.4	43.8	45.2	46.5	47.9	49.3
1: 2	**14**	1	45.4265	0.03012	1.3683	41.3	42.7	44.1	45.4	46.8	48.2	49.5
1: 3	**15**	1	45.6551	0.03006	1.3724	41.5	42.9	44.3	45.7	47.0	48.4	49.8
1: 4	**16**	1	45.8650	0.02999	1.3755	41.7	43.1	44.5	45.9	47.2	48.6	50.0
1: 5	**17**	1	46.0598	0.02993	1.3786	41.9	43.3	44.7	46.1	47.4	48.8	50.2
1: 6	**18**	1	46.2424	0.02987	1.3813	42.1	43.5	44.9	46.2	47.6	49.0	50.4
1: 7	**19**	1	46.4152	0.02982	1.3841	42.3	43.6	45.0	46.4	47.8	49.2	50.6
1: 8	**20**	1	46.5801	0.02977	1.3867	42.4	43.8	45.2	46.6	48.0	49.4	50.7
1: 9	**21**	1	46.7384	0.02972	1.3891	42.6	44.0	45.3	46.7	48.1	49.5	50.9
1:10	**22**	1	46.8913	0.02967	1.3913	42.7	44.1	45.5	46.9	48.3	49.7	51.1
1:11	**23**	1	47.0391	0.02962	1.3933	42.9	44.3	45.6	47.0	48.4	49.8	51.2
2: 0	**24**	1	47.1822	0.02957	1.3952	43.0	44.4	45.8	47.2	48.6	50.0	51.4

Table 17 Head circumference-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	SD	Z-scores (head circumference in cm)						
						-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
2: 1	**25**	1	47.3204	0.02953	1.3974	43.1	44.5	45.9	47.3	48.7	50.1	51.5
2: 2	**26**	1	47.4536	0.02949	1.3994	43.3	44.7	46.1	47.5	48.9	50.3	51.7
2: 3	**27**	1	47.5817	0.02945	1.4013	43.4	44.8	46.2	47.6	49.0	50.4	51.8
2: 4	**28**	1	47.7045	0.02941	1.4030	43.5	44.9	46.3	47.7	49.1	50.5	51.9
2: 5	**29**	1	47.8219	0.02937	1.4045	43.6	45.0	46.4	47.8	49.2	50.6	52.0
2: 6	**30**	1	47.9340	0.02933	1.4059	43.7	45.1	46.5	47.9	49.3	50.7	52.2
2: 7	**31**	1	48.0410	0.02929	1.4071	43.8	45.2	46.6	48.0	49.4	50.9	52.3
2: 8	**32**	1	48.1432	0.02926	1.4087	43.9	45.3	46.7	48.1	49.6	51.0	52.4
2: 9	**33**	1	48.2408	0.02922	1.4096	44.0	45.4	46.8	48.2	49.7	51.1	52.5
2:10	**34**	1	48.3343	0.02919	1.4109	44.1	45.5	46.9	48.3	49.7	51.2	52.6
2:11	**35**	1	48.4239	0.02915	1.4116	44.2	45.6	47.0	48.4	49.8	51.2	52.7
3: 0	**36**	1	48.5099	0.02912	1.4126	44.3	45.7	47.1	48.5	49.9	51.3	52.7
3: 1	**37**	1	48.5926	0.02909	1.4136	44.4	45.8	47.2	48.6	50.0	51.4	52.8
3: 2	**38**	1	48.6722	0.02906	1.4144	44.4	45.8	47.3	48.7	50.1	51.5	52.9
3: 3	**39**	1	48.7489	0.02903	1.4152	44.5	45.9	47.3	48.7	50.2	51.6	53.0
3: 4	**40**	1	48.8228	0.02900	1.4159	44.6	46.0	47.4	48.8	50.2	51.7	53.1
3: 5	**41**	1	48.8941	0.02897	1.4165	44.6	46.1	47.5	48.9	50.3	51.7	53.1
3: 6	**42**	1	48.9629	0.02894	1.4170	44.7	46.1	47.5	49.0	50.4	51.8	53.2
3: 7	**43**	1	49.0294	0.02891	1.4174	44.8	46.2	47.6	49.0	50.4	51.9	53.3
3: 8	**44**	1	49.0937	0.02888	1.4178	44.8	46.3	47.7	49.1	50.5	51.9	53.3
3: 9	**45**	1	49.1560	0.02886	1.4186	44.9	46.3	47.7	49.2	50.6	52.0	53.4
3:10	**46**	1	49.2164	0.02883	1.4189	45.0	46.4	47.8	49.2	50.6	52.1	53.5
3:11	**47**	1	49.2751	0.02880	1.4191	45.0	46.4	47.9	49.3	50.7	52.1	53.5
4: 0	**48**	1	49.3321	0.02878	1.4198	45.1	46.5	47.9	49.3	50.8	52.2	53.6

Table 17 Head circumference-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	SD	Z-scores (head circumference in cm)						
						-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	**49**	1	49.3877	0.02875	1.4199	45.1	46.5	48.0	49.4	50.8	52.2	53.6
4: 2	**50**	1	49.4419	0.02873	1.4205	45.2	46.6	48.0	49.4	50.9	52.3	53.7
4: 3	**51**	1	49.4947	0.02870	1.4205	45.2	46.7	48.1	49.5	50.9	52.3	53.8
4: 4	**52**	1	49.5464	0.02868	1.4210	45.3	46.7	48.1	49.5	51.0	52.4	53.8
4: 5	**53**	1	49.5969	0.02865	1.4210	45.3	46.8	48.2	49.6	51.0	52.4	53.9
4: 6	**54**	1	49.6464	0.02863	1.4214	45.4	46.8	48.2	49.6	51.1	52.5	53.9
4: 7	**55**	1	49.6947	0.02861	1.4218	45.4	46.9	48.3	49.7	51.1	52.5	54.0
4: 8	**56**	1	49.7421	0.02859	1.4221	45.5	46.9	48.3	49.7	51.2	52.6	54.0
4: 9	**57**	1	49.7885	0.02856	1.4220	45.5	46.9	48.4	49.8	51.2	52.6	54.1
4:10	**58**	1	49.8341	0.02854	1.4223	45.6	47.0	48.4	49.8	51.3	52.7	54.1
4:11	**59**	1	49.8789	0.02852	1.4226	45.6	47.0	48.5	49.9	51.3	52.7	54.1
5: 0	**60**	1	49.9229	0.02850	1.4228	45.7	47.1	48.5	49.9	51.3	52.8	54.2

3.4 Comparisons between boys and girls

This section presents the head circumference-for-age z-score comparisons between boys and girls for the WHO standards (Figure 21).

3.4.1 WHO

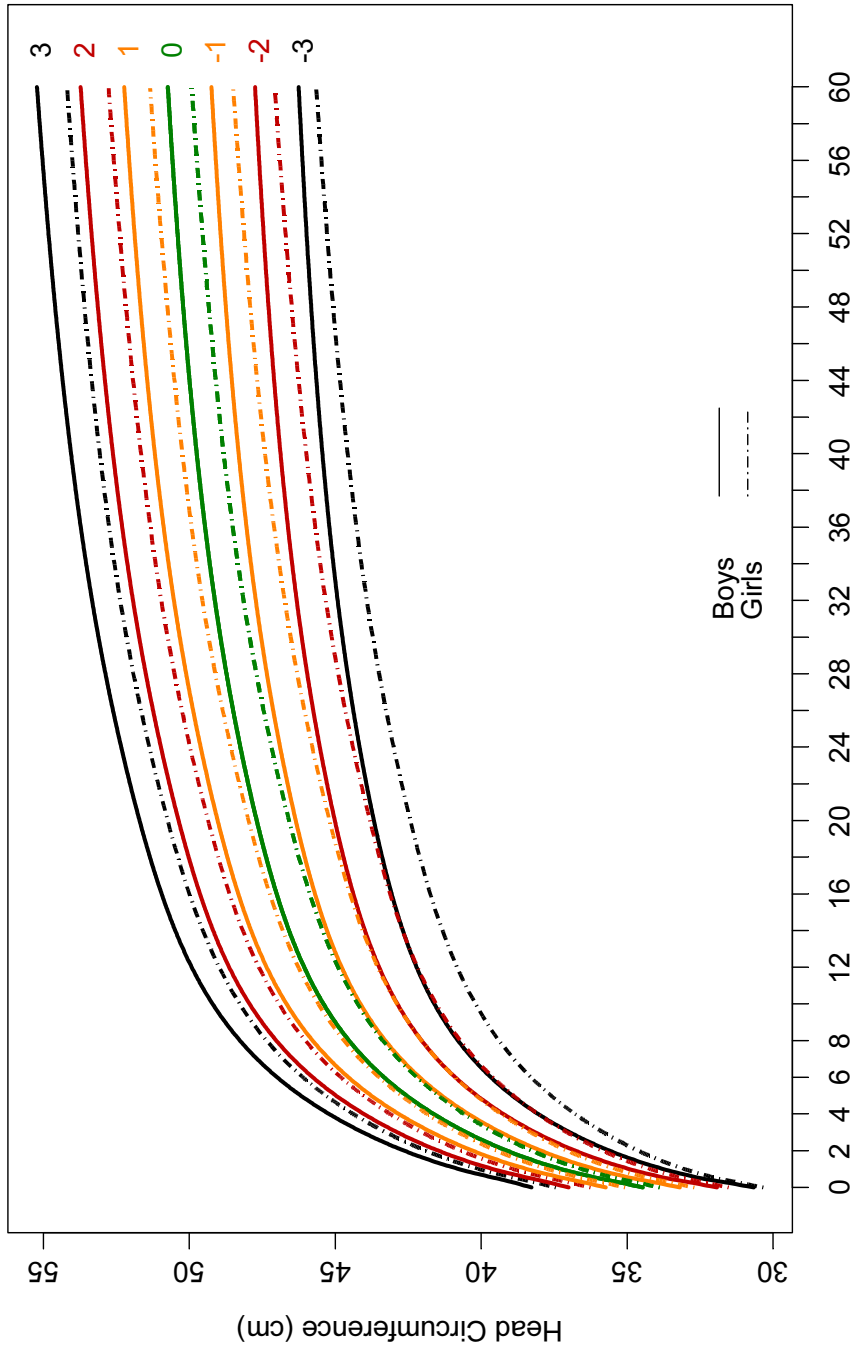


Figure 21 Comparison of boys' and girls' head circumference-for-age z-scores

4. CONSTRUCTION OF THE ARM CIRCUMFERENCE-FOR-AGE STANDARDS

4.1 Indicator-specific methodology

Similar steps to those described for the head circumference-for-age growth curves were followed to construct the arm circumference-for-age growth curves. The diagnostic tools applied to evaluate and compare candidate models were also similar. All data up to 71 months were used for modelling the arm circumference-for-age growth curves and the standards afterwards truncated at 60 completed months to correct for the right-edge effect (Borghi et al., 2006).

4.2 Arm circumference-for-age for boys

4.2.1 Sample size

There were a total of 10 770 arm circumference observations for boys. The longitudinal and cross-sectional sample sizes by visit and age are presented in Tables 18 and 19. The measurement of arm circumference started at 3 months of age (de Onis et al., 2004b).

Table 18 Longitudinal sample sizes for arm circumference-for-age for boys

Visit	**5**	**6**	**7**	**8**	**9**	**10**
Age	**3 mo**	**4 mo**	**5 mo**	**6 mo**	**7 mo**	**8 mo**
N	413	407	412	417	415	415
Visit	**11**	**12**	**13**	**14**	**15**	**16**
Age	**9 mo**	**10 mo**	**11 mo**	**12 mo**	**14 mo**	**16 mo**
N	409	407	418	414	416	417
Visit	**17**	**18**	**19**	**20**		
Age	**18 mo**	**20 mo**	**22 mo**	**24 mo**		
N	416	422	415	421		

Table 19 Cross-sectional sample sizes for arm circumference-for-age for boys

Age (mo)	**<18**	**18–20**	**21–23**	**24–26**	**27–29**	**30–32**	**33–35**
N	3	177	183	236	257	218	252
Age (mo)	**36–38**	**39–41**	**42–44**	**45–47**	**48–50**	**51–53**	**54–56**
N	266	249	255	237	237	221	225
Age (mo)	**57–59**	**60–62**	**63–65**	**66–68**	**69–71**	**>71**	
N	241	228	216	217	214	4	

4.2.2 Model selection and results

To construct the arm circumference-for-age growth curves, the model BCPE($x=age^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) was used as a starting point to search for the best value of the age-transformation power λ by examining changes in global deviance. Note that, the empirical distribution clearly indicated right-skewness, thus the starting arbitrary model included degrees of freedom for ν. Table 20 shows the global deviance for values of λ from 0.05 to 1. The smallest value of global deviance was associated with λ=0.35 and thus this age transformation power was selected.

Table 20 Global deviance (GD) for models within the class BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) for arm circumference-for-age for boys

λ	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**
GD[a]	230.1	229.6	229.1	228.7	228.4	228.2	228.1	228.2	228.4	228.8
λ	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
GD[a]	229.4	230.2	231.4	232.9	234.9	237.3	240.2	243.8	248.0	252.9

[a] In excess of 34 000.

The search for the best df(μ) and df(σ) followed, using λ=0.35, and fixing ν=1 and τ=2. All possible combinations with df(μ) values ranging from 7 to 15 and df(σ) from 2 to 10 were considered and partial results are presented in Table 21. No fitted model minimized both *AIC* and *GAIC(3)* simultaneously. Overall it was noticed that for data with a higher dispersion such as arm circumference and skinfolds, the criterion *GAIC(3)* provided more parsimonious models, and therefore only this criterion was considered in selecting the final models for the construction of the standards for these indicators. For boys' the arm circumference-for-age *GAIC(3)* was most minimized by the combination df(μ)=8 and df(σ)=4. This model was thus selected for further evaluation.

Table 21 Goodness-of-fit summary for models using the BCPE distribution with fixed ν=1 and τ=2 for arm circumference-for-age for boys

df(μ)	**df(σ)**	**GD[a]**	**AIC[a]**	**GAIC(3)[a]**	**Total df**
7	**2**	360.9	378.9	387.9	9
	3	351.9	371.9	381.9	10
	4	348.6	370.6	381.6	11
	5	347.2	371.2	383.2	12
	6	346.1	372.1	385.1	13
8	**2**	357.5	377.5	387.5	10
	3	348.5	370.5	381.5	11
	4	345.2	369.2	381.2	12
	5	343.7	369.7	382.7	13
	6	342.6	370.6	384.6	14
9	**2**	355.5	377.5	388.5	11
	3	346.5	370.5	382.5	12
	4	343.2	369.2	382.2	13
	5	341.8	369.8	383.8	14
	6	340.6	370.6	385.6	15
10	**2**	354.2	378.2	390.2	12
	3	345.2	371.2	384.2	13
	4	341.8	369.8	383.8	14
	5	340.4	370.4	385.4	15
	6	339.3	371.3	387.3	16
11	**2**	353.2	379.2	392.2	13
	3	344.2	372.2	386.2	14
	4	340.8	370.8	385.8	15
	5	339.4	371.4	387.4	16
	6	338.2	372.2	389.2	17

GD, Global Deviance; AIC, Akaike Information Criterion;
GAIC(3), Generalized AIC with penalty equal to 3;
[a] In excess of 34 000.

Model 1: BCPE(x=age$^{0.35}$, df(μ)=8, df(σ)=4, ν=1, τ=2)

For this model, both the worm plots (Figure 22) and the Q-test results (Table 22) indicated good model fit of the μ and σ curves but pointed to the need to adjust for skewness. The worms had a U-shape in most age groups after 12 months, indicating residual skewness. This finding was confirmed by the Q-test results (Table 22), which showed various groups in the same age range with absolute values of z3 higher than 2. The overall test for skewness was significant (p-value < 0.01). Only two age groups presented absolute values of z4 higher than 2, indicating residual kurtosis.

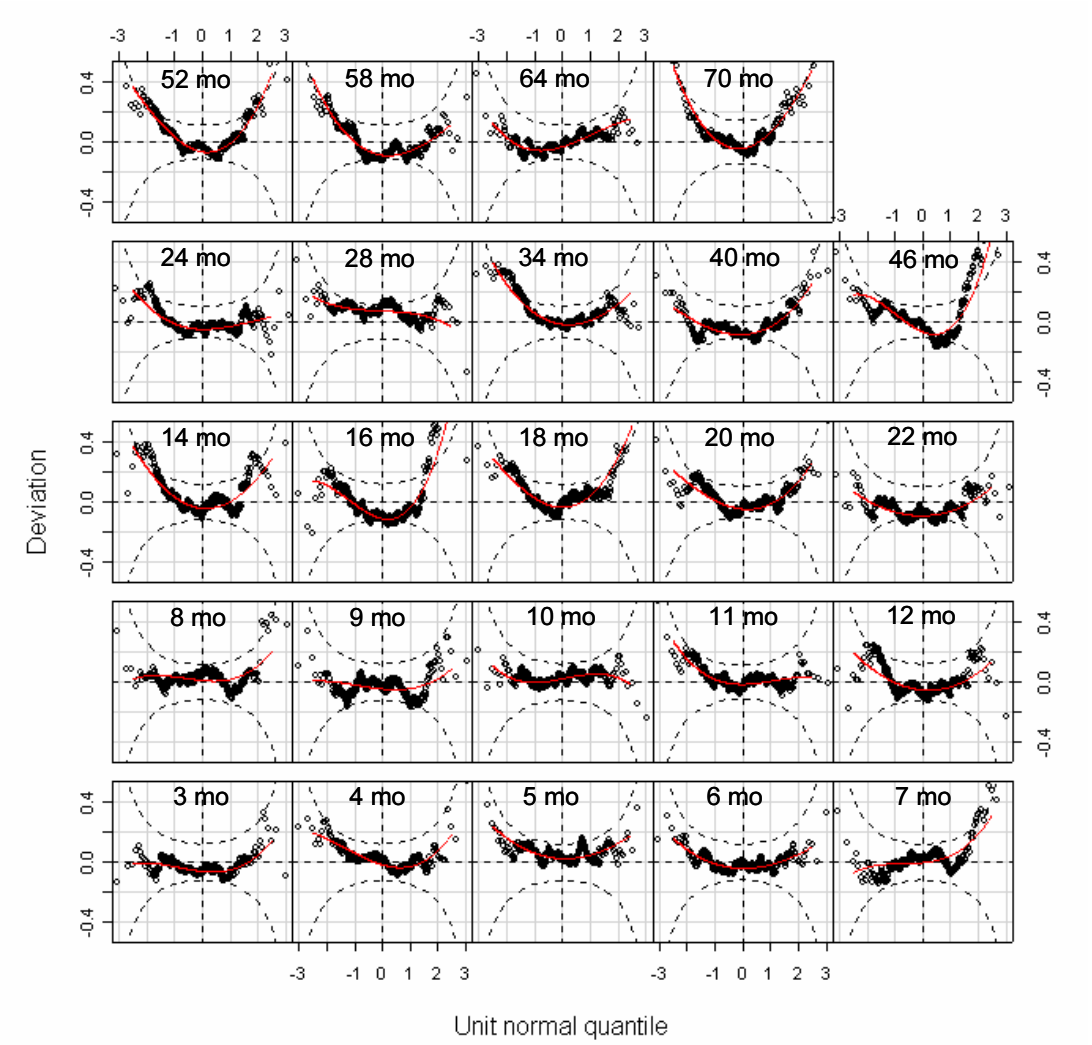


Figure 22 Worm plots of z-scores for Model 1 for arm circumference-for-age for boys

Table 22 Q-test for z-scores from Model 1 [BCPE(x=age$^{0.35}$, df(μ)=8, df(σ)=4, ν=1, τ=2)] for arm circumference-for-age for boys

Age (days)	Group	N	z1	z2	z3	z4
79 to 99	**3 mo**	409	-0.85	0.15	1.02	0.70
100 to 129	**4 mo**	404	0.23	-0.76	1.79	0.99
130 to 159	**5 mo**	409	1.15	-0.28	1.51	0.35
160 to 189	**6 mo**	411	-0.32	-0.38	1.33	-0.03
190 to 219	**7 mo**	406	0.25	1.44	1.03	1.08
220 to 249	**8 mo**	420	0.37	0.30	1.08	1.06
250 to 279	**9 mo**	392	-0.83	0.11	1.01	0.73
280 to 309	**10 mo**	399	0.41	0.53	0.19	-1.14
310 to 349	**11 mo**	461	0.24	-0.65	1.37	-0.67
350 to 379	**12 mo**	409	-0.39	-0.32	1.69	0.26
380 to 439	**14 mo**	418	0.33	-0.37	2.87	0.49
440 to 499	**16 mo**	415	-0.60	1.15	4.15	2.48
500 to 559	**18 mo**	442	0.66	0.80	3.52	1.59
560 to 619	**20 mo**	523	-0.04	0.05	2.43	0.65
620 to 679	**22 mo**	545	-1.38	-0.13	1.83	0.16
680 to 749	**24 mo**	591	-0.70	-0.69	1.69	-0.33
750 to 929	**28 mo**	471	1.58	-0.74	0.00	-0.42
930 to 1119	**34 mo**	510	1.01	-1.24	3.29	-0.07
1120 to 1309	**40 mo**	511	-1.01	0.64	2.24	0.73
1310 to 1499	**46 mo**	508	0.12	0.36	4.32	2.81
1500 to 1689	**52 mo**	487	0.21	-0.02	4.03	1.59
1690 to 1879	**58 mo**	482	-0.64	-1.15	2.91	0.00
1880 to 2069	**64 mo**	461	-0.14	1.06	1.31	-0.48
2070 to 2249	**70 mo**	286	0.67	0.44	3.18	0.64
Overall Q stats		**10 770**	**12.22**	**11.66**	**137.37**	**27.45**
degrees of freedom			**16.0**	**21.5**	**24.0**	**24.0**
p-value			**0.7284**	**0.9569**	**<0.01**	**0.2841**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

The next step involved fitting the parameter ν for skewness using the BCPE distribution with fixed parameter τ=2, keeping the degrees of freedom for the μ and σ curves selected for Model 1. Table 23 shows the *GAIC(3)* values for various degrees of freedom for the ν curve.

Table 23 Goodness-of-fit summary for models BCPE(x=age$^{0.35}$, df(μ)=8, df(σ)=4, df(ν)=?, τ=2) for arm circumference-for-age for boys

df(ν)	GD[a]	GAIC(3)[a]	Total df
1	238.3	277.3	13
2	232.0	274.0	14
3	231.4	276.4	15
4	230.2	278.3	16
5	228.1	279.1	17
6	225.1	279.1	18
7	222.2	279.2	19

GD, Global Deviance; GAIC(3), Generalized Akaike Information Criterion with penalty equal to 3;
[a] In excess of 34 000.

The smallest *GAIC(3)* value corresponded to df(ν)=2. A new iteration was performed using df(ν)=2 to re-search for df(μ) and df(σ). This search led to similar results as before, i.e. df(μ)=8 and df(σ)=4 was still the best combination (*GAIC(3)*=34274.0), but the combination df(μ)=7 and df(σ)=4 yielded a very similar *GAIC(3)* value (34274.5) and thus it was selected in the interest of further smoothing the median curve. A new search for the best df(ν) and, subsequently, age-transformation power λ using this model was carried out, but results indicated no need to update the selected model. Thus, the model BCPE(x=age$^{0.35}$, df(μ)=7, df(σ)=4, df(ν)=2, τ=2) was further evaluated.

Model 2: BCPE(x= age$^{0.35}$, df(μ)=7, df(σ)=4, df(ν)=2, τ=2)

Figure 23 shows the fitting of the parameters μ, σ and ν for Model 2 with their respective sample estimates, that is, the median for μ and Box-Cox transform power for ν. It should be noted that the sample estimate for the parameter σ is no longer the coefficient of variation when the distribution departs significantly from the normal distribution. In this case, the best estimator of σ is the sample standard deviation of the Box-Cox transformed data (Cole and Green, 1992).

Figures 24 and 25 show the distribution of differences between empirical values and fitted centiles for the longitudinal and cross-sectional samples, respectively. There was indication of systematic bias between 3 and 24 months only for the 90th centile (Figure 24), and between 24 and 71 months only for the 10th centile (Figure 25).

The worm plots for this model (Figure 26) were significantly improved compared to those of Model 1 (Figure 22). The U-shaped worms flattened out significantly (Figure 26), indicating that the residual skewness associated with Model 1 had been corrected. There was indication of remaining skewness only for one age group (28 mo). Another two groups presented slightly S-shaped worm (16 mo and 46 mo) suggesting residual kurtosis but it was contained within the 95% confidence interval.

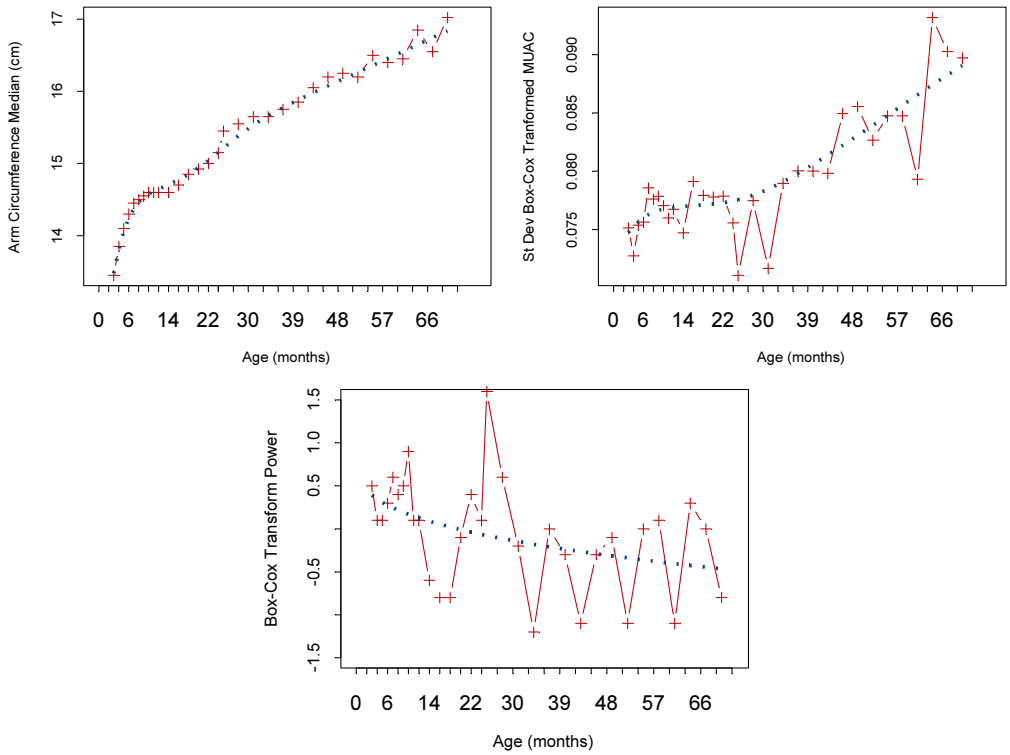


Figure 23 Fitting of the μ, σ, and ν curves of Model 2 for arm circumference-for-age for boys from 3 to 71 months (dotted line) and their respective sample estimates (points with solid line)

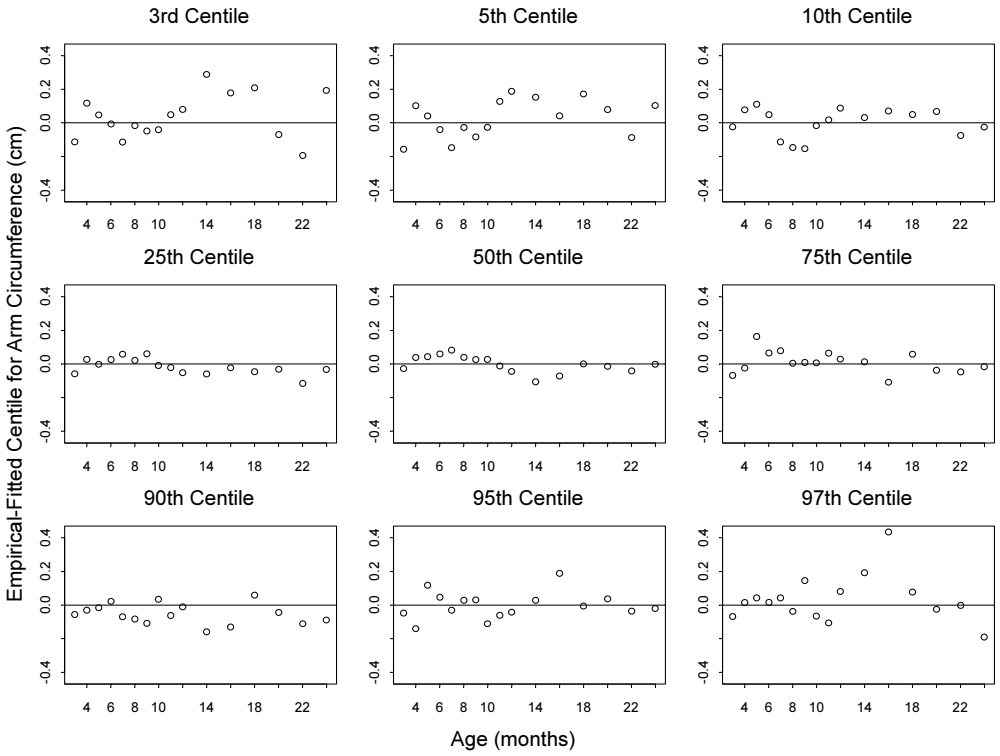


Figure 24 Centile residuals from fitting Model 2 for arm circumference-for-age from 3 to 24 months for boys

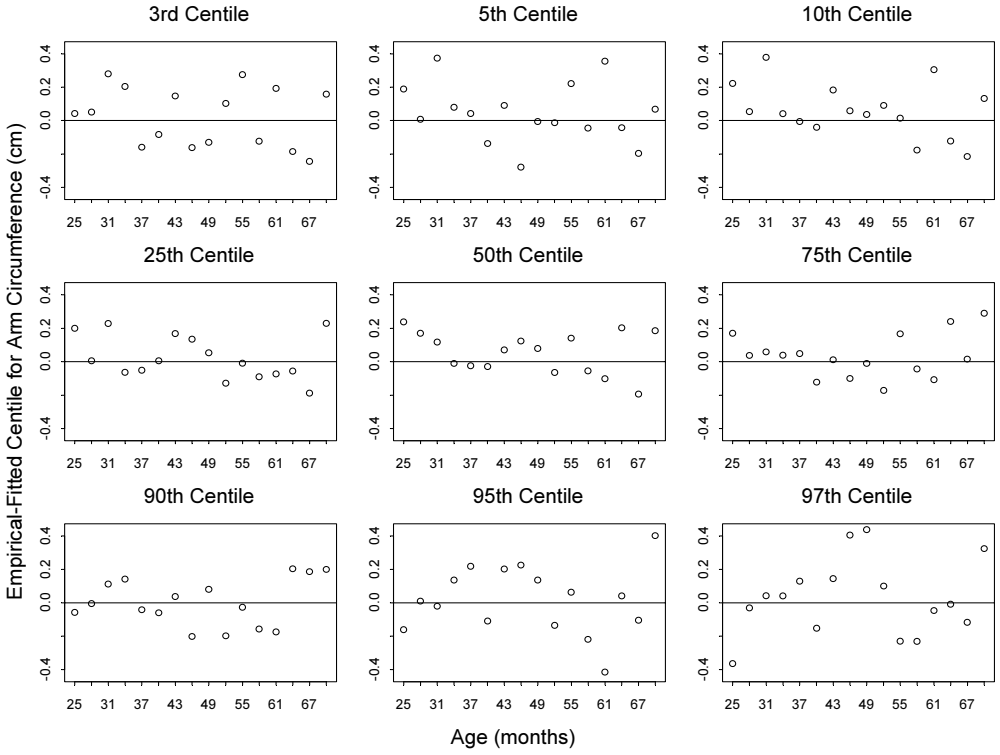


Figure 25 Centile residuals from fitting Model 2 for arm circumference-for-age from 24 to 71 months for boys

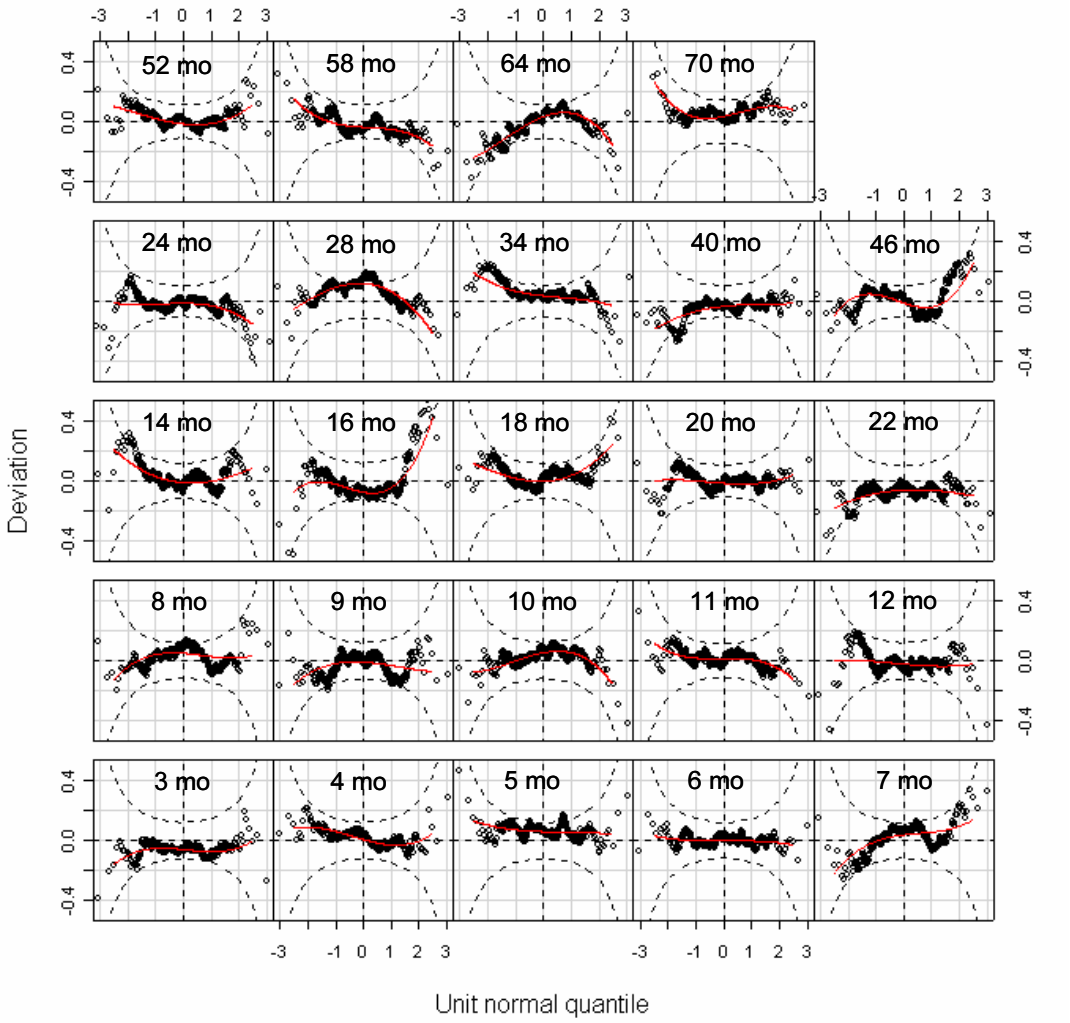


Figure 26 Worm plots of z-scores for Model 2 for arm circumference-for-age for boys

The Q-test results from Model 2 are shown in Table 24. There were two age groups with an absolute value larger than 2 for the statistic z3 (16 mo and 28 mo) suggesting remaining skewness. No group presented an absolute value of z4 greater than 2, indicating no remaining kurtosis. The overall Q-test p-values were all non-significant, indicating an adequate fit of the boys' arm circumference-for-age curves and presenting no justification for increasing the complexity of the model by adjusting for kurtosis (modelling τ).

Table 25 presents observed percentages with arm circumferences below the fitted centiles. Age groups above 24 months presented larger differences compared to the age range younger than 24 months, yet there was no detectable pattern suggesting systematic bias.

Table 24 Q-test for z-scores from Model 2 [BCPE(x=age$^{0.35}$, df(μ)=7, df(σ)=4, df(ν)=2, τ=2)] for arm circumference-for-age for boys

Age (days)	Group	N	z1	z2	z3	z4
79 to 99	**3 mo**	409	-1.30	0.17	-0.21	0.71
100 to 129	**4 mo**	404	0.24	-0.85	0.54	0.65
130 to 159	**5 mo**	409	1.36	-0.40	0.25	-0.02
160 to 189	**6 mo**	411	-0.05	-0.37	0.02	-0.25
190 to 219	**7 mo**	406	0.43	1.47	-0.59	0.69
220 to 249	**8 mo**	420	0.54	0.32	-0.58	0.73
250 to 279	**9 mo**	392	-0.73	0.24	-0.60	0.49
280 to 309	**10 mo**	399	0.43	0.64	-1.21	-0.82
310 to 349	**11 mo**	461	0.26	-0.64	-0.16	-0.86
350 to 379	**12 mo**	409	-0.42	-0.28	0.02	0.41
380 to 439	**14 mo**	418	0.28	-0.53	1.25	0.02
440 to 499	**16 mo**	415	-0.73	0.94	2.03	1.96
500 to 559	**18 mo**	442	0.53	0.54	1.53	0.52
560 to 619	**20 mo**	523	-0.20	0.04	0.24	0.25
620 to 679	**22 mo**	545	-1.56	0.10	-0.44	0.06
680 to 749	**24 mo**	591	-0.77	-0.51	-0.61	-0.31
750 to 929	**28 mo**	471	1.72	-0.61	-2.12	0.00
930 to 1119	**34 mo**	510	1.27	-1.51	1.19	-1.28
1120 to 1309	**40 mo**	511	-1.03	0.90	-0.62	0.20
1310 to 1499	**46 mo**	508	0.04	0.15	0.87	1.88
1500 to 1689	**52 mo**	487	0.08	-0.26	1.05	0.40
1690 to 1879	**58 mo**	482	-0.66	-1.07	0.14	-0.94
1880 to 2069	**64 mo**	461	-0.14	1.45	-1.80	-0.72
2070 to 2249	**70 mo**	286	0.91	0.08	0.80	-0.78
Overall Q stats		**10 770**	**15.93**	**12.75**	**23.65**	**15.46**
degrees of freedom			**17.0**	**21.5**	**22.0**	**24.0**
p-value			**0.5289**	**0.9291**	**0.3657**	**0.9064**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

In conclusion, the model selected for constructing the arm circumference-for-age growth curves for boys was BCPE(x=age$^{0.35}$, df(μ)=7, df(σ)=4, df(ν)=2, τ=2) that adjusts only for skewness, and thus reduces in essence to the LMS method (Cole and Green, 1992). The fitted centile curves and empirical centiles are shown in Figures 27 to 30.

Table 25 Observed proportions of children with measurements below the fitted centiles from Model 2, arm circumference-for-age for boys

Expected	3 mo	4 mo	5 mo	6 mo	7 mo	8 mo	9 mo	10 mo	11 mo
1	1.0	1.0	0.7	1.0	1.7	1.2	1.3	1.5	1.1
3	4.2	2.0	2.7	2.7	4.4	3.1	4.1	3.8	2.4
5	6.1	4.2	4.6	5.4	6.7	5.2	5.6	5.5	3.9
10	10.5	8.7	8.1	9.2	11.6	10.5	12.5	9.8	8.9
25	27.6	24.3	24.9	25.3	23.9	24.0	22.7	25.6	24.7
50	52.1	49.5	47.9	48.9	47.8	46.9	50.5	47.1	50.5
75	78.5	76.5	72.1	73.5	72.7	74.3	75.5	72.4	73.5
90	91.2	90.1	90.2	90.0	90.1	90.7	92.1	88.7	90.9
95	95.6	95.5	94.1	95.1	94.6	94.8	94.9	95.7	96.1
97	97.1	96.8	96.6	96.8	95.8	97.1	96.7	97.2	97.4
99	98.5	99.0	98.8	99.0	98.0	98.3	98.7	99.2	99.1
Expected	**12 mo**	**14 mo**	**16 mo**	**18 mo**	**20 mo**	**22 mo**	**24 mo**	**28 mo**	**34 mo**
1	1.2	0.7	1.0	0.9	1.5	1.1	1.0	1.1	0.4
3	2.2	1.9	2.4	2.0	3.1	4.0	2.4	3.2	1.4
5	3.4	2.6	4.6	3.6	4.6	5.7	4.1	4.9	2.9
10	9.3	9.3	9.4	9.3	9.2	10.8	10.7	8.7	7.3
25	26.9	26.3	26.3	25.8	26.4	28.8	27.1	21.9	23.5
50	51.8	52.2	53.3	49.3	50.1	51.4	51.3	46.3	48.6
75	75.1	73.4	78.3	72.9	74.8	78.0	75.5	71.5	73.5
90	91.0	91.1	91.3	89.1	91.0	92.1	91.4	91.1	89.2
95	95.1	94.3	93.7	95.5	94.5	94.9	95.1	95.1	94.3
97	96.3	95.9	95.9	96.4	97.3	96.9	97.3	97.2	96.7
99	99.3	98.8	97.8	98.4	98.9	99.3	99.5	99.2	99.4

Table 25 Observed proportions of children with measurements below the fitted centiles from Model 2, arm circumference-for-age for boys (cont)

Expected	40 mo	46 mo	52 mo	58 mo	64 mo	70 mo	Overall
1	1.2	1.2	1.0	1.0	1.3	0.0	1.1
3	5.3	4.1	2.5	2.3	4.1	3.1	3.1
5	6.8	5.5	4.1	4.8	7.6	4.5	4.9
10	11.2	8.7	9.7	9.5	11.1	10.1	9.7
25	25.2	22.8	26.3	28.4	27.3	22.7	25.5
50	51.9	48.6	49.5	51.7	49.7	49.3	49.9
75	75.9	78.3	75.6	75.5	71.6	71.7	74.7
90	90.8	90.7	89.9	92.1	89.2	88.1	90.6
95	94.9	93.7	94.3	95.2	95.7	93.0	94.8
97	97.1	95.7	96.7	97.5	97.4	96.5	96.8
99	99.0	98.4	98.8	99.6	99.3	99.0	98.9

Note: Group labels correspond to the age intervals in Table 24.

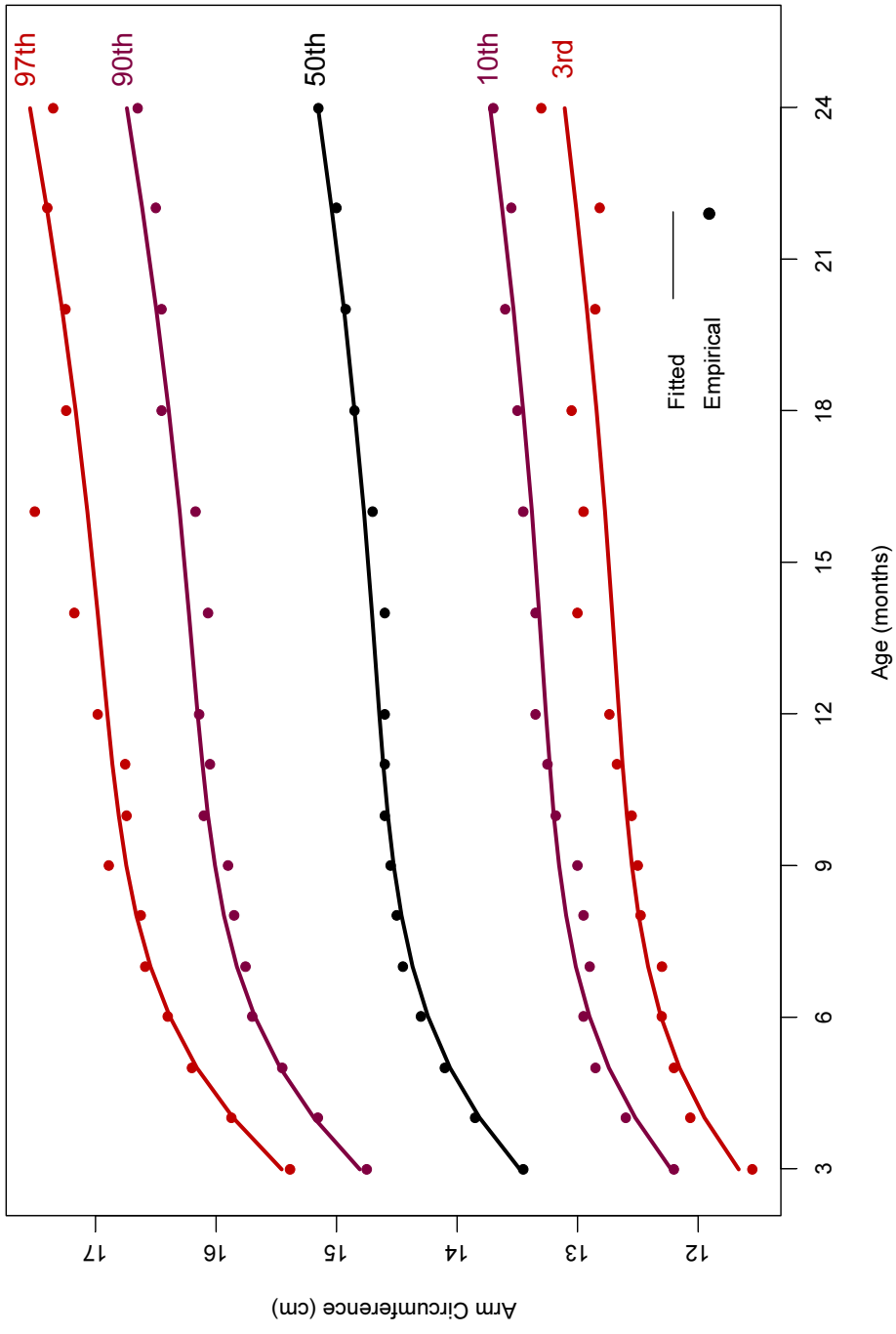


Figure 27 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: arm circumference-for-age for boys from 3 to 24 months

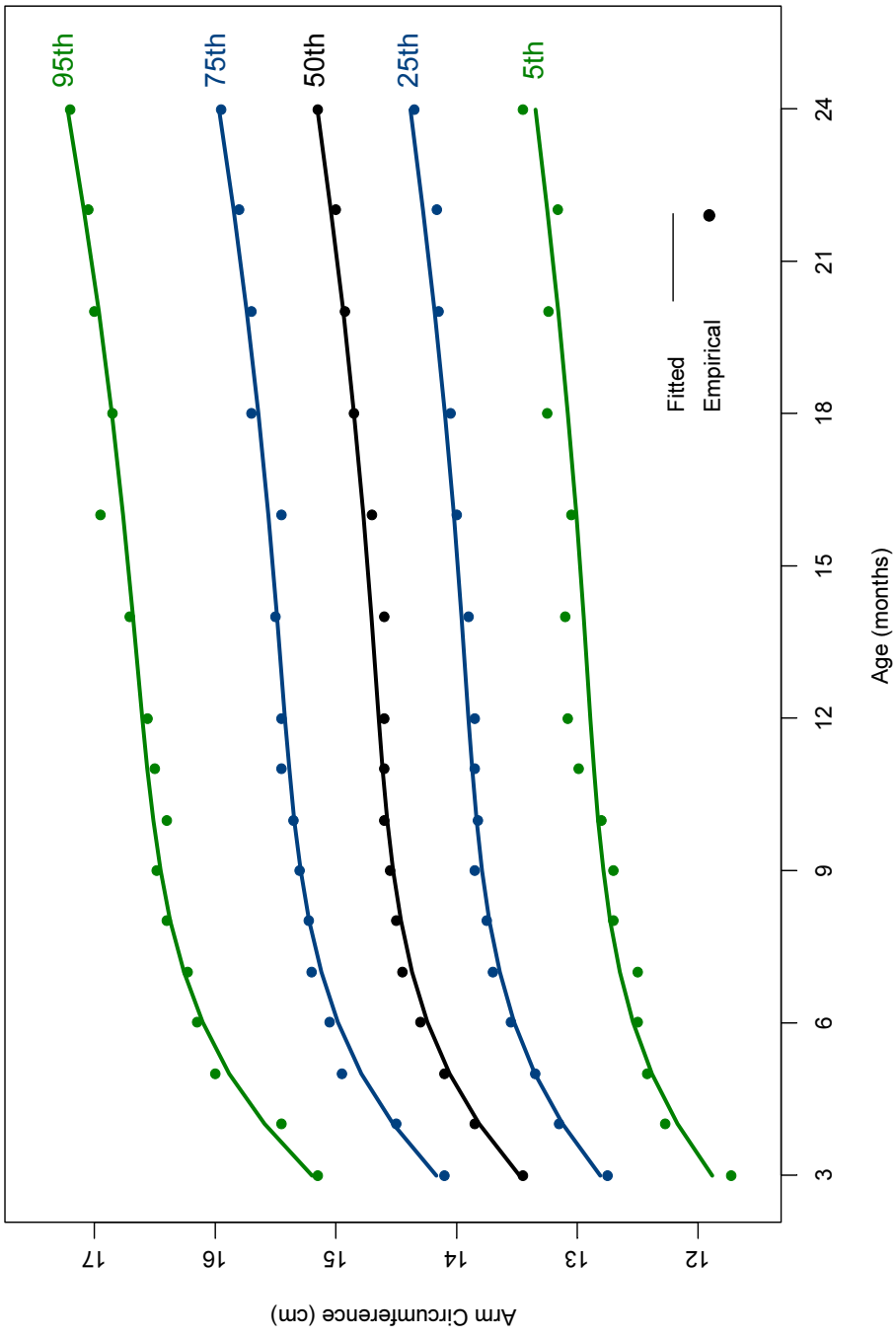


Figure 28 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: arm circumference-for-age for boys from 3 to 24 months

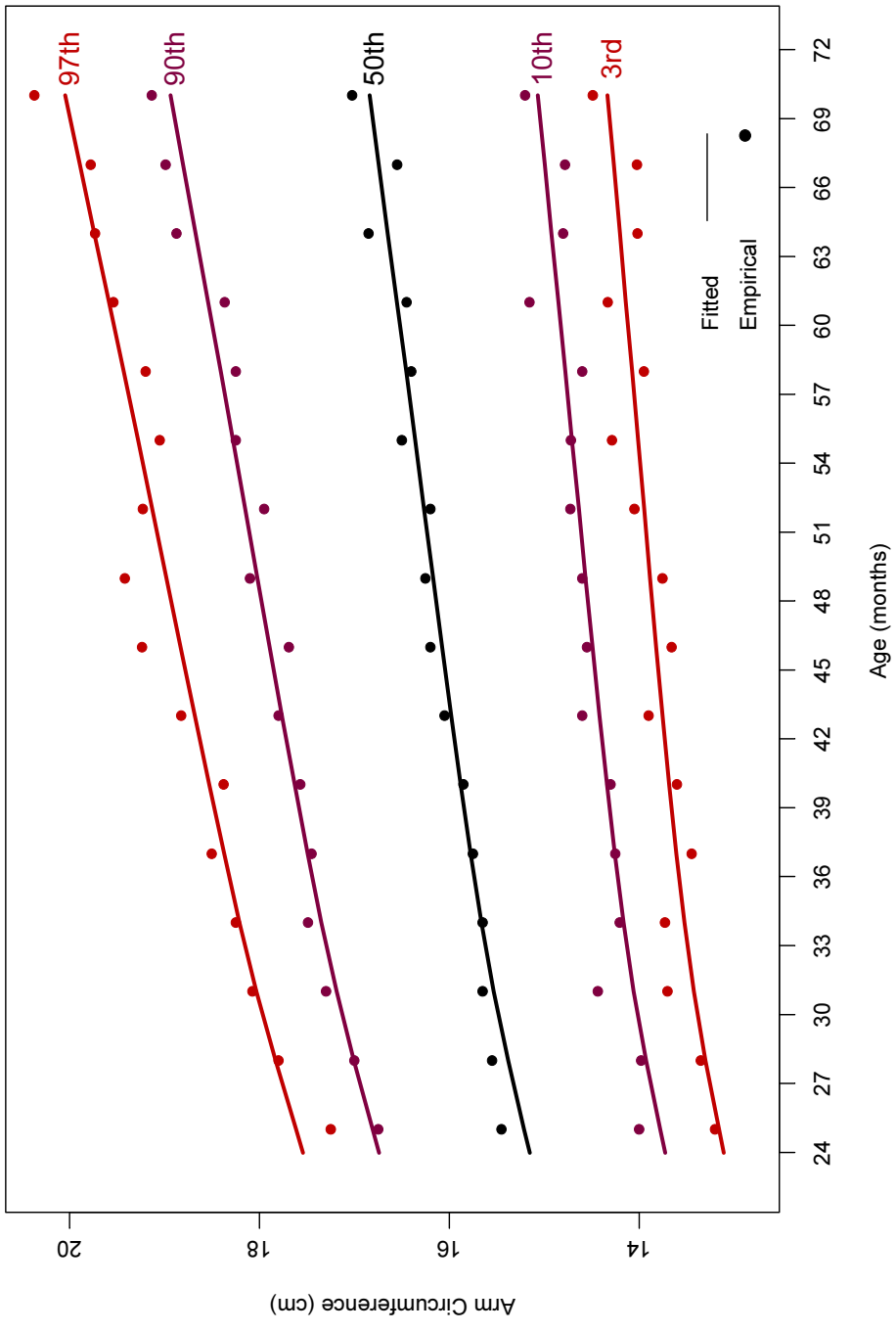


Figure 29 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: arm circumference-for-age for boys from 24 to 71 months

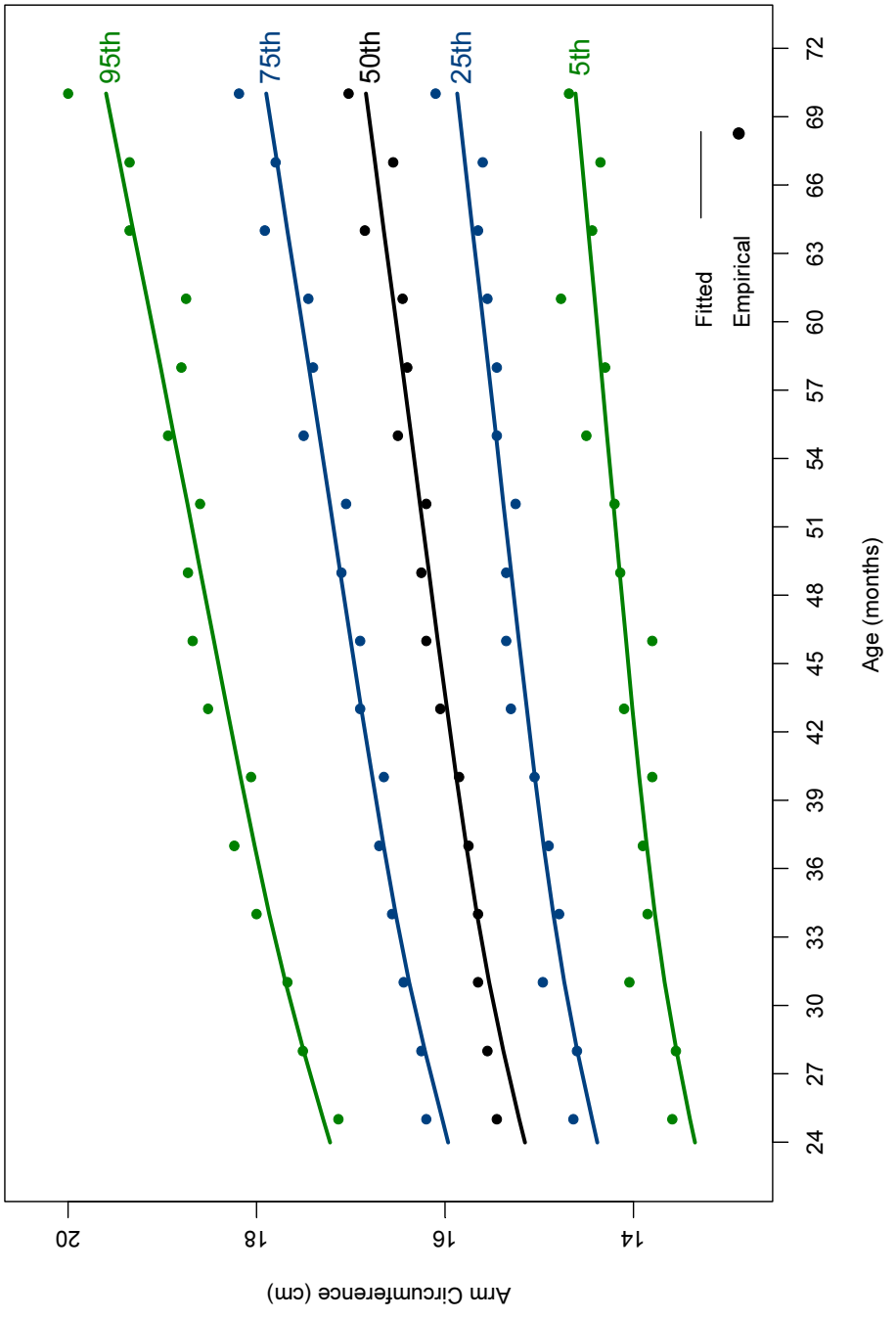


Figure 30 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: arm circumference-for-age for boys from 24 to 71 months

4.2.3 WHO standards

This section presents the final WHO arm circumference-for-age z-score and percentile charts (Figures 31 and 32) and table (Table 26) for boys.

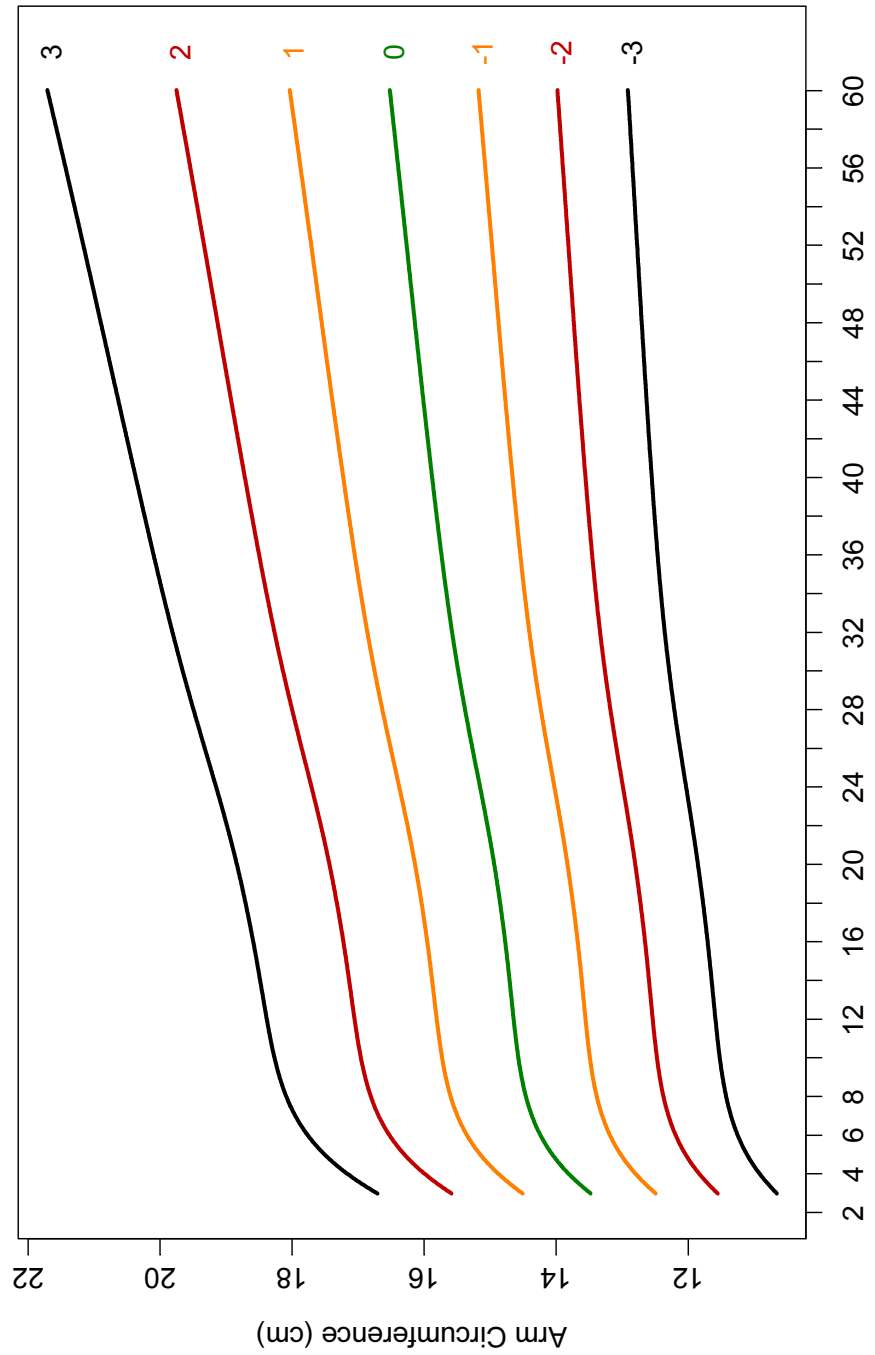


Figure 31 WHO arm circumference-for-age z-scores for boys from 3 to 60 months

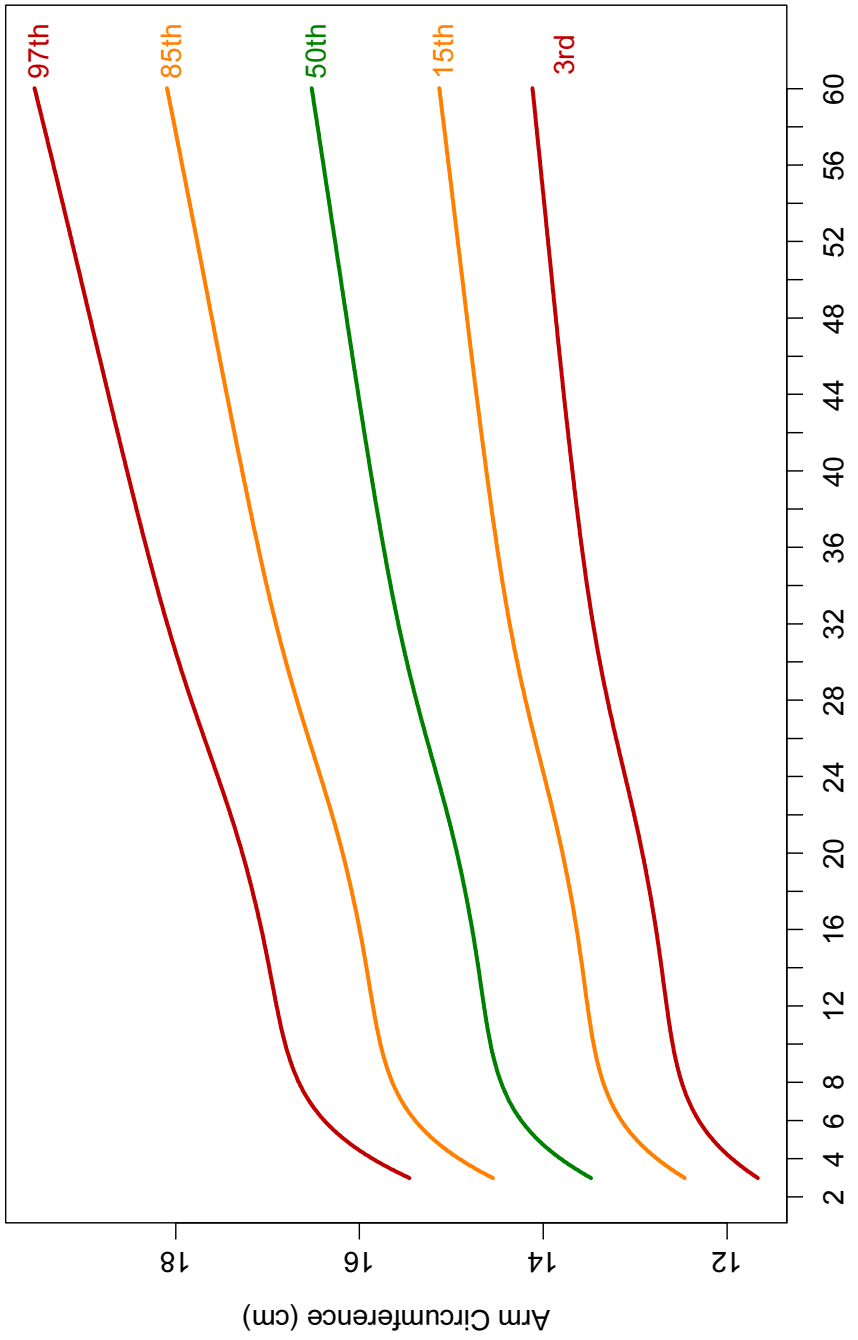


Figure 32 WHO arm circumference-for-age percentiles for boys from 3 to 60 months

Table 26 Arm circumference-for-age for boys, age in years and months

Year: Month	Month	L	M	S	Percentiles (arm circumference in cm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
0: 3	**3**	0.3928	13.4817	0.07475	11.3	11.7	11.9	12.5	12.8	13.5	14.2	14.6	15.2	15.5	16.0
0: 4	**4**	0.3475	13.8097	0.07523	11.5	11.9	12.2	12.8	13.1	13.8	14.5	14.9	15.6	15.9	16.4
0: 5	**5**	0.3092	14.0585	0.07566	11.7	12.2	12.4	13.0	13.4	14.1	14.8	15.2	15.9	16.2	16.7
0: 6	**6**	0.2755	14.2389	0.07601	11.9	12.3	12.5	13.1	13.5	14.2	15.0	15.4	16.1	16.4	16.9
0: 7	**7**	0.2453	14.3678	0.07629	12.0	12.4	12.6	13.3	13.6	14.4	15.1	15.5	16.3	16.5	17.1
0: 8	**8**	0.2179	14.4591	0.07650	12.1	12.5	12.7	13.3	13.7	14.5	15.2	15.6	16.4	16.7	17.2
0: 9	**9**	0.1925	14.5245	0.07665	12.1	12.5	12.8	13.4	13.8	14.5	15.3	15.7	16.5	16.7	17.3
0:10	**10**	0.1690	14.5733	0.07676	12.2	12.6	12.8	13.5	13.8	14.6	15.3	15.8	16.5	16.8	17.4
0:11	**11**	0.1469	14.6119	0.07683	12.2	12.6	12.9	13.5	13.9	14.6	15.4	15.8	16.6	16.9	17.4
1: 0	**12**	0.1261	14.6449	0.07689	12.2	12.7	12.9	13.5	13.9	14.6	15.4	15.9	16.6	16.9	17.5
1: 1	**13**	0.1064	14.6758	0.07694	12.2	12.7	12.9	13.5	13.9	14.7	15.5	15.9	16.6	16.9	17.5
1: 2	**14**	0.0876	14.7063	0.07699	12.3	12.7	12.9	13.6	14.0	14.7	15.5	15.9	16.7	17.0	17.6
1: 3	**15**	0.0697	14.7380	0.07703	12.3	12.7	13.0	13.6	14.0	14.7	15.5	16.0	16.7	17.0	17.6
1: 4	**16**	0.0526	14.7723	0.07707	12.3	12.8	13.0	13.6	14.0	14.8	15.6	16.0	16.8	17.1	17.7
1: 5	**17**	0.0362	14.8095	0.07710	12.4	12.8	13.0	13.7	14.1	14.8	15.6	16.0	16.8	17.1	17.7
1: 6	**18**	0.0204	14.8496	0.07713	12.4	12.8	13.1	13.7	14.1	14.8	15.6	16.1	16.9	17.2	17.8
1: 7	**19**	0.0051	14.8926	0.07717	12.4	12.9	13.1	13.7	14.1	14.9	15.7	16.1	16.9	17.2	17.8
1: 8	**20**	-0.0097	14.9388	0.07721	12.5	12.9	13.2	13.8	14.2	14.9	15.7	16.2	17.0	17.3	17.9
1: 9	**21**	-0.0239	14.9883	0.07725	12.5	13.0	13.2	13.8	14.2	15.0	15.8	16.2	17.0	17.3	17.9
1:10	**22**	-0.0378	15.0410	0.07731	12.6	13.0	13.2	13.9	14.3	15.0	15.8	16.3	17.1	17.4	18.0
1:11	**23**	-0.0512	15.0964	0.07738	12.6	13.1	13.3	13.9	14.3	15.1	15.9	16.4	17.2	17.5	18.1
2: 0	**24**	-0.0643	15.1536	0.07746	12.7	13.1	13.3	14.0	14.4	15.2	16.0	16.4	17.2	17.5	18.2

Table 26 Arm circumference-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Percentiles (arm circumference in cm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
2: 1	**25**	-0.0770	15.2115	0.07755	12.7	13.2	13.4	14.0	14.4	15.2	16.0	16.5	17.3	17.6	18.2
2: 2	**26**	-0.0894	15.2693	0.07767	12.8	13.2	13.4	14.1	14.5	15.3	16.1	16.6	17.4	17.7	18.3
2: 3	**27**	-0.1014	15.3259	0.07780	12.8	13.3	13.5	14.1	14.5	15.3	16.2	16.6	17.4	17.8	18.4
2: 4	**28**	-0.1132	15.3808	0.07794	12.9	13.3	13.5	14.2	14.6	15.4	16.2	16.7	17.5	17.8	18.5
2: 5	**29**	-0.1248	15.4336	0.07810	12.9	13.3	13.6	14.2	14.6	15.4	16.3	16.7	17.6	17.9	18.5
2: 6	**30**	-0.1360	15.4839	0.07827	12.9	13.4	13.6	14.3	14.7	15.5	16.3	16.8	17.6	18.0	18.6
2: 7	**31**	-0.1470	15.5317	0.07846	13.0	13.4	13.7	14.3	14.7	15.5	16.4	16.9	17.7	18.0	18.7
2: 8	**32**	-0.1578	15.5771	0.07866	13.0	13.5	13.7	14.4	14.8	15.6	16.4	16.9	17.8	18.1	18.8
2: 9	**33**	-0.1684	15.6201	0.07887	13.0	13.5	13.7	14.4	14.8	15.6	16.5	17.0	17.8	18.2	18.8
2:10	**34**	-0.1788	15.6611	0.07909	13.1	13.5	13.8	14.4	14.9	15.7	16.5	17.0	17.9	18.2	18.9
2:11	**35**	-0.1890	15.7003	0.07933	13.1	13.6	13.8	14.5	14.9	15.7	16.6	17.1	17.9	18.3	18.9
3: 0	**36**	-0.1989	15.7380	0.07956	13.1	13.6	13.8	14.5	14.9	15.7	16.6	17.1	18.0	18.3	19.0
3: 1	**37**	-0.2087	15.7745	0.07981	13.1	13.6	13.9	14.5	15.0	15.8	16.7	17.1	18.0	18.4	19.1
3: 2	**38**	-0.2184	15.8101	0.08006	13.2	13.6	13.9	14.6	15.0	15.8	16.7	17.2	18.1	18.4	19.1
3: 3	**39**	-0.2278	15.8450	0.08032	13.2	13.7	13.9	14.6	15.0	15.8	16.7	17.2	18.1	18.5	19.2
3: 4	**40**	-0.2372	15.8793	0.08058	13.2	13.7	13.9	14.6	15.0	15.9	16.8	17.3	18.2	18.5	19.2
3: 5	**41**	-0.2463	15.9132	0.08085	13.2	13.7	14.0	14.6	15.1	15.9	16.8	17.3	18.2	18.6	19.3
3: 6	**42**	-0.2553	15.9467	0.08112	13.3	13.7	14.0	14.7	15.1	15.9	16.9	17.4	18.3	18.6	19.3
3: 7	**43**	-0.2642	15.9797	0.08139	13.3	13.8	14.0	14.7	15.1	16.0	16.9	17.4	18.3	18.7	19.4
3: 8	**44**	-0.2730	16.0124	0.08166	13.3	13.8	14.0	14.7	15.2	16.0	16.9	17.4	18.4	18.7	19.5
3: 9	**45**	-0.2816	16.0447	0.08194	13.3	13.8	14.1	14.8	15.2	16.0	17.0	17.5	18.4	18.8	19.5
3:10	**46**	-0.2901	16.0767	0.08222	13.3	13.8	14.1	14.8	15.2	16.1	17.0	17.5	18.5	18.8	19.6
3:11	**47**	-0.2985	16.1085	0.08250	13.4	13.8	14.1	14.8	15.2	16.1	17.0	17.6	18.5	18.9	19.6
4: 0	**48**	-0.3067	16.1400	0.08278	13.4	13.9	14.1	14.8	15.3	16.1	17.1	17.6	18.5	18.9	19.7

Table 26 Arm circumference-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Percentiles (arm circumference in cm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
4: 1	**49**	-0.3149	16.1714	0.08307	13.4	13.9	14.1	14.9	15.3	16.2	17.1	17.6	18.6	19.0	19.7
4: 2	**50**	-0.3229	16.2027	0.08335	13.4	13.9	14.2	14.9	15.3	16.2	17.1	17.7	18.6	19.0	19.8
4: 3	**51**	-0.3309	16.2340	0.08364	13.4	13.9	14.2	14.9	15.4	16.2	17.2	17.7	18.7	19.1	19.9
4: 4	**52**	-0.3387	16.2654	0.08392	13.5	13.9	14.2	14.9	15.4	16.3	17.2	17.8	18.7	19.1	19.9
4: 5	**53**	-0.3464	16.2968	0.08421	13.5	14.0	14.2	15.0	15.4	16.3	17.3	17.8	18.8	19.2	20.0
4: 6	**54**	-0.3541	16.3283	0.08450	13.5	14.0	14.3	15.0	15.4	16.3	17.3	17.8	18.8	19.2	20.0
4: 7	**55**	-0.3616	16.3599	0.08479	13.5	14.0	14.3	15.0	15.5	16.4	17.3	17.9	18.9	19.3	20.1
4: 8	**56**	-0.3691	16.3916	0.08508	13.5	14.0	14.3	15.0	15.5	16.4	17.4	17.9	18.9	19.3	20.1
4: 9	**57**	-0.3765	16.4233	0.08537	13.6	14.1	14.3	15.1	15.5	16.4	17.4	18.0	19.0	19.4	20.2
4:10	**58**	-0.3838	16.4551	0.08566	13.6	14.1	14.3	15.1	15.5	16.5	17.4	18.0	19.0	19.4	20.2
4:11	**59**	-0.3910	16.4871	0.08595	13.6	14.1	14.4	15.1	15.6	16.5	17.5	18.1	19.1	19.5	20.3
5: 0	**60**	-0.3981	16.5191	0.08624	13.6	14.1	14.4	15.1	15.6	16.5	17.5	18.1	19.1	19.5	20.4

Table 26 Arm circumference-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (arm circumference in cm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 3	**3**	0.3928	13.4817	0.07475	10.7	11.6	12.5	13.5	14.5	15.6	16.7
0: 4	**4**	0.3475	13.8097	0.07523	10.9	11.8	12.8	13.8	14.9	16.0	17.2
0: 5	**5**	0.3092	14.0585	0.07566	11.1	12.0	13.0	14.1	15.2	16.3	17.5
0: 6	**6**	0.2755	14.2389	0.07601	11.3	12.2	13.2	14.2	15.4	16.5	17.8
0: 7	**7**	0.2453	14.3678	0.07629	11.4	12.3	13.3	14.4	15.5	16.7	18.0
0: 8	**8**	0.2179	14.4591	0.07650	11.4	12.4	13.4	14.5	15.6	16.8	18.1
0: 9	**9**	0.1925	14.5245	0.07665	11.5	12.4	13.4	14.5	15.7	16.9	18.2
0:10	**10**	0.1690	14.5733	0.07676	11.5	12.5	13.5	14.6	15.7	17.0	18.3
0:11	**11**	0.1469	14.6119	0.07683	11.6	12.5	13.5	14.6	15.8	17.0	18.3
1: 0	**12**	0.1261	14.6449	0.07689	11.6	12.5	13.6	14.6	15.8	17.1	18.4
1: 1	**13**	0.1064	14.6758	0.07694	11.6	12.6	13.6	14.7	15.8	17.1	18.4
1: 2	**14**	0.0876	14.7063	0.07699	11.6	12.6	13.6	14.7	15.9	17.1	18.5
1: 3	**15**	0.0697	14.7380	0.07703	11.7	12.6	13.6	14.7	15.9	17.2	18.5
1: 4	**16**	0.0526	14.7723	0.07707	11.7	12.7	13.7	14.8	16.0	17.2	18.6
1: 5	**17**	0.0362	14.8095	0.07710	11.7	12.7	13.7	14.8	16.0	17.3	18.6
1: 6	**18**	0.0204	14.8496	0.07713	11.8	12.7	13.7	14.8	16.0	17.3	18.7
1: 7	**19**	0.0051	14.8926	0.07717	11.8	12.8	13.8	14.9	16.1	17.4	18.8
1: 8	**20**	-0.0097	14.9388	0.07721	11.9	12.8	13.8	14.9	16.1	17.4	18.8
1: 9	**21**	-0.0239	14.9883	0.07725	11.9	12.8	13.9	15.0	16.2	17.5	18.9
1:10	**22**	-0.0378	15.0410	0.07731	11.9	12.9	13.9	15.0	16.3	17.6	19.0
1:11	**23**	-0.0512	15.0964	0.07738	12.0	12.9	14.0	15.1	16.3	17.6	19.1
2: 0	**24**	-0.0643	15.1536	0.07746	12.0	13.0	14.0	15.2	16.4	17.7	19.2

Table 26 Arm circumference-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (arm circumference in cm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
2: 1	**25**	-0.0770	15.2115	0.07755	12.1	13.0	14.1	15.2	16.4	17.8	19.2
2: 2	**26**	-0.0894	15.2693	0.07767	12.1	13.1	14.1	15.3	16.5	17.9	19.3
2: 3	**27**	-0.1014	15.3259	0.07780	12.2	13.1	14.2	15.3	16.6	17.9	19.4
2: 4	**28**	-0.1132	15.3808	0.07794	12.2	13.2	14.2	15.4	16.6	18.0	19.5
2: 5	**29**	-0.1248	15.4336	0.07810	12.3	13.2	14.3	15.4	16.7	18.1	19.6
2: 6	**30**	-0.1360	15.4839	0.07827	12.3	13.3	14.3	15.5	16.8	18.1	19.7
2: 7	**31**	-0.1470	15.5317	0.07846	12.3	13.3	14.4	15.5	16.8	18.2	19.7
2: 8	**32**	-0.1578	15.5771	0.07866	12.4	13.3	14.4	15.6	16.9	18.3	19.8
2: 9	**33**	-0.1684	15.6201	0.07887	12.4	13.4	14.4	15.6	16.9	18.3	19.9
2:10	**34**	-0.1788	15.6611	0.07909	12.4	13.4	14.5	15.7	17.0	18.4	20.0
2:11	**35**	-0.1890	15.7003	0.07933	12.4	13.4	14.5	15.7	17.0	18.4	20.0
3: 0	**36**	-0.1989	15.7380	0.07956	12.5	13.5	14.5	15.7	17.1	18.5	20.1
3: 1	**37**	-0.2087	15.7745	0.07981	12.5	13.5	14.6	15.8	17.1	18.6	20.2
3: 2	**38**	-0.2184	15.8101	0.08006	12.5	13.5	14.6	15.8	17.1	18.6	20.2
3: 3	**39**	-0.2278	15.8450	0.08032	12.5	13.5	14.6	15.8	17.2	18.7	20.3
3: 4	**40**	-0.2372	15.8793	0.08058	12.6	13.6	14.7	15.9	17.2	18.7	20.4
3: 5	**41**	-0.2463	15.9132	0.08085	12.6	13.6	14.7	15.9	17.3	18.8	20.4
3: 6	**42**	-0.2553	15.9467	0.08112	12.6	13.6	14.7	15.9	17.3	18.8	20.5
3: 7	**43**	-0.2642	15.9797	0.08139	12.6	13.6	14.7	16.0	17.4	18.9	20.6
3: 8	**44**	-0.2730	16.0124	0.08166	12.6	13.6	14.8	16.0	17.4	18.9	20.6
3: 9	**45**	-0.2816	16.0447	0.08194	12.7	13.7	14.8	16.0	17.4	19.0	20.7
3:10	**46**	-0.2901	16.0767	0.08222	12.7	13.7	14.8	16.1	17.5	19.0	20.8
3:11	**47**	-0.2985	16.1085	0.08250	12.7	13.7	14.8	16.1	17.5	19.1	20.8
4: 0	**48**	-0.3067	16.1400	0.08278	12.7	13.7	14.9	16.1	17.6	19.1	20.9

Table 26 Arm circumference-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (arm circumference in cm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	**49**	-0.3149	16.1714	0.08307	12.7	13.8	14.9	16.2	17.6	19.2	21.0
4: 2	**50**	-0.3229	16.2027	0.08335	12.7	13.8	14.9	16.2	17.6	19.2	21.0
4: 3	**51**	-0.3309	16.2340	0.08364	12.8	13.8	14.9	16.2	17.7	19.3	21.1
4: 4	**52**	-0.3387	16.2654	0.08392	12.8	13.8	15.0	16.3	17.7	19.3	21.2
4: 5	**53**	-0.3464	16.2968	0.08421	12.8	13.8	15.0	16.3	17.8	19.4	21.2
4: 6	**54**	-0.3541	16.3283	0.08450	12.8	13.9	15.0	16.3	17.8	19.4	21.3
4: 7	**55**	-0.3616	16.3599	0.08479	12.8	13.9	15.0	16.4	17.8	19.5	21.4
4: 8	**56**	-0.3691	16.3916	0.08508	12.8	13.9	15.1	16.4	17.9	19.5	21.4
4: 9	**57**	-0.3765	16.4233	0.08537	12.9	13.9	15.1	16.4	17.9	19.6	21.5
4:10	**58**	-0.3838	16.4551	0.08566	12.9	13.9	15.1	16.5	18.0	19.6	21.6
4:11	**59**	-0.3910	16.4871	0.08595	12.9	14.0	15.2	16.5	18.0	19.7	21.6
5: 0	**60**	-0.3981	16.5191	0.08624	12.9	14.0	15.2	16.5	18.0	19.8	21.7

4.3 Arm circumference-for-age for girls

Steps similar to those described in the preceding sections were followed to select the best model to fit the arm circumference-for-age growth curves for girls.

4.3.1 Sample size

There were a total of 10 970 arm circumference measurements for girls. The longitudinal and cross-sectional sample sizes by visit and age are presented in Tables 27 and 28.

Table 27 Longitudinal sample sizes for arm circumference-for-age for girls

Visit	**5**	**6**	**7**	**8**	**9**	**10**
Age	**3 mo**	**4 mo**	**5 mo**	**6 mo**	**7 mo**	**8 mo**
N	437	440	447	445	444	440
Visit	**11**	**12**	**13**	**14**	**15**	**16**
Age	**9 mo**	**10 mo**	**11 mo**	**12 mo**	**14 mo**	**16 mo**
N	445	444	441	449	447	442
Visit	**17**	**18**	**19**	**20**		
Age	**18 mo**	**20 mo**	**22 mo**	**24 mo**		
N	445	443	434	446		

Table 28 Cross-sectional sample sizes for arm circumference-for-age for girls

Age (mo)	**<18**	**18–20**	**21–23**	**24–26**	**27–29**	**30–32**	**33–35**
N	2	159	167	238	214	227	223
Age (mo)	**36–38**	**39–41**	**42–44**	**45–47**	**48–50**	**51–53**	**54–56**
N	220	235	246	208	224	201	230
Age (mo)	**57–59**	**60–62**	**63–65**	**66–68**	**69–71**	**>71**	
N	239	217	205	225	201	0	

4.3.2 Model selection and results

The initial step in the modelling process was to search for the best age power transformation using the same starting model as that used for boys. Table 29 shows the values of global deviance for a grid of possible powers from 0.05 to 1. The smallest global deviance value was associated with λ=0.35, and thus it was selected as the age-transformation power.

Table 29 Global deviance (GD) for models within the class BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) for arm circumference-for-age for girls

λ	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
GD[a]	975.6	974.9	974.3	973.8	973.5	973.2	973.1	973.2	973.3	973.6
λ	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
GD[a]	974.1	974.7	975.5	976.6	978.0	979.7	981.7	984.1	986.9	990.2

[a] In excess of 35 000.

Using λ=0.35, optimal values for df(μ) and df(σ) were sought fixing ν=1 and τ=2. All possible combinations of df(μ) values from 7 to 15 and df(σ) from 2 to 10 were considered. Partial results are presented in Table 30. The smallest value of *GAIC(3)* corresponded to df(μ)=8 and df(σ)=4. Thus this model was selected and further evaluated.

Table 30 Goodness-of-fit summary for models using the BCPE distribution with fixed ν=1 and τ=2 for arm circumference-for-age for girls

df(μ)	df(σ)	GD[a]	AIC[a]	GAIC(3)[a]	Total df
	2	1170.7	1188.7	1197.7	9
	3	1143.0	1163.0	1173.0	10
7	**4**	1133.6	1155.6	1166.6	11
	5	1130.6	1154.6	1166.6	12
	6	1129.5	1155.5	1168.5	13
	2	1167.5	1187.5	1197.5	10
	3	1139.6	1161.6	1172.6	11
8	**4**	1130.2	1154.2	1166.2	12
	5	1127.2	1153.2	1166.2	13
	6	1126.0	1154.0	1168.0	14
	2	1165.0	1187.0	1198.0	11
	3	1137.2	1161.2	1173.2	12
9	**4**	1127.6	1153.6	1166.6	13
	5	1124.7	1152.7	1166.7	14
	6	1123.5	1153.5	1168.5	15
	2	1163.0	1187.0	1199.0	12
	3	1135.1	1161.1	1174.1	13
10	**4**	1125.4	1153.4	1167.4	14
	5	1122.4	1152.4	1167.4	15
	6	1121.3	1153.3	1169.3	16
	2	1161.0	1187.0	1200.0	13
	3	1133.0	1161.0	1175.0	14
11	**4**	1123.3	1153.3	1168.3	15
	5	1120.2	1152.2	1168.2	16
	6	1119.1	1153.1	1170.1	17

GD, Global Deviance; AIC, Akaike Information Criterion;
GAIC(3), Generalized AIC with penalty equal to 3;
[a] In excess of 35 000.

Model 1: BCPE(x=age$^{0.35}$, df(μ)=8, df(σ)=4, ν=1, τ=2)

The worm plots (Figure 33) pointed to the need to adjust for skewness, as the worms were U-shaped in most age groups. This finding was confirmed by the Q-test results (Table 31), which show various groups with absolute values of z3 higher than 2. Only one age group presented an absolute value of z4 higher than 2, indicating residual kurtosis. The overall test for skewness was significant (p-value < 0.01).

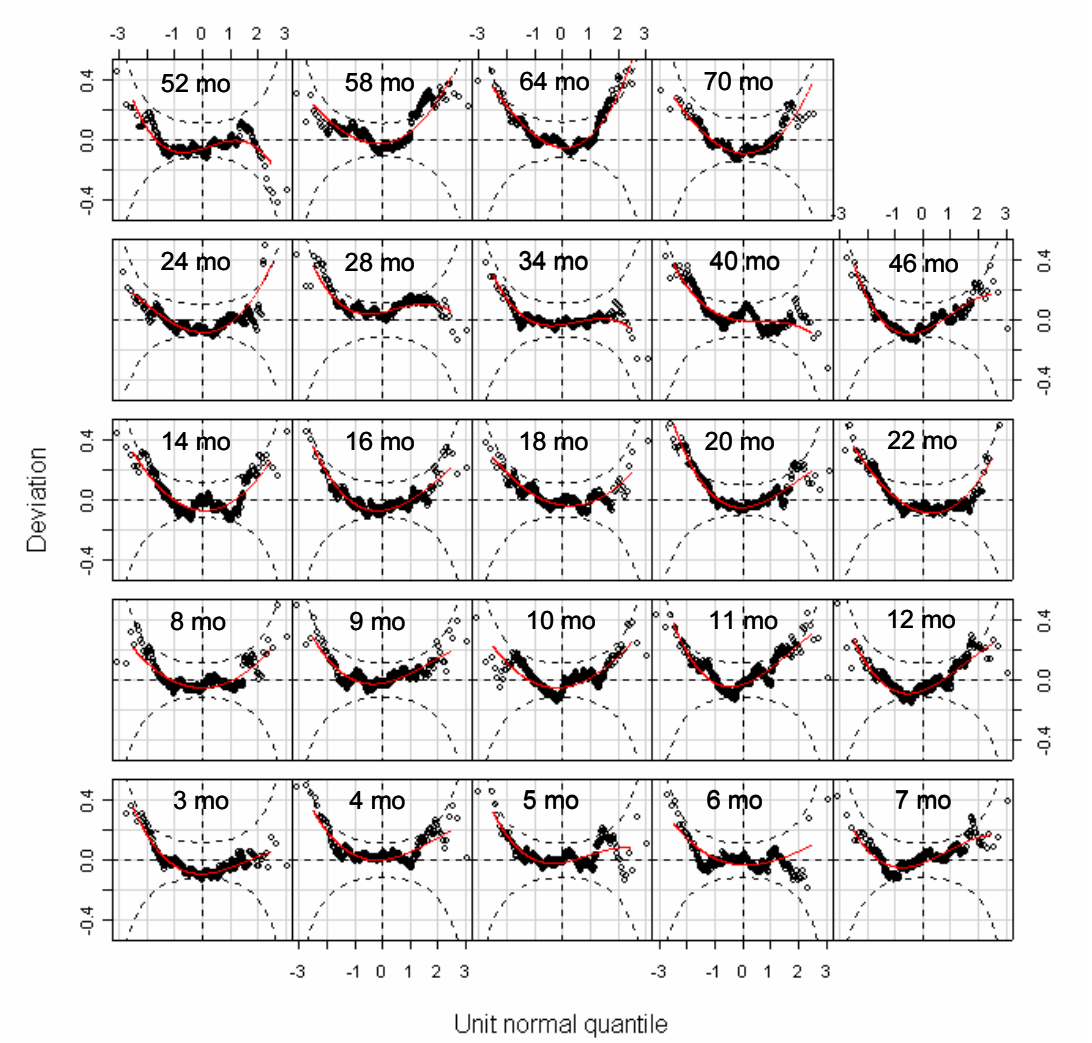


Figure 33 Worm plots of z-scores for Model 1 for arm circumference-for-age for girls

Table 31 Q-test for z-scores from Model 1 [BCPE(x=age$^{0.35}$, df(μ)=8, df(σ)=4, ν=1, τ=2)] for arm circumference-for-age for girls

Age (days)	Group	N	z1	z2	z3	z4
83 to 99	**3 mo**	430	-0.92	-0.67	2.23	-0.68
100 to 129	**4 mo**	440	0.82	-0.06	2.15	-0.19
130 to 159	**5 mo**	441	0.29	-0.15	1.76	-0.81
160 to 189	**6 mo**	441	-0.10	-0.52	1.91	0.68
190 to 219	**7 mo**	432	0.28	1.13	1.51	-0.87
220 to 249	**8 mo**	435	-0.32	0.24	2.18	0.27
250 to 279	**9 mo**	438	0.47	0.00	1.85	-0.17
280 to 309	**10 mo**	444	-0.42	0.42	2.38	0.26
310 to 349	**11 mo**	477	0.67	0.91	2.82	-0.71
350 to 379	**12 mo**	451	-0.42	1.03	2.45	-0.71
380 to 439	**14 mo**	444	-0.26	-0.18	2.92	0.63
440 to 499	**16 mo**	444	-0.31	-0.02	2.73	-0.04
500 to 559	**18 mo**	467	0.09	-0.56	2.32	0.56
560 to 619	**20 mo**	543	0.28	-0.67	3.44	-0.42
620 to 679	**22 mo**	538	-0.42	-0.86	3.71	1.58
680 to 749	**24 mo**	592	-0.64	0.69	3.52	1.82
750 to 929	**28 mo**	456	1.53	-0.29	1.26	-1.54
930 to 1119	**34 mo**	470	-0.15	-0.58	1.16	-1.50
1120 to 1309	**40 mo**	475	0.27	-1.67	1.23	-1.12
1310 to 1499	**46 mo**	453	-0.44	0.66	2.54	-1.16
1500 to 1689	**52 mo**	451	-1.09	-0.31	0.94	-2.38
1690 to 1879	**58 mo**	494	0.67	1.10	2.98	0.48
1880 to 2069	**64 mo**	418	0.52	0.48	3.78	1.49
2070 to 2191	**70 mo**	296	-0.42	0.16	2.77	0.90
Overall Q stats		**10 970**	**8.35**	**11.36**	**148.40**	**26.39**
degrees of freedom			**16.0**	**21.5**	**24.0**	**24.0**
p-value			**0.9376**	**0.9629**	**< 0.01**	**0.3338**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

The next step involved fitting the parameter ν for skewness using the BCPE distribution with fixed parameter τ=2 and keeping the degrees of freedom for the μ and σ curves selected for Model 1. Table 32 shows the *GAIC(3)* values for various degrees of freedom for the ν curve.

Table 32 Goodness-of-fit summary for models BCPE(x=age$^{0.35}$, df(μ)=8, df(σ)=4, df(ν)=?, τ=2) for arm circumference-for-age for girls

df(ν)	GD[a]	GAIC(3)[a]	Total df
1	978.9	1018.0	13
2	978.9	1020.9	14
3	977.7	1022.8	15
4	975.6	1023.6	16
5	973.8	1024.8	17
6	972.8	1026.8	18
7	972.2	1029.2	19

GD, Global Deviance; GAIC(3), Generalized Akaike Information Criterion with penalty equal to 3;
[a] In excess of 35 000.

The smallest *GAIC(3)* value corresponded to df(ν)=1 (i.e. fitting a constant for the ν curve). A new iteration was performed using df(ν)=1 to re-search for df(μ) and df(σ). The best combination remained df(μ)=8 and df(σ)=4. A new search for the best age-transformation power λ using this model was carried out but results indicated no need to update the model. The model with λ=0.35, df(μ)=8, df(σ)=4 and df(ν)=1 was thus further evaluated.

Model 2: BCPE(x= age$^{0.35}$, df(μ)=8, df(σ)=4, df(ν)=1, τ=2)

Figure 34 shows the fitting of the parameters μ, σ and ν for Model 2 with their respective sample estimates, that is, the median for μ and Box-Cox transform power for ν. The fitted curve for σ ignores a dip in the sample between 30 and 39 months, but overall the degree of smoothness for this parameter seemed adequate. Similarly, the ν curve fitting smoothed out the zigzagging of empirical values. Figures 35 and 36 show the distribution of differences between empirical values and fitted centiles for the longitudinal and cross-sectional samples, respectively. There was some indication of bias in the 3rd centile between 3 and 24 months (Figure 35) and also between 24 and 71 months, the average bias being between 1 mm and 2 mm (Figure 36).

The worm plots for this model (Figure 37) were better conformed to a flat shape than the significant deviations depicted by those from Model 1 (Figure 33). There was no indication of remaining skewness or kurtosis.

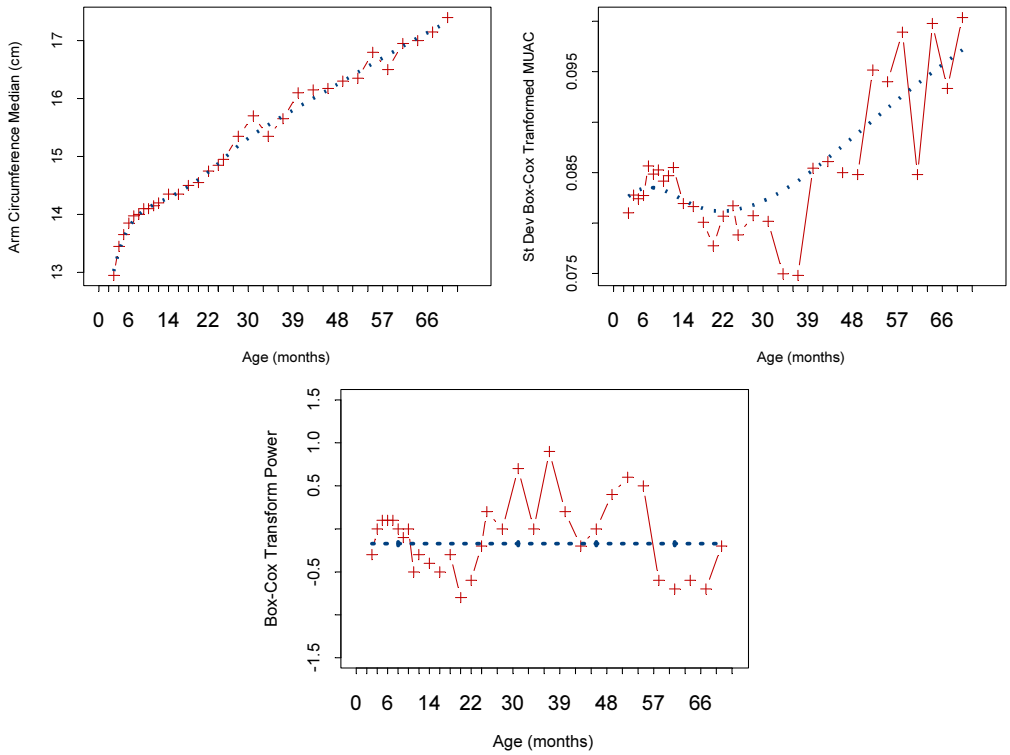


Figure 34 Fitting of the μ, σ, and ν curves of Model 2 for arm circumference-for-age for girls from 3 to 71 months (dotted line) and their respective sample estimates (points with solid line)

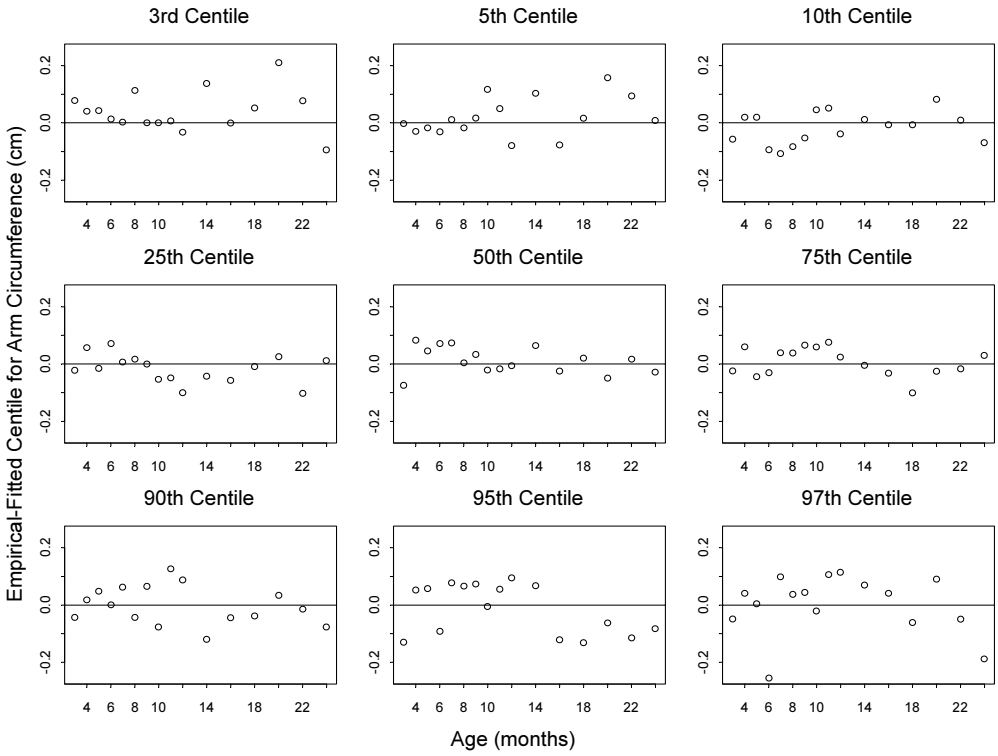


Figure 35 Centile residuals from fitting Model 2 for arm circumference-for-age from 3 to 24 months for girls

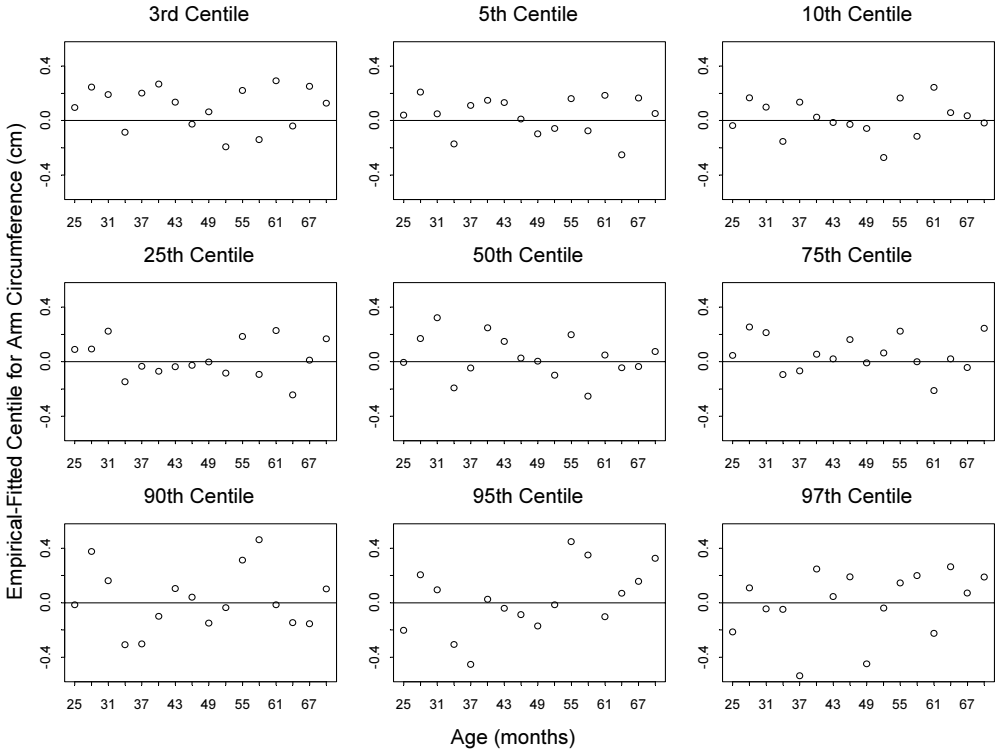


Figure 36 Centile residuals from fitting Model 2 for arm circumference-for-age from 24 to 71 months for girls

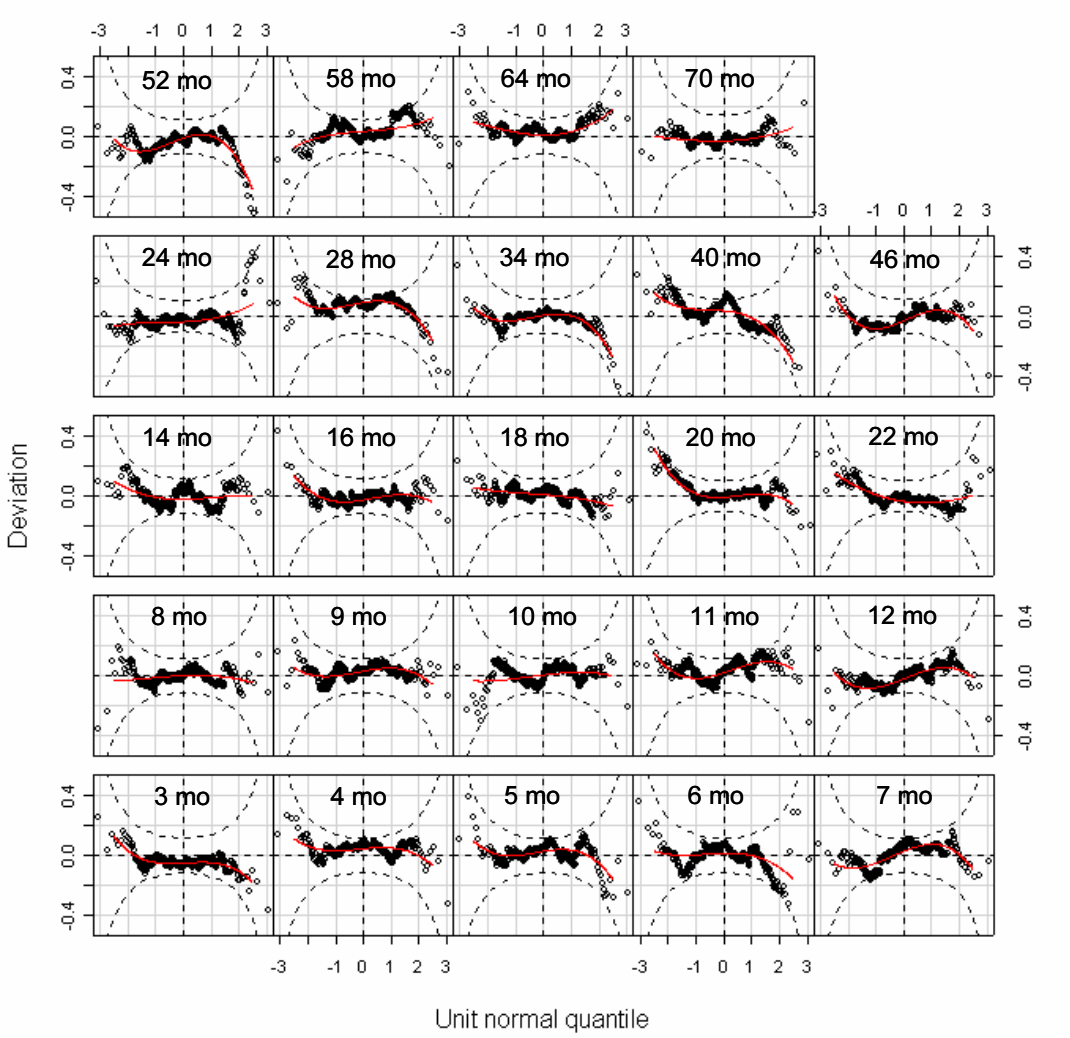


Figure 37 Worm plots of z-scores for Model 2 for arm circumference-for-age for girls

The Q-test results from Model 2 are shown in Table 33. Only one age group (46 mo) had a z4 absolute value larger than 2, suggesting remaining kurtosis. The overall Q-test p-values were all non-significant, indicating an adequate fit of the girls' arm circumference-for-age curves. There was thus no need for modelling τ to adjust for kurtosis.

Table 34 presents observed percentages with arm circumferences below the fitted centiles. As was the case for the boys, no systematic bias was detected.

Table 33 Q-test for z-scores from Model 2 [BCPE(x=age$^{0.35}$, df(μ)=8, df(σ)=4, df(ν)=1, τ=2)] for arm circumference-for-age for girls

Age (days)	Group	N	z1	z2	z3	z4
83 to 99	**3 mo**	430	-0.98	-0.61	0.15	-1.25
100 to 129	**4 mo**	440	0.77	-0.20	-0.12	-0.79
130 to 159	**5 mo**	441	0.28	-0.15	-0.41	-1.25
160 to 189	**6 mo**	441	-0.05	-0.46	-0.52	-0.38
190 to 219	**7 mo**	432	0.25	1.20	-0.74	-1.34
220 to 249	**8 mo**	435	-0.25	0.31	-0.26	-0.17
250 to 279	**9 mo**	438	0.57	0.01	-0.46	-0.74
280 to 309	**10 mo**	444	-0.34	0.49	-0.09	-0.08
310 to 349	**11 mo**	477	0.73	0.74	0.57	-1.37
350 to 379	**12 mo**	451	-0.40	1.08	0.21	-1.25
380 to 439	**14 mo**	444	-0.22	-0.21	0.58	-0.33
440 to 499	**16 mo**	444	-0.34	-0.02	0.54	-1.00
500 to 559	**18 mo**	467	0.06	-0.51	-0.11	-0.22
560 to 619	**20 mo**	543	0.25	-0.85	1.25	-1.55
620 to 679	**22 mo**	538	-0.43	-0.95	1.09	0.19
680 to 749	**24 mo**	592	-0.73	0.69	0.48	0.55
750 to 929	**28 mo**	456	1.51	-0.35	-0.84	-1.35
930 to 1119	**34 mo**	470	-0.25	-0.41	-0.98	-1.54
1120 to 1309	**40 mo**	475	0.27	-1.59	-0.95	-1.38
1310 to 1499	**46 mo**	453	-0.52	0.63	0.35	-2.09
1500 to 1689	**52 mo**	451	-1.03	0.08	-1.24	-1.95
1690 to 1879	**58 mo**	494	0.70	0.98	-0.03	0.31
1880 to 2069	**64 mo**	418	0.59	0.21	1.01	0.32
2070 to 2191	**70 mo**	296	-0.35	0.19	0.41	0.08
Overall Q stats		**10 970**	**8.56**	**10.83**	**10.72**	**28.08**
degrees of freedom			**16.0**	**21.5**	**23.0**	**24.0**
p-value			**0.9306**	**0.9720**	**0.9859**	**0.2569**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

In conclusion, the model selected for constructing the arm circumference-for-age growth curves for girls was BCPE(x=age$^{0.35}$, df(μ)=8, df(σ)=4, df(ν)=1, τ=2) that adjusts only for skewness, and thus reduces to the LMS method. The fitted centile curves and empirical centiles are shown in Figures 38 to 41.

Table 34 Observed proportions of children with measurements below the fitted centiles from Model 2, arm circumference-for-age for girls

Expected	3 mo	4 mo	5 mo	6 mo	7 mo	8 mo	9 mo	10 mo	11 mo
1	0.7	0.5	0.2	0.7	1.2	0.9	0.7	1.8	0.6
3	2.3	2.3	2.7	2.9	3.2	2.8	2.5	3.2	2.7
5	5.1	5.5	5.2	5.7	5.6	5.3	4.8	4.3	4.6
10	10.9	9.1	10.2	11.1	12.7	11.0	11.4	9.9	8.6
25	27.2	23.6	26.1	24.3	25.5	24.8	24.4	26.8	26.2
50	51.9	48.0	49.0	47.8	47.5	50.1	48.6	51.4	49.5
75	76.7	73.9	75.3	75.5	73.8	75.2	72.4	74.1	70.9
90	90.5	90.0	89.1	89.8	88.4	90.6	89.7	91.2	87.8
95	95.6	94.1	93.9	96.8	94.4	94.3	95.7	94.8	93.7
97	97.9	96.6	96.8	98.4	95.8	96.6	97.0	97.1	96.2
99	99.3	99.1	99.5	99.1	99.1	99.1	99.1	98.9	98.5
Expected	**12 mo**	**14 mo**	**16 mo**	**18 mo**	**20 mo**	**22 mo**	**24 mo**	**28 mo**	**34 mo**
1	1.1	0.9	0.9	1.1	0.4	0.4	1.4	0.7	1.1
3	3.3	2.0	3.4	3.2	1.7	2.6	3.7	1.8	3.0
5	5.5	3.8	5.9	4.1	3.7	3.9	5.1	4.4	6.6
10	10.4	10.1	10.6	10.1	8.7	9.3	11.1	9.4	10.4
25	27.3	27.0	27.9	25.9	25.2	27.0	25.3	21.7	25.3
50	50.3	47.3	51.4	49.3	50.6	50.0	50.8	47.1	49.4
75	73.4	75.9	75.0	76.7	74.8	76.4	75.0	71.9	74.7
90	88.7	91.0	90.1	90.1	89.1	91.4	90.4	88.4	90.4
95	94.2	94.4	95.5	96.4	95.2	96.3	94.9	94.3	95.7
97	95.8	96.4	96.8	97.4	96.3	97.4	97.6	97.1	97.2
99	99.1	98.9	98.6	99.1	99.3	98.7	98.5	99.6	99.8

Table 34 Observed proportions of children with measurements below the fitted centiles from Model 2, arm circumference-for-age for girls (cont)

Expected	40 mo	46 mo	52 mo	58 mo	64 mo	70 mo	Overall
1	0.6	0.7	1.3	1.4	0.5	1.0	0.9
3	2.1	3.1	2.7	3.4	2.6	2.7	2.8
5	3.6	5.7	6.0	5.3	5.0	4.4	4.9
10	9.9	11.5	12.6	10.3	9.1	11.1	10.4
25	26.5	27.4	27.1	23.7	24.4	25.3	25.7
50	47.6	51.0	51.7	50.4	49.0	50.7	49.6
75	77.1	73.3	74.9	73.9	74.9	75.7	74.6
90	91.6	89.4	90.7	87.0	89.5	89.9	89.8
95	95.8	95.1	95.3	92.9	93.8	94.3	94.9
97	97.1	96.7	98.4	95.5	95.9	96.3	96.9
99	99.6	99.1	99.8	99.0	98.6	99.3	99.1

Note: Group labels correspond to the age intervals in Table 33.

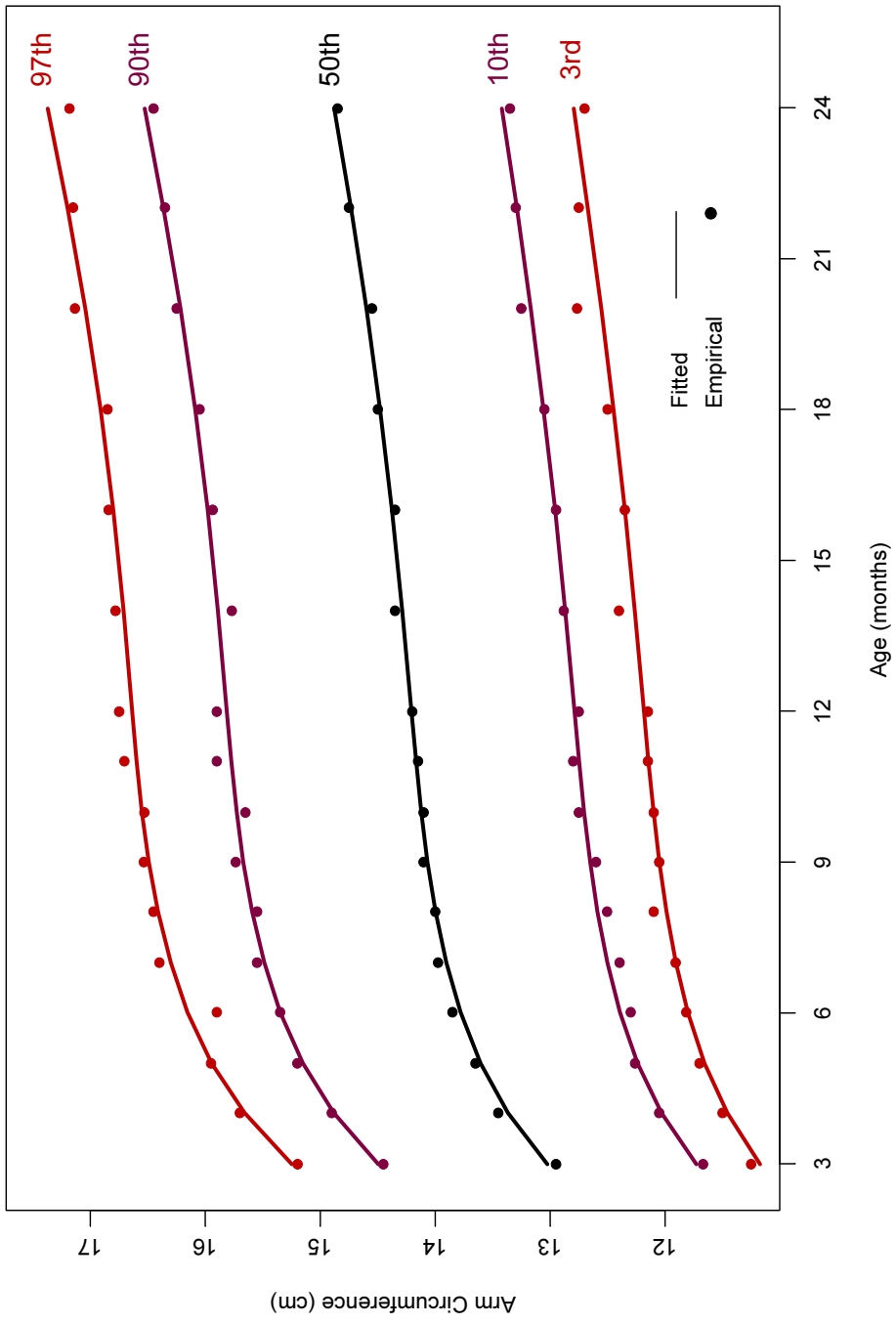


Figure 38 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: arm circumference-for-age for girls from 3 to 24 months

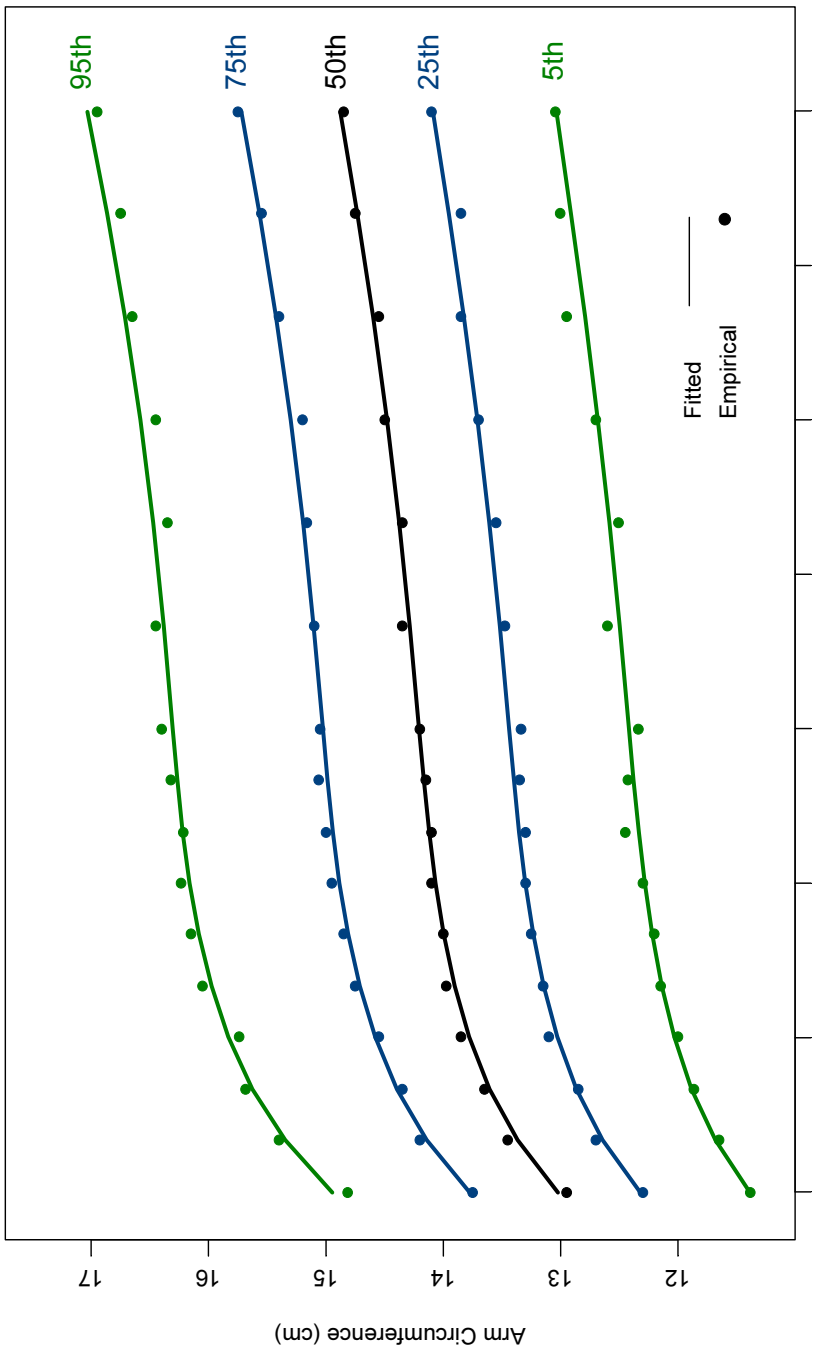


Figure 39 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: arm circumference-for-age for girls from 3 to 24 months

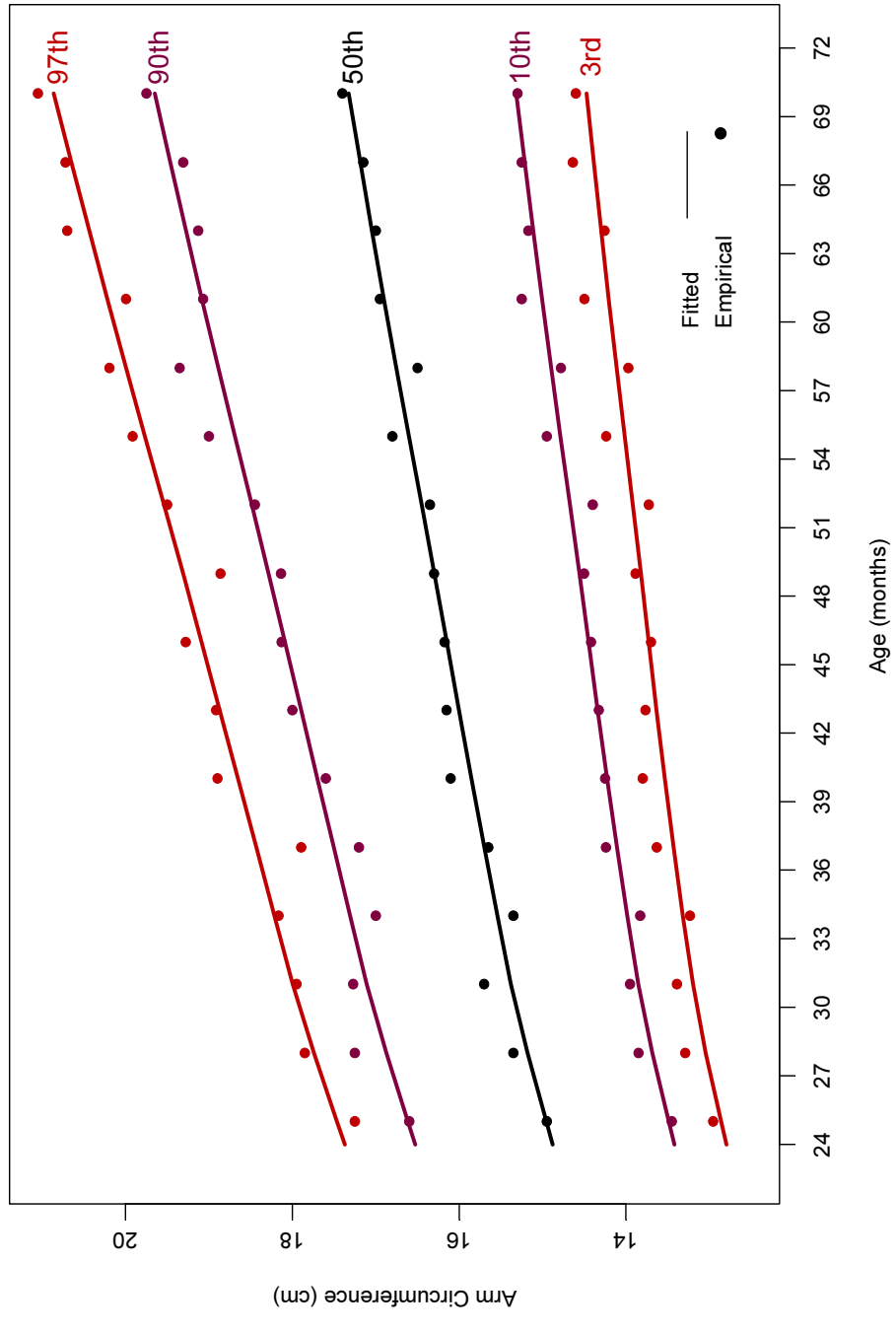


Figure 40 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: arm circumference-for-age for girls from 24 to 71 months

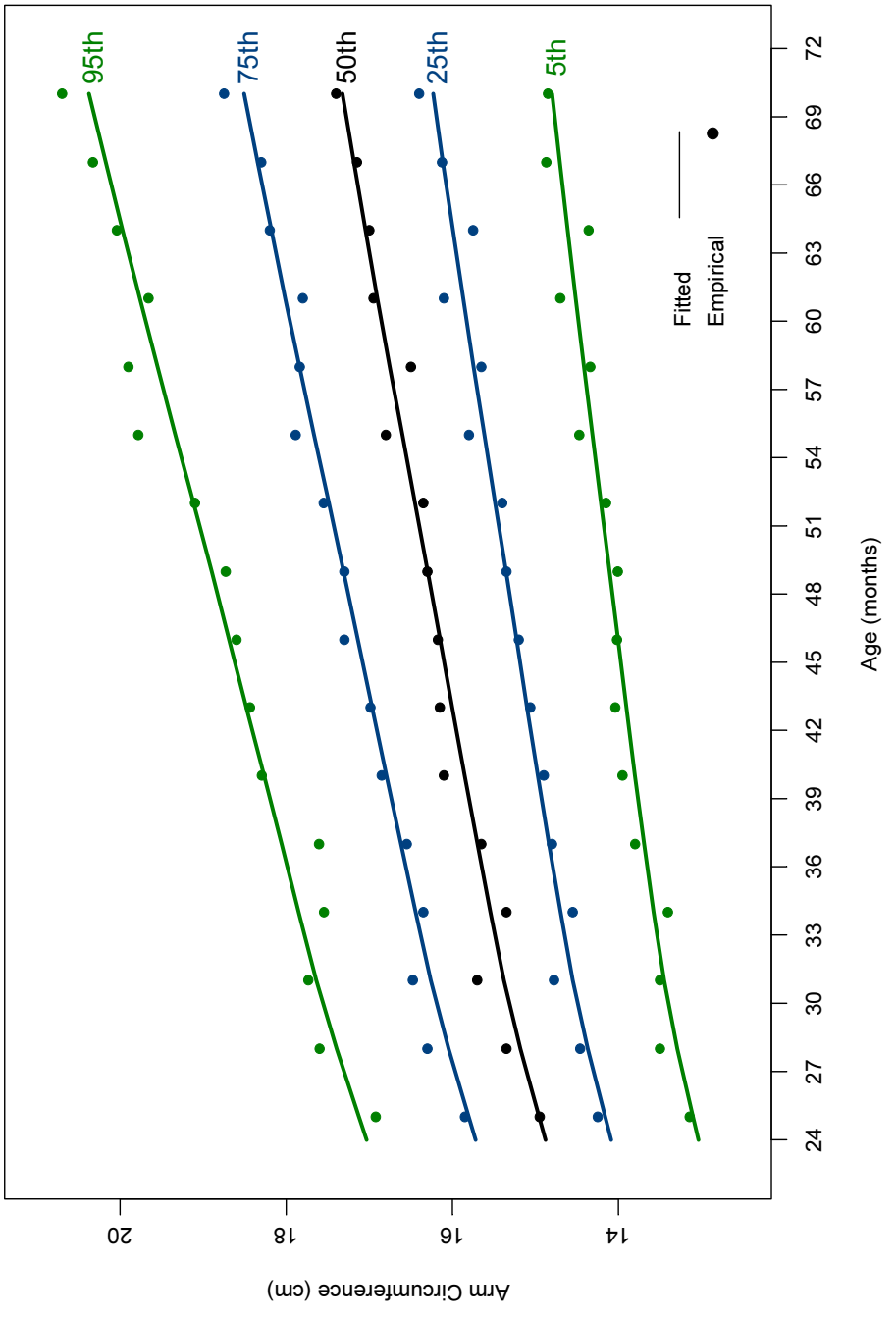


Figure 41 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: arm circumference-for-age for girls from 24 to 71 months

4.3.3 WHO standards

This section presents the final WHO arm circumference-for-age z-score and percentile charts (Figures 42 and 43) and table (Table 35) for girls.

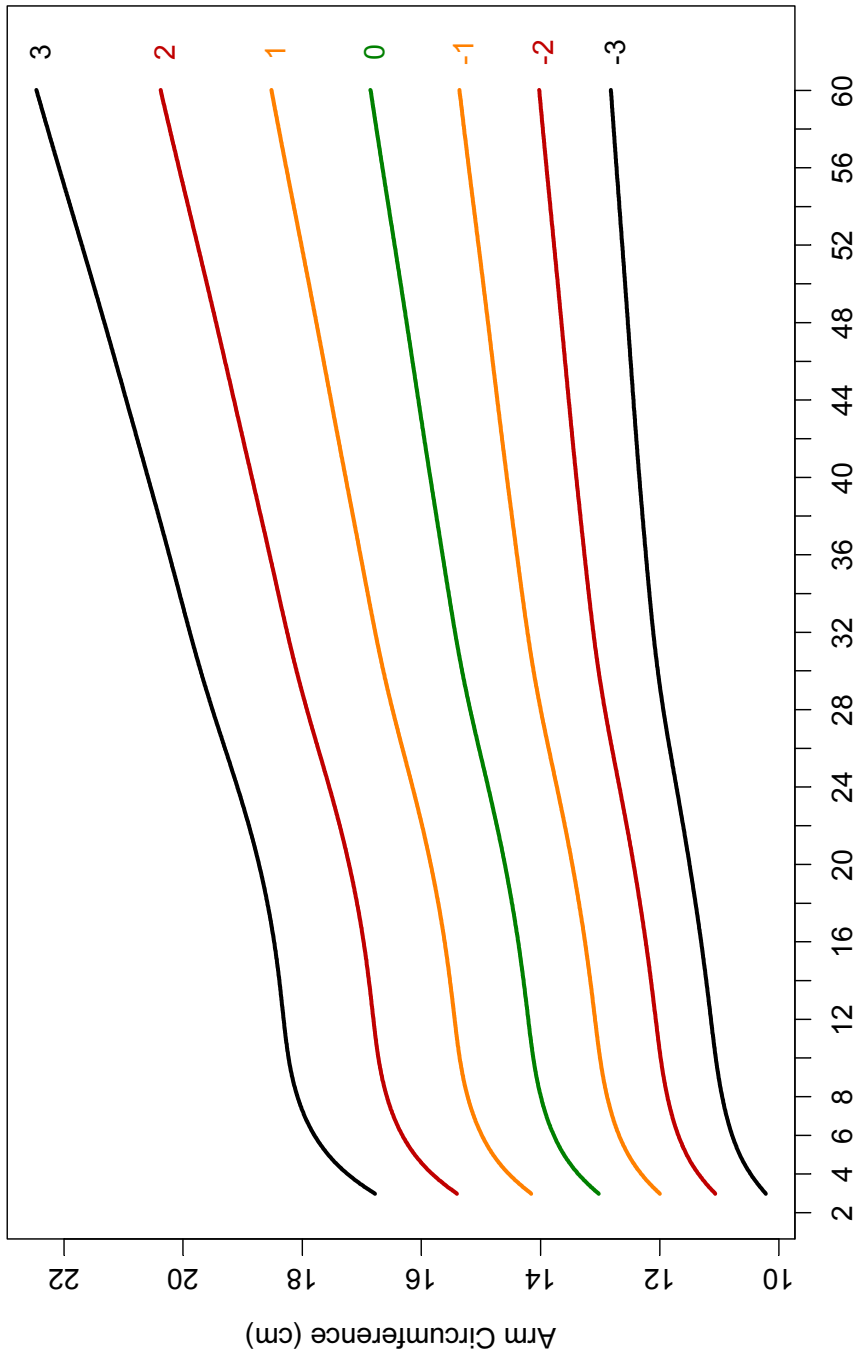


Figure 42 WHO arm circumference-for-age z-scores for girls from 3 to 60 months

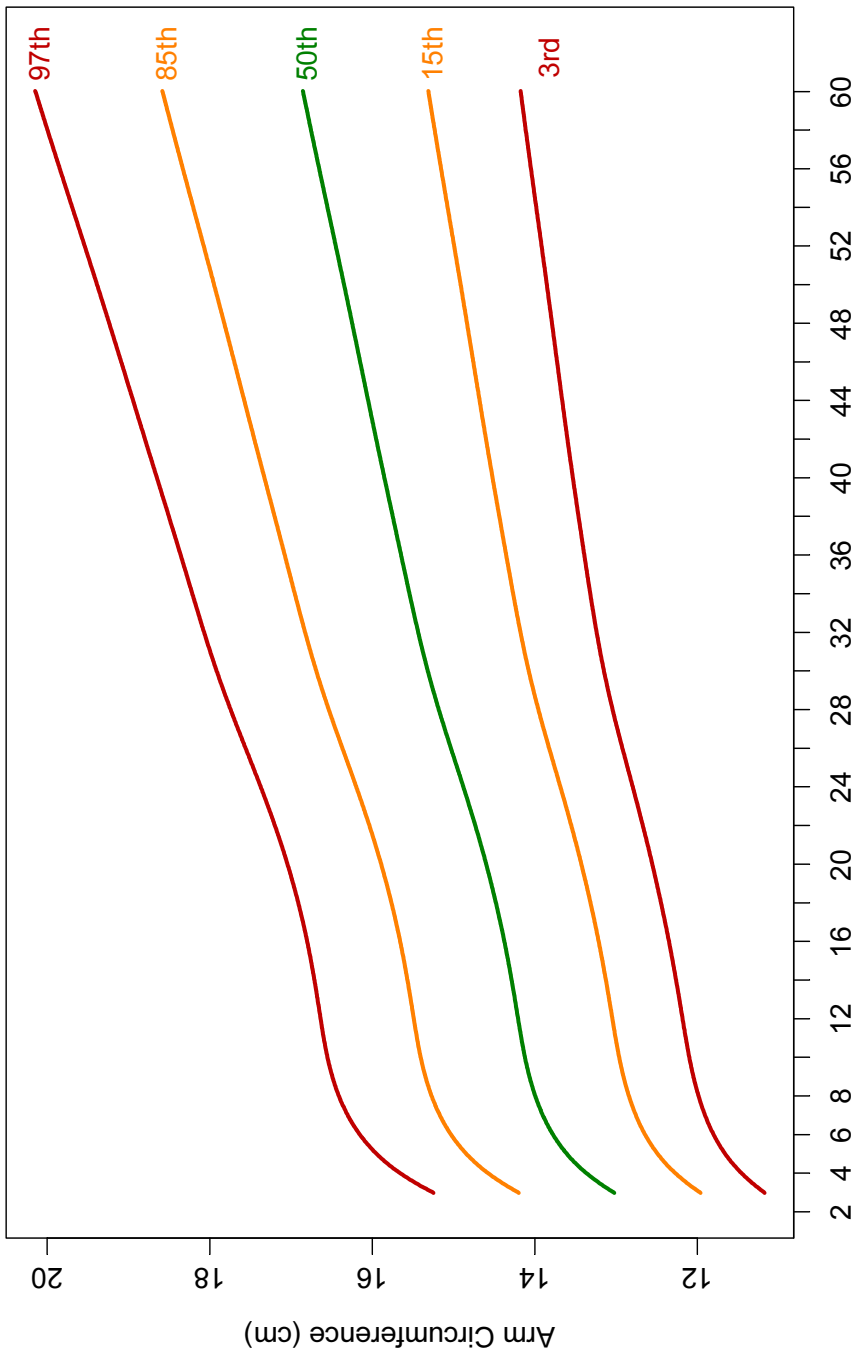


Figure 43 WHO arm circumference-for-age percentiles for girls from 3 to 60 months

Table 35 Arm circumference-for-age for girls, age in years and months

Year: Month	Month	L	M	S	Percentiles (arm circumference in cm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
0: 3	**3**	-0.1733	13.0284	0.08263	10.8	11.2	11.4	12.0	12.3	13.0	13.8	14.2	14.9	15.3	15.8
0: 4	**4**	-0.1733	13.3649	0.08298	11.1	11.5	11.7	12.3	12.6	13.4	14.1	14.6	15.3	15.7	16.3
0: 5	**5**	-0.1733	13.6061	0.08325	11.2	11.7	11.9	12.5	12.9	13.6	14.4	14.8	15.6	15.9	16.6
0: 6	**6**	-0.1733	13.7771	0.08343	11.4	11.8	12.0	12.6	13.0	13.8	14.6	15.0	15.8	16.2	16.8
0: 7	**7**	-0.1733	13.9018	0.08352	11.5	11.9	12.1	12.8	13.1	13.9	14.7	15.2	16.0	16.3	16.9
0: 8	**8**	-0.1733	13.9952	0.08351	11.6	12.0	12.2	12.8	13.2	14.0	14.8	15.3	16.1	16.4	17.1
0: 9	**9**	-0.1733	14.0665	0.08342	11.6	12.0	12.3	12.9	13.3	14.1	14.9	15.3	16.2	16.5	17.1
0:10	**10**	-0.1733	14.1217	0.08326	11.7	12.1	12.3	13.0	13.4	14.1	14.9	15.4	16.2	16.6	17.2
0:11	**11**	-0.1733	14.1667	0.08305	11.7	12.1	12.4	13.0	13.4	14.2	15.0	15.5	16.3	16.6	17.2
1: 0	**12**	-0.1733	14.2065	0.08280	11.8	12.2	12.4	13.0	13.4	14.2	15.0	15.5	16.3	16.6	17.3
1: 1	**13**	-0.1733	14.2455	0.08254	11.8	12.2	12.5	13.1	13.5	14.2	15.1	15.5	16.3	16.7	17.3
1: 2	**14**	-0.1733	14.2859	0.08227	11.8	12.3	12.5	13.1	13.5	14.3	15.1	15.6	16.4	16.7	17.4
1: 3	**15**	-0.1733	14.3289	0.08202	11.9	12.3	12.5	13.2	13.6	14.3	15.1	15.6	16.4	16.8	17.4
1: 4	**16**	-0.1733	14.3752	0.08179	11.9	12.4	12.6	13.2	13.6	14.4	15.2	15.7	16.5	16.8	17.4
1: 5	**17**	-0.1733	14.4254	0.08160	12.0	12.4	12.6	13.3	13.7	14.4	15.2	15.7	16.5	16.9	17.5
1: 6	**18**	-0.1733	14.4795	0.08143	12.0	12.4	12.7	13.3	13.7	14.5	15.3	15.8	16.6	16.9	17.6
1: 7	**19**	-0.1733	14.5372	0.08131	12.1	12.5	12.7	13.4	13.8	14.5	15.4	15.8	16.6	17.0	17.6
1: 8	**20**	-0.1733	14.5987	0.08123	12.1	12.6	12.8	13.4	13.8	14.6	15.4	15.9	16.7	17.0	17.7
1: 9	**21**	-0.1733	14.6639	0.08118	12.2	12.6	12.9	13.5	13.9	14.7	15.5	16.0	16.8	17.1	17.8
1:10	**22**	-0.1733	14.7328	0.08118	12.2	12.7	12.9	13.6	14.0	14.7	15.6	16.0	16.9	17.2	17.9
1:11	**23**	-0.1733	14.8049	0.08121	12.3	12.7	13.0	13.6	14.0	14.8	15.6	16.1	16.9	17.3	17.9
2: 0	**24**	-0.1733	14.8795	0.08127	12.4	12.8	13.0	13.7	14.1	14.9	15.7	16.2	17.0	17.4	18.0

Table 35 Arm circumference-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Percentiles (arm circumference in cm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
2: 1	**25**	-0.1733	14.9559	0.08136	12.4	12.9	13.1	13.8	14.2	15.0	15.8	16.3	17.1	17.5	18.1
2: 2	**26**	-0.1733	15.0327	0.08147	12.5	12.9	13.2	13.8	14.2	15.0	15.9	16.4	17.2	17.6	18.2
2: 3	**27**	-0.1733	15.1085	0.08161	12.5	13.0	13.2	13.9	14.3	15.1	16.0	16.5	17.3	17.7	18.3
2: 4	**28**	-0.1733	15.1817	0.08178	12.6	13.0	13.3	14.0	14.4	15.2	16.0	16.5	17.4	17.7	18.4
2: 5	**29**	-0.1733	15.2514	0.08196	12.6	13.1	13.3	14.0	14.4	15.3	16.1	16.6	17.5	17.8	18.5
2: 6	**30**	-0.1733	15.3168	0.08217	12.7	13.2	13.4	14.1	14.5	15.3	16.2	16.7	17.6	17.9	18.6
2: 7	**31**	-0.1733	15.3779	0.08240	12.7	13.2	13.4	14.1	14.6	15.4	16.3	16.8	17.6	18.0	18.7
2: 8	**32**	-0.1733	15.4351	0.08265	12.8	13.2	13.5	14.2	14.6	15.4	16.3	16.8	17.7	18.1	18.8
2: 9	**33**	-0.1733	15.4895	0.08292	12.8	13.3	13.5	14.2	14.7	15.5	16.4	16.9	17.8	18.1	18.8
2:10	**34**	-0.1733	15.5423	0.08320	12.8	13.3	13.6	14.3	14.7	15.5	16.4	17.0	17.9	18.2	18.9
2:11	**35**	-0.1733	15.5941	0.08351	12.9	13.4	13.6	14.3	14.7	15.6	16.5	17.0	17.9	18.3	19.0
3: 0	**36**	-0.1733	15.6456	0.08383	12.9	13.4	13.7	14.4	14.8	15.6	16.6	17.1	18.0	18.4	19.1
3: 1	**37**	-0.1733	15.6969	0.08416	12.9	13.4	13.7	14.4	14.8	15.7	16.6	17.1	18.1	18.4	19.2
3: 2	**38**	-0.1733	15.7483	0.08451	13.0	13.5	13.7	14.4	14.9	15.7	16.7	17.2	18.1	18.5	19.2
3: 3	**39**	-0.1733	15.7997	0.08487	13.0	13.5	13.8	14.5	14.9	15.8	16.7	17.3	18.2	18.6	19.3
3: 4	**40**	-0.1733	15.8509	0.08525	13.0	13.5	13.8	14.5	15.0	15.9	16.8	17.3	18.3	18.6	19.4
3: 5	**41**	-0.1733	15.9016	0.08563	13.1	13.6	13.8	14.6	15.0	15.9	16.9	17.4	18.3	18.7	19.5
3: 6	**42**	-0.1733	15.9518	0.08602	13.1	13.6	13.9	14.6	15.1	16.0	16.9	17.5	18.4	18.8	19.6
3: 7	**43**	-0.1733	16.0016	0.08642	13.1	13.6	13.9	14.6	15.1	16.0	17.0	17.5	18.5	18.9	19.6
3: 8	**44**	-0.1733	16.0509	0.08683	13.2	13.7	13.9	14.7	15.1	16.1	17.0	17.6	18.5	18.9	19.7
3: 9	**45**	-0.1733	16.1001	0.08723	13.2	13.7	14.0	14.7	15.2	16.1	17.1	17.6	18.6	19.0	19.8
3:10	**46**	-0.1733	16.1491	0.08765	13.2	13.7	14.0	14.8	15.2	16.1	17.1	17.7	18.7	19.1	19.9
3:11	**47**	-0.1733	16.1983	0.08806	13.2	13.8	14.0	14.8	15.3	16.2	17.2	17.8	18.8	19.2	20.0
4: 0	**48**	-0.1733	16.2477	0.08848	13.3	13.8	14.1	14.8	15.3	16.2	17.3	17.8	18.8	19.2	20.0

Table 35 Arm circumference-for-age for girls, age in years and months (continued)

					Percentiles (arm circumference in cm)										
Year: Month	**Month**	**L**	**M**	**S**	**1st**	**3rd**	**5th**	**15th**	**25th**	**50th**	**75th**	**85th**	**95th**	**97th**	**99th**
4: 1	**49**	-0.1733	16.2974	0.08890	13.3	13.8	14.1	14.9	15.4	16.3	17.3	17.9	18.9	19.3	20.1
4: 2	**50**	-0.1733	16.3475	0.08932	13.3	13.9	14.1	14.9	15.4	16.3	17.4	17.9	19.0	19.4	20.2
4: 3	**51**	-0.1733	16.3981	0.08974	13.4	13.9	14.2	15.0	15.4	16.4	17.4	18.0	19.0	19.5	20.3
4: 4	**52**	-0.1733	16.4490	0.09016	13.4	13.9	14.2	15.0	15.5	16.4	17.5	18.1	19.1	19.5	20.4
4: 5	**53**	-0.1733	16.5001	0.09057	13.4	14.0	14.2	15.0	15.5	16.5	17.5	18.1	19.2	19.6	20.5
4: 6	**54**	-0.1733	16.5514	0.09099	13.4	14.0	14.3	15.1	15.6	16.6	17.6	18.2	19.3	19.7	20.5
4: 7	**55**	-0.1733	16.6026	0.09140	13.5	14.0	14.3	15.1	15.6	16.6	17.7	18.3	19.3	19.8	20.6
4: 8	**56**	-0.1733	16.6534	0.09181	13.5	14.0	14.3	15.2	15.7	16.7	17.7	18.3	19.4	19.8	20.7
4: 9	**57**	-0.1733	16.7039	0.09221	13.5	14.1	14.4	15.2	15.7	16.7	17.8	18.4	19.5	19.9	20.8
4:10	**58**	-0.1733	16.7539	0.09262	13.6	14.1	14.4	15.2	15.7	16.8	17.8	18.5	19.6	20.0	20.9
4:11	**59**	-0.1733	16.8034	0.09301	13.6	14.1	14.4	15.3	15.8	16.8	17.9	18.5	19.6	20.1	20.9
5: 0	**60**	-0.1733	16.8526	0.09341	13.6	14.2	14.5	15.3	15.8	16.9	18.0	18.6	19.7	20.1	21.0

Table 35 Arm circumference-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (arm circumference in cm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 3	**3**	-0.1733	13.0284	0.08263	10.2	11.1	12.0	13.0	14.2	15.4	16.8
0: 4	**4**	-0.1733	13.3649	0.08298	10.5	11.3	12.3	13.4	14.5	15.8	17.2
0: 5	**5**	-0.1733	13.6061	0.08325	10.7	11.5	12.5	13.6	14.8	16.1	17.6
0: 6	**6**	-0.1733	13.7771	0.08343	10.8	11.7	12.7	13.8	15.0	16.3	17.8
0: 7	**7**	-0.1733	13.9018	0.08352	10.9	11.8	12.8	13.9	15.1	16.5	18.0
0: 8	**8**	-0.1733	13.9952	0.08351	11.0	11.9	12.9	14.0	15.2	16.6	18.1
0: 9	**9**	-0.1733	14.0665	0.08342	11.0	11.9	12.9	14.1	15.3	16.7	18.2
0:10	**10**	-0.1733	14.1217	0.08326	11.1	12.0	13.0	14.1	15.4	16.7	18.2
0:11	**11**	-0.1733	14.1667	0.08305	11.1	12.0	13.0	14.2	15.4	16.8	18.3
1: 0	**12**	-0.1733	14.2065	0.08280	11.1	12.1	13.1	14.2	15.4	16.8	18.3
1: 1	**13**	-0.1733	14.2455	0.08254	11.2	12.1	13.1	14.2	15.5	16.8	18.3
1: 2	**14**	-0.1733	14.2859	0.08227	11.2	12.1	13.2	14.3	15.5	16.9	18.4
1: 3	**15**	-0.1733	14.3289	0.08202	11.3	12.2	13.2	14.3	15.6	16.9	18.4
1: 4	**16**	-0.1733	14.3752	0.08179	11.3	12.2	13.3	14.4	15.6	17.0	18.5
1: 5	**17**	-0.1733	14.4254	0.08160	11.4	12.3	13.3	14.4	15.7	17.0	18.5
1: 6	**18**	-0.1733	14.4795	0.08143	11.4	12.3	13.4	14.5	15.7	17.1	18.6
1: 7	**19**	-0.1733	14.5372	0.08131	11.4	12.4	13.4	14.5	15.8	17.1	18.7
1: 8	**20**	-0.1733	14.5987	0.08123	11.5	12.4	13.5	14.6	15.8	17.2	18.7
1: 9	**21**	-0.1733	14.6639	0.08118	11.6	12.5	13.5	14.7	15.9	17.3	18.8
1:10	**22**	-0.1733	14.7328	0.08118	11.6	12.6	13.6	14.7	16.0	17.4	18.9
1:11	**23**	-0.1733	14.8049	0.08121	11.7	12.6	13.7	14.8	16.1	17.5	19.0
2: 0	**24**	-0.1733	14.8795	0.08127	11.7	12.7	13.7	14.9	16.1	17.5	19.1

Table 35 Arm circumference-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (arm circumference in cm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
2: 1	**25**	-0.1733	14.9559	0.08136	11.8	12.7	13.8	15.0	16.2	17.6	19.2
2: 2	**26**	-0.1733	15.0327	0.08147	11.8	12.8	13.9	15.0	16.3	17.7	19.3
2: 3	**27**	-0.1733	15.1085	0.08161	11.9	12.9	13.9	15.1	16.4	17.8	19.4
2: 4	**28**	-0.1733	15.1817	0.08178	11.9	12.9	14.0	15.2	16.5	17.9	19.5
2: 5	**29**	-0.1733	15.2514	0.08196	12.0	13.0	14.1	15.3	16.6	18.0	19.6
2: 6	**30**	-0.1733	15.3168	0.08217	12.0	13.0	14.1	15.3	16.6	18.1	19.7
2: 7	**31**	-0.1733	15.3779	0.08240	12.1	13.1	14.2	15.4	16.7	18.2	19.8
2: 8	**32**	-0.1733	15.4351	0.08265	12.1	13.1	14.2	15.4	16.8	18.3	19.9
2: 9	**33**	-0.1733	15.4895	0.08292	12.1	13.2	14.3	15.5	16.8	18.3	20.0
2:10	**34**	-0.1733	15.5423	0.08320	12.2	13.2	14.3	15.5	16.9	18.4	20.1
2:11	**35**	-0.1733	15.5941	0.08351	12.2	13.2	14.4	15.6	17.0	18.5	20.1
3: 0	**36**	-0.1733	15.6456	0.08383	12.2	13.3	14.4	15.6	17.0	18.5	20.2
3: 1	**37**	-0.1733	15.6969	0.08416	12.3	13.3	14.4	15.7	17.1	18.6	20.3
3: 2	**38**	-0.1733	15.7483	0.08451	12.3	13.3	14.5	15.7	17.1	18.7	20.4
3: 3	**39**	-0.1733	15.7997	0.08487	12.3	13.4	14.5	15.8	17.2	18.8	20.5
3: 4	**40**	-0.1733	15.8509	0.08525	12.3	13.4	14.6	15.9	17.3	18.8	20.6
3: 5	**41**	-0.1733	15.9016	0.08563	12.4	13.4	14.6	15.9	17.3	18.9	20.7
3: 6	**42**	-0.1733	15.9518	0.08602	12.4	13.5	14.6	16.0	17.4	19.0	20.8
3: 7	**43**	-0.1733	16.0016	0.08642	12.4	13.5	14.7	16.0	17.5	19.1	20.9
3: 8	**44**	-0.1733	16.0509	0.08683	12.4	13.5	14.7	16.1	17.5	19.1	21.0
3: 9	**45**	-0.1733	16.1001	0.08723	12.5	13.6	14.8	16.1	17.6	19.2	21.0
3:10	**46**	-0.1733	16.1491	0.08765	12.5	13.6	14.8	16.1	17.6	19.3	21.1
3:11	**47**	-0.1733	16.1983	0.08806	12.5	13.6	14.8	16.2	17.7	19.4	21.2
4: 0	**48**	-0.1733	16.2477	0.08848	12.5	13.6	14.9	16.2	17.8	19.4	21.3

Table 35 Arm circumference-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (arm circumference in cm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	**49**	-0.1733	16.2974	0.08890	12.6	13.7	14.9	16.3	17.8	19.5	21.4
4: 2	**50**	-0.1733	16.3475	0.08932	12.6	13.7	15.0	16.3	17.9	19.6	21.5
4: 3	**51**	-0.1733	16.3981	0.08974	12.6	13.7	15.0	16.4	18.0	19.7	21.6
4: 4	**52**	-0.1733	16.4490	0.09016	12.6	13.8	15.0	16.4	18.0	19.8	21.7
4: 5	**53**	-0.1733	16.5001	0.09057	12.7	13.8	15.1	16.5	18.1	19.8	21.8
4: 6	**54**	-0.1733	16.5514	0.09099	12.7	13.8	15.1	16.6	18.1	19.9	21.9
4: 7	**55**	-0.1733	16.6026	0.09140	12.7	13.9	15.2	16.6	18.2	20.0	22.0
4: 8	**56**	-0.1733	16.6534	0.09181	12.7	13.9	15.2	16.7	18.3	20.1	22.1
4: 9	**57**	-0.1733	16.7039	0.09221	12.7	13.9	15.2	16.7	18.3	20.1	22.2
4:10	**58**	-0.1733	16.7539	0.09262	12.8	14.0	15.3	16.8	18.4	20.2	22.3
4:11	**59**	-0.1733	16.8034	0.09301	12.8	14.0	15.3	16.8	18.5	20.3	22.4
5: 0	**60**	-0.1733	16.8526	0.09341	12.8	14.0	15.4	16.9	18.5	20.4	22.5

4.4 Comparisons between boys and girls

This section presents the arm circumference-for-age z-score comparisons between boys and girls for the WHO standards (Figure 44)

4.4.1 WHO

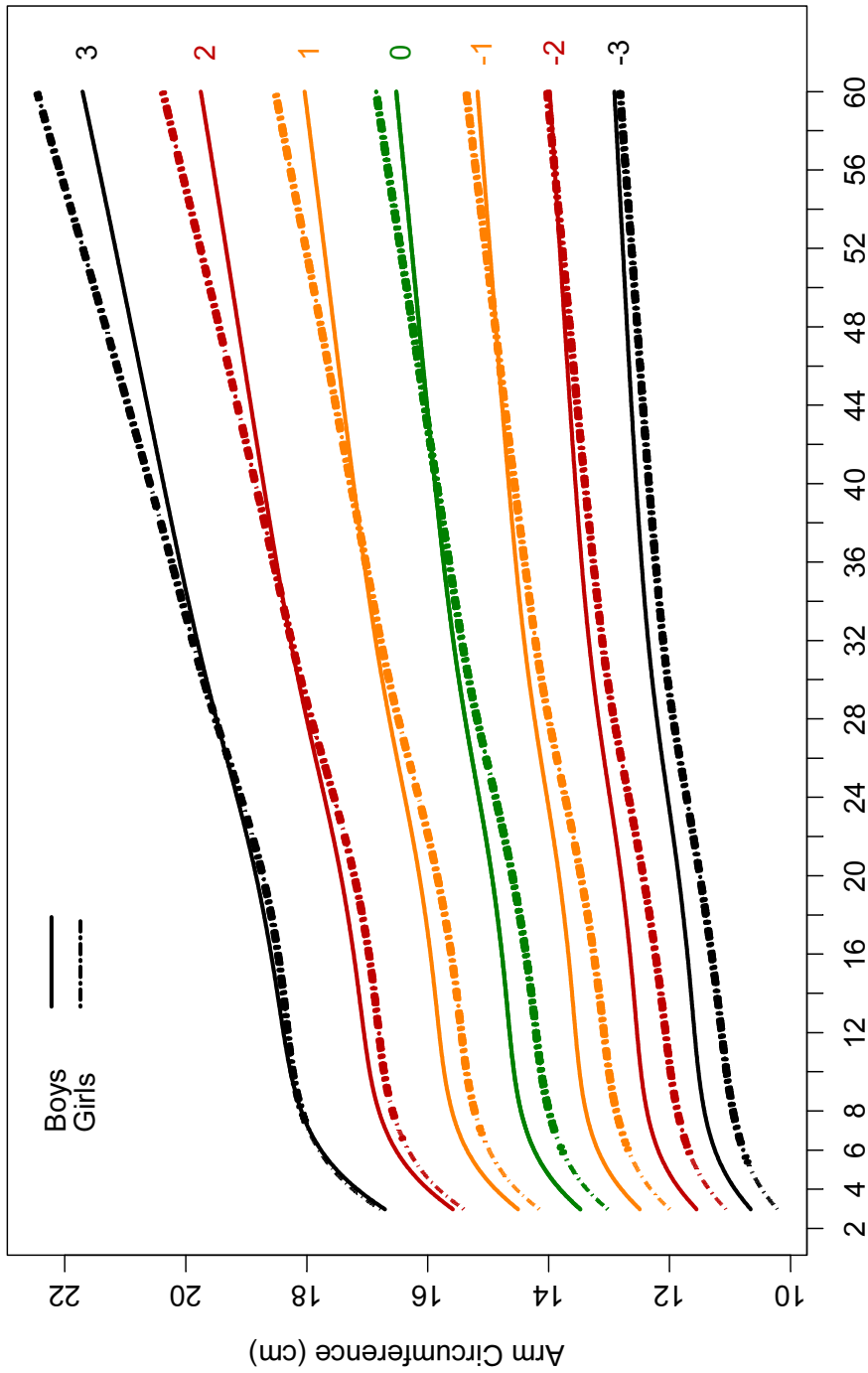


Figure 44 Comparison of boys' and girls' arm circumference-for-age z-scores

5. CONSTRUCTION OF THE TRICEPS SKINFOLD-FOR-AGE STANDARDS

5.1 Indicator-specific methodology

Similar steps to those described to select the best model for the head circumference-for-age and arm-circumference-for-age curves were followed to select the best model to construct the triceps skinfold-for-age standards. The diagnostic tools applied to evaluate and compare candidate models were the same. All data up to 71 months were used for modelling the triceps skinfold-for-age growth curves and the standards afterwards truncated at 60 completed months to correct for the right-edge effect (Borghi et al., 2006).

5.2 Triceps skinfold-for-age for boys

5.2.1 Sample size

There were a total of 10 762 triceps skinfold observations for boys. The longitudinal and cross-sectional sample sizes by visit and age are presented in Tables 36 and 37. The measurement of triceps skinfold started at 3 months of age (de Onis et al., 2004b).

Table 36 Longitudinal sample sizes for triceps skinfold-for-age for boys

Visit	**5**	**6**	**7**	**8**	**9**	**10**
Age	**3 mo**	**4 mo**	**5 mo**	**6 mo**	**7 mo**	**8 mo**
N	419	411	412	417	414	414
Visit	**11**	**12**	**13**	**14**	**15**	**16**
Age	**9 mo**	**10 mo**	**11 mo**	**12 mo**	**14 mo**	**16 mo**
N	407	407	418	412	416	417
Visit	**17**	**18**	**19**	**20**		
Age	**18 mo**	**20 mo**	**22 mo**	**24 mo**		
N	415	421	415	421		

Table 37 Cross-sectional sample sizes for triceps skinfold-for-age for boys

Age (mo)	**<18**	**18–20**	**21–23**	**24–26**	**27–29**	**30–32**	**33–35**
N	3	175	183	236	255	217	252
Age (mo)	**36–38**	**39–41**	**42–44**	**45–47**	**48–50**	**51–53**	**54–56**
N	265	249	255	236	236	221	225
Age (mo)	**57–59**	**60–62**	**63–65**	**66–68**	**69–71**	**>71**	
N	239	228	216	217	214	4	

5.2.2 Model selection and results

To search for the best value of the age-transformation power λ, the model BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) was used as a starting point. Table 38 shows the global deviance for values of λ from 0.05 to 1. The global deviance value was smallest for λ=0.30 and thus this age-transformation power was selected.

Table 38 Global deviance (GD) for models within the class BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) for triceps skinfold-for-age for boys

λ	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
GD[a]	628.4	627.7	627.1	626.8	626.6	626.5	626.6	626.8	627.2	627.6
λ	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
GD[a]	628.2	628.9	629.6	630.3	631.0	631.7	632.4	633.1	633.8	634.5

[a] In excess of 41 000.

The search for the best df(μ) and df(σ) followed, fixing λ=0.30, ν=1 and τ=2. All possible combinations with df(μ) values ranging from 6 to 15 and df(σ) from 2 to 10 were considered and partial results are presented in Table 39. The criterion considered was the *GAIC(3)*, as for the construction of arm circumference-for-age (see Section 4.2.2). The model with df(μ)=8 and df(σ)=5 provided the smallest value of *GAIC(3)* but the model with df(μ)=7 and df(σ)=5, with a smoother median curve, yielded a very similar *GAIC(3)* value and thus the latter was selected for further evaluation.

Table 39 Goodness-of-fit summary for models using the BCPE distribution with fixed ν=1 and τ=2 for triceps skinfold-for-age for boys

df(μ)	df(σ)	GD[a]	AIC[a]	GAIC(3)[a]	Total df
	3	1 597.8	1 615.8	1 624.8	9
	4	1 585.3	1 605.3	1 615.3	10
6	**5**	1 579.8	1 601.8	1 612.8	11
	6	1 576.8	1 600.8	1 612.8	12
	7	1 574.2	1 600.2	1 613.2	13
	3	1 591.7	1 611.7	1 621.7	10
	4	1 579.1	1 601.1	1 612.1	11
7	**5**	1 573.7	1 597.7	1 609.7	12
	6	1 570.8	1 596.8	1 609.8	13
	7	1 568.3	1 596.3	1 610.3	14
	3	1 588.3	1 610.3	1 621.3	11
	4	1 575.6	1 599.6	1 611.6	12
8	**5**	1 570.3	1 596.3	1 609.3	13
	6	1 567.3	1 595.4	1 609.4	14
	7	1 564.9	1 594.9	1 609.9	15
	3	1 585.7	1 609.7	1 621.7	12
	4	1 573.0	1 599.0	1 612.0	13
9	**5**	1 567.7	1 595.7	1 609.7	14
	6	1 564.8	1 594.8	1 609.8	15
	7	1 562.4	1 594.4	1 610.4	16
	3	1 583.5	1 609.5	1 622.5	13
	4	1 570.8	1 598.8	1 612.8	14
10	**5**	1 565.4	1 595.5	1 610.5	15
	6	1 562.6	1 594.6	1 610.6	16
	7	1 560.2	1 594.2	1 611.2	17

GD, Global Deviance; AIC, Akaike Information Criterion;
GAIC(3), Generalized AIC with penalty equal to 3;
[a] In excess of 41 000.

Model 1: BCPE(x=age$^{0.30}$, df(μ)=7, df(σ)=5, ν=1, τ=2)

This model was inadequate as there was clear evidence of residual skewness in both the worm plots (Figure 45) and the Q-test results (Table 40). The worms depicted U-shapes for most age groups and Q-test results (Table 40) showed all groups with absolute values of z3 higher than 2. Most of the age groups also presented absolute values of z4 higher than 2, indicating residual kurtosis. The overall tests for skewness and kurtosis were significant (p-values < 0.01). Only two groups presented absolute values of z2 larger than 2, indicating misfit of the variance (40 mo and 58 mo).

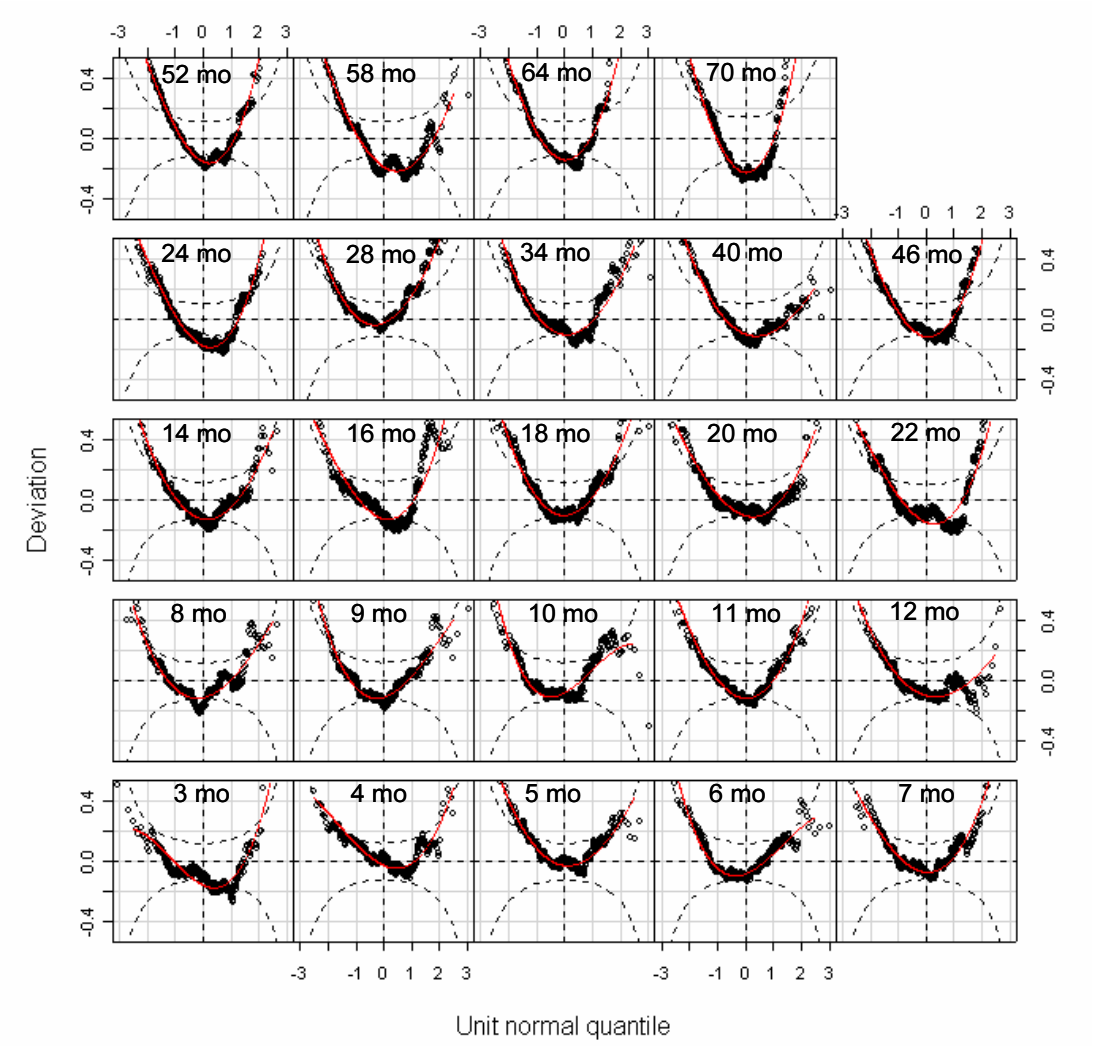


Figure 45 Worm plots of z-scores for Model 1 for triceps skinfold-for-age for boys

Table 40 Q-test for z-scores from Model 1 [BCPE(x=age$^{0.30}$, df(μ)=7, df(σ)=5, ν=1, τ=2)] for triceps skinfold-for-age for boys

Age (days)	Group	N	z1	z2	z3	z4
79 to 99	**3 mo**	415	-1.4	0.0	4.9	3.4
100 to 129	**4 mo**	408	1.0	-0.8	4.1	2.5
130 to 159	**5 mo**	409	1.4	-0.7	4.1	0.9
160 to 189	**6 mo**	411	0.0	0.4	3.6	-0.7
190 to 219	**7 mo**	405	0.8	0.8	4.9	2.5
220 to 249	**8 mo**	419	-0.7	0.4	4.0	0.5
250 to 279	**9 mo**	390	-0.3	0.6	4.1	0.0
280 to 309	**10 mo**	399	0.1	0.9	3.4	-1.5
310 to 349	**11 mo**	461	0.0	0.6	5.7	2.7
350 to 379	**12 mo**	407	-0.5	-1.6	3.7	1.1
380 to 439	**14 mo**	418	-0.4	-0.7	5.0	1.7
440 to 499	**16 mo**	415	0.0	0.6	5.9	2.9
500 to 559	**18 mo**	441	0.3	0.2	5.5	1.7
560 to 619	**20 mo**	521	-0.2	-0.6	5.2	2.7
620 to 679	**22 mo**	544	-0.7	-0.2	6.9	3.9
680 to 749	**24 mo**	591	-0.9	0.0	8.1	4.6
750 to 929	**28 mo**	469	1.8	1.7	4.8	1.0
930 to 1119	**34 mo**	509	0.4	-0.5	5.6	1.5
1120 to 1309	**40 mo**	510	-0.2	-2.4	4.9	0.7
1310 to 1499	**46 mo**	506	0.8	0.9	7.2	3.5
1500 to 1689	**52 mo**	487	0.3	0.4	8.2	4.8
1690 to 1879	**58 mo**	480	-1.6	-2.7	6.1	2.5
1880 to 2069	**64 mo**	461	0.7	1.3	7.5	3.5
2070 to 2249	**70 mo**	286	-0.2	1.8	6.9	3.4
Overall Q stats		**10 762**	**14.9**	**29.8**	**752.4**	**162.1**
degrees of freedom			**17.0**	**21.0**	**24.0**	**24.0**
p-value			**0.6013**	**0.0958**	**<0.01**	**<0.01**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

The next step involved fitting the parameter ν for skewness using the BCPE distribution with fixed parameter τ=2 and keeping the degrees of freedom for the μ and σ curves selected for Model 1. Table 41 shows the *GAIC(3)* values for various degrees of freedom for the ν curve.

Table 41 Goodness-of-fit summary for models BCPE(x=age$^{0.30}$, df(μ)=7, df(σ)=5, df(ν)=?, τ=2) for triceps skinfold-for-age for boys

df(ν)	GD[a]	GAIC(3)[a]	Total df
1	634.1	673.1	13
2	627.6	669.6	14
3	627.3	672.3	15
4	626.8	674.8	16
5	626.3	677.3	17
6	625.7	679.7	18
7	625.0	682.0	19

GD, Global Deviance; GAIC(3), Generalized Akaike Information Criterion with penalty equal to 3;
[a] In excess of 41 000.

The smallest *GAIC(3)* value corresponded to df(ν)=2. Fixing df(ν)=2, a re-search for the best df(μ) and df(σ) was carried out but results indicated that there was no need for updating the model. A re-search for the best age-transformation power followed. Models using λ from 0.05 to 0.30 were smallest and very similar and thus the value of 0.30 was kept unchanged.

Model 2: BCPE(x= age$^{0.30}$, df(μ)=7, df(σ)=5, df(ν)=2, τ=2)

Figure 46 shows the fitting of the parameters μ, σ and ν for Model 2 with their respective sample estimates, that is, the median for μ, the sample standard deviation of the Box-Cox transformed data for σ and Box-Cox transform power for ν.

Figures 47 and 48 show the distribution of the empirical minus fitted centile differences for the longitudinal and cross-sectional samples, respectively. There was no indication of systematic biases either between 3 and 24 months (Figure 47), or between 24 and 71 months (Figure 48).

The worm plots for this model (Figure 49) were significantly improved compared to those of Model 1 (Figure 45). The U-shaped worms flattened out significantly (Figure 49), indicating that the residual skewness associated with Model 1 had been corrected. There was indication of residual kurtosis for only four age groups but their respective worms were contained within the 95% confidence interval.

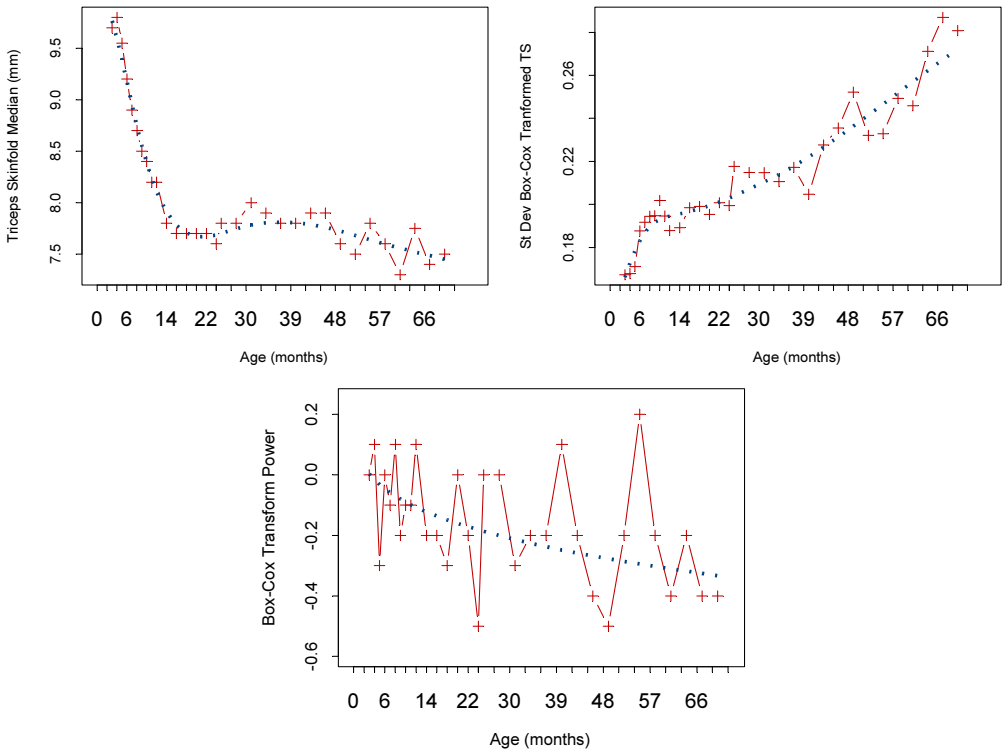


Figure 46 Fitting of the μ, σ, and ν curves of Model 2 for triceps skinfold-for-age for boys from 3 to 71 months (dotted line) and their respective sample estimates (points with solid line)

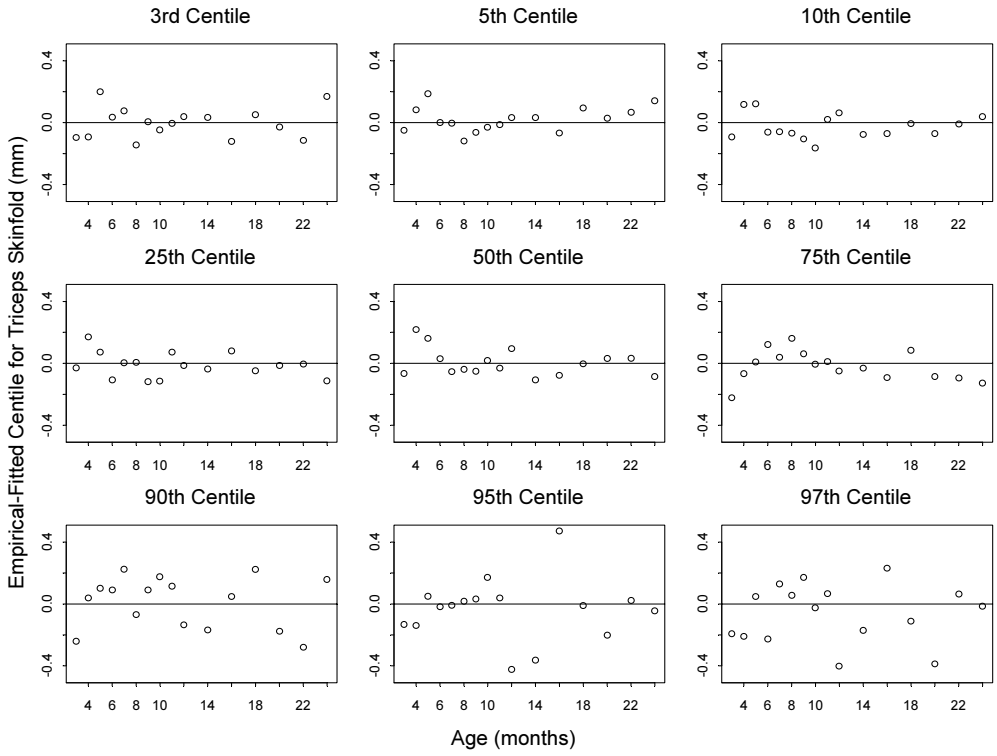


Figure 47 Centile residuals from fitting Model 2 for triceps skinfold-for-age from 3 to 24 months for boys

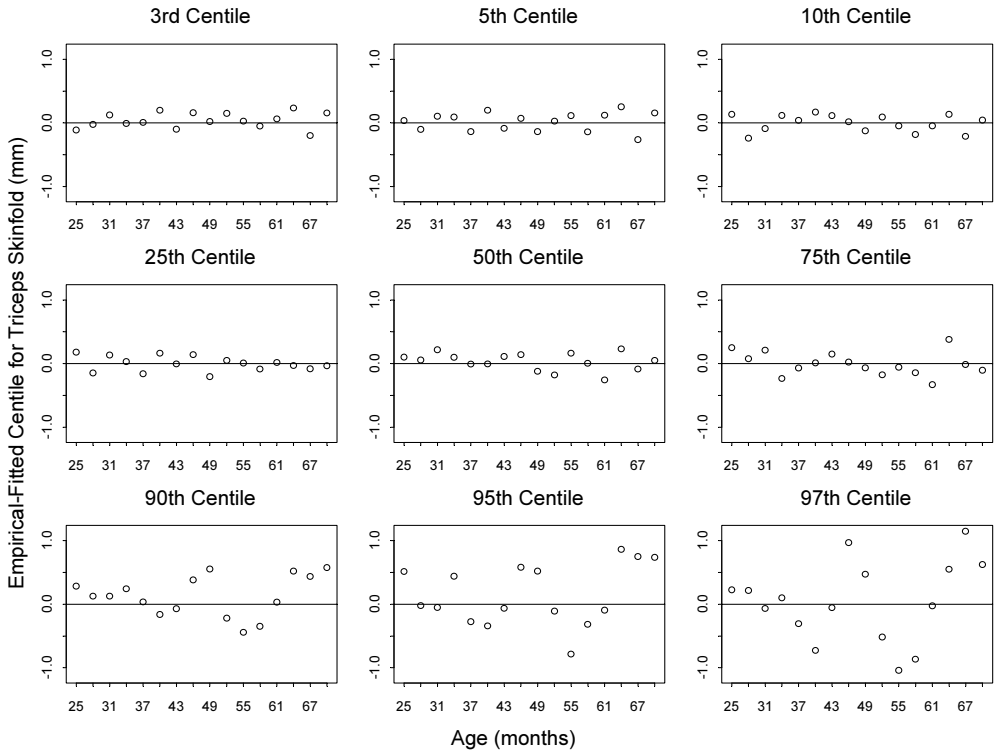


Figure 48 Centile residuals from fitting Model 2 for triceps skinfold-for-age from 24 to 71 months for boys

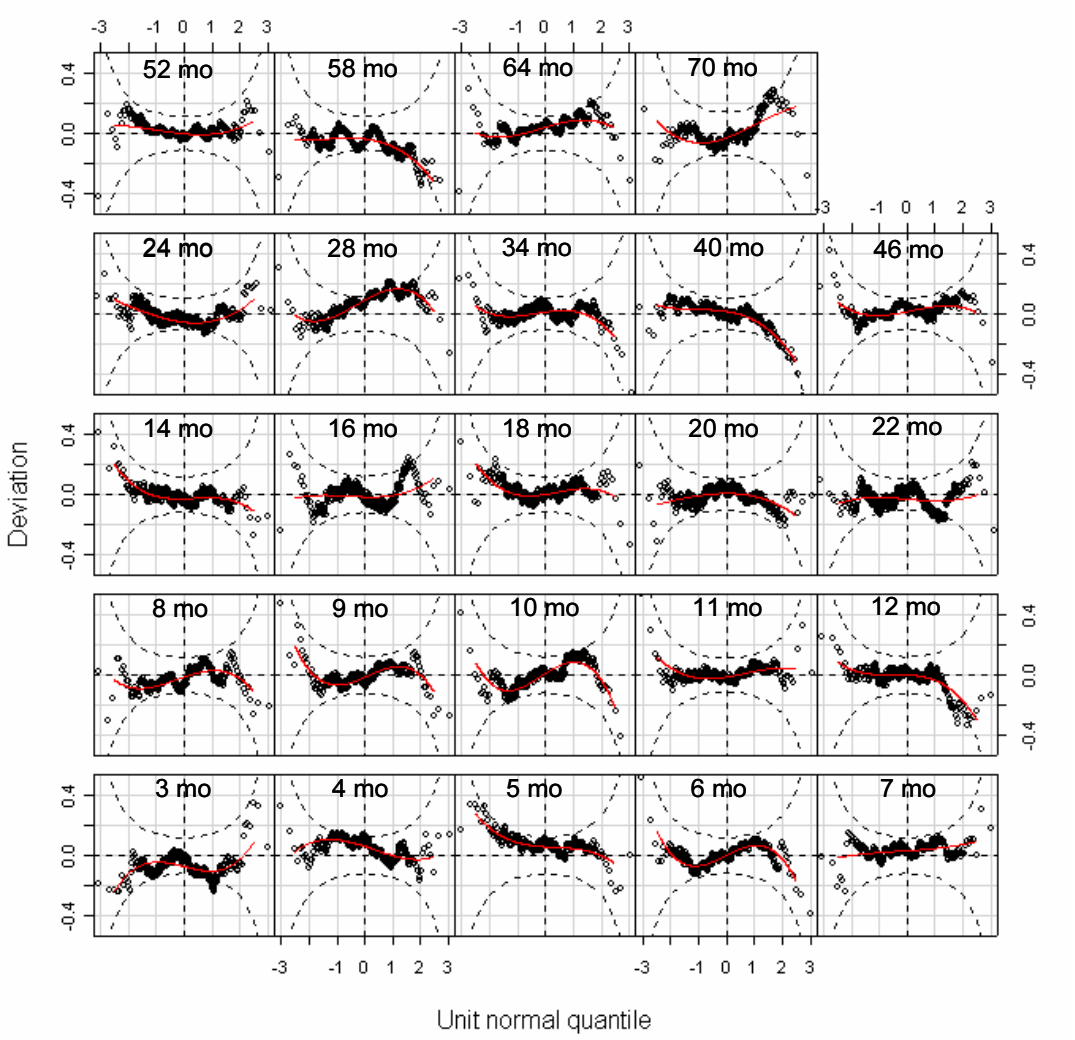


Figure 49 Worm plots of z-scores for Model 2 for triceps skinfold-for-age for boys

The Q-test results from Model 2 are shown in Table 42. There were no longer indications of misfit of variance, as no z2 absolute values were larger than 2. There were also no groups with absolute value larger than 2 for the statistic z3 that would suggest remaining skewness. Three age groups presented absolute values of z4 greater than 2, indicating remaining kurtosis, but the overall test statistic for kurtosis had a p-value not significant at the 5% level. The overall Q-test p-values were all non-significant, indicating an adequate fit of the boys' triceps skinfold-for-age curves and providing no justification for increasing the complexity of the model by adjusting for kurtosis (modelling τ).

Table 43 presents observed percentages with triceps skinfolds below the fitted centiles. There was no detectable pattern suggesting a systematic bias.

Table 42 Q-test for z-scores from Model 2 [BCPE(x=age$^{0.30}$, df(μ)=7, df(σ)=5, df(ν)=2, τ=2)] for triceps skinfold-for-age for boys

Age (days)	Group	N	z1	z2	z3	z4
79 to 99	**3 mo**	415	-1.6	0.2	0.1	1.5
100 to 129	**4 mo**	408	1.0	-1.0	-0.4	0.8
130 to 159	**5 mo**	409	1.4	-1.0	0.3	-0.9
160 to 189	**6 mo**	411	0.0	0.5	0.0	-2.4
190 to 219	**7 mo**	405	0.8	0.4	0.1	0.3
220 to 249	**8 mo**	419	-0.7	0.8	-0.4	-1.0
250 to 279	**9 mo**	390	-0.3	0.6	0.3	-2.3
280 to 309	**10 mo**	399	0.1	1.1	-0.6	-2.4
310 to 349	**11 mo**	461	0.0	0.2	0.7	-0.5
350 to 379	**12 mo**	407	-0.3	-1.1	-0.8	-1.1
380 to 439	**14 mo**	418	-0.4	-0.8	0.6	-1.1
440 to 499	**16 mo**	415	-0.2	0.3	0.5	0.5
500 to 559	**18 mo**	441	0.3	-0.1	0.8	-1.0
560 to 619	**20 mo**	521	-0.2	-0.1	-1.0	-0.2
620 to 679	**22 mo**	544	-0.6	-0.2	0.4	0.2
680 to 749	**24 mo**	591	-0.9	-0.4	1.5	0.5
750 to 929	**28 mo**	469	1.6	1.6	-0.8	-1.5
930 to 1119	**34 mo**	509	0.3	-0.4	-0.3	-1.1
1120 to 1309	**40 mo**	510	-0.2	-1.6	-1.3	-0.6
1310 to 1499	**46 mo**	506	0.5	0.5	0.2	-0.7
1500 to 1689	**52 mo**	487	0.2	-0.2	0.6	0.5
1690 to 1879	**58 mo**	480	-1.3	-1.2	-1.3	-0.4
1880 to 2069	**64 mo**	461	0.8	1.0	-0.2	-0.6
2070 to 2249	**70 mo**	286	-0.1	1.1	1.0	-0.4
Overall Q stats		**10 762**	**13.3**	**16.0**	**12.2**	**31.0**
degrees of freedom			**17.0**	**21.0**	**22.0**	**24.0**
p-value			**0.7179**	**0.7701**	**0.9522**	**0.1551**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

In conclusion, the model selected for constructing the triceps skinfold-for-age growth curves for boys was BCPE(x=age$^{0.30}$, df(μ)=7, df(σ)=5, df(ν)=2, τ=2) that adjusts only for skewness, and thus reduces to the LMS method. The fitted centile curves and empirical centiles are shown in Figures 50 to 53.

Table 43 Observed proportions of children with measurements below the fitted centiles from Model 2, triceps skinfold-for-age for boys

Expected	3 mo	4 mo	5 mo	6 mo	7 mo	8 mo	9 mo	10 mo	11 mo
1	1.7	1.0	0.5	1.2	1.5	0.7	0.8	1.5	0.7
3	3.4	3.2	1.5	3.2	2.2	3.8	2.8	3.0	3.3
5	6.0	4.7	3.4	4.9	4.0	6.0	6.4	5.8	5.4
10	11.6	9.1	7.1	12.2	9.9	11.7	11.3	11.8	10.6
25	27.2	21.1	23.0	27.0	23.5	25.8	27.9	26.6	24.5
50	51.3	45.8	45.7	50.1	48.9	52.7	52.8	47.9	51.8
75	78.6	75.5	74.8	72.5	74.3	74.2	74.1	73.7	74.6
90	91.6	89.2	88.5	88.6	87.9	90.2	89.7	87.7	88.5
95	95.9	95.3	94.6	94.6	94.8	94.7	94.4	93.7	94.4
97	97.6	97.8	96.6	97.3	96.8	96.2	96.4	97.5	96.5
99	98.6	98.5	99.5	99.5	98.8	99.5	99.5	100.0	99.1
Expected	**12 mo**	**14 mo**	**16 mo**	**18 mo**	**20 mo**	**22 mo**	**24 mo**	**28 mo**	**34 mo**
1	0.5	0.5	0.5	0.9	1.2	0.9	0.7	1.3	0.6
3	2.9	2.9	4.1	2.3	3.8	3.7	3.2	3.8	2.8
5	4.9	4.5	6.0	3.6	5.0	4.4	4.2	5.1	5.1
10	10.1	10.0	10.1	10.4	10.7	10.3	9.3	10.4	9.6
25	25.6	25.1	24.1	26.1	25.5	27.9	27.4	24.5	23.8
50	49.4	51.7	50.6	50.6	47.6	49.1	51.3	48.4	48.3
75	75.7	75.6	76.6	74.4	75.6	76.5	78.5	70.8	75.0
90	91.6	90.4	89.2	88.2	90.6	91.5	89.5	87.0	88.6
95	96.8	95.9	93.0	95.0	96.0	94.9	95.3	93.4	94.9
97	98.5	97.1	95.4	96.8	97.7	96.7	97.3	95.9	96.9
99	99.5	99.5	99.3	98.6	99.0	98.7	98.5	99.1	99.4

Table 43 Observed proportions of children with measurements below the fitted centiles from Model 2, triceps skinfold-for-age for boys (cont)

Expected	40 mo	46 mo	52 mo	58 mo	64 mo	70 mo	Overall
1	1.0	0.4	1.0	0.8	0.7	1.4	0.9
3	2.4	3.4	2.1	3.1	3.5	2.8	3.1
5	4.7	5.7	4.3	5.6	5.0	4.9	5.0
10	8.8	10.9	9.7	11.9	10.2	9.4	10.3
25	23.5	25.1	24.4	25.0	24.7	28.0	25.3
50	51.0	47.6	50.5	51.7	48.2	51.4	49.7
75	74.1	75.7	74.9	77.9	73.1	76.9	75.2
90	91.4	89.1	90.3	91.9	87.9	87.4	89.5
95	96.7	94.3	95.1	97.1	93.9	92.3	94.9
97	98.2	96.2	96.5	98.3	95.2	95.1	96.9
99	99.8	98.6	98.6	99.6	98.7	98.3	99.1

Note: Group labels correspond to the age intervals in Table 42.

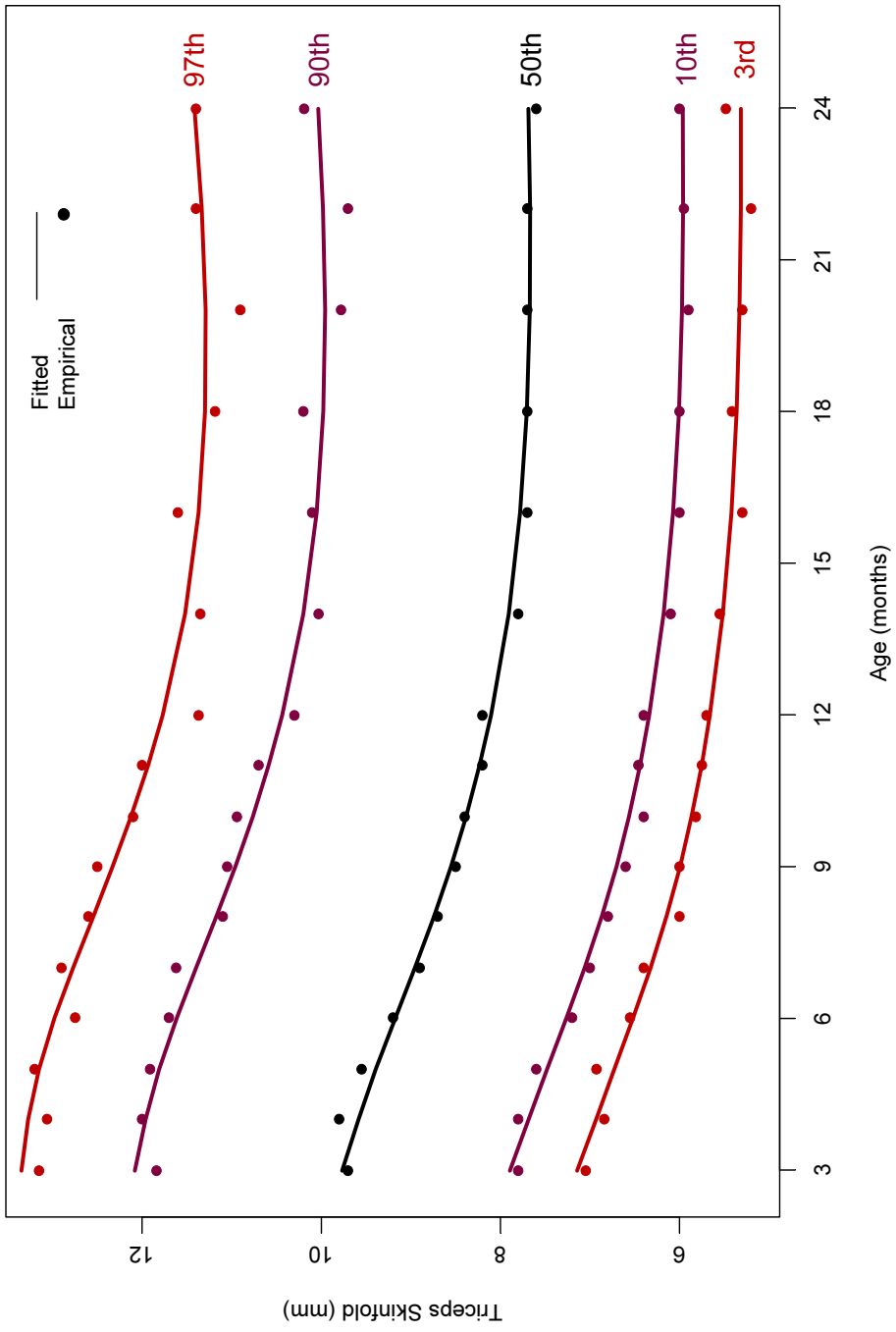


Figure 50 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: triceps skinfold-for-age for boys from 3 to 24 months

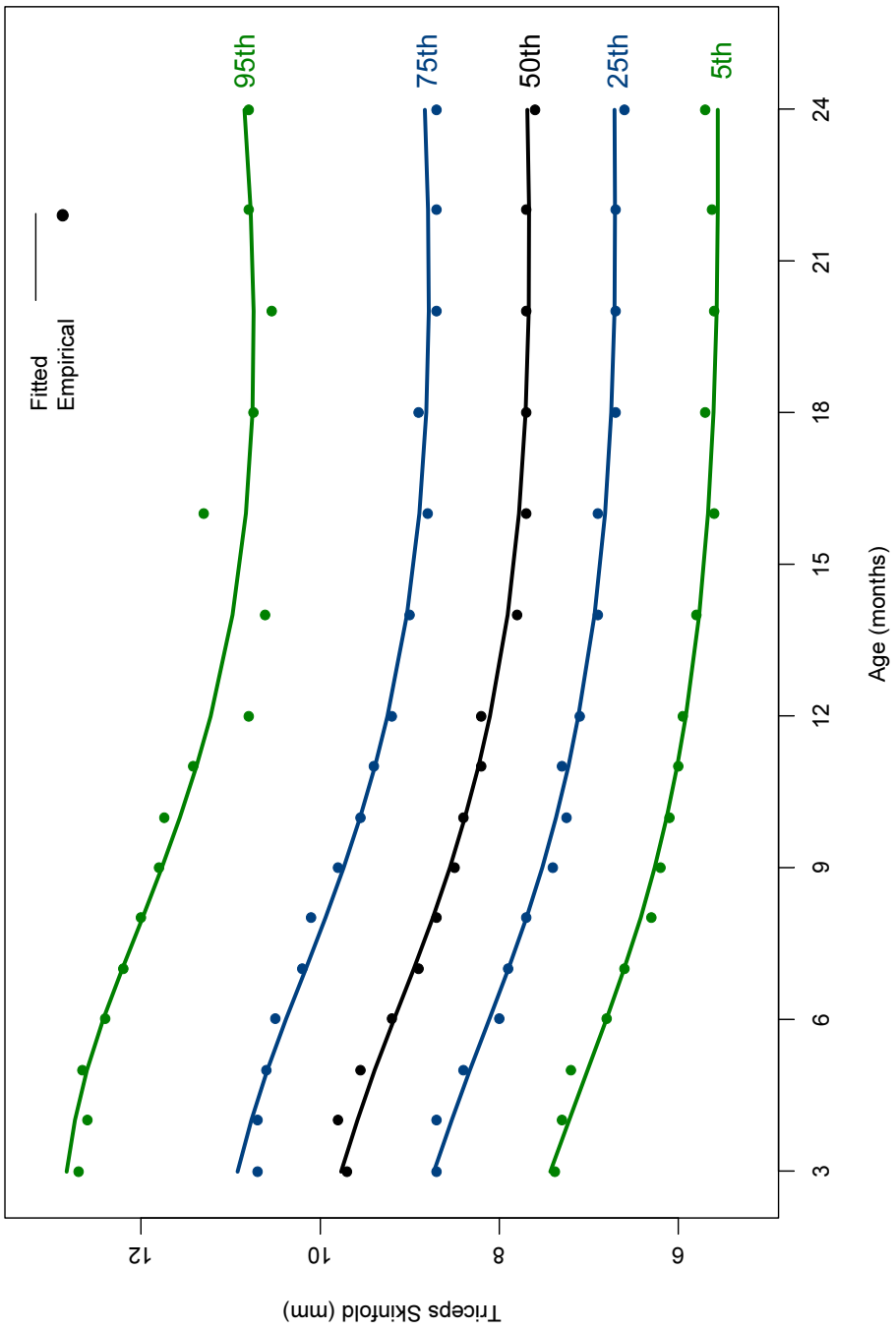


Figure 51 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: triceps skinfold-for-age for boys from 3 to 24 months

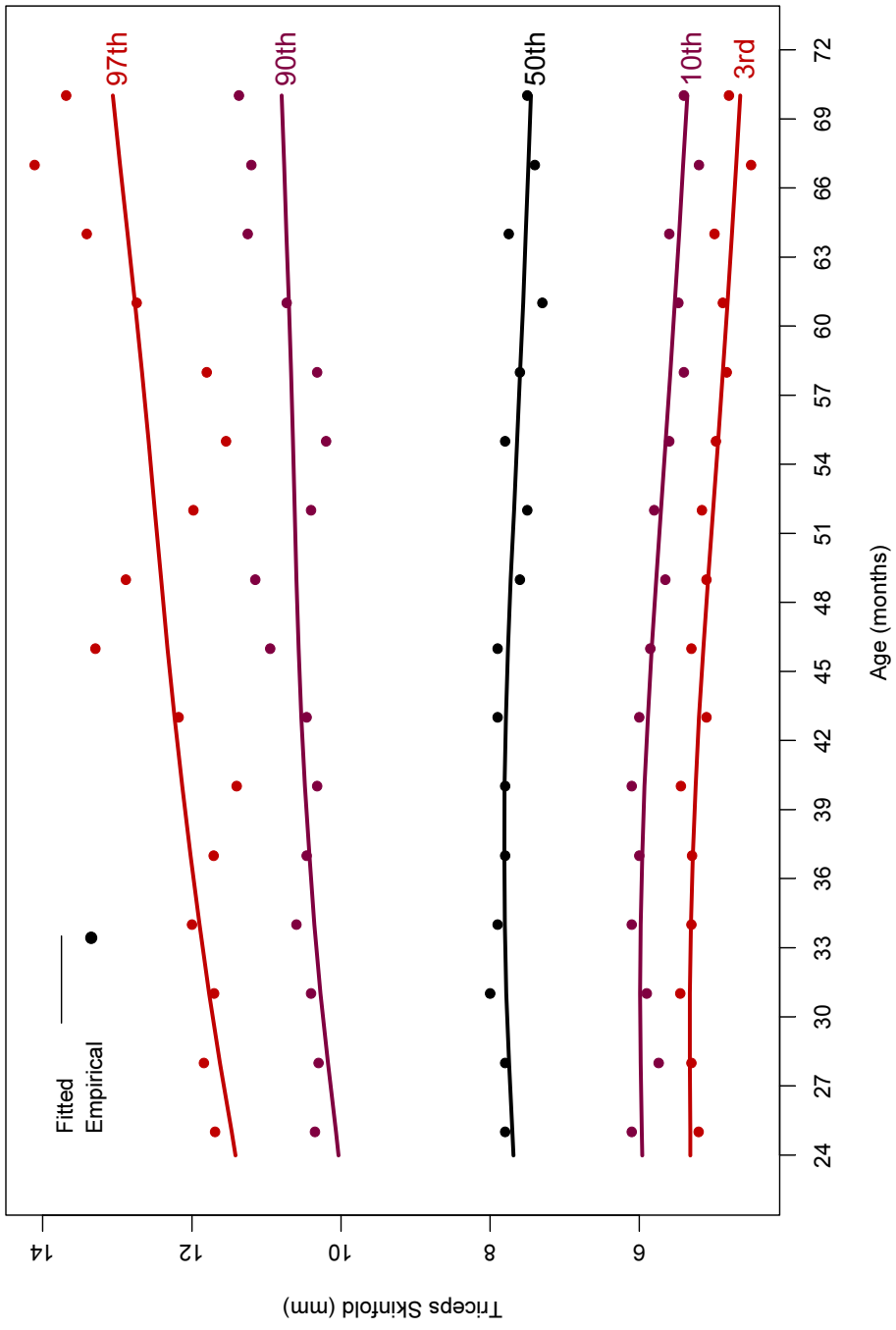


Figure 52 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: triceps skinfold-for-age for boys from 24 to 71 months

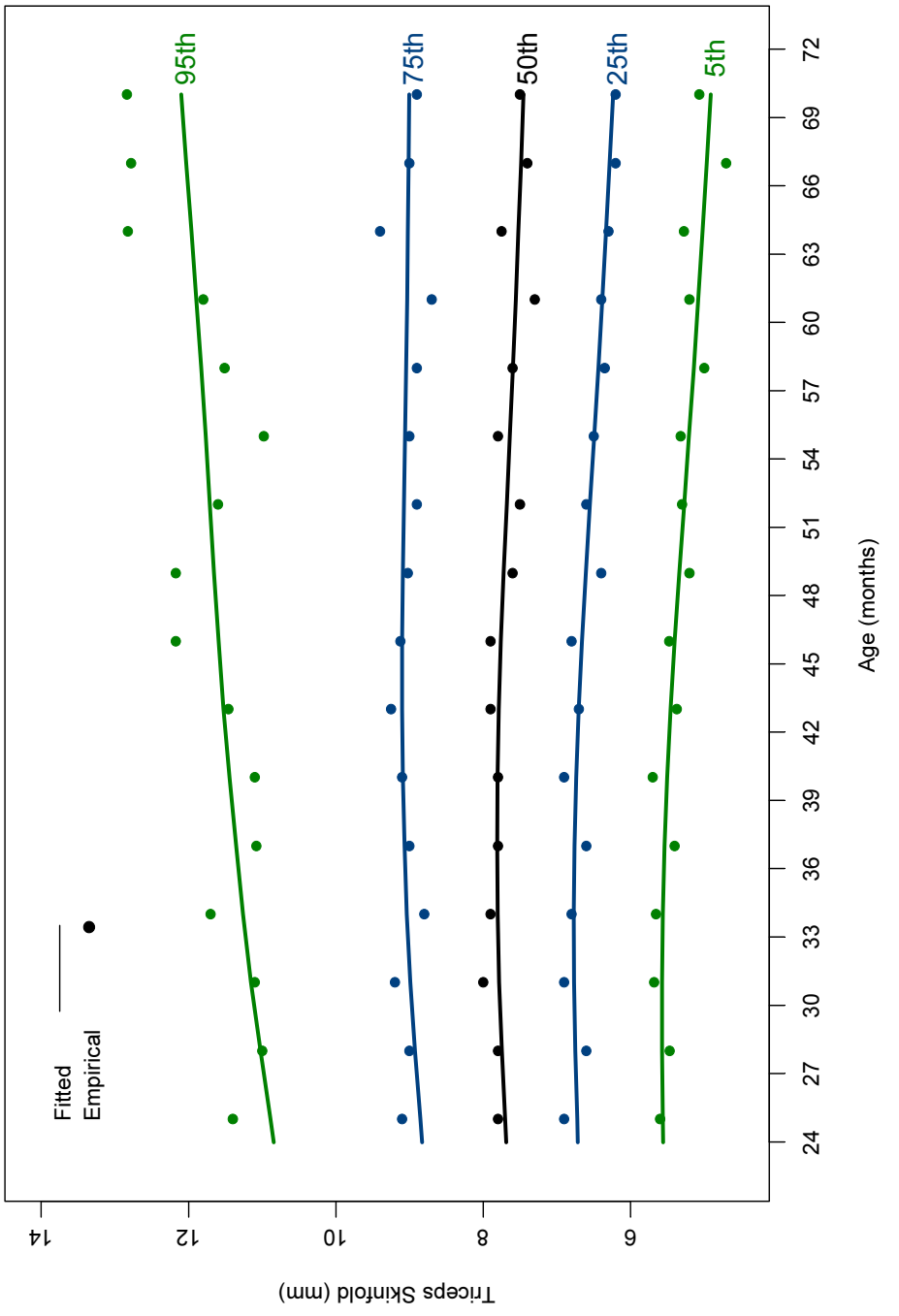


Figure 53 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: triceps skinfold-for-age for boys from 24 to 71 months

5.2.3 WHO standards

This section presents the final WHO triceps skinfold-for-age z-score and percentile charts (Figures 54 and 55) and table (Table 44) for boys.

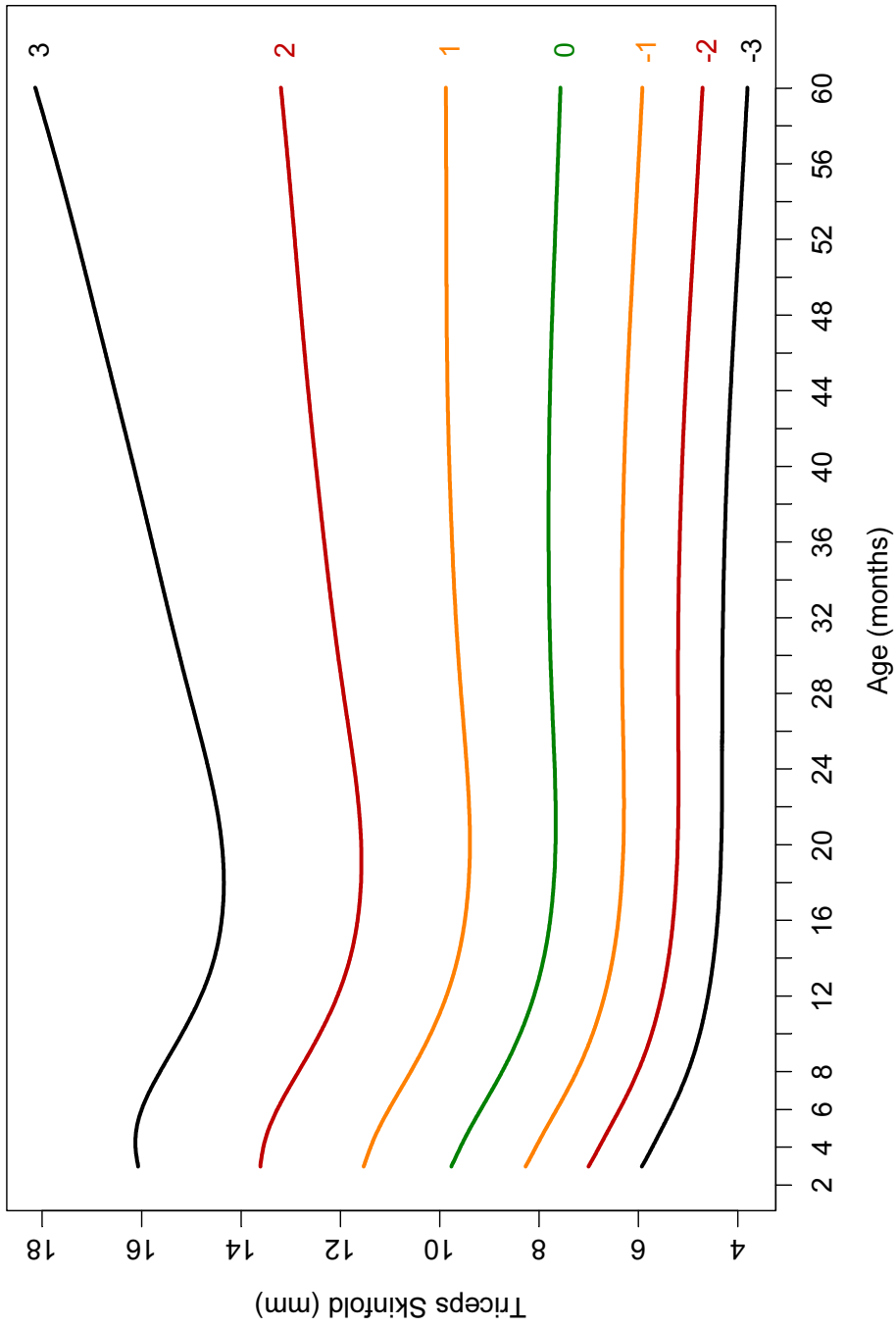


Figure 54 WHO triceps skinfold-for-age z-scores for boys from 3 to 60 months

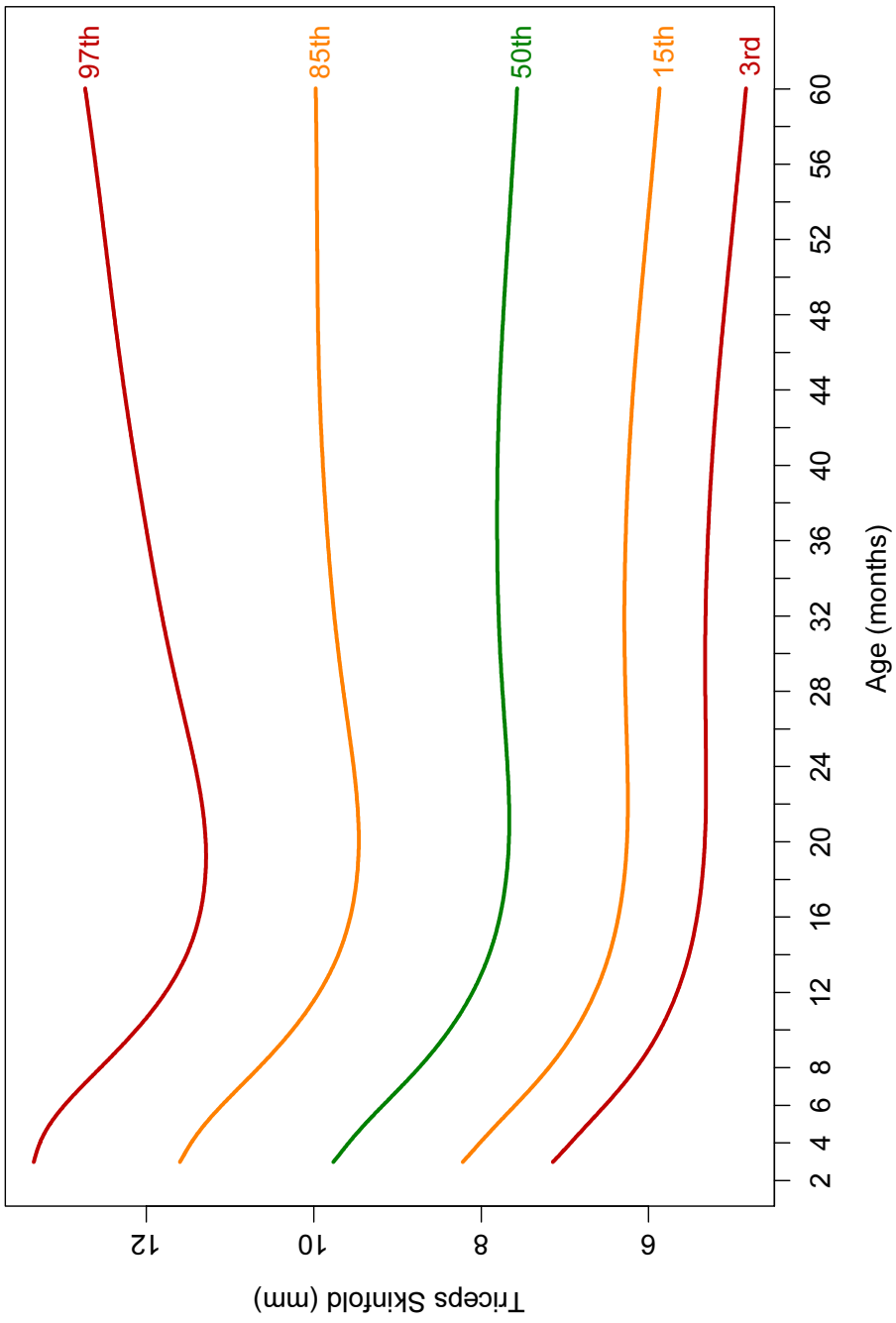


Figure 55 WHO triceps skinfold-for-age percentiles for boys from 3 to 60 months

Table 44 Triceps skinfold-for-age for boys, age in years and months

Year: Month	Month	L	M	S	Percentiles (triceps skinfold in mm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
0: 3	**3**	0.0027	9.7639	0.16618	6.6	7.1	7.4	8.2	8.7	9.8	10.9	11.6	12.8	13.3	14.4
0: 4	**4**	-0.0165	9.5840	0.17264	6.4	6.9	7.2	8.0	8.5	9.6	10.8	11.5	12.7	13.3	14.3
0: 5	**5**	-0.0326	9.3885	0.17824	6.2	6.7	7.0	7.8	8.3	9.4	10.6	11.3	12.6	13.2	14.3
0: 6	**6**	-0.0466	9.1729	0.18304	6.0	6.5	6.8	7.6	8.1	9.2	10.4	11.1	12.4	13.0	14.1
0: 7	**7**	-0.0590	8.9535	0.18685	5.8	6.3	6.6	7.4	7.9	9.0	10.2	10.9	12.2	12.8	13.9
0: 8	**8**	-0.0703	8.7435	0.18968	5.7	6.1	6.4	7.2	7.7	8.7	9.9	10.7	12.0	12.5	13.7
0: 9	**9**	-0.0806	8.5518	0.19166	5.5	6.0	6.3	7.0	7.5	8.6	9.7	10.4	11.8	12.3	13.5
0:10	**10**	-0.0901	8.3812	0.19300	5.4	5.9	6.1	6.9	7.4	8.4	9.6	10.3	11.6	12.1	13.3
0:11	**11**	-0.0990	8.2323	0.19389	5.3	5.8	6.0	6.7	7.2	8.2	9.4	10.1	11.4	11.9	13.1
1: 0	**12**	-0.1073	8.1041	0.19453	5.2	5.7	5.9	6.6	7.1	8.1	9.2	9.9	11.2	11.8	12.9
1: 1	**13**	-0.1152	7.9958	0.19506	5.1	5.6	5.8	6.5	7.0	8.0	9.1	9.8	11.1	11.6	12.7
1: 2	**14**	-0.1227	7.9064	0.19558	5.1	5.5	5.8	6.5	6.9	7.9	9.0	9.7	11.0	11.5	12.6
1: 3	**15**	-0.1297	7.8345	0.19612	5.0	5.5	5.7	6.4	6.9	7.8	9.0	9.6	10.9	11.4	12.5
1: 4	**16**	-0.1365	7.7781	0.19668	5.0	5.4	5.7	6.4	6.8	7.8	8.9	9.6	10.8	11.4	12.5
1: 5	**17**	-0.1430	7.7351	0.19728	5.0	5.4	5.6	6.3	6.8	7.7	8.8	9.5	10.8	11.3	12.4
1: 6	**18**	-0.1492	7.7036	0.19793	4.9	5.4	5.6	6.3	6.7	7.7	8.8	9.5	10.8	11.3	12.4
1: 7	**19**	-0.1552	7.6821	0.19862	4.9	5.3	5.6	6.3	6.7	7.7	8.8	9.5	10.7	11.3	12.4
1: 8	**20**	-0.1609	7.6697	0.19937	4.9	5.3	5.6	6.3	6.7	7.7	8.8	9.5	10.7	11.3	12.4
1: 9	**21**	-0.1665	7.6652	0.20018	4.9	5.3	5.6	6.3	6.7	7.7	8.8	9.5	10.8	11.3	12.4
1:10	**22**	-0.1719	7.6675	0.20105	4.9	5.3	5.6	6.2	6.7	7.7	8.8	9.5	10.8	11.3	12.5
1:11	**23**	-0.1771	7.6750	0.20196	4.9	5.3	5.6	6.2	6.7	7.7	8.8	9.5	10.8	11.4	12.5
2: 0	**24**	-0.1821	7.6863	0.20293	4.9	5.3	5.6	6.3	6.7	7.7	8.8	9.5	10.8	11.4	12.6

Table 44 Triceps skinfold-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Percentiles (triceps skinfold in mm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
2: 1	**25**	-0.1870	7.7003	0.20394	4.9	5.3	5.6	6.3	6.7	7.7	8.9	9.6	10.9	11.5	12.7
2: 2	**26**	-0.1918	7.7156	0.20497	4.9	5.3	5.6	6.3	6.7	7.7	8.9	9.6	10.9	11.5	12.7
2: 3	**27**	-0.1965	7.7312	0.20603	4.9	5.3	5.6	6.3	6.7	7.7	8.9	9.6	11.0	11.6	12.8
2: 4	**28**	-0.2010	7.7463	0.20710	4.9	5.3	5.6	6.3	6.7	7.7	8.9	9.6	11.0	11.6	12.9
2: 5	**29**	-0.2054	7.7602	0.20818	4.9	5.3	5.6	6.3	6.8	7.8	8.9	9.7	11.1	11.7	12.9
2: 6	**30**	-0.2097	7.7726	0.20928	4.9	5.3	5.6	6.3	6.8	7.8	9.0	9.7	11.1	11.7	13.0
2: 7	**31**	-0.2139	7.7832	0.21039	4.9	5.3	5.6	6.3	6.8	7.8	9.0	9.7	11.2	11.8	13.1
2: 8	**32**	-0.2180	7.7920	0.21153	4.9	5.3	5.6	6.3	6.8	7.8	9.0	9.8	11.2	11.8	13.1
2: 9	**33**	-0.2221	7.7989	0.21269	4.9	5.3	5.6	6.3	6.8	7.8	9.0	9.8	11.2	11.9	13.2
2:10	**34**	-0.2260	7.8040	0.21389	4.9	5.3	5.6	6.3	6.8	7.8	9.0	9.8	11.3	11.9	13.2
2:11	**35**	-0.2299	7.8074	0.21513	4.9	5.3	5.6	6.3	6.8	7.8	9.0	9.8	11.3	11.9	13.3
3: 0	**36**	-0.2336	7.8094	0.21641	4.9	5.3	5.5	6.3	6.8	7.8	9.1	9.8	11.3	12.0	13.3
3: 1	**37**	-0.2374	7.8101	0.21773	4.8	5.3	5.5	6.3	6.8	7.8	9.1	9.8	11.4	12.0	13.4
3: 2	**38**	-0.2410	7.8096	0.21909	4.8	5.3	5.5	6.3	6.8	7.8	9.1	9.9	11.4	12.1	13.5
3: 3	**39**	-0.2446	7.8080	0.22049	4.8	5.3	5.5	6.3	6.7	7.8	9.1	9.9	11.4	12.1	13.5
3: 4	**40**	-0.2481	7.8051	0.22194	4.8	5.2	5.5	6.2	6.7	7.8	9.1	9.9	11.4	12.1	13.6
3: 5	**41**	-0.2515	7.8009	0.22343	4.8	5.2	5.5	6.2	6.7	7.8	9.1	9.9	11.5	12.2	13.6
3: 6	**42**	-0.2549	7.7954	0.22496	4.8	5.2	5.5	6.2	6.7	7.8	9.1	9.9	11.5	12.2	13.7
3: 7	**43**	-0.2583	7.7885	0.22653	4.8	5.2	5.5	6.2	6.7	7.8	9.1	9.9	11.5	12.2	13.7
3: 8	**44**	-0.2616	7.7804	0.22813	4.7	5.2	5.4	6.2	6.7	7.8	9.1	9.9	11.5	12.3	13.8
3: 9	**45**	-0.2648	7.7710	0.22975	4.7	5.2	5.4	6.2	6.7	7.8	9.1	9.9	11.6	12.3	13.8
3:10	**46**	-0.2680	7.7605	0.23140	4.7	5.1	5.4	6.2	6.7	7.8	9.1	9.9	11.6	12.3	13.9
3:11	**47**	-0.2711	7.7489	0.23306	4.7	5.1	5.4	6.1	6.6	7.7	9.1	9.9	11.6	12.4	13.9
4: 0	**48**	-0.2742	7.7364	0.23473	4.7	5.1	5.4	6.1	6.6	7.7	9.1	10.0	11.6	12.4	14.0

Table 44 Triceps skinfold-for-age for boys, age in years and months (continued)

					Percentiles (triceps skinfold in mm)										
Year: Month	**Month**	**L**	**M**	**S**	**1st**	**3rd**	**5th**	**15th**	**25th**	**50th**	**75th**	**85th**	**95th**	**97th**	**99th**
4: 1	**49**	-0.2772	7.7233	0.23642	4.6	5.1	5.3	6.1	6.6	7.7	9.1	10.0	11.7	12.4	14.0
4: 2	**50**	-0.2802	7.7096	0.23811	4.6	5.1	5.3	6.1	6.6	7.7	9.1	10.0	11.7	12.4	14.1
4: 3	**51**	-0.2832	7.6955	0.23981	4.6	5.0	5.3	6.1	6.6	7.7	9.1	10.0	11.7	12.5	14.1
4: 4	**52**	-0.2861	7.6812	0.24151	4.6	5.0	5.3	6.0	6.6	7.7	9.1	10.0	11.7	12.5	14.2
4: 5	**53**	-0.2890	7.6669	0.24322	4.5	5.0	5.3	6.0	6.5	7.7	9.1	10.0	11.7	12.5	14.2
4: 6	**54**	-0.2918	7.6525	0.24494	4.5	5.0	5.2	6.0	6.5	7.7	9.1	10.0	11.7	12.6	14.3
4: 7	**55**	-0.2946	7.6383	0.24666	4.5	4.9	5.2	6.0	6.5	7.6	9.1	10.0	11.8	12.6	14.3
4: 8	**56**	-0.2974	7.6242	0.24839	4.5	4.9	5.2	5.9	6.5	7.6	9.1	10.0	11.8	12.6	14.4
4: 9	**57**	-0.3001	7.6104	0.25013	4.5	4.9	5.2	5.9	6.5	7.6	9.0	10.0	11.8	12.6	14.4
4:10	**58**	-0.3028	7.5968	0.25186	4.4	4.9	5.1	5.9	6.4	7.6	9.0	10.0	11.8	12.7	14.5
4:11	**59**	-0.3055	7.5835	0.25360	4.4	4.9	5.1	5.9	6.4	7.6	9.0	10.0	11.8	12.7	14.5
5: 0	**60**	-0.3081	7.5706	0.25533	4.4	4.8	5.1	5.9	6.4	7.6	9.0	10.0	11.9	12.7	14.6

Table 44 Triceps skinfold-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (triceps skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 3	**3**	0.0027	9.7639	0.16618	5.9	7.0	8.3	9.8	11.5	13.6	16.1
0: 4	**4**	-0.0165	9.5840	0.17264	5.7	6.8	8.1	9.6	11.4	13.5	16.1
0: 5	**5**	-0.0326	9.3885	0.17824	5.5	6.6	7.9	9.4	11.2	13.4	16.1
0: 6	**6**	-0.0466	9.1729	0.18304	5.3	6.4	7.6	9.2	11.0	13.3	16.0
0: 7	**7**	-0.0590	8.9535	0.18685	5.2	6.2	7.4	9.0	10.8	13.1	15.8
0: 8	**8**	-0.0703	8.7435	0.18968	5.0	6.0	7.2	8.7	10.6	12.8	15.6
0: 9	**9**	-0.0806	8.5518	0.19166	4.9	5.9	7.1	8.6	10.4	12.6	15.4
0:10	**10**	-0.0901	8.3812	0.19300	4.8	5.7	6.9	8.4	10.2	12.4	15.2
0:11	**11**	-0.0990	8.2323	0.19389	4.7	5.6	6.8	8.2	10.0	12.2	15.0
1: 0	**12**	-0.1073	8.1041	0.19453	4.6	5.5	6.7	8.1	9.9	12.1	14.8
1: 1	**13**	-0.1152	7.9958	0.19506	4.5	5.5	6.6	8.0	9.7	11.9	14.7
1: 2	**14**	-0.1227	7.9064	0.19558	4.5	5.4	6.5	7.9	9.6	11.8	14.5
1: 3	**15**	-0.1297	7.8345	0.19612	4.4	5.3	6.5	7.8	9.6	11.7	14.4
1: 4	**16**	-0.1365	7.7781	0.19668	4.4	5.3	6.4	7.8	9.5	11.7	14.4
1: 5	**17**	-0.1430	7.7351	0.19728	4.4	5.3	6.4	7.7	9.4	11.6	14.4
1: 6	**18**	-0.1492	7.7036	0.19793	4.4	5.2	6.3	7.7	9.4	11.6	14.3
1: 7	**19**	-0.1552	7.6821	0.19862	4.3	5.2	6.3	7.7	9.4	11.6	14.4
1: 8	**20**	-0.1609	7.6697	0.19937	4.3	5.2	6.3	7.7	9.4	11.6	14.4
1: 9	**21**	-0.1665	7.6652	0.20018	4.3	5.2	6.3	7.7	9.4	11.6	14.4
1:10	**22**	-0.1719	7.6675	0.20105	4.3	5.2	6.3	7.7	9.4	11.6	14.5
1:11	**23**	-0.1771	7.6750	0.20196	4.3	5.2	6.3	7.7	9.4	11.7	14.6
2: 0	**24**	-0.1821	7.6863	0.20293	4.3	5.2	6.3	7.7	9.5	11.7	14.7

Table 44 Triceps skinfold-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (triceps skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
2: 1	**25**	-0.1870	7.7003	0.20394	4.3	5.2	6.3	7.7	9.5	11.8	14.7
2: 2	**26**	-0.1918	7.7156	0.20497	4.3	5.2	6.3	7.7	9.5	11.8	14.8
2: 3	**27**	-0.1965	7.7312	0.20603	4.3	5.2	6.3	7.7	9.5	11.9	14.9
2: 4	**28**	-0.2010	7.7463	0.20710	4.3	5.2	6.3	7.7	9.6	11.9	15.0
2: 5	**29**	-0.2054	7.7602	0.20818	4.3	5.2	6.3	7.8	9.6	12.0	15.1
2: 6	**30**	-0.2097	7.7726	0.20928	4.3	5.2	6.3	7.8	9.6	12.0	15.2
2: 7	**31**	-0.2139	7.7832	0.21039	4.3	5.2	6.3	7.8	9.7	12.1	15.3
2: 8	**32**	-0.2180	7.7920	0.21153	4.3	5.2	6.3	7.8	9.7	12.1	15.4
2: 9	**33**	-0.2221	7.7989	0.21269	4.3	5.2	6.3	7.8	9.7	12.2	15.5
2:10	**34**	-0.2260	7.8040	0.21389	4.3	5.2	6.3	7.8	9.7	12.2	15.6
2:11	**35**	-0.2299	7.8074	0.21513	4.3	5.2	6.3	7.8	9.7	12.3	15.7
3: 0	**36**	-0.2336	7.8094	0.21641	4.3	5.2	6.3	7.8	9.8	12.3	15.8
3: 1	**37**	-0.2374	7.8101	0.21773	4.3	5.2	6.3	7.8	9.8	12.4	15.9
3: 2	**38**	-0.2410	7.8096	0.21909	4.2	5.1	6.3	7.8	9.8	12.4	16.0
3: 3	**39**	-0.2446	7.8080	0.22049	4.2	5.1	6.3	7.8	9.8	12.5	16.1
3: 4	**40**	-0.2481	7.8051	0.22194	4.2	5.1	6.3	7.8	9.8	12.5	16.2
3: 5	**41**	-0.2515	7.8009	0.22343	4.2	5.1	6.3	7.8	9.8	12.5	16.3
3: 6	**42**	-0.2549	7.7954	0.22496	4.2	5.1	6.3	7.8	9.8	12.6	16.3
3: 7	**43**	-0.2583	7.7885	0.22653	4.2	5.1	6.2	7.8	9.8	12.6	16.4
3: 8	**44**	-0.2616	7.7804	0.22813	4.1	5.1	6.2	7.8	9.8	12.6	16.5
3: 9	**45**	-0.2648	7.7710	0.22975	4.1	5.0	6.2	7.8	9.8	12.7	16.6
3:10	**46**	-0.2680	7.7605	0.23140	4.1	5.0	6.2	7.8	9.9	12.7	16.7
3:11	**47**	-0.2711	7.7489	0.23306	4.1	5.0	6.2	7.7	9.9	12.8	16.8
4: 0	**48**	-0.2742	7.7364	0.23473	4.1	5.0	6.2	7.7	9.9	12.8	16.9

Table 44 Triceps skinfold-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (triceps skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	**49**	-0.2772	7.7233	0.23642	4.0	5.0	6.1	7.7	9.9	12.8	17.0
4: 2	**50**	-0.2802	7.7096	0.23811	4.0	4.9	6.1	7.7	9.9	12.9	17.1
4: 3	**51**	-0.2832	7.6955	0.23981	4.0	4.9	6.1	7.7	9.9	12.9	17.2
4: 4	**52**	-0.2861	7.6812	0.24151	4.0	4.9	6.1	7.7	9.9	12.9	17.3
4: 5	**53**	-0.2890	7.6669	0.24322	4.0	4.9	6.1	7.7	9.9	13.0	17.4
4: 6	**54**	-0.2918	7.6525	0.24494	3.9	4.8	6.0	7.7	9.9	13.0	17.5
4: 7	**55**	-0.2946	7.6383	0.24666	3.9	4.8	6.0	7.6	9.9	13.0	17.6
4: 8	**56**	-0.2974	7.6242	0.24839	3.9	4.8	6.0	7.6	9.9	13.1	17.7
4: 9	**57**	-0.3001	7.6104	0.25013	3.9	4.8	6.0	7.6	9.9	13.1	17.8
4:10	**58**	-0.3028	7.5968	0.25186	3.8	4.8	6.0	7.6	9.9	13.1	17.9
4:11	**59**	-0.3055	7.5835	0.25360	3.8	4.7	5.9	7.6	9.9	13.2	18.0
5: 0	**60**	-0.3081	7.5706	0.25533	3.8	4.7	5.9	7.6	9.9	13.2	18.1

5.3 Triceps skinfold-for-age for girls

Steps similar to those described in the preceding sections were followed to select the best model to fit the triceps skinfold-for-age growth standard for girls.

5.3.1 Sample size

There were a total of 10 943 triceps skinfold observations for girls. The longitudinal and cross-sectional sample sizes by visit and age are presented in Tables 45 and 46. The measurement of triceps skinfold started at 3 months of age (de Onis et al., 2004b).

Table 45 Longitudinal sample sizes for triceps skinfold-for-age for girls

Visit	**5**	**6**	**7**	**8**	**9**	**10**
Age	**3 mo**	**4 mo**	**5 mo**	**6 mo**	**7 mo**	**8 mo**
N	446	443	447	445	444	440
Visit	**11**	**12**	**13**	**14**	**15**	**16**
Age	**9 mo**	**10 mo**	**11 mo**	**12 mo**	**14 mo**	**16 mo**
N	444	442	438	449	446	441
Visit	**17**	**18**	**19**	**20**		
Age	**18 mo**	**20 mo**	**22 mo**	**24 mo**		
N	445	443	434	446		

Table 46 Cross-sectional sample sizes for triceps skinfold-for-age for girls

Age (mo)	**<18**	**18–20**	**21–23**	**24–26**	**27–29**	**30–32**	**33–35**
N	2	158	165	235	214	225	222
Age (mo)	**36–38**	**39–41**	**42–44**	**45–47**	**48–50**	**51–53**	**54–56**
N	216	232	244	207	220	199	229
Age (mo)	**57–59**	**60–62**	**63–65**	**66–68**	**69–71**	**>71**	
N	238	216	204	224	200	0	

5.3.2 Model selection and results

The model BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) was used as a starting point to search for the best value of the age-transformation power λ. Table 47 shows the global deviance for values of λ from 0.05 to 1. Global deviance values were smallest for λ 0.15 and 0.20, and λ=0.15 was selected.

Table 47 Global deviance (GD) for models within the class BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) for triceps skinfold-for-age for girls

λ	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
GD[a]	761.4	761.1	761.0	761.0	761.3	761.8	762.4	763.3	764.2	765.4
λ	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
GD[a]	766.7	768.0	769.4	770.8	772.3	773.7	775.1	776.4	777.7	779.0

[a] In excess of 43 000.

The search for the best df(μ) and df(σ) followed, fixing λ=0.15, ν=1 and τ=2. All possible combinations with df(μ) values ranging from 6 to 15 and df(σ) from 2 to 10 were considered and partial results are presented in Table 48. Only *GAIC(3)* was considered for selecting the best combination. The model with df(μ)=7 and df(σ)=5 provided the smallest value of *GAIC(3)* and it was thus selected for further evaluation.

Table 48 Goodness-of-fit summary for models using the BCPE distribution with fixed ν=1 and τ=2 for triceps skinfold-for-age for girls

df(μ)	df(σ)	GD[a]	AIC[a]	GAIC(3)[a]	Total df
	3	1775.3	1793.3	1802.3	9.0
	4	1759.0	1779.0	1789.0	10.0
6	**5**	1753.2	1775.2	1786.2	11.0
	6	1751.2	1775.2	1787.2	12.0
	7	1749.9	1775.9	1788.9	13.0
	3	1770.9	1790.9	1800.9	10.0
	4	1754.5	1776.5	1787.5	11.0
7	**5**	1748.4	1772.4	1784.4	12.0
	6	1746.2	1772.2	1785.2	13.0
	7	1744.9	1772.9	1786.9	14.0
	3	1768.3	1790.3	1801.3	11.0
	4	1751.7	1775.7	1787.7	12.0
8	**5**	1745.5	1771.5	1784.5	13.0
	6	1743.2	1771.2	1785.2	14.0
	7	1741.8	1771.8	1786.8	15.0
	3	1766.4	1790.4	1802.4	12.0
	4	1749.7	1775.7	1788.7	13.0
9	**5**	1743.4	1771.4	1785.4	14.0
	6	1741.1	1771.1	1786.1	15.0
	7	1739.7	1771.7	1787.7	16.0
	3	1764.9	1790.9	1803.9	13.0
	4	1748.2	1776.2	1790.2	14.0
10	**5**	1741.8	1771.8	1786.8	15.0
	6	1739.5	1771.5	1787.5	16.0
	7	1738.0	1772.0	1789.0	17.0

GD, Global Deviance; AIC, Akaike Information Criterion;
GAIC(3), Generalized AIC with penalty equal to 3;
[a] In excess of 43 000.

Model 1: BCPE(x=age$^{0.15}$, df(μ)=7, df(σ)=5, ν=1, τ=2)

This model showed inadequacy as it clearly pointed to residual skewness in both the worm plots (Figure 56) and the Q-test results (Table 49). The worms presented U-shapes in all age groups and the Q-test results (Table 49) showed all groups with absolute values of z3 higher than 2. Most of the age groups also presented absolute values of z4 higher than 2, indicating residual kurtosis. Both overall tests for skewness and kurtosis were significant (p-value < 0.01). No misfit could be detected in the mean and the variance.

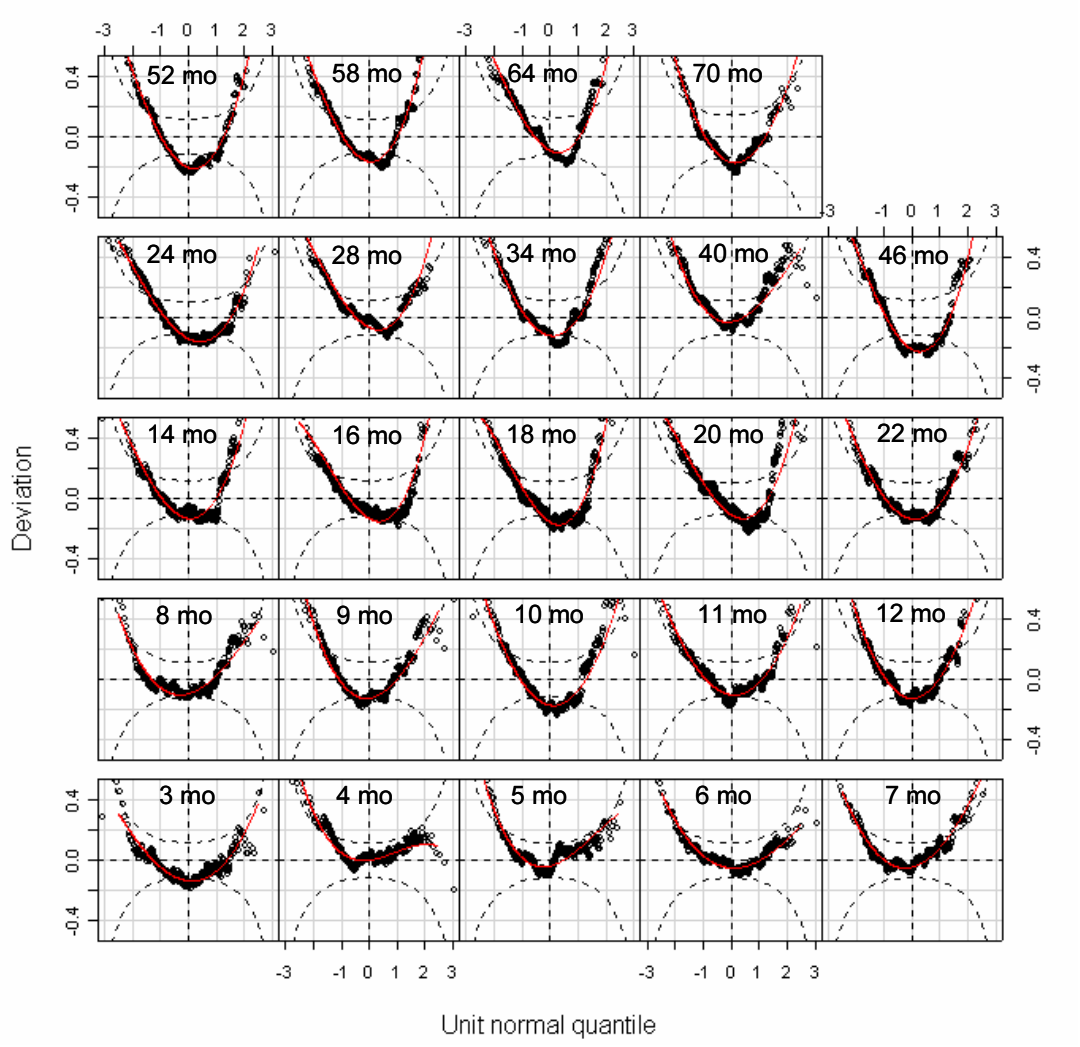


Figure 56 Worm plots of z-scores for Model 1 for triceps skinfold-for-age for girls

Table 49 Q-test for z-scores from Model 1 [BCPE(x=age$^{0.15}$, df(μ)=7, df(σ)=5, ν=1, τ=2)] for triceps skinfold-for-age for girls

Age (days)	Group	N	z1	z2	z3	z4
83 to 99	**3 mo**	439	-1.3	0.1	3.9	1.8
100 to 129	**4 mo**	443	1.1	-0.8	2.5	-1.5
130 to 159	**5 mo**	441	0.9	0.1	3.5	-0.2
160 to 189	**6 mo**	441	0.2	-0.7	3.0	0.3
190 to 219	**7 mo**	432	0.9	1.1	4.0	1.2
220 to 249	**8 mo**	435	-0.5	0.9	3.6	0.1
250 to 279	**9 mo**	437	-0.2	0.1	5.1	0.7
280 to 309	**10 mo**	442	-1.4	-0.3	5.9	2.2
310 to 349	**11 mo**	474	-0.1	-0.2	5.1	1.7
350 to 379	**12 mo**	451	0.2	0.3	6.1	2.2
380 to 439	**14 mo**	443	0.1	1.2	6.4	3.2
440 to 499	**16 mo**	443	0.0	0.0	7.0	4.9
500 to 559	**18 mo**	467	-0.1	0.6	7.8	5.1
560 to 619	**20 mo**	542	0.3	-1.0	6.9	3.8
620 to 679	**22 mo**	538	-0.3	0.2	6.3	2.7
680 to 749	**24 mo**	589	-0.9	-1.5	6.1	3.2
750 to 929	**28 mo**	454	1.1	-0.6	6.4	3.9
930 to 1119	**34 mo**	466	0.3	0.2	6.4	2.6
1120 to 1309	**40 mo**	469	1.6	-0.2	4.8	0.3
1310 to 1499	**46 mo**	448	-1.1	-0.3	7.6	4.2
1500 to 1689	**52 mo**	446	-1.1	0.0	7.3	3.9
1690 to 1879	**58 mo**	492	0.0	1.7	8.0	4.3
1880 to 2069	**64 mo**	416	1.1	-0.1	6.9	3.6
2070 to 2191	**70 mo**	295	-0.4	-0.6	5.4	2.4
Overall Q stats		**10 943**	**15.6**	**12.3**	**829.4**	**203.5**
degrees of freedom			**17.0**	**21.0**	**24.0**	**24.0**
p-value			**0.5551**	**0.9307**	**<0.01**	**<0.01**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

The next step involved fitting the parameter ν for skewness using the BCPE distribution with fixed parameter τ=2 and keeping the degrees of freedom for the μ and σ curves selected for Model 1. Table 50 shows the *GAIC(3)* values for various degrees of freedom for the ν curve.

Table 50 Goodness-of-fit summary for models BCPE(x=age$^{0.15}$, df(μ)=7, df(σ)=5 df(ν)=?, τ=2) for triceps skinfold-for-age for girls

df(ν)	GD[a]	GAIC(3)[a]	Total df
1	773.6	812.6	13
2	766.1	808.1	14
3	762.3	807.3	15
4	760.8	808.8	16
5	759.6	810.6	17
6	758.4	812.4	18
7	757.3	814.3	19

GD, Global Deviance; GAIC(3), Generalized Akaike Information Criterion with penalty equal to 3;
[a] In excess of 43 000.

The smallest *GAIC(3)* value corresponded to df(ν)=3. Using df(ν)=3, a re-search for the best df(μ) and df(σ) was carried out. The smallest value of *GAIC(3)* was associated with df(μ)=8 and df(σ)=5 (43807.0), very similar to those of the previously selected model (43807.3, Table 50). A new search for best λ was carried out but there were no changes in the previous results and therefore the model was not further updated.

Model 2: BCPE(x= age$^{0.15}$, df(μ)=7, df(σ)=5, df(ν)=3, τ=2)

Figure 57 shows the fitting of the parameters μ, σ and ν for Model 2 with their respective sample estimates, that is, the median for μ, the sample standard deviation of the Box-Cox transformed data for σ and Box-Cox transform power for ν.

Figures 58 and 59 show the distribution of the empirical minus fitted centile differences for the longitudinal and cross-sectional samples, respectively. There was some indication of bias only for the 95th and 97th centiles for ages between 3 and 24 months (Figure 58), yet the maximum difference between the empirical and the fitted centile was only 0.4 mm. There was no indication of systematic bias for ages between 24 and 71 months (Figure 59).

The worm plots for this model (Figure 60) show that the adjustment for skewness was effective (none of the age groups presented U-shaped worms with Model 2). There were few age groups with S-shaped worms, suggesting some remaining kurtosis (e.g. 5 mo), but those were contained within the 95% confidence intervals.

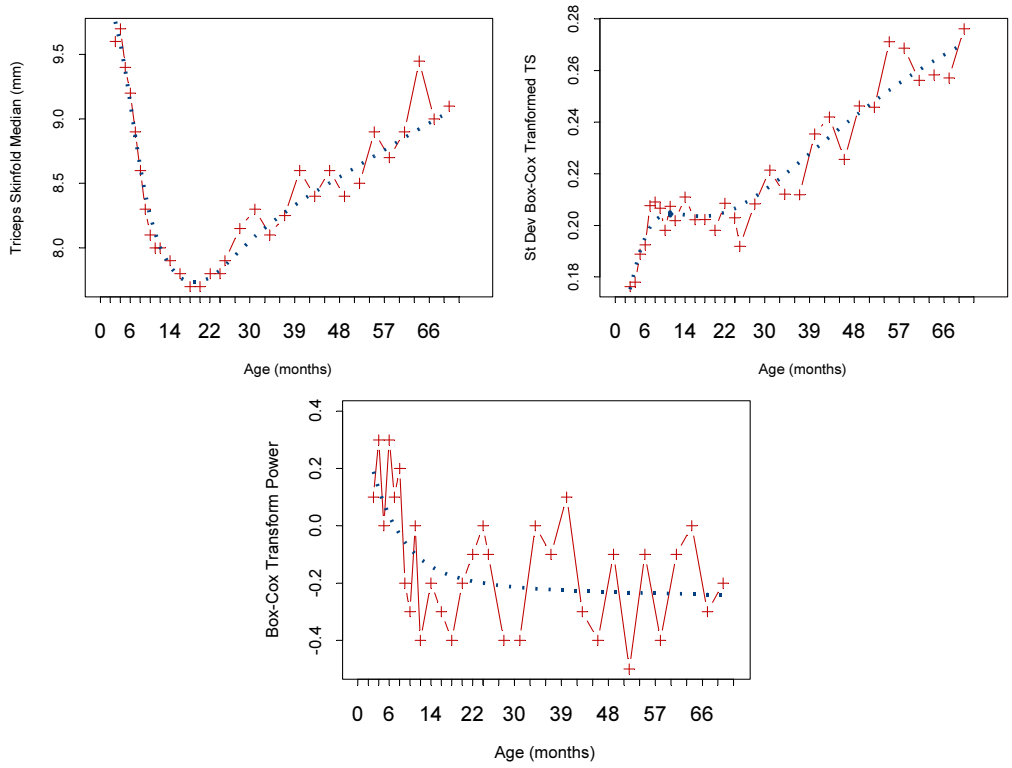


Figure 57 Fitting of the μ, σ, and ν curves of Model 2 for triceps skinfold-for-age for girls from 3 to 71 months (dotted line) and their respective sample estimates (points with solid line)

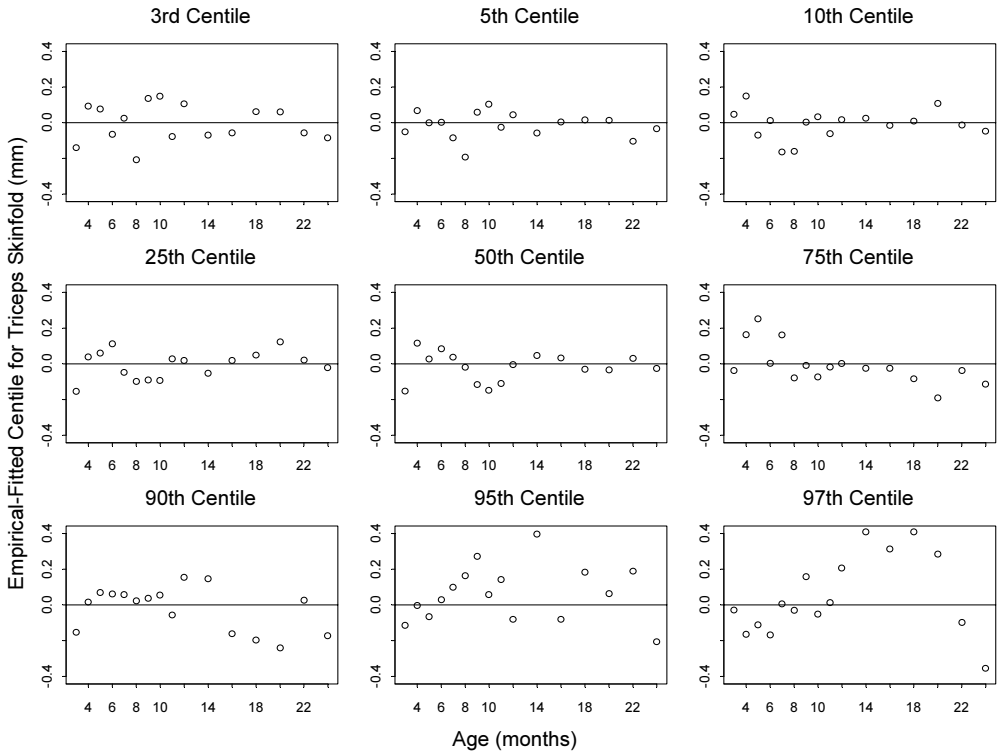


Figure 58 Centile residuals from fitting Model 2 for triceps skinfold-for-age from 3 to 24 months for girls

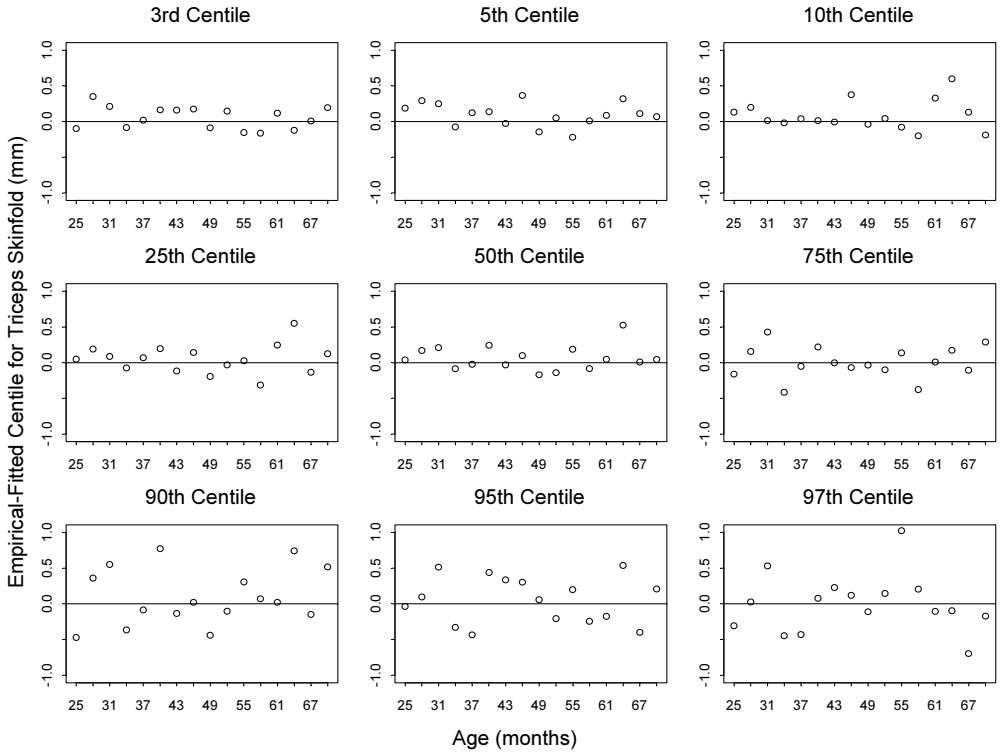


Figure 59 Centile residuals from fitting Model 2 for triceps skinfold-for-age from 24 to 71 months for girls

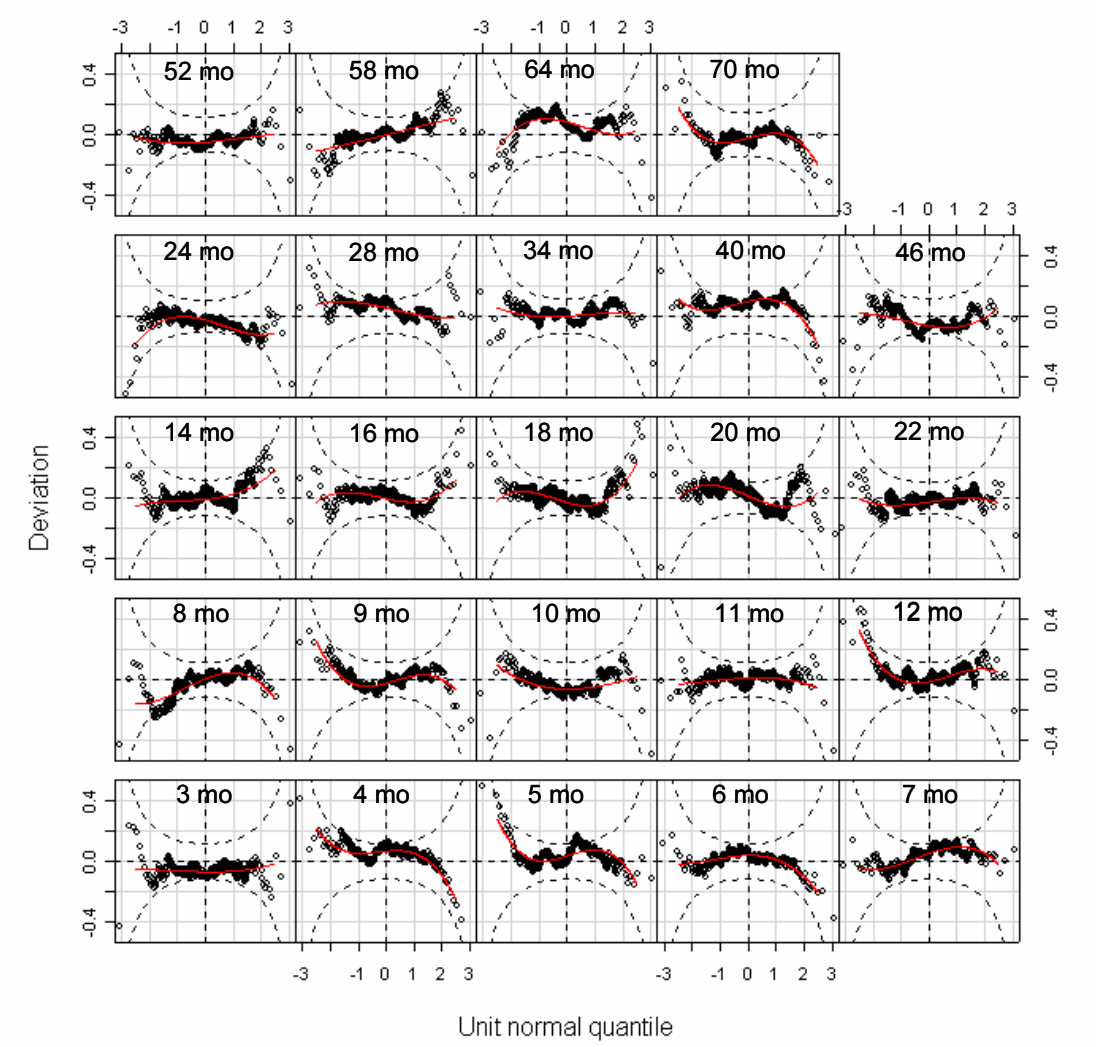


Figure 60 Worm plots of z-scores for Model 2 for triceps skinfold-for-age for girls

The Q-test results from Model 2 are shown in Table 51. There was no indication of misfit of the mean or variance, as neither z1 nor z2 absolute values were larger than 2. There were also no groups with z3 absolute value larger than 2, indicating no remaining skewness. Only one age group presented an absolute value of z4 greater than 2 (5 mo), suggesting remaining kurtosis, but the overall test statistic for kurtosis had a p-value that was not significant at the 5% level. The overall Q-test p-values were all non-significant, indicating an adequate fit of the girls' triceps skinfold-for-age curves and providing no justification for increasing the complexity of the model by adjusting for kurtosis (modelling τ).

Table 52 presents observed percentages with triceps skinfolds below the fitted centiles. There was no detectable pattern suggesting systematic bias, even though some detectable deviations occur sporadically (e.g. only 0.9 % of children have triceps skinfolds below the 3rd centile at age 12 months).

Table 51 Q-test for z-scores from Model 2 [BCPE(x=age$^{0.15}$, df(μ)=7, df(σ)=5, df(ν)=3, τ=2)] for triceps skinfold-for-age for girls

Age (days)	Group	N	z1	z2	z3	z4
83 to 99	**3 mo**	439	-1.4	0.1	0.3	0.3
100 to 129	**4 mo**	443	1.1	-1.0	-0.6	-1.9
130 to 159	**5 mo**	441	0.9	-0.1	0.1	-2.5
160 to 189	**6 mo**	441	0.3	-0.4	-1.3	-0.6
190 to 219	**7 mo**	432	0.8	1.0	-0.6	-0.9
220 to 249	**8 mo**	435	-0.5	1.4	-1.1	-0.9
250 to 279	**9 mo**	437	-0.1	-0.1	1.0	-1.9
280 to 309	**10 mo**	442	-1.3	-0.2	1.1	0.1
310 to 349	**11 mo**	474	0.1	0.1	-0.4	-0.1
350 to 379	**12 mo**	451	0.3	-0.1	1.5	-1.3
380 to 439	**14 mo**	443	0.0	1.0	0.5	0.7
440 to 499	**16 mo**	443	0.1	-0.2	0.5	1.1
500 to 559	**18 mo**	467	-0.2	0.1	1.2	1.6
560 to 619	**20 mo**	542	0.3	-1.1	0.0	1.5
620 to 679	**22 mo**	538	-0.6	0.5	0.0	-0.5
680 to 749	**24 mo**	589	-1.1	-0.6	-1.4	1.6
750 to 929	**28 mo**	454	1.0	-0.9	-0.1	0.4
930 to 1119	**34 mo**	466	0.2	0.1	0.3	-0.3
1120 to 1309	**40 mo**	469	1.6	-0.1	-1.0	-1.4
1310 to 1499	**46 mo**	448	-1.0	-0.3	0.8	0.6
1500 to 1689	**52 mo**	446	-1.0	0.2	0.5	-0.1
1690 to 1879	**58 mo**	492	-0.1	1.4	0.1	0.1
1880 to 2069	**64 mo**	416	1.3	-0.4	-1.0	1.2
2070 to 2191	**70 mo**	295	-0.4	-0.2	0.1	-1.7
Overall Q stats		**10 943**	**16.0**	**10.4**	**15.6**	**33.7**
degrees of freedom			**17.0**	**21.0**	**21.0**	**24.0**
p-value			**0.5206**	**0.9736**	**0.7938**	**0.0899**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

The model BCPE(x=age$^{0.15}$, df(μ)=7, df(σ)=5, df(ν)=3, τ=2) was considered adequate and thus selected for constructing the triceps skinfold-for-age growth curves for girls. It adjusts only for skewness, since there was no evidence of significant kurtosis. The fitted centile curves and empirical centiles are shown in Figures 61 to 64.

Table 52 Observed proportions of children with measurements below the fitted centiles from Model 2, triceps skinfold-for-age for girls

Expected	3 mo	4 mo	5 mo	6 mo	7 mo	8 mo	9 mo	10 mo	11 mo
1	0.5	0.7	0.2	1.1	1.2	0.7	0.5	0.7	0.8
3	4.3	2.7	2.0	3.4	2.5	5.1	1.8	2.3	3.4
5	5.7	4.3	5.2	5.2	5.6	7.1	3.9	5.4	5.5
10	9.8	7.7	11.1	10.0	11.1	13.1	9.8	10.2	9.9
25	27.3	24.8	23.8	24.0	25.0	26.4	27.2	26.9	23.4
50	54.0	46.0	49.7	47.6	48.4	50.6	51.0	53.4	51.9
75	75.2	73.4	72.1	74.8	71.1	74.5	75.3	77.1	75.1
90	91.1	89.6	89.1	90.2	89.4	88.7	89.9	89.8	90.5
95	95.4	94.8	95.0	95.2	93.8	94.0	95.2	94.6	94.5
97	97.0	97.1	97.1	97.7	96.5	97.2	96.1	96.8	96.8
99	99.3	99.8	99.3	99.5	98.8	99.1	99.3	99.1	98.9
Expected	**12 mo**	**14 mo**	**16 mo**	**18 mo**	**20 mo**	**22 mo**	**24 mo**	**28 mo**	**34 mo**
1	0.4	0.7	0.7	0.9	1.1	0.9	1.2	0.4	1.3
3	0.9	4.1	3.4	2.8	2.6	3.5	3.1	2.9	2.8
5	4.7	5.6	5.2	4.5	4.6	6.7	5.4	4.0	4.5
10	9.8	9.9	10.4	9.0	8.7	11.0	10.4	8.8	9.7
25	23.1	26.0	23.7	24.8	22.1	25.1	25.8	23.3	24.2
50	50.8	48.5	47.9	52.7	50.0	49.8	51.3	47.1	49.4
75	74.1	76.3	76.3	75.8	76.9	76.8	77.1	76.0	75.1
90	89.1	88.5	91.6	90.8	91.1	90.0	91.7	89.9	89.5
95	95.3	93.5	95.3	94.0	94.3	94.2	95.9	95.4	94.0
97	96.0	96.4	96.6	95.9	96.1	97.4	98.1	97.6	96.1
99	98.9	98.2	98.4	98.9	99.3	99.1	98.8	98.7	99.1

Table 52 Observed proportions of children with measurements below the fitted centiles from Model 2, triceps skinfold-for-age for girls (cont)

Expected	40 mo	46 mo	52 mo	58 mo	64 mo	70 mo	Overall
1	0.9	1.1	1.1	1.8	1.4	0.7	0.9
3	2.6	2.5	3.4	3.7	3.1	2.4	3.0
5	4.5	5.1	5.6	5.1	4.1	5.1	5.1
10	9.2	10.0	9.4	11.4	7.9	12.2	10.0
25	22.0	26.8	26.0	25.8	22.6	25.8	24.8
50	46.7	52.0	53.6	49.0	46.9	51.9	50.0
75	72.9	77.5	76.5	75.6	75.7	74.2	75.3
90	87.8	91.3	90.6	89.0	88.7	90.5	90.0
95	94.5	94.2	94.8	94.9	94.0	95.3	94.7
97	96.6	96.9	96.6	96.1	97.1	98.0	96.8
99	99.8	98.7	98.9	98.6	98.3	99.3	99.0

Note: Group labels correspond to the age intervals in Table 51.

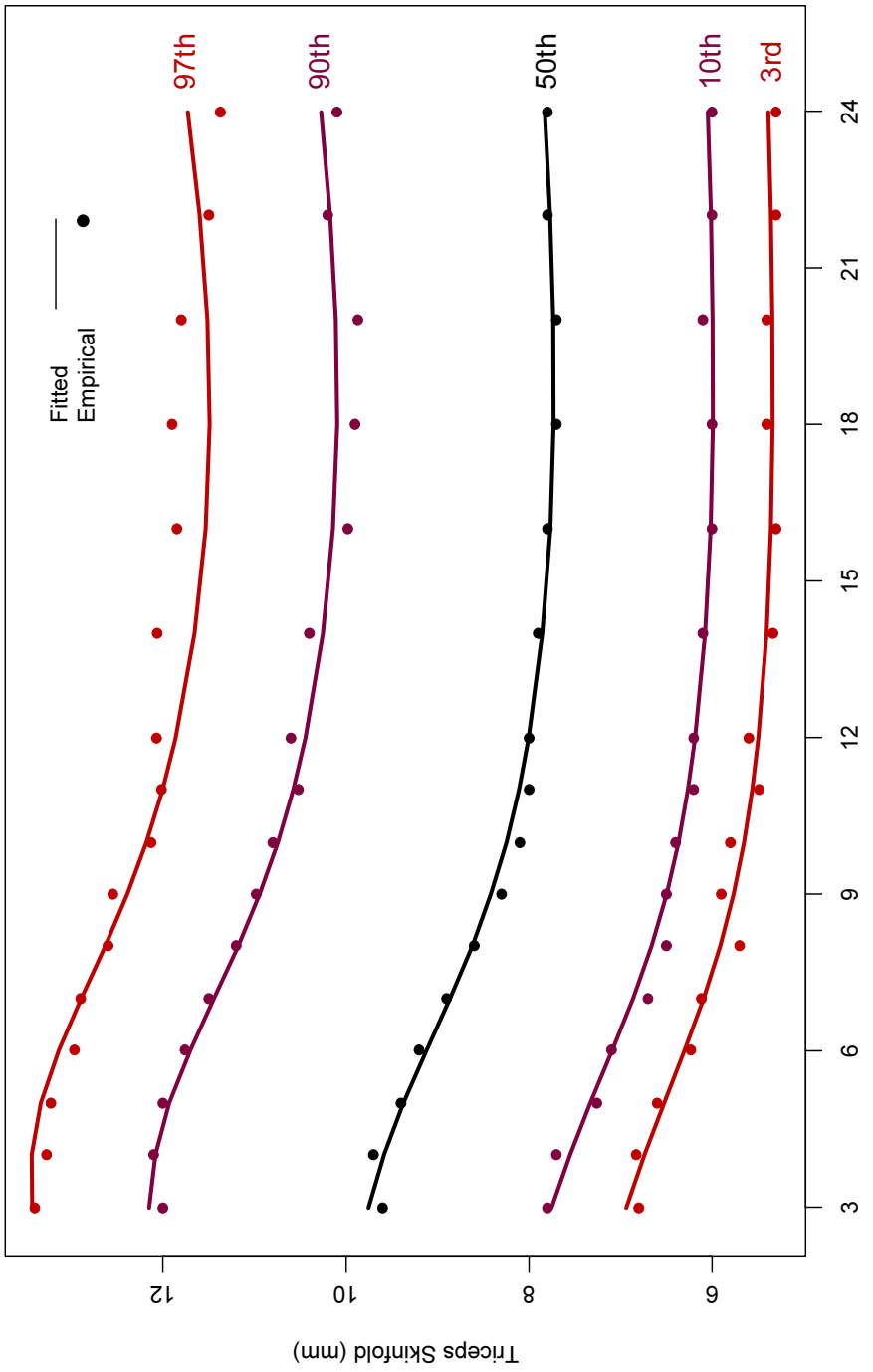


Figure 61 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: triceps skinfold-for-age for girls from 3 to 24 months

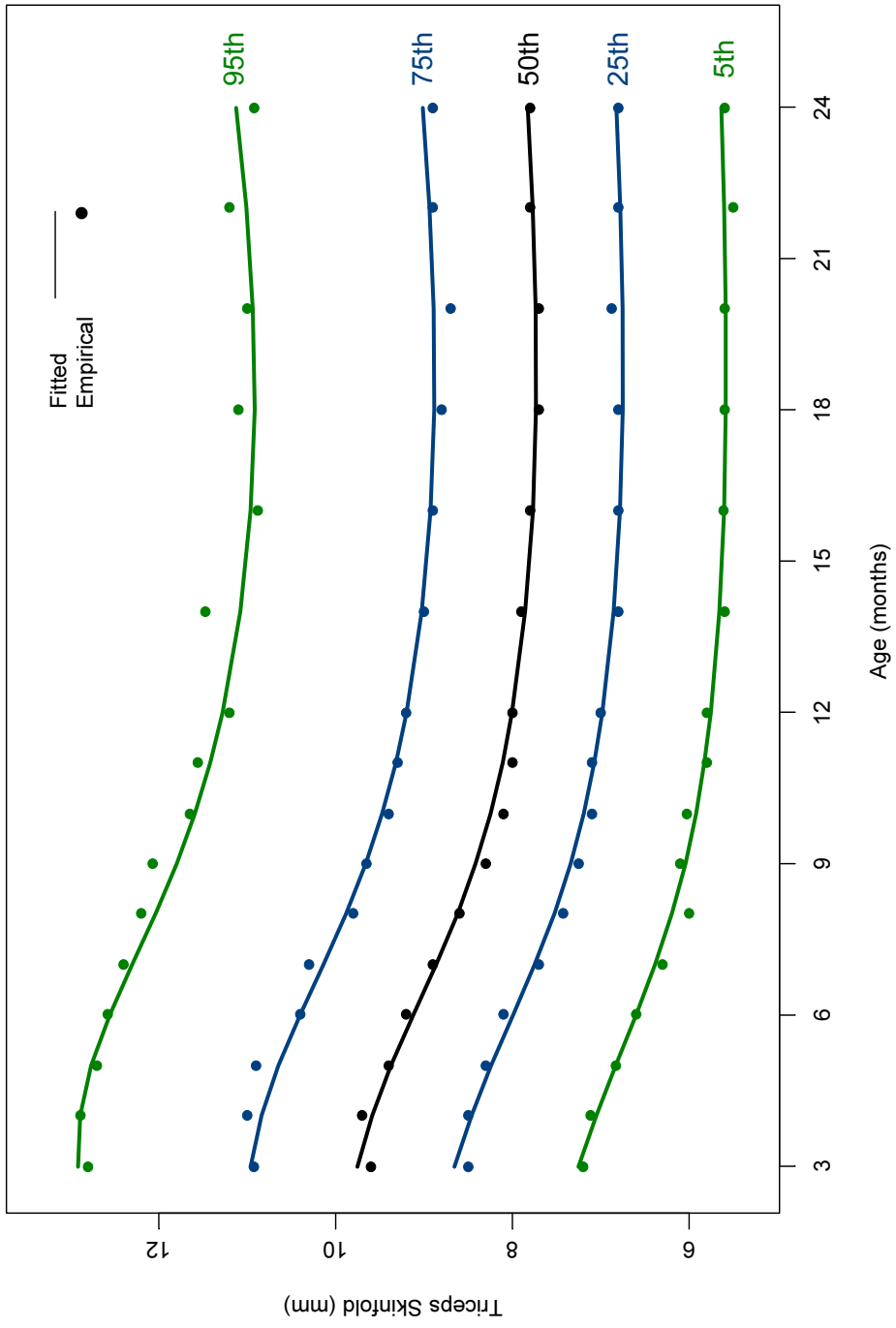


Figure 62 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: triceps skinfold-for-age for girls from 3 to 24 months

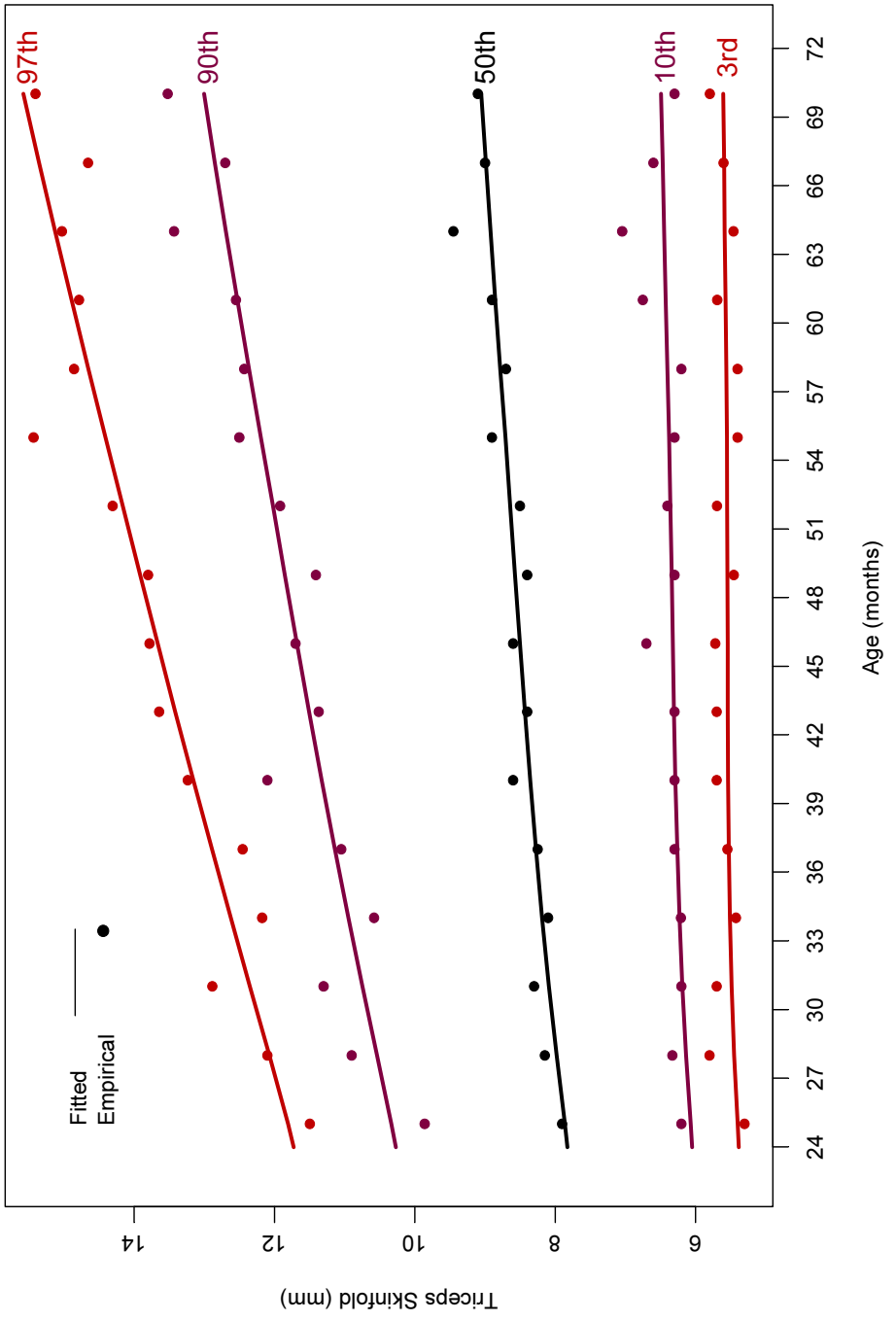


Figure 63 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: triceps skinfold-for-age for girls from 24 to 71 months

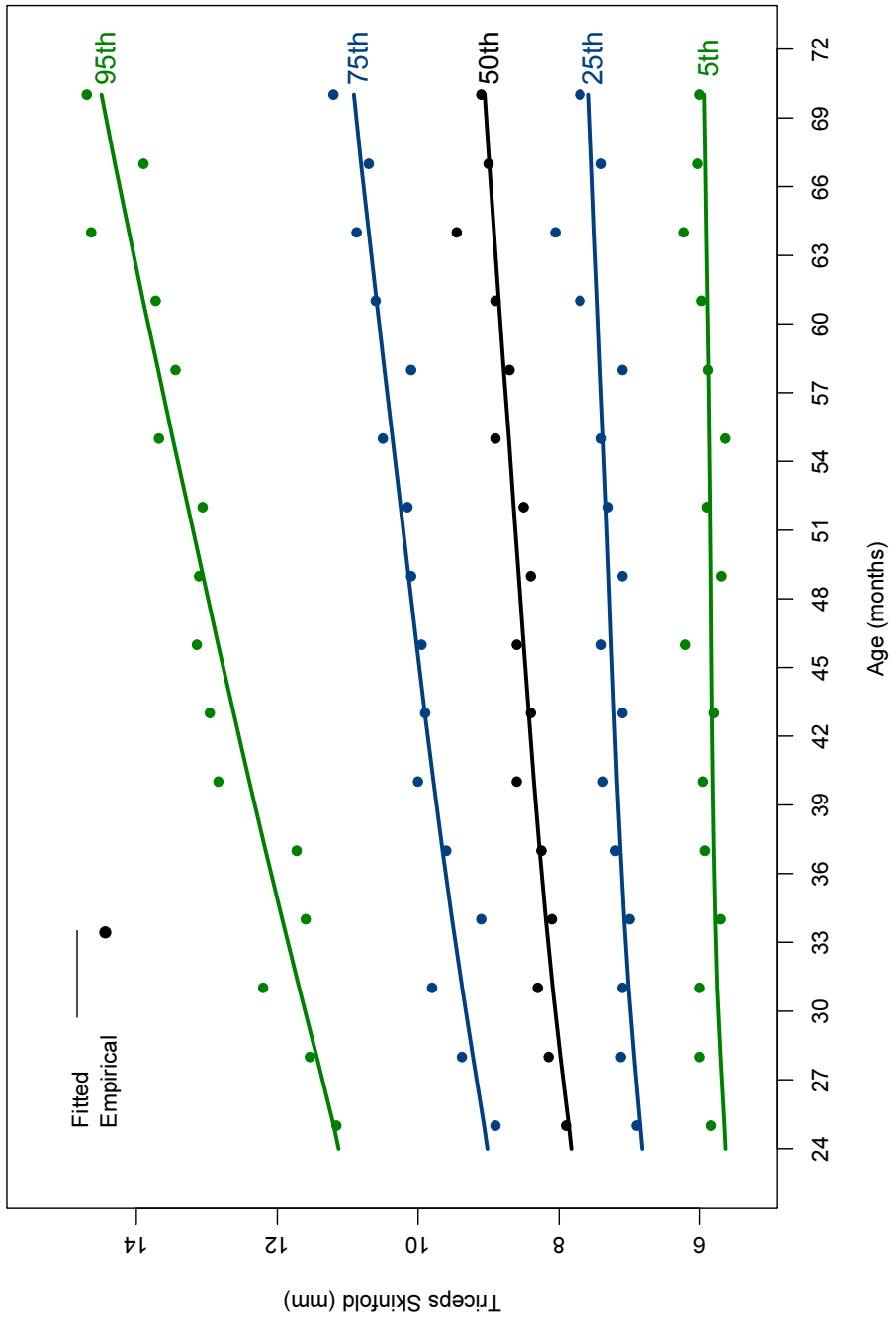


Figure 64 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: triceps skinfold-for-age for girls from 24 to 71 months

5.3.3 WHO standards

This section presents the final WHO triceps skinfold-for-age z-score and percentile charts (Figures 65 and 66) and table (Table 53) for girls.

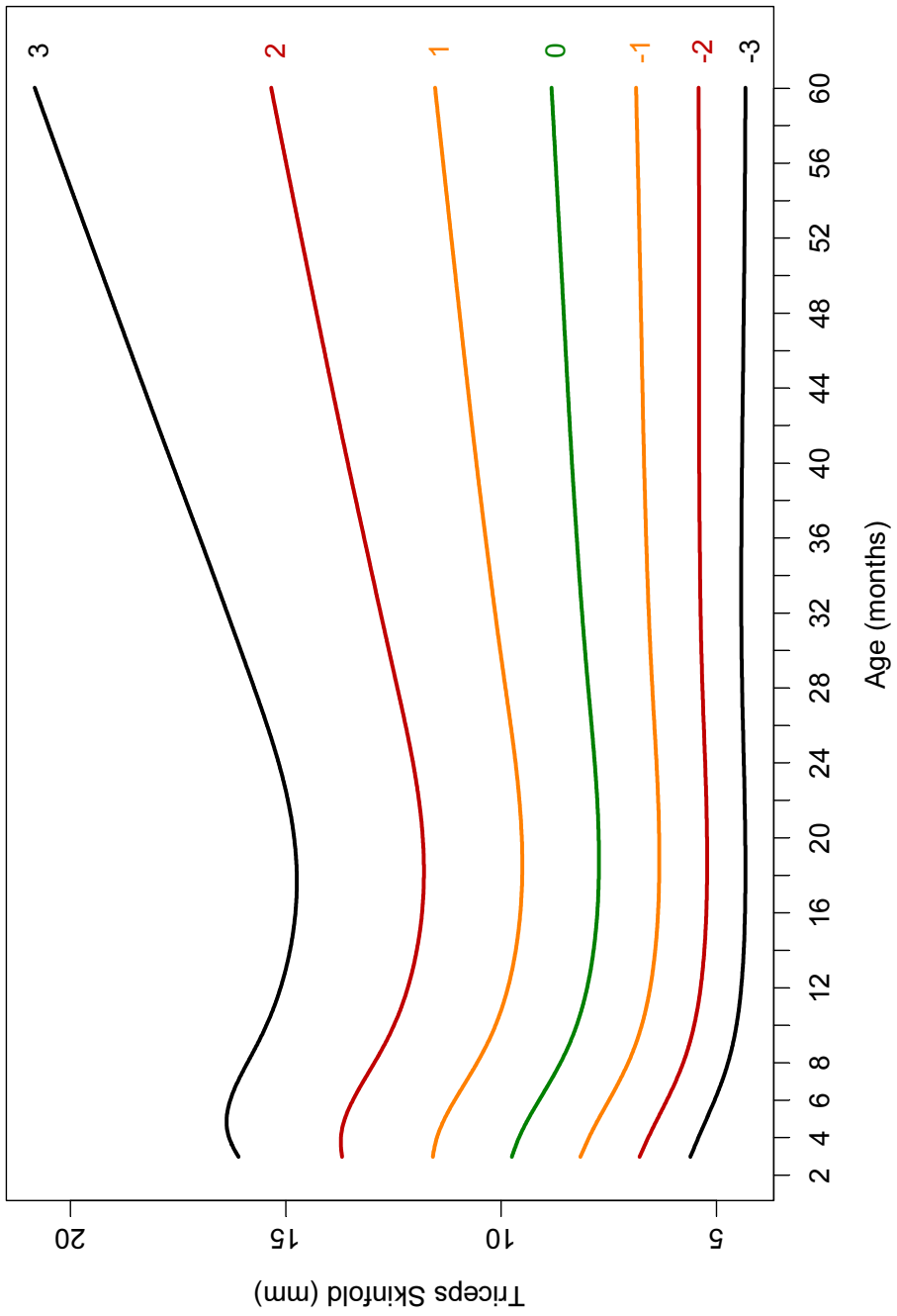


Figure 65 WHO triceps skinfold-for-age z-scores for girls from 3 to 60 months

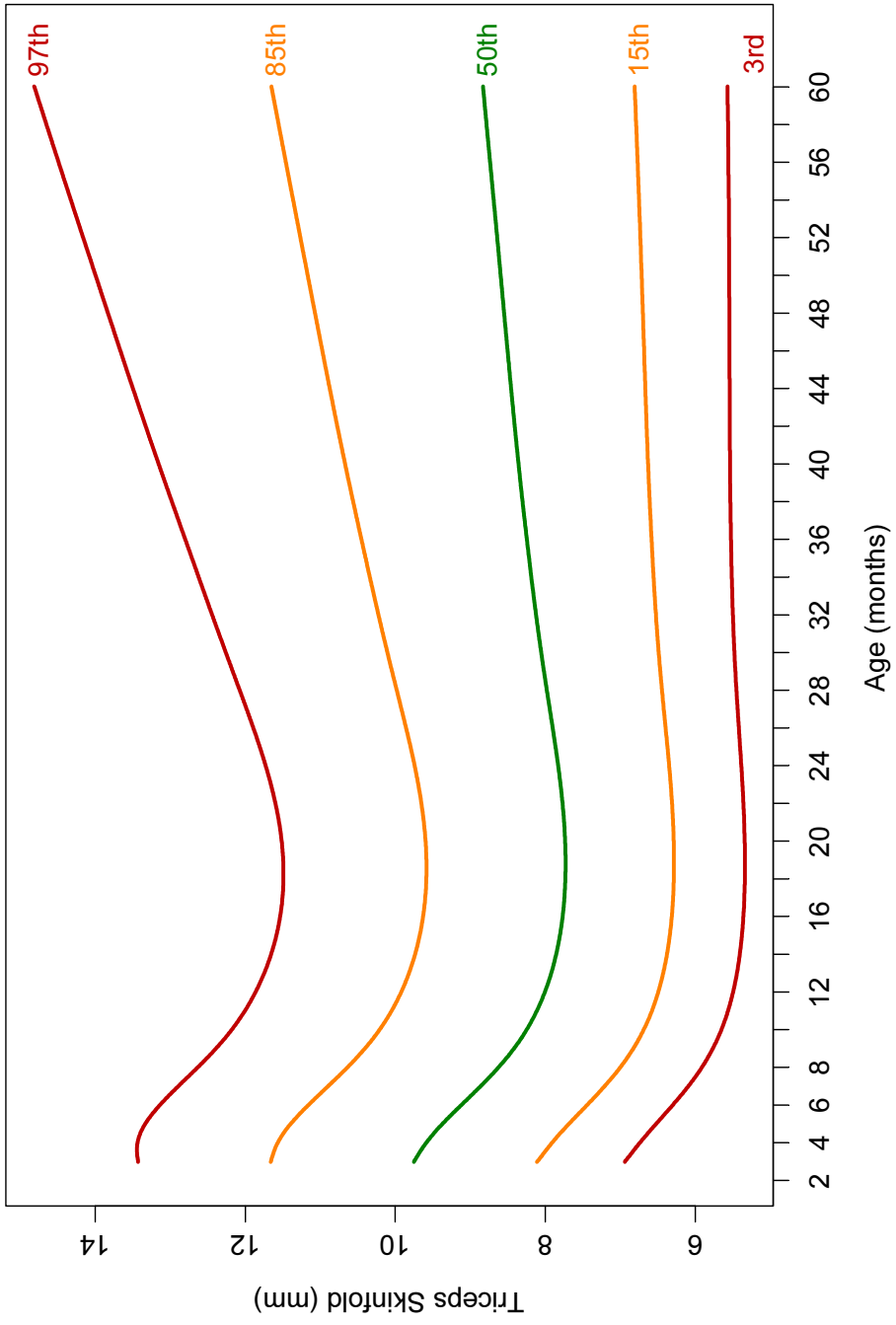


Figure 66 WHO triceps skinfold-for-age percentiles for girls from 3 to 60 months

Table 53 Triceps skinfold-for-age for girls, age in years and months

					Percentiles (triceps skinfold in mm)										
Year: Month	**Month**	**L**	**M**	**S**	**1st**	**3rd**	**5th**	**15th**	**25th**	**50th**	**75th**	**85th**	**95th**	**97th**	**99th**
0: 3	**3**	0.1875	9.7516	0.17535	6.4	6.9	7.2	8.1	8.7	9.8	11.0	11.7	12.9	13.4	14.4
0: 4	**4**	0.1256	9.5866	0.18337	6.2	6.7	7.0	7.9	8.5	9.6	10.8	11.6	12.9	13.4	14.5
0: 5	**5**	0.0761	9.3716	0.19007	6.0	6.5	6.8	7.7	8.2	9.4	10.6	11.4	12.8	13.3	14.5
0: 6	**6**	0.0349	9.1194	0.19540	5.8	6.3	6.6	7.4	8.0	9.1	10.4	11.2	12.6	13.1	14.3
0: 7	**7**	-0.0003	8.8621	0.19934	5.6	6.1	6.4	7.2	7.7	8.9	10.1	10.9	12.3	12.9	14.1
0: 8	**8**	-0.0307	8.6228	0.20192	5.4	5.9	6.2	7.0	7.5	8.6	9.9	10.6	12.0	12.6	13.8
0: 9	**9**	-0.0572	8.4164	0.20339	5.3	5.8	6.0	6.8	7.3	8.4	9.7	10.4	11.8	12.4	13.6
0:10	**10**	-0.0799	8.2468	0.20413	5.2	5.7	5.9	6.7	7.2	8.2	9.5	10.2	11.6	12.2	13.4
0:11	**11**	-0.0995	8.1114	0.20442	5.1	5.6	5.8	6.6	7.1	8.1	9.3	10.0	11.4	12.0	13.2
1: 0	**12**	-0.1161	8.0042	0.20445	5.0	5.5	5.8	6.5	7.0	8.0	9.2	9.9	11.3	11.9	13.1
1: 1	**13**	-0.1303	7.9197	0.20432	5.0	5.4	5.7	6.4	6.9	7.9	9.1	9.8	11.2	11.7	12.9
1: 2	**14**	-0.1424	7.8538	0.20409	5.0	5.4	5.7	6.4	6.9	7.9	9.0	9.7	11.1	11.7	12.8
1: 3	**15**	-0.1527	7.8041	0.20384	4.9	5.4	5.6	6.3	6.8	7.8	9.0	9.7	11.0	11.6	12.8
1: 4	**16**	-0.1615	7.7681	0.20363	4.9	5.4	5.6	6.3	6.8	7.8	8.9	9.6	11.0	11.5	12.7
1: 5	**17**	-0.1690	7.7443	0.20350	4.9	5.3	5.6	6.3	6.8	7.7	8.9	9.6	10.9	11.5	12.7
1: 6	**18**	-0.1755	7.7315	0.20350	4.9	5.3	5.6	6.3	6.8	7.7	8.9	9.6	10.9	11.5	12.7
1: 7	**19**	-0.1811	7.7287	0.20364	4.9	5.3	5.6	6.3	6.7	7.7	8.9	9.6	10.9	11.5	12.7
1: 8	**20**	-0.1859	7.7347	0.20393	4.9	5.3	5.6	6.3	6.8	7.7	8.9	9.6	10.9	11.5	12.7
1: 9	**21**	-0.1901	7.7484	0.20437	4.9	5.3	5.6	6.3	6.8	7.7	8.9	9.6	11.0	11.5	12.8
1:10	**22**	-0.1939	7.7692	0.20496	4.9	5.4	5.6	6.3	6.8	7.8	8.9	9.7	11.0	11.6	12.8
1:11	**23**	-0.1973	7.7958	0.20568	4.9	5.4	5.6	6.3	6.8	7.8	9.0	9.7	11.1	11.7	12.9
2: 0	**24**	-0.2004	7.8273	0.20652	4.9	5.4	5.6	6.3	6.8	7.8	9.0	9.7	11.1	11.7	13.0

Table 53 Triceps skinfold-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Percentiles (triceps skinfold in mm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
2: 1	**25**	-0.2032	7.8628	0.20748	5.0	5.4	5.7	6.4	6.8	7.9	9.1	9.8	11.2	11.8	13.1
2: 2	**26**	-0.2058	7.9006	0.20855	5.0	5.4	5.7	6.4	6.9	7.9	9.1	9.9	11.3	11.9	13.2
2: 3	**27**	-0.2081	7.9396	0.20971	5.0	5.4	5.7	6.4	6.9	7.9	9.2	9.9	11.4	12.0	13.3
2: 4	**28**	-0.2103	7.9786	0.21096	5.0	5.5	5.7	6.4	6.9	8.0	9.2	10.0	11.4	12.1	13.4
2: 5	**29**	-0.2122	8.0167	0.21228	5.0	5.5	5.7	6.5	7.0	8.0	9.3	10.0	11.5	12.2	13.5
2: 6	**30**	-0.2140	8.0535	0.21366	5.0	5.5	5.7	6.5	7.0	8.1	9.3	10.1	11.6	12.3	13.6
2: 7	**31**	-0.2155	8.0887	0.21509	5.0	5.5	5.8	6.5	7.0	8.1	9.4	10.2	11.7	12.4	13.7
2: 8	**32**	-0.2170	8.1224	0.21657	5.0	5.5	5.8	6.5	7.0	8.1	9.4	10.2	11.8	12.4	13.8
2: 9	**33**	-0.2183	8.1545	0.21809	5.0	5.5	5.8	6.5	7.1	8.2	9.5	10.3	11.8	12.5	14.0
2:10	**34**	-0.2195	8.1855	0.21964	5.0	5.5	5.8	6.6	7.1	8.2	9.5	10.3	11.9	12.6	14.1
2:11	**35**	-0.2207	8.2156	0.22122	5.0	5.5	5.8	6.6	7.1	8.2	9.6	10.4	12.0	12.7	14.2
3: 0	**36**	-0.2217	8.2450	0.22282	5.0	5.5	5.8	6.6	7.1	8.2	9.6	10.5	12.1	12.8	14.3
3: 1	**37**	-0.2227	8.2738	0.22444	5.0	5.5	5.8	6.6	7.1	8.3	9.7	10.5	12.2	12.9	14.4
3: 2	**38**	-0.2237	8.3019	0.22608	5.0	5.5	5.8	6.6	7.1	8.3	9.7	10.6	12.2	13.0	14.5
3: 3	**39**	-0.2246	8.3294	0.22772	5.0	5.5	5.8	6.6	7.2	8.3	9.7	10.6	12.3	13.1	14.6
3: 4	**40**	-0.2254	8.3560	0.22937	5.0	5.5	5.8	6.6	7.2	8.4	9.8	10.7	12.4	13.2	14.8
3: 5	**41**	-0.2262	8.3818	0.23101	5.0	5.5	5.8	6.6	7.2	8.4	9.8	10.7	12.5	13.2	14.9
3: 6	**42**	-0.2270	8.4068	0.23264	5.0	5.5	5.8	6.6	7.2	8.4	9.9	10.8	12.5	13.3	15.0
3: 7	**43**	-0.2278	8.4311	0.23427	5.0	5.5	5.8	6.7	7.2	8.4	9.9	10.8	12.6	13.4	15.1
3: 8	**44**	-0.2285	8.4550	0.23587	5.0	5.5	5.8	6.7	7.2	8.5	9.9	10.9	12.7	13.5	15.2
3: 9	**45**	-0.2292	8.4786	0.23747	5.0	5.5	5.8	6.7	7.2	8.5	10.0	10.9	12.8	13.6	15.3
3:10	**46**	-0.2298	8.5019	0.23904	5.0	5.5	5.8	6.7	7.3	8.5	10.0	11.0	12.8	13.7	15.4
3:11	**47**	-0.2304	8.5250	0.24060	5.0	5.5	5.8	6.7	7.3	8.5	10.1	11.0	12.9	13.7	15.5
4: 0	**48**	-0.2310	8.5481	0.24215	5.0	5.5	5.8	6.7	7.3	8.5	10.1	11.1	13.0	13.8	15.6

Table 53 Triceps skinfold-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Percentiles (triceps skinfold in mm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
4: 1	**49**	-0.2316	8.5711	0.24367	5.0	5.5	5.8	6.7	7.3	8.6	10.1	11.1	13.1	13.9	15.7
4: 2	**50**	-0.2321	8.5942	0.24517	5.0	5.5	5.8	6.7	7.3	8.6	10.2	11.2	13.1	14.0	15.8
4: 3	**51**	-0.2326	8.6174	0.24665	5.0	5.5	5.8	6.7	7.3	8.6	10.2	11.2	13.2	14.1	16.0
4: 4	**52**	-0.2331	8.6406	0.24811	5.0	5.5	5.9	6.7	7.3	8.6	10.2	11.3	13.3	14.2	16.1
4: 5	**53**	-0.2336	8.6641	0.24954	5.0	5.6	5.9	6.7	7.3	8.7	10.3	11.3	13.3	14.2	16.2
4: 6	**54**	-0.2341	8.6876	0.25095	5.0	5.6	5.9	6.7	7.4	8.7	10.3	11.4	13.4	14.3	16.3
4: 7	**55**	-0.2346	8.7112	0.25233	5.0	5.6	5.9	6.8	7.4	8.7	10.4	11.4	13.5	14.4	16.4
4: 8	**56**	-0.2350	8.7349	0.25369	5.0	5.6	5.9	6.8	7.4	8.7	10.4	11.5	13.6	14.5	16.5
4: 9	**57**	-0.2355	8.7586	0.25502	5.0	5.6	5.9	6.8	7.4	8.8	10.4	11.5	13.6	14.6	16.6
4:10	**58**	-0.2359	8.7824	0.25633	5.0	5.6	5.9	6.8	7.4	8.8	10.5	11.6	13.7	14.7	16.7
4:11	**59**	-0.2363	8.8061	0.25761	5.0	5.6	5.9	6.8	7.4	8.8	10.5	11.6	13.8	14.7	16.8
5: 0	**60**	-0.2368	8.8298	0.25887	5.0	5.6	5.9	6.8	7.4	8.8	10.6	11.7	13.8	14.8	16.9

Table 53 Triceps skinfold-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (triceps skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 3	**3**	0.1875	9.7516	0.17535	5.6	6.8	8.2	9.8	11.6	13.7	16.1
0: 4	**4**	0.1256	9.5866	0.18337	5.4	6.6	8.0	9.6	11.5	13.7	16.3
0: 5	**5**	0.0761	9.3716	0.19007	5.2	6.4	7.7	9.4	11.3	13.6	16.4
0: 6	**6**	0.0349	9.1194	0.19540	5.0	6.2	7.5	9.1	11.1	13.4	16.3
0: 7	**7**	-0.0003	8.8621	0.19934	4.9	5.9	7.3	8.9	10.8	13.2	16.1
0: 8	**8**	-0.0307	8.6228	0.20192	4.7	5.8	7.1	8.6	10.6	12.9	15.9
0: 9	**9**	-0.0572	8.4164	0.20339	4.6	5.6	6.9	8.4	10.3	12.7	15.7
0:10	**10**	-0.0799	8.2468	0.20413	4.5	5.5	6.7	8.2	10.1	12.5	15.5
0:11	**11**	-0.0995	8.1114	0.20442	4.5	5.4	6.6	8.1	10.0	12.3	15.3
1: 0	**12**	-0.1161	8.0042	0.20445	4.4	5.4	6.5	8.0	9.8	12.2	15.1
1: 1	**13**	-0.1303	7.9197	0.20432	4.4	5.3	6.5	7.9	9.7	12.1	15.0
1: 2	**14**	-0.1424	7.8538	0.20409	4.4	5.3	6.4	7.9	9.7	12.0	14.9
1: 3	**15**	-0.1527	7.8041	0.20384	4.3	5.3	6.4	7.8	9.6	11.9	14.8
1: 4	**16**	-0.1615	7.7681	0.20363	4.3	5.2	6.4	7.8	9.6	11.8	14.8
1: 5	**17**	-0.1690	7.7443	0.20350	4.3	5.2	6.3	7.7	9.5	11.8	14.8
1: 6	**18**	-0.1755	7.7315	0.20350	4.3	5.2	6.3	7.7	9.5	11.8	14.7
1: 7	**19**	-0.1811	7.7287	0.20364	4.3	5.2	6.3	7.7	9.5	11.8	14.8
1: 8	**20**	-0.1859	7.7347	0.20393	4.3	5.2	6.3	7.7	9.5	11.8	14.8
1: 9	**21**	-0.1901	7.7484	0.20437	4.3	5.2	6.3	7.7	9.5	11.9	14.9
1:10	**22**	-0.1939	7.7692	0.20496	4.3	5.2	6.4	7.8	9.6	11.9	15.0
1:11	**23**	-0.1973	7.7958	0.20568	4.4	5.2	6.4	7.8	9.6	12.0	15.1
2: 0	**24**	-0.2004	7.8273	0.20652	4.4	5.3	6.4	7.8	9.7	12.0	15.2

Table 53 Triceps skinfold-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (triceps skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
2: 1	**25**	-0.2032	7.8628	0.20748	4.4	5.3	6.4	7.9	9.7	12.1	15.3
2: 2	**26**	-0.2058	7.9006	0.20855	4.4	5.3	6.4	7.9	9.8	12.2	15.4
2: 3	**27**	-0.2081	7.9396	0.20971	4.4	5.3	6.5	7.9	9.8	12.3	15.6
2: 4	**28**	-0.2103	7.9786	0.21096	4.4	5.3	6.5	8.0	9.9	12.4	15.7
2: 5	**29**	-0.2122	8.0167	0.21228	4.4	5.3	6.5	8.0	10.0	12.5	15.9
2: 6	**30**	-0.2140	8.0535	0.21366	4.4	5.4	6.5	8.1	10.0	12.6	16.0
2: 7	**31**	-0.2155	8.0887	0.21509	4.4	5.4	6.6	8.1	10.1	12.7	16.2
2: 8	**32**	-0.2170	8.1224	0.21657	4.4	5.4	6.6	8.1	10.1	12.8	16.4
2: 9	**33**	-0.2183	8.1545	0.21809	4.4	5.4	6.6	8.2	10.2	12.9	16.5
2:10	**34**	-0.2195	8.1855	0.21964	4.4	5.4	6.6	8.2	10.3	13.0	16.7
2:11	**35**	-0.2207	8.2156	0.22122	4.4	5.4	6.6	8.2	10.3	13.1	16.8
3: 0	**36**	-0.2217	8.2450	0.22282	4.4	5.4	6.6	8.2	10.4	13.2	17.0
3: 1	**37**	-0.2227	8.2738	0.22444	4.4	5.4	6.6	8.3	10.4	13.3	17.2
3: 2	**38**	-0.2237	8.3019	0.22608	4.4	5.4	6.7	8.3	10.5	13.4	17.3
3: 3	**39**	-0.2246	8.3294	0.22772	4.4	5.4	6.7	8.3	10.5	13.5	17.5
3: 4	**40**	-0.2254	8.3560	0.22937	4.4	5.4	6.7	8.4	10.6	13.6	17.6
3: 5	**41**	-0.2262	8.3818	0.23101	4.4	5.4	6.7	8.4	10.6	13.7	17.8
3: 6	**42**	-0.2270	8.4068	0.23264	4.4	5.4	6.7	8.4	10.7	13.7	18.0
3: 7	**43**	-0.2278	8.4311	0.23427	4.4	5.4	6.7	8.4	10.7	13.8	18.1
3: 8	**44**	-0.2285	8.4550	0.23587	4.4	5.4	6.7	8.5	10.8	13.9	18.3
3: 9	**45**	-0.2292	8.4786	0.23747	4.4	5.4	6.7	8.5	10.8	14.0	18.5
3:10	**46**	-0.2298	8.5019	0.23904	4.4	5.4	6.7	8.5	10.9	14.1	18.6
3:11	**47**	-0.2304	8.5250	0.24060	4.4	5.4	6.7	8.5	10.9	14.2	18.8
4: 0	**48**	-0.2310	8.5481	0.24215	4.4	5.4	6.8	8.5	11.0	14.3	18.9

Table 53 Triceps skinfold-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (triceps skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	**49**	-0.2316	8.5711	0.24367	4.4	5.4	6.8	8.6	11.0	14.4	19.1
4: 2	**50**	-0.2321	8.5942	0.24517	4.4	5.4	6.8	8.6	11.1	14.5	19.3
4: 3	**51**	-0.2326	8.6174	0.24665	4.4	5.4	6.8	8.6	11.1	14.6	19.4
4: 4	**52**	-0.2331	8.6406	0.24811	4.3	5.4	6.8	8.6	11.2	14.6	19.6
4: 5	**53**	-0.2336	8.6641	0.24954	4.3	5.4	6.8	8.7	11.2	14.7	19.7
4: 6	**54**	-0.2341	8.6876	0.25095	4.3	5.4	6.8	8.7	11.3	14.8	19.9
4: 7	**55**	-0.2346	8.7112	0.25233	4.3	5.4	6.8	8.7	11.3	14.9	20.0
4: 8	**56**	-0.2350	8.7349	0.25369	4.3	5.4	6.8	8.7	11.3	15.0	20.2
4: 9	**57**	-0.2355	8.7586	0.25502	4.3	5.4	6.8	8.8	11.4	15.1	20.4
4:10	**58**	-0.2359	8.7824	0.25633	4.3	5.4	6.8	8.8	11.4	15.2	20.5
4:11	**59**	-0.2363	8.8061	0.25761	4.3	5.4	6.9	8.8	11.5	15.3	20.7
5: 0	**60**	-0.2368	8.8298	0.25887	4.3	5.4	6.9	8.8	11.5	15.3	20.8

5.4 Comparisons between boys and girls

This section presents the triceps skinfold-for-age z-score comparisons between boys and girls for the WHO standards (Figure 67).

5.4.1 WHO

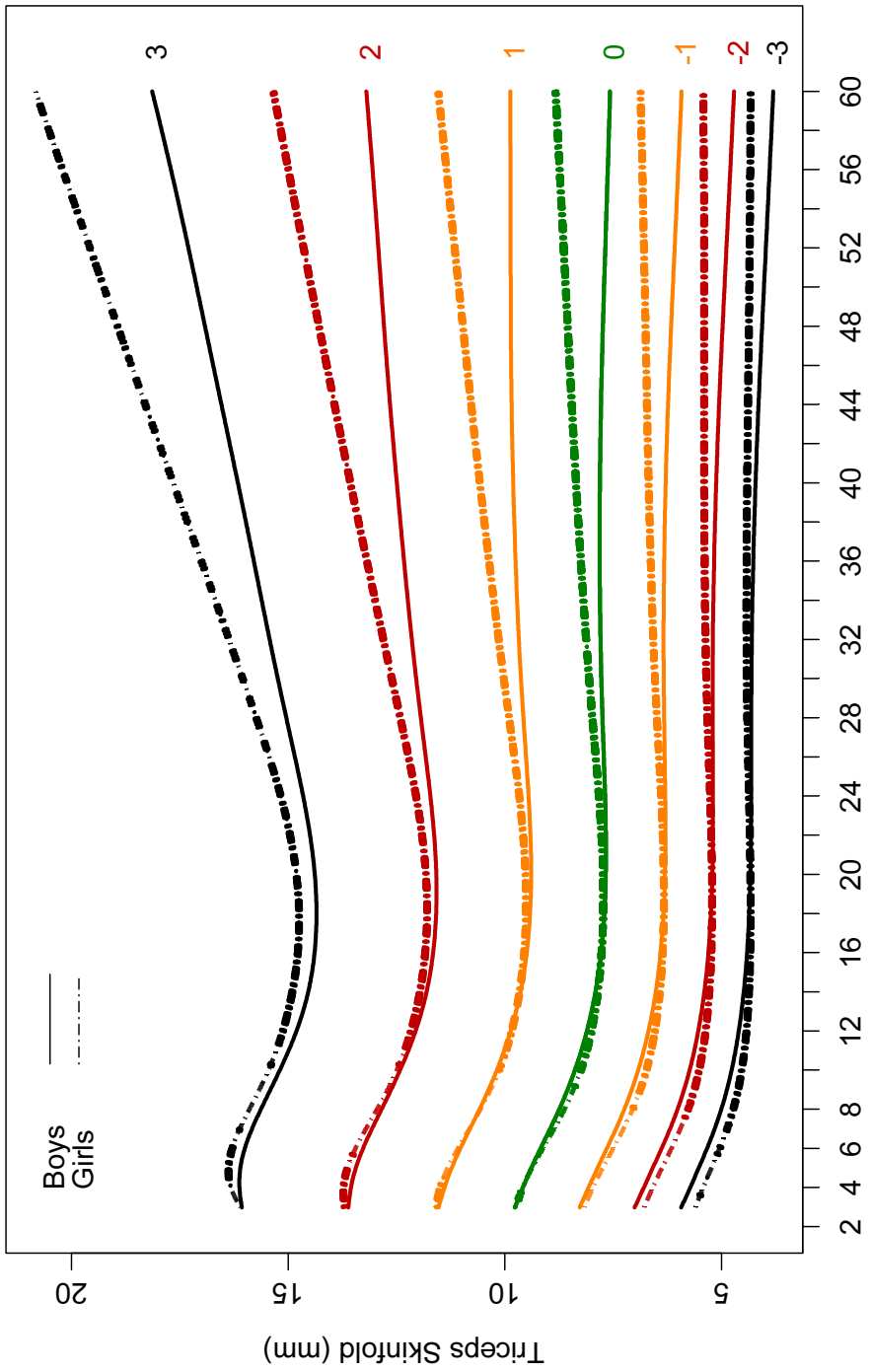


Figure 67 Comparison of boys' and girls' triceps skinfold-for-age z-scores

6. CONSTRUCTION OF THE SUBSCAPULAR SKINFOLD-FOR-AGE STANDARDS

6.1 Indicator-specific methodology

Similar steps to those described to select the best model for the head circumference-for-age, arm-circumference-for-age and triceps skinfold-for-age growth curves were followed to select the best model to construct the subscapular skinfold-for-age growth standards. The diagnostic tools applied to evaluate and compare candidate models were the same. All data up to 71 months were used for modelling the subscapular skinfold-for-age growth curves and the standards afterwards truncated at 60 completed months to correct for the right-edge effect (Borghi et al., 2006).

6.2 Subscapular skinfold-for-age for boys

6.2.1 Sample size

There were a total of 10 757 subscapular skinfold observations for boys. The longitudinal and cross-sectional sample sizes by visit and age are presented in Tables 54 and 55. The measurement of subscapular skinfold started at 3 months of age (de Onis et al., 2004b).

Table 54 Longitudinal sample sizes for subscapular skinfold-for-age for boys

Visit	**5**	**6**	**7**	**8**	**9**	**10**
Age	**3 mo**	**4 mo**	**5 mo**	**6 mo**	**7 mo**	**8 mo**
N	418	410	413	417	415	415
Visit	**11**	**12**	**13**	**14**	**15**	**16**
Age	**9 mo**	**10 mo**	**11 mo**	**12 mo**	**14 mo**	**16 mo**
N	408	407	417	415	416	417
Visit	**17**	**18**	**19**	**20**		
Age	**18 mo**	**20 mo**	**22 mo**	**24 mo**		
N	415	422	417	421		

Table 55 Cross-sectional sample sizes for subscapular skinfold-for-age for boys

Age (mo)	**<18**	**18–20**	**21–23**	**24–26**	**27–29**	**30–32**	**33–35**
N	3	176	183	236	255	215	251
Age (mo)	**36–38**	**39–41**	**42–44**	**45–47**	**48–50**	**51–53**	**54–56**
N	264	248	254	235	235	218	225
Age (mo)	**57–59**	**60–62**	**63–65**	**66–68**	**69–71**	**>71**	
N	239	228	216	216	213	4	

6.2.2 Model selection and results

To search for the best value of the age-transformation power λ, the model BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) was used as a starting point when constructing the subscapular skinfold-for-age growth curves. Table 56 shows the global deviance for values of λ from 0.05 to 1. Global deviance values were smallest for λ 0.55 to 0.75 and we selected λ=0.65.

Table 56 Global deviance (GD) for models within the class BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) for subscapular skinfold-for-age for boys

λ	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
GD[a]	323.1	323.0	322.8	322.7	322.6	322.5	322.4	322.4	322.3	322.3
λ	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
GD[a]	322.2	322.2	322.2	322.2	322.2	322.3	322.5	322.8	323.3	324.1

[a] In excess of 33 000.

The search for the best df(μ) and df(σ) followed, fixing λ=0.65, ν=1 and τ=2. All possible combinations with df(μ) values ranging from 5 to 15 and df(σ) from 2 to 10 were considered and partial results are presented in Table 57. As for arm circumference-for-age and triceps skinfold-for-age, we considered only the criterion *GAIC(3)* to select the best combination. The model with df(μ)=7 and df(σ)=3 provided the smallest value of *GAIC(3)*, but the model with the smoother μ curve, with df(μ)=6 and df(σ)=3, yielded similar *GAIC(3)* values. The latter model was thus selected for further evaluation.

Table 57 Goodness-of-fit summary for models using the BCPE distribution with fixed ν=1 and τ=2 for subscapular skinfold-for-age for boys

df(μ)	df(σ)	GD[a]	AIC[a]	GAIC(3)[a]	Total df
5	**2**	1895.9	1909.9	1916.9	7
	3	1891.3	1907.3	1915.3	8
	4	1888.9	1906.9	1915.9	9
	5	1886.0	1906.0	1916.0	10
	6	1882.7	1904.7	1915.7	11
6	**2**	1888.3	1904.3	1912.3	8
	3	1883.8	1901.8	1910.8	9
	4	1881.4	1901.4	1911.4	10
	5	1878.6	1900.6	1911.6	11
	6	1875.5	1899.6	1911.6	12
7	**2**	1885.0	1903.0	1912.0	9
	3	1880.5	1900.5	1910.5	10
	4	1878.1	1900.1	1911.1	11
	5	1875.4	1899.4	1911.4	12
	6	1872.5	1898.5	1911.5	13
8	**2**	1882.8	1902.8	1912.8	10
	3	1878.3	1900.3	1911.3	11
	4	1875.9	1899.9	1911.9	12
	5	1873.4	1899.4	1912.4	13
	6	1870.5	1898.5	1912.5	14
9	**2**	1881.0	1903.0	1914.0	11
	3	1876.5	1900.5	1912.5	12
	4	1874.2	1900.2	1913.2	13
	5	1871.6	1899.6	1913.6	14
	6	1868.9	1898.9	1913.9	15

GD, Global Deviance; AIC, Akaike Information Criterion;
GAIC(3), Generalized AIC with penalty equal to 3;
[a] In excess of 33 000.

Model 1: BCPE(x=age$^{0.65}$, df(μ)=6, df(σ)=3, ν=1, τ=2)

This model was inadequate with evidence of residual skewness in both the worm plots (Figure 68) and the Q-test results (Table 58). The worms presented U-shapes in all age groups and the Q-test results (Table 58) showed all groups with absolute values of z3 higher than 2. Most of the age groups also presented absolute values of z4 higher than 2, indicating residual kurtosis. The overall tests for skewness and kurtosis also were significant (p-values < 0.01).

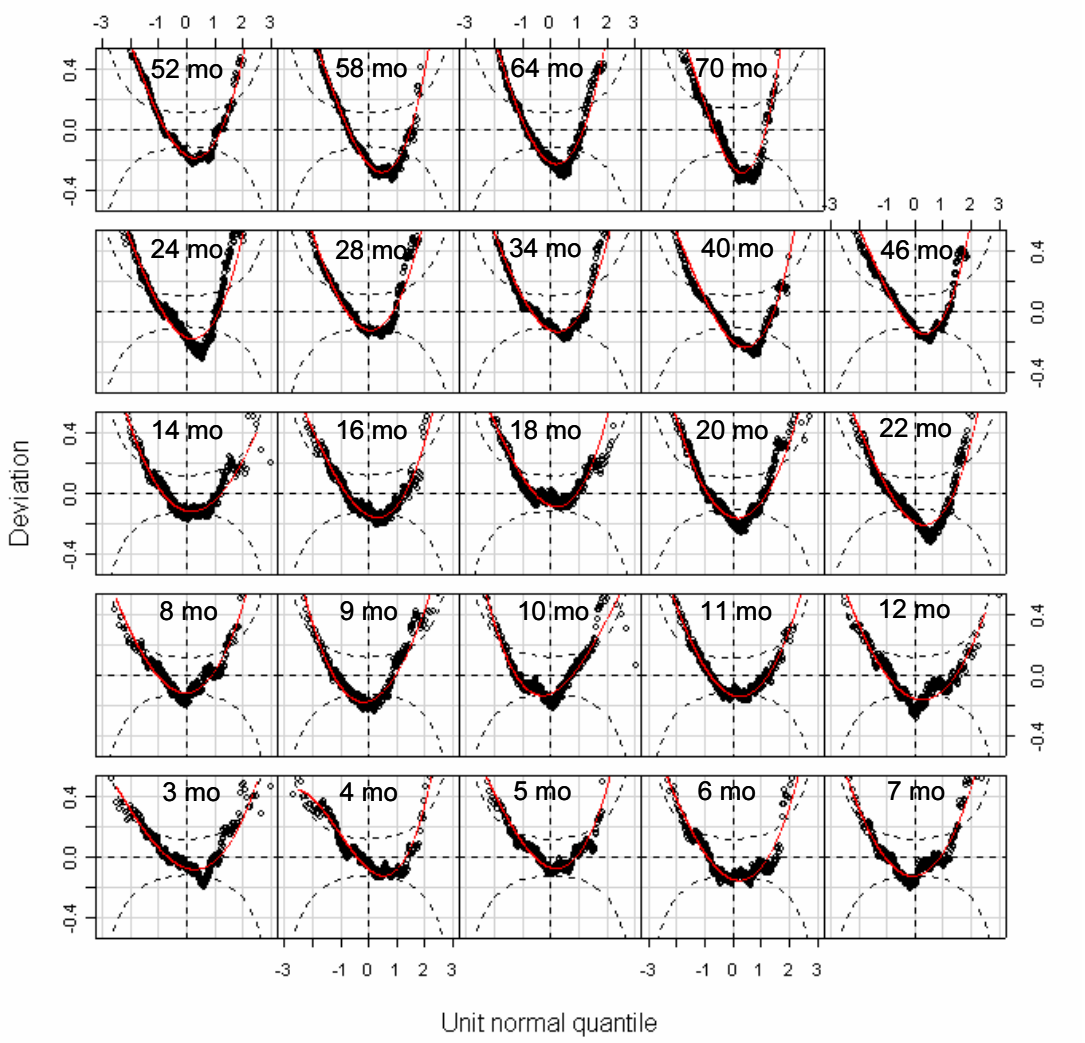


Figure 68 Worm plots of z-scores for Model 1 for subscapular skinfold-for-age for boys

Table 58 Q-test for z-scores from Model 1 [BCPE(x=age$^{0.65}$, df(μ)=6, df(σ)=3, ν=1, τ=2)] for subscapular skinfold-for-age for boys

Age (days)	Group	N	z1	z2	z3	z4
79 to 99	**3 mo**	414	0.3	-0.5	4.4	1.7
100 to 129	**4 mo**	407	0.5	-0.9	6.2	4.5
130 to 159	**5 mo**	410	1.2	0.3	6.0	3.2
160 to 189	**6 mo**	411	-0.7	-0.3	6.0	3.2
190 to 219	**7 mo**	406	0.1	1.2	5.6	2.4
220 to 249	**8 mo**	420	0.0	1.2	5.5	2.6
250 to 279	**9 mo**	391	-0.7	1.3	5.6	1.8
280 to 309	**10 mo**	399	-0.1	1.3	4.8	0.3
310 to 349	**11 mo**	460	-0.1	-0.9	6.3	2.9
350 to 379	**12 mo**	410	-1.1	-0.9	4.9	1.8
380 to 439	**14 mo**	418	-0.1	-1.2	5.2	1.3
440 to 499	**16 mo**	415	-0.3	-0.6	6.4	3.5
500 to 559	**18 mo**	440	1.2	0.3	7.2	5.1
560 to 619	**20 mo**	523	-0.3	-0.6	7.0	2.5
620 to 679	**22 mo**	547	-0.9	-0.6	8.0	4.2
680 to 749	**24 mo**	591	-0.2	0.6	8.8	4.6
750 to 929	**28 mo**	469	1.0	1.2	7.7	3.9
930 to 1119	**34 mo**	505	1.0	-0.2	7.7	4.1
1120 to 1309	**40 mo**	509	-0.9	-1.3	8.8	5.8
1310 to 1499	**46 mo**	505	1.1	0.4	9.1	5.8
1500 to 1689	**52 mo**	482	0.0	-0.4	8.4	4.7
1690 to 1879	**58 mo**	480	-1.0	-1.7	9.6	6.0
1880 to 2069	**64 mo**	460	-0.2	0.8	9.1	5.3
2070 to 2249	**70 mo**	285	0.5	2.0	9.3	6.2
Overall Q stats		**10 757**	**11.5**	**23.0**	**1227.4**	**378.9**
degrees of freedom			**18.0**	**22.0**	**24.0**	**24.0**
p-value			**0.8718**	**0.4023**	**<0.01**	**<0.01**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

The next step involved fitting the parameter ν for skewness using the BCPE distribution with fixed parameter τ=2 and keeping the degrees of freedom for the μ and σ curves identical to those selected for Model 1. Table 59 shows the *GAIC(3)* values for various degrees of freedom for the ν curve.

Table 59 Goodness-of-fit summary for models BCPE(x=age$^{0.65}$, df(μ)=6, df(σ)=3, df(ν)=?, τ=2) for subscapular skinfold-for-age for boys

df(ν)	GD[a]	GAIC(3)[a]	Total df
1	361.9	391.9	10
2	330.8	363.8	11
3	330.0	366.0	12
4	328.6	367.6	13
5	327.5	369.5	14
6	326.5	371.6	15
7	325.7	373.7	16

GD, Global Deviance; GAIC(3), Generalized Akaike Information Criterion with penalty equal to 3;
[a] In excess of 33 000.

The smallest *GAIC(3)* value corresponded to df(ν)=2. Fixing df(ν)=2, a re-search for the best df(μ) and df(σ) was carried out. The summary of the results is shown in Table 60.

Table 60 Goodness-of-fit summary for models using the BCPE distribution with df(ν)=2 and τ=2 for subscapular skinfold-for-age for boys

df(μ)	df(σ)	GD[a]	AIC[a]	GAIC(3)[a]	Total df
	1	372.5	388.5	396.5	8
	2	339.4	357.4	366.4	9
5	**3**	338.7	358.7	368.7	10
	4	337.7	359.7	370.7	11
	5	336.3	360.3	372.3	12
	1	364.1	382.1	391.1	9
	2	331.5	351.5	361.5	10
6	**3**	330.8	352.8	363.8	11
	4	329.9	353.9	365.9	12
	5	328.5	354.5	367.5	13
	1	361.1	381.1	391.1	10
	2	328.7	350.7	361.7	11
7	**3**	328.0	352.0	364.0	12
	4	327.1	353.1	366.1	13
	5	325.8	353.8	367.8	14
	1	359.5	381.5	392.5	11
	2	327.2	351.2	363.2	12
8	**3**	326.6	352.6	365.6	13
	4	325.7	353.7	367.7	14
	5	324.3	354.3	369.3	15
	1	358.4	382.4	394.4	12
	2	326.1	352.2	365.2	13
9	**3**	325.5	353.5	367.5	14
	4	324.6	354.6	369.6	15
	5	323.2	355.2	371.2	16

GD, Global Deviance; AIC, Akaike Information Criterion;
GAIC(3), Generalized AIC with penalty equal to 3;
[a] In excess of 33 000.

The smallest value of *GAIC(3)* was associated with df(μ)=6 and df(σ)=2 and thus this model was selected. A new search for the best λ was carried out but global deviance values were similar for λ from 0.45 to 0.65, implying no need to update the model further.

Model 2: BCPE(x= age$^{0.65}$, df(μ)=6, df(σ)=2, df(ν)=2, τ=2)

Figure 69 shows the fitting of the parameters μ, σ and ν for Model 2 with their respective sample estimates, that is, the median for μ, the sample standard deviation of the Box-Cox transformed data for σ, and the Box-Cox transform power for ν. The selected model for the median curve smoothed the slightly wiggly pattern observed in the empirical values for ages above 24 months.

Figures 70 and 71 show the distribution of differences between empirical values and fitted centiles for the longitudinal and cross-sectional samples, respectively. There was no indication of systematic bias for ages between 3 and 24 months (Figure 70) or between 24 and 71 months (Figure 71).

The worm plots for this model (Figure 72) were significantly improved compared to those of Model 1 (Figure 68). The U-shaped worms flattened out significantly (Figure 72), indicating that the residual skewness associated with Model 1 had been corrected. There were three age groups with slight S-shaped worms that could suggest remaining kurtosis (4 mo, 9 mo and 10 mo) but the worms were contained within the 95% confidence interval.

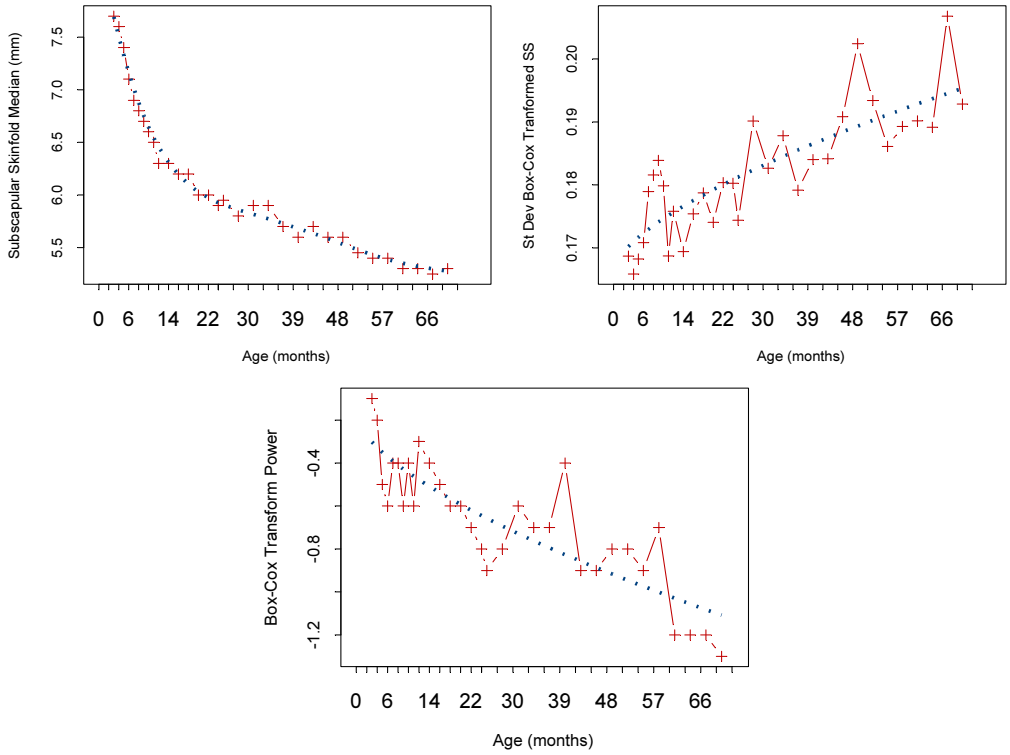


Figure 69 Fitting of the μ, σ, and ν curves of Model 2 for subscapular skinfold-for-age for boys from 3 to 71 months (dotted line) and their respective sample estimates (points with solid line)

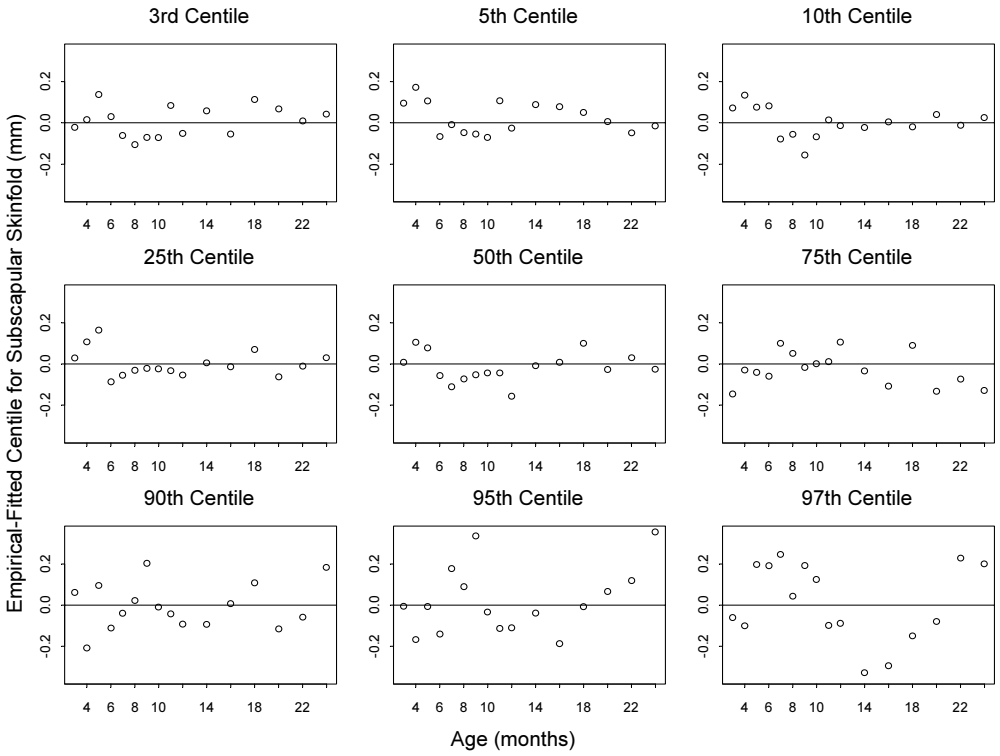


Figure 70 Centile residuals from fitting Model 2 for subscapular skinfold-for-age from 3 to 24 months for boys

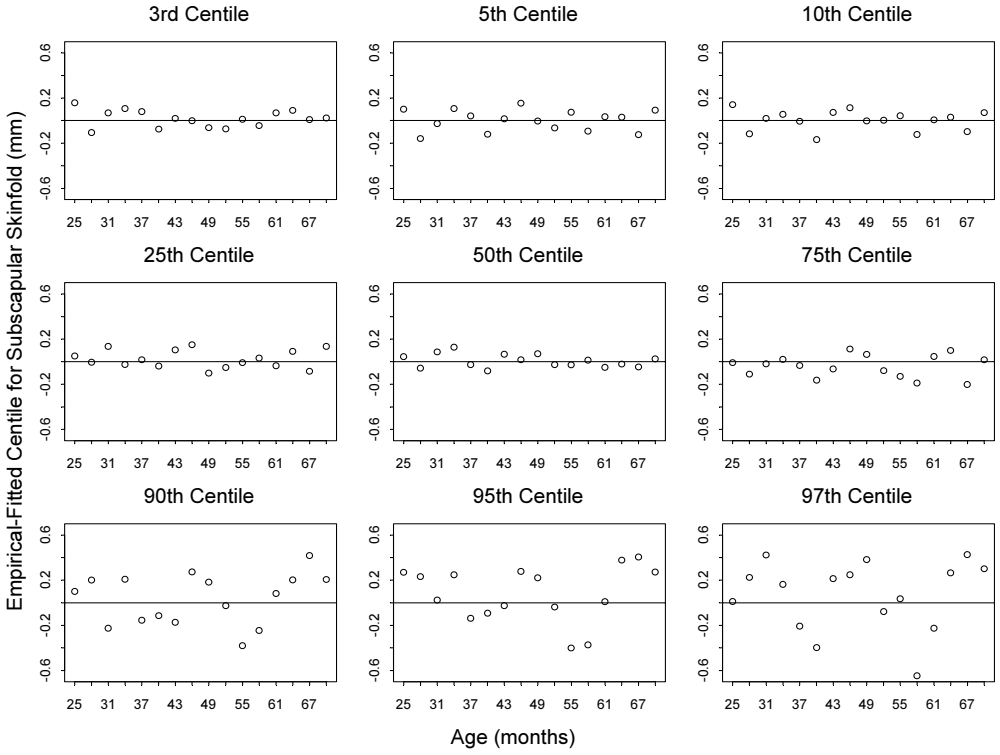


Figure 71 Centile residuals from fitting Model 2 for subscapular skinfold-for-age from 24 to 71 months for boys

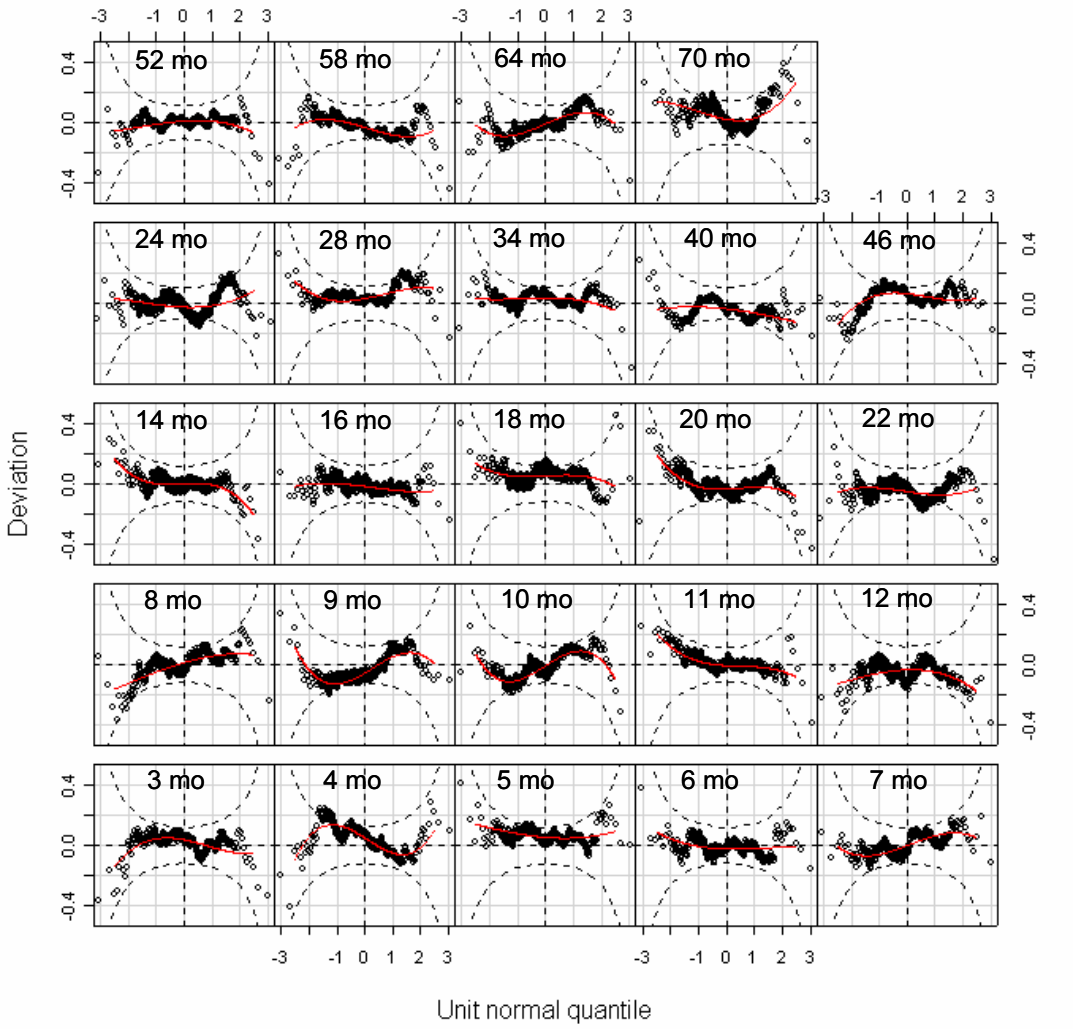


Figure 72 Worm plots of z-scores for Model 2 for subscapular skinfold-for-age for boys

The Q-test results from Model 2 are shown in Table 61. There were no groups with absolute values larger than 2 for the statistic z3 that would suggest remaining skewness. Two age groups had absolute values of z4 greater than 2 (4 mo and 10 mo), indicating local remaining kurtosis, but the overall test statistic for kurtosis had a p-value that was not significant at the 5% level. The overall Q-test p-values were all non-significant, indicating an adequate fit of the boys' subscapular skinfold-for-age curves and providing no justification for increasing the complexity of the model by adjusting for kurtosis (modelling τ).

Table 62 presents observed percentages with subscapular skinfolds below the fitted centiles. There was no detectable pattern of a systematic bias.

Table 61 Q-test for z-scores from Model 2 [BCPE(x=age$^{0.65}$, df(μ)=6, df(σ)=2, df(ν)=2, τ=2)] for subscapular skinfold-for-age for boys

Age (days)	Group	N	z1	z2	z3	z4
79 to 99	**3 mo**	414	0.3	-0.2	-1.1	1.0
100 to 129	**4 mo**	407	0.7	-1.2	-0.4	2.2
130 to 159	**5 mo**	410	1.3	-0.3	0.5	0.1
160 to 189	**6 mo**	411	-0.5	-0.4	0.6	0.0
190 to 219	**7 mo**	406	0.1	1.0	0.4	-1.0
220 to 249	**8 mo**	420	0.0	1.4	-0.6	0.2
250 to 279	**9 mo**	391	-0.8	1.4	0.8	-1.7
280 to 309	**10 mo**	399	-0.3	1.6	0.0	-2.3
310 to 349	**11 mo**	460	0.1	-1.0	0.6	-0.7
350 to 379	**12 mo**	410	-1.1	0.0	-0.9	-0.2
380 to 439	**14 mo**	418	-0.1	-0.8	-0.1	-1.3
440 to 499	**16 mo**	415	-0.4	-0.5	-0.1	0.3
500 to 559	**18 mo**	440	1.1	-0.3	0.1	-0.4
560 to 619	**20 mo**	523	-0.3	-0.6	0.7	-0.9
620 to 679	**22 mo**	547	-0.9	-0.4	0.1	0.7
680 to 749	**24 mo**	591	-0.4	0.2	0.9	0.3
750 to 929	**28 mo**	469	0.9	0.4	0.7	-0.6
930 to 1119	**34 mo**	505	1.0	-0.4	-0.4	-0.2
1120 to 1309	**40 mo**	509	-1.0	-0.6	-0.5	0.1
1310 to 1499	**46 mo**	505	1.0	0.2	-1.2	1.0
1500 to 1689	**52 mo**	482	-0.1	0.2	-0.6	-0.1
1690 to 1879	**58 mo**	480	-0.7	-1.0	-0.1	1.0
1880 to 2069	**64 mo**	460	-0.2	1.4	0.0	-1.2
2070 to 2249	**70 mo**	285	0.8	-0.1	1.3	0.7
Overall Q stats		**10 757**	**11.8**	**15.3**	**9.9**	**22.9**
degrees of freedom			**18.0**	**22.5**	**22.0**	**24.0**
p-value			**0.8550**	**0.8681**	**0.9870**	**0.5273**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

In conclusion, the model selected for constructing the subscapular skinfold-for-age growth curves for boys was BCPE(x=age$^{0.65}$, df(μ)=6, df(σ)=2, df(ν)=2, τ=2) that adjusts only for skewness, and thus reduces to the LMS method. The fitted centile curves and empirical centiles are shown in Figures 73 to 76.

Table 62 Observed proportions of children with measurements below the fitted centiles from Model 2, subscapular skinfold-for-age for boys

Expected	3 mo	4 mo	5 mo	6 mo	7 mo	8 mo	9 mo	10 mo	11 mo
1	1.2	1.5	0.7	1.0	0.7	2.1	0.5	0.8	0.7
3	3.1	2.9	2.4	2.9	3.4	4.0	3.6	3.0	2.0
5	4.1	4.4	3.7	5.8	4.9	5.5	6.6	5.8	3.5
10	9.4	7.1	9.3	9.0	10.8	10.2	11.8	13.0	8.3
25	22.9	23.1	22.7	26.3	26.1	25.5	29.2	27.3	25.4
50	46.4	47.7	49.5	51.3	51.5	51.4	52.7	52.9	50.4
75	77.1	76.2	75.1	76.2	73.2	72.4	76.2	71.7	74.1
90	89.6	91.9	89.3	91.7	89.7	90.0	88.5	88.5	90.2
95	94.9	95.8	94.9	96.1	94.3	94.5	93.1	94.7	95.7
97	96.9	97.1	96.8	96.4	96.3	96.7	96.4	95.5	97.2
99	99.3	98.8	98.3	98.5	98.8	98.1	99.0	99.2	98.7
Expected	**12 mo**	**14 mo**	**16 mo**	**18 mo**	**20 mo**	**22 mo**	**24 mo**	**28 mo**	**34 mo**
1	1.7	0.5	1.0	0.7	0.4	1.3	1.0	0.6	0.8
3	3.7	2.9	3.6	2.3	2.7	2.9	2.4	3.0	2.6
5	5.9	4.5	4.8	4.3	3.6	5.1	5.9	4.9	4.6
10	11.0	10.3	9.2	10.5	9.2	11.5	10.0	9.2	10.1
25	26.8	24.9	27.7	25.2	24.1	26.5	23.4	23.5	23.2
50	53.9	51.7	49.4	46.4	53.0	49.7	52.8	49.9	45.9
75	73.9	76.6	76.9	74.5	75.3	77.9	77.7	74.8	74.9
90	90.5	90.2	89.9	89.1	90.1	90.9	89.3	87.6	90.1
95	96.3	95.2	96.1	95.5	94.1	94.5	93.2	93.4	94.1
97	98.0	97.6	97.1	97.7	97.1	96.9	95.6	96.2	96.4
99	99.3	99.8	98.6	98.9	99.6	98.7	99.2	98.3	99.0

Table 62 Observed proportions of children with measurements below the fitted centiles from Model 2, subscapular skinfold-for-age for boys (cont)

Expected	40 mo	46 mo	52 mo	58 mo	64 mo	70 mo	Overall
1	1.2	1.8	1.0	1.0	1.1	0.7	1.0
3	3.7	4.0	3.3	2.1	3.3	2.1	3.0
5	6.5	5.9	4.8	4.4	6.7	4.9	5.1
10	11.2	9.5	8.9	10.0	11.5	10.2	10.0
25	24.8	20.6	25.9	24.8	26.5	20.4	24.8
50	52.7	46.3	50.0	51.5	49.8	48.8	50.2
75	78.6	74.7	74.9	76.7	75.4	75.8	75.5
90	91.0	90.1	89.4	90.8	88.0	87.7	89.8
95	95.7	93.7	95.2	95.8	93.5	93.7	94.7
97	97.6	97.0	96.7	96.9	97.0	95.1	96.8
99	99.4	99.0	99.0	99.4	98.9	97.5	98.9

Note: Group labels correspond to the age intervals in Table 61.

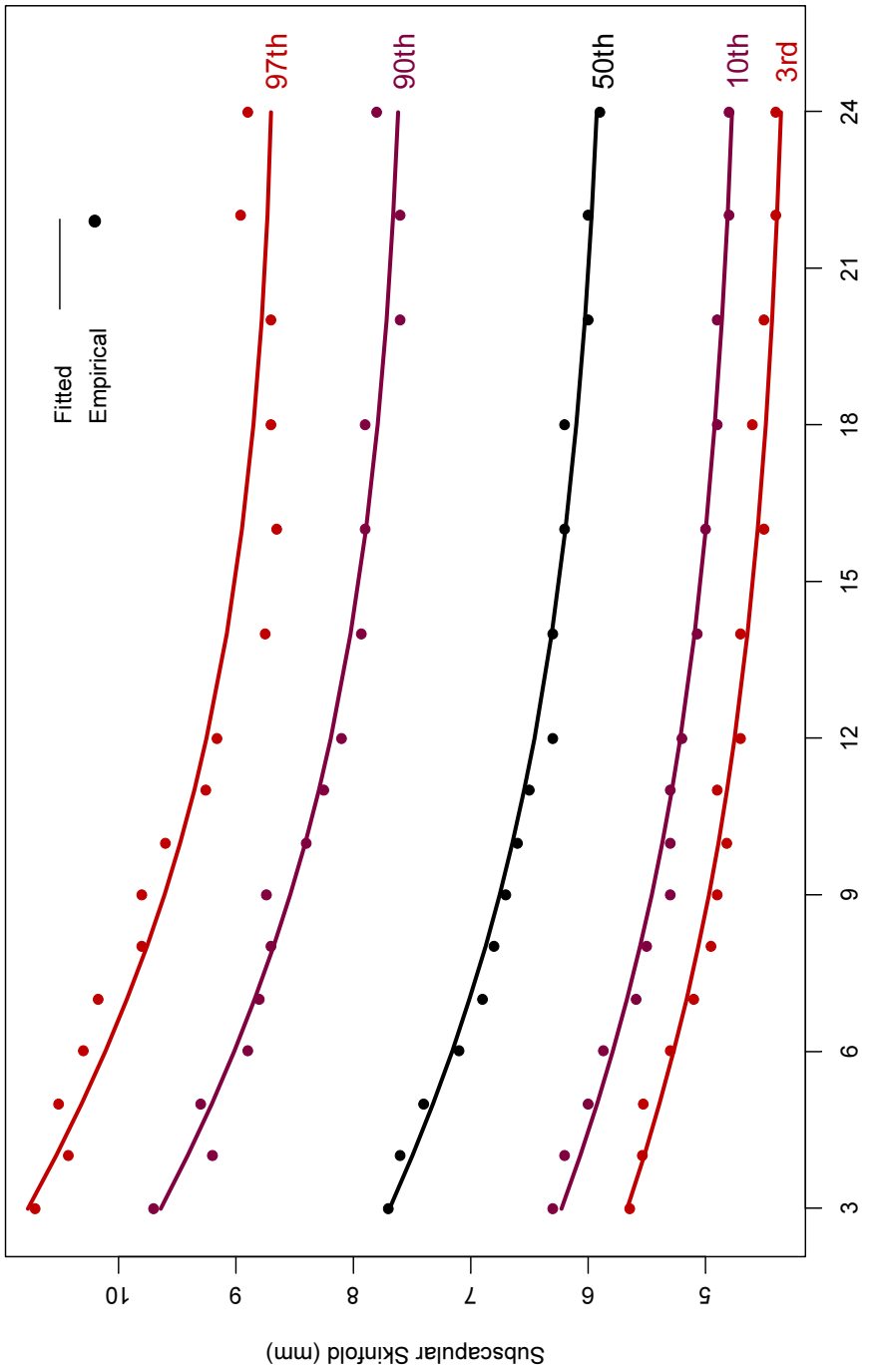


Figure 73 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: subscapular skinfold-for-age for boys from 3 to 24 months

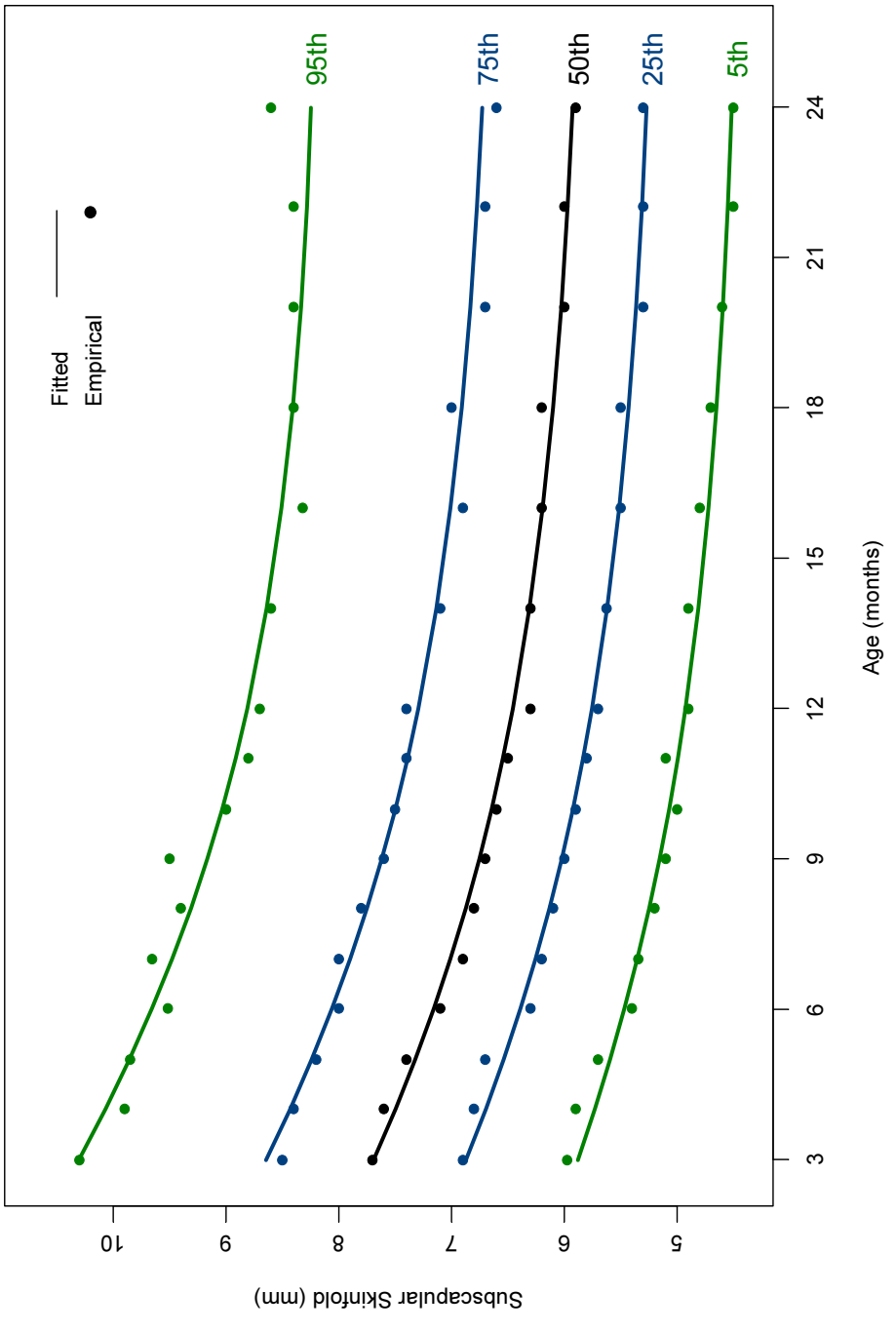


Figure 74 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: subscapular skinfold-for-age for boys from 3 to 24 months

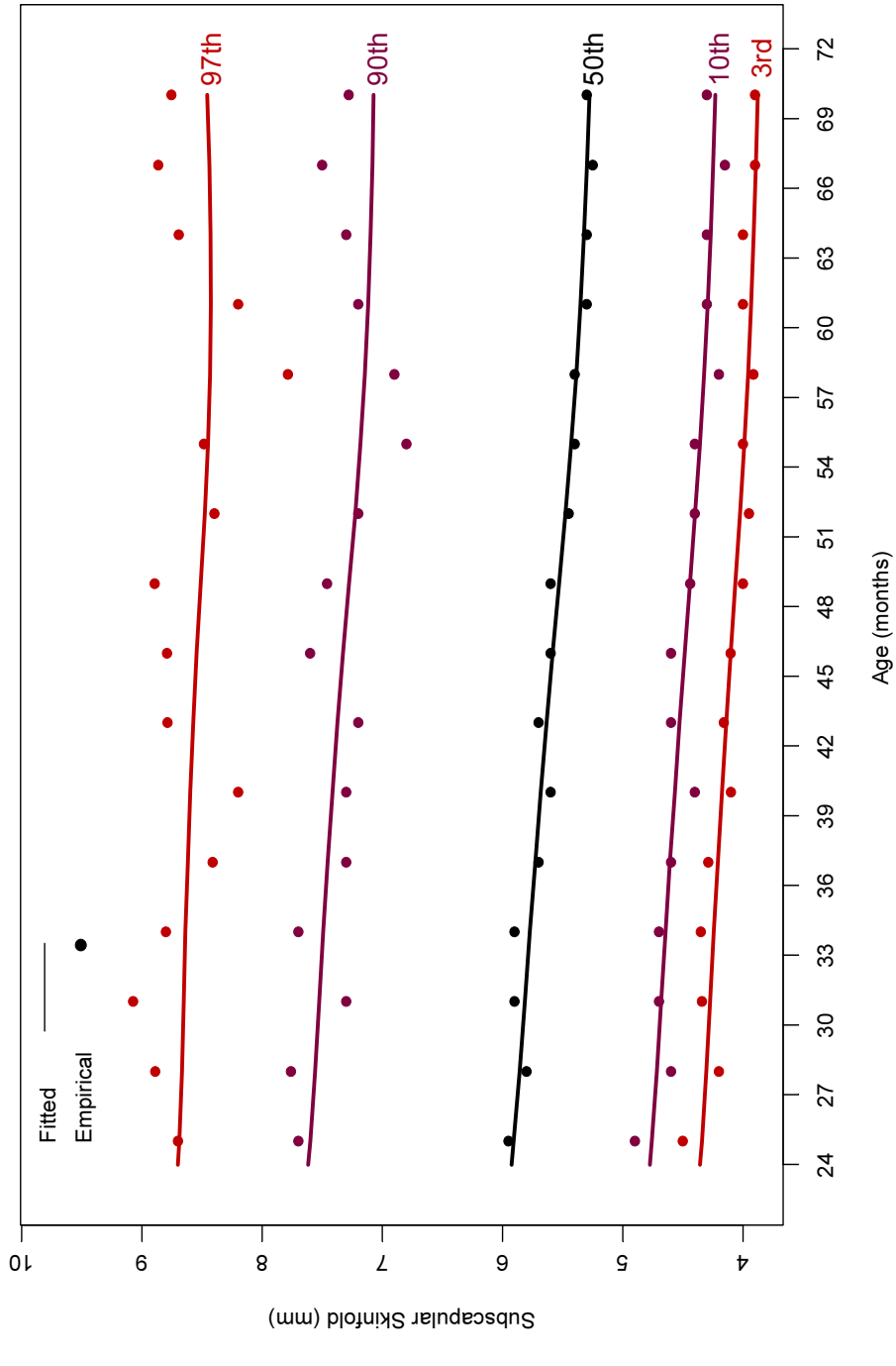


Figure 75 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: subscapular skinfold-for-age for boys from 24 to 71 months

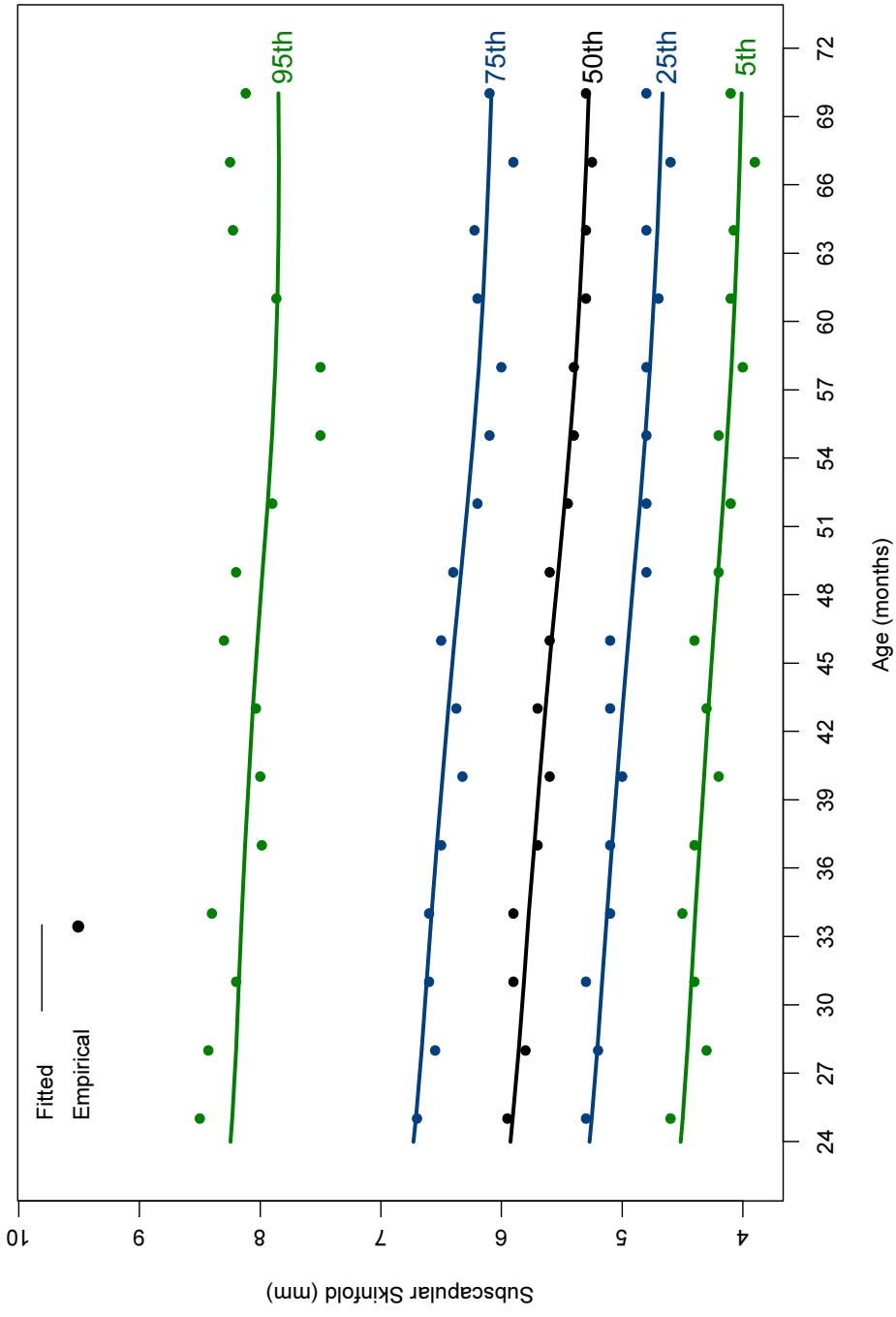


Figure 76 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: subscapular skinfold-for-age for boys from 24 to 71 months

6.2.3 WHO standards

This section presents the final WHO subscapular skinfold-for-age z-score and percentile charts (Figures 77 and 78) and table (Table 63) for boys.

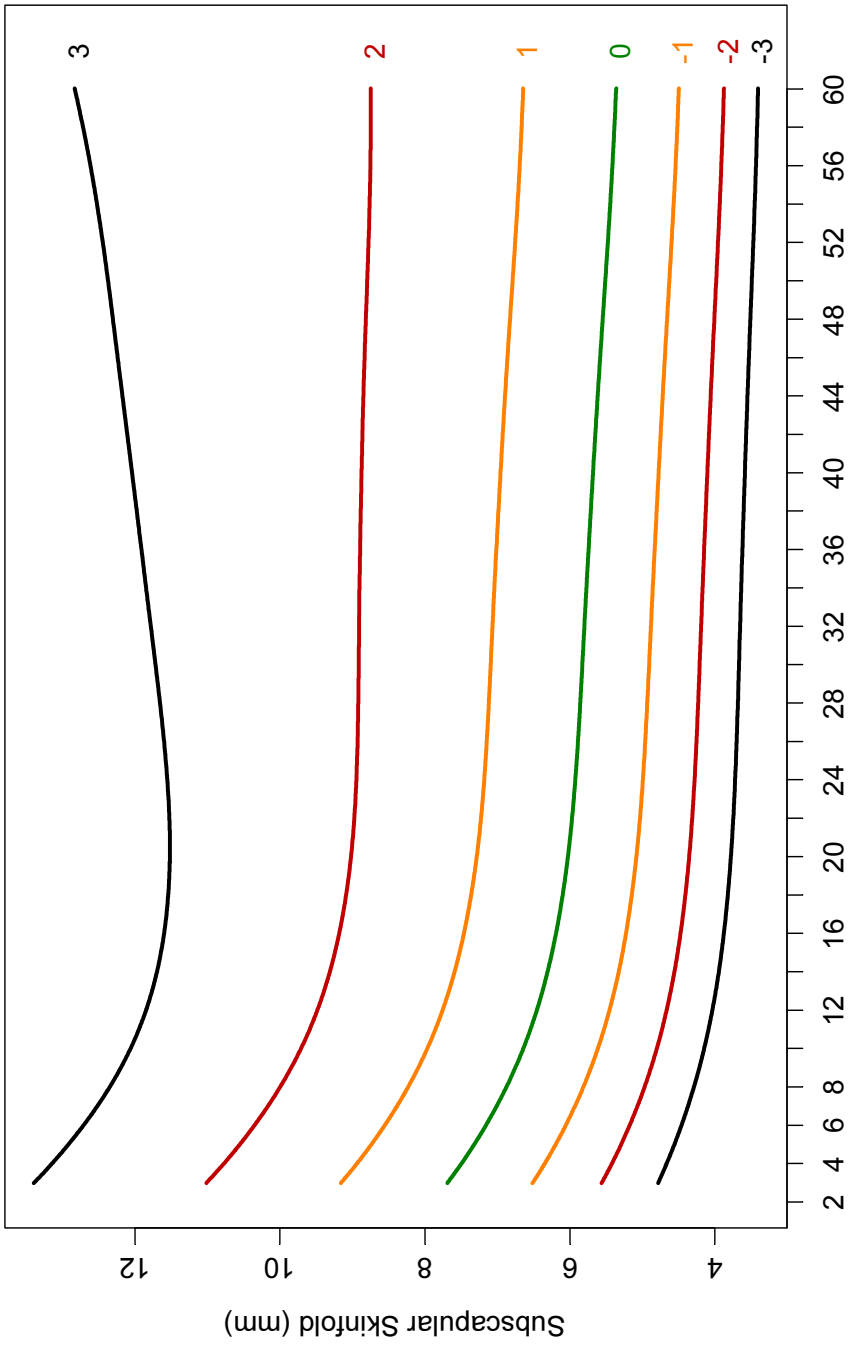


Figure 77 WHO subscapular skinfold-for-age z-scores for boys from 3 to 60 months

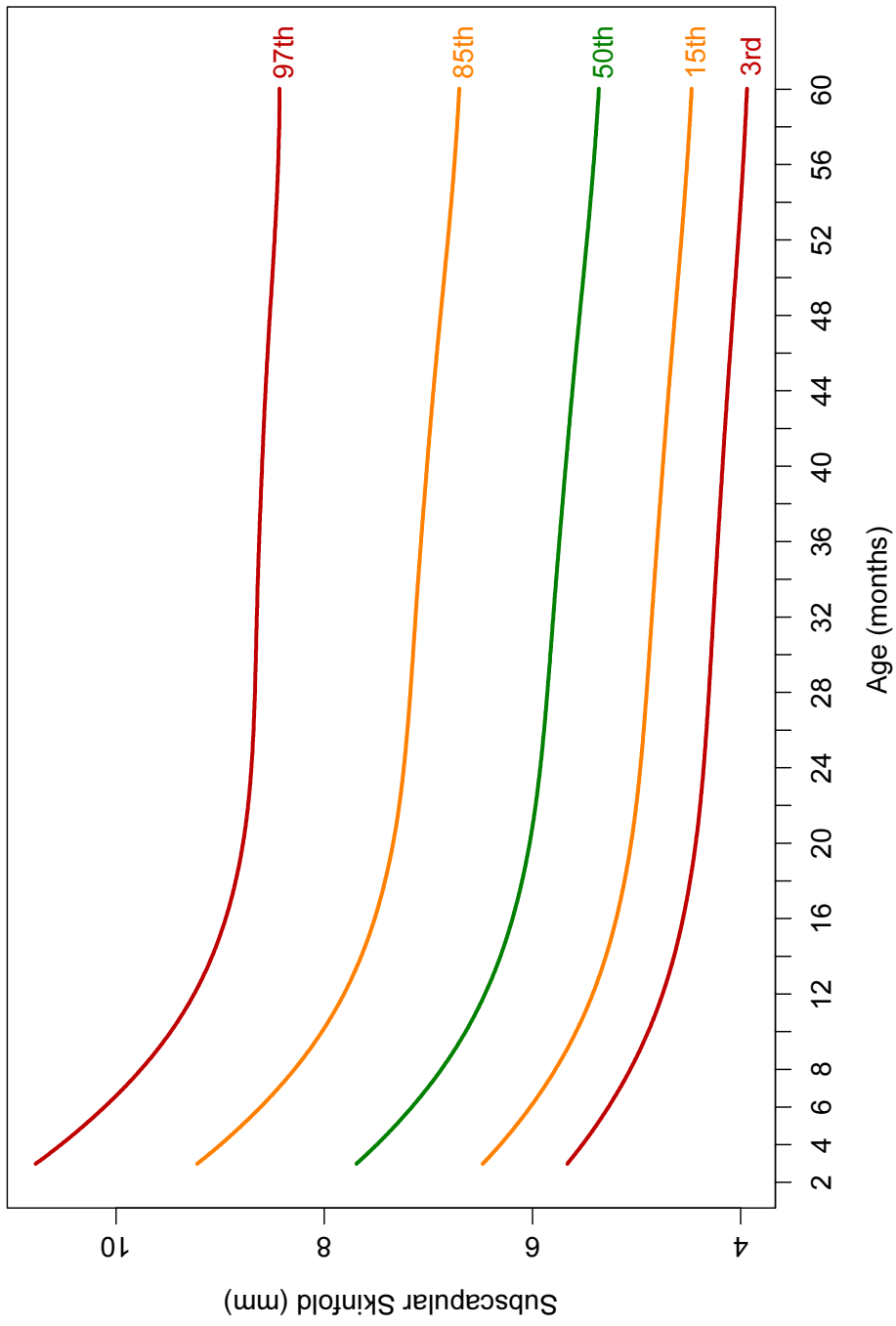


Figure 78 WHO subscapular skinfold-for-age percentiles for boys from 3 to 60 months

Table 63 Subscapular skinfold-for-age for boys, age in years and months

Year: Month	Month	L	M	S	Percentiles (subscapular skinfold in mm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
0: 3	**3**	-0.3033	7.6899	0.17020	5.3	5.7	5.9	6.5	6.9	7.7	8.6	9.2	10.3	10.8	11.7
0: 4	**4**	-0.3278	7.4968	0.17097	5.2	5.5	5.7	6.3	6.7	7.5	8.4	9.0	10.1	10.5	11.5
0: 5	**5**	-0.3503	7.3207	0.17167	5.0	5.4	5.6	6.2	6.5	7.3	8.2	8.8	9.9	10.3	11.3
0: 6	**6**	-0.3712	7.1588	0.17232	4.9	5.3	5.5	6.0	6.4	7.2	8.1	8.6	9.7	10.1	11.0
0: 7	**7**	-0.3909	7.0104	0.17293	4.8	5.2	5.4	5.9	6.3	7.0	7.9	8.4	9.5	9.9	10.9
0: 8	**8**	-0.4097	6.8753	0.17352	4.7	5.1	5.2	5.8	6.1	6.9	7.8	8.3	9.3	9.8	10.7
0: 9	**9**	-0.4276	6.7530	0.17408	4.6	5.0	5.2	5.7	6.0	6.8	7.6	8.1	9.2	9.6	10.5
0:10	**10**	-0.4449	6.6428	0.17462	4.6	4.9	5.1	5.6	5.9	6.6	7.5	8.0	9.0	9.5	10.4
0:11	**11**	-0.4616	6.5442	0.17514	4.5	4.8	5.0	5.5	5.8	6.5	7.4	7.9	8.9	9.4	10.3
1: 0	**12**	-0.4777	6.4562	0.17564	4.4	4.8	4.9	5.4	5.8	6.5	7.3	7.8	8.8	9.2	10.2
1: 1	**13**	-0.4934	6.3780	0.17613	4.4	4.7	4.9	5.4	5.7	6.4	7.2	7.7	8.7	9.2	10.1
1: 2	**14**	-0.5087	6.3085	0.17660	4.3	4.6	4.8	5.3	5.6	6.3	7.1	7.6	8.6	9.1	10.0
1: 3	**15**	-0.5236	6.2468	0.17707	4.3	4.6	4.8	5.2	5.6	6.2	7.1	7.6	8.6	9.0	9.9
1: 4	**16**	-0.5381	6.1921	0.17752	4.3	4.6	4.7	5.2	5.5	6.2	7.0	7.5	8.5	8.9	9.9
1: 5	**17**	-0.5524	6.1435	0.17797	4.2	4.5	4.7	5.2	5.5	6.1	7.0	7.5	8.5	8.9	9.8
1: 6	**18**	-0.5663	6.1003	0.17840	4.2	4.5	4.7	5.1	5.4	6.1	6.9	7.4	8.4	8.9	9.8
1: 7	**19**	-0.5800	6.0617	0.17883	4.2	4.5	4.6	5.1	5.4	6.1	6.9	7.4	8.4	8.8	9.8
1: 8	**20**	-0.5934	6.0274	0.17925	4.2	4.4	4.6	5.1	5.4	6.0	6.8	7.3	8.3	8.8	9.7
1: 9	**21**	-0.6066	5.9972	0.17966	4.1	4.4	4.6	5.0	5.3	6.0	6.8	7.3	8.3	8.8	9.7
1:10	**22**	-0.6196	5.9706	0.18006	4.1	4.4	4.5	5.0	5.3	6.0	6.8	7.3	8.3	8.7	9.7
1:11	**23**	-0.6324	5.9470	0.18046	4.1	4.4	4.5	5.0	5.3	5.9	6.8	7.3	8.3	8.7	9.7
2: 0	**24**	-0.6449	5.9258	0.18085	4.1	4.4	4.5	5.0	5.3	5.9	6.7	7.2	8.2	8.7	9.7

Table 63 Subscapular skinfold-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Percentiles (subscapular skinfold in mm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
2: 1	**25**	-0.6573	5.9067	0.18124	4.1	4.3	4.5	4.9	5.3	5.9	6.7	7.2	8.2	8.7	9.7
2: 2	**26**	-0.6695	5.8891	0.18162	4.1	4.3	4.5	4.9	5.2	5.9	6.7	7.2	8.2	8.7	9.7
2: 3	**27**	-0.6816	5.8729	0.18199	4.0	4.3	4.5	4.9	5.2	5.9	6.7	7.2	8.2	8.7	9.7
2: 4	**28**	-0.6935	5.8576	0.18237	4.0	4.3	4.5	4.9	5.2	5.9	6.7	7.2	8.2	8.7	9.7
2: 5	**29**	-0.7053	5.8431	0.18273	4.0	4.3	4.4	4.9	5.2	5.8	6.6	7.2	8.2	8.7	9.7
2: 6	**30**	-0.7169	5.8290	0.18309	4.0	4.3	4.4	4.9	5.2	5.8	6.6	7.1	8.2	8.7	9.7
2: 7	**31**	-0.7283	5.8150	0.18345	4.0	4.3	4.4	4.9	5.2	5.8	6.6	7.1	8.2	8.7	9.7
2: 8	**32**	-0.7397	5.8011	0.18381	4.0	4.3	4.4	4.9	5.2	5.8	6.6	7.1	8.2	8.6	9.7
2: 9	**33**	-0.7509	5.7870	0.18416	4.0	4.3	4.4	4.8	5.1	5.8	6.6	7.1	8.2	8.6	9.7
2:10	**34**	-0.7620	5.7727	0.18450	4.0	4.2	4.4	4.8	5.1	5.8	6.6	7.1	8.2	8.6	9.7
2:11	**35**	-0.7730	5.7580	0.18485	4.0	4.2	4.4	4.8	5.1	5.8	6.6	7.1	8.1	8.6	9.7
3: 0	**36**	-0.7839	5.7430	0.18519	4.0	4.2	4.4	4.8	5.1	5.7	6.5	7.1	8.1	8.6	9.7
3: 1	**37**	-0.7947	5.7278	0.18552	4.0	4.2	4.4	4.8	5.1	5.7	6.5	7.1	8.1	8.6	9.7
3: 2	**38**	-0.8054	5.7125	0.18585	3.9	4.2	4.3	4.8	5.1	5.7	6.5	7.0	8.1	8.6	9.7
3: 3	**39**	-0.8159	5.6971	0.18618	3.9	4.2	4.3	4.8	5.1	5.7	6.5	7.0	8.1	8.6	9.7
3: 4	**40**	-0.8264	5.6815	0.18651	3.9	4.2	4.3	4.7	5.0	5.7	6.5	7.0	8.1	8.6	9.7
3: 5	**41**	-0.8368	5.6658	0.18684	3.9	4.2	4.3	4.7	5.0	5.7	6.5	7.0	8.1	8.6	9.7
3: 6	**42**	-0.8471	5.6500	0.18716	3.9	4.2	4.3	4.7	5.0	5.6	6.5	7.0	8.1	8.6	9.7
3: 7	**43**	-0.8574	5.6339	0.18748	3.9	4.1	4.3	4.7	5.0	5.6	6.4	7.0	8.1	8.6	9.7
3: 8	**44**	-0.8675	5.6174	0.18779	3.9	4.1	4.3	4.7	5.0	5.6	6.4	7.0	8.0	8.6	9.7
3: 9	**45**	-0.8775	5.6006	0.18811	3.9	4.1	4.3	4.7	5.0	5.6	6.4	6.9	8.0	8.6	9.7
3:10	**46**	-0.8875	5.5834	0.18842	3.9	4.1	4.2	4.7	4.9	5.6	6.4	6.9	8.0	8.5	9.7
3:11	**47**	-0.8974	5.5659	0.18873	3.8	4.1	4.2	4.6	4.9	5.6	6.4	6.9	8.0	8.5	9.7
4: 0	**48**	-0.9073	5.5482	0.18903	3.8	4.1	4.2	4.6	4.9	5.5	6.4	6.9	8.0	8.5	9.7

Table 63 Subscapular skinfold-for-age for boys, age in years and months (continued)

					Percentiles (subscapular skinfold in mm)										
Year: Month	**Month**	**L**	**M**	**S**	**1st**	**3rd**	**5th**	**15th**	**25th**	**50th**	**75th**	**85th**	**95th**	**97th**	**99th**
4: 1	**49**	-0.9170	5.5303	0.18934	3.8	4.1	4.2	4.6	4.9	5.5	6.3	6.9	8.0	8.5	9.7
4: 2	**50**	-0.9267	5.5125	0.18964	3.8	4.1	4.2	4.6	4.9	5.5	6.3	6.8	8.0	8.5	9.7
4: 3	**51**	-0.9363	5.4948	0.18994	3.8	4.0	4.2	4.6	4.9	5.5	6.3	6.8	8.0	8.5	9.7
4: 4	**52**	-0.9459	5.4774	0.19024	3.8	4.0	4.2	4.6	4.9	5.5	6.3	6.8	7.9	8.5	9.7
4: 5	**53**	-0.9554	5.4606	0.19053	3.8	4.0	4.2	4.6	4.8	5.5	6.3	6.8	7.9	8.5	9.7
4: 6	**54**	-0.9648	5.4443	0.19083	3.8	4.0	4.1	4.5	4.8	5.4	6.2	6.8	7.9	8.5	9.7
4: 7	**55**	-0.9742	5.4288	0.19112	3.8	4.0	4.1	4.5	4.8	5.4	6.2	6.8	7.9	8.5	9.7
4: 8	**56**	-0.9835	5.4140	0.19141	3.7	4.0	4.1	4.5	4.8	5.4	6.2	6.8	7.9	8.4	9.7
4: 9	**57**	-0.9928	5.4000	0.19170	3.7	4.0	4.1	4.5	4.8	5.4	6.2	6.7	7.9	8.4	9.7
4:10	**58**	-1.0020	5.3868	0.19199	3.7	4.0	4.1	4.5	4.8	5.4	6.2	6.7	7.9	8.4	9.7
4:11	**59**	-1.0111	5.3744	0.19227	3.7	3.9	4.1	4.5	4.8	5.4	6.2	6.7	7.9	8.4	9.7
5: 0	**60**	-1.0202	5.3628	0.19255	3.7	3.9	4.1	4.5	4.7	5.4	6.2	6.7	7.9	8.4	9.8

Table 63 Subscapular skinfold-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (subscapular skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 3	**3**	-0.3033	7.6899	0.17020	4.8	5.6	6.5	7.7	9.2	11.0	13.4
0: 4	**4**	-0.3278	7.4968	0.17097	4.7	5.4	6.3	7.5	8.9	10.8	13.1
0: 5	**5**	-0.3503	7.3207	0.17167	4.6	5.3	6.2	7.3	8.7	10.6	12.9
0: 6	**6**	-0.3712	7.1588	0.17232	4.5	5.2	6.1	7.2	8.6	10.4	12.7
0: 7	**7**	-0.3909	7.0104	0.17293	4.4	5.1	5.9	7.0	8.4	10.2	12.5
0: 8	**8**	-0.4097	6.8753	0.17352	4.3	5.0	5.8	6.9	8.2	10.0	12.3
0: 9	**9**	-0.4276	6.7530	0.17408	4.2	4.9	5.7	6.8	8.1	9.8	12.2
0:10	**10**	-0.4449	6.6428	0.17462	4.1	4.8	5.6	6.6	8.0	9.7	12.1
0:11	**11**	-0.4616	6.5442	0.17514	4.1	4.7	5.5	6.5	7.9	9.6	11.9
1: 0	**12**	-0.4777	6.4562	0.17564	4.0	4.7	5.5	6.5	7.8	9.5	11.8
1: 1	**13**	-0.4934	6.3780	0.17613	4.0	4.6	5.4	6.4	7.7	9.4	11.8
1: 2	**14**	-0.5087	6.3085	0.17660	3.9	4.6	5.3	6.3	7.6	9.3	11.7
1: 3	**15**	-0.5236	6.2468	0.17707	3.9	4.5	5.3	6.2	7.5	9.2	11.6
1: 4	**16**	-0.5381	6.1921	0.17752	3.9	4.5	5.2	6.2	7.5	9.2	11.6
1: 5	**17**	-0.5524	6.1435	0.17797	3.8	4.4	5.2	6.1	7.4	9.1	11.6
1: 6	**18**	-0.5663	6.1003	0.17840	3.8	4.4	5.1	6.1	7.4	9.1	11.5
1: 7	**19**	-0.5800	6.0617	0.17883	3.8	4.4	5.1	6.1	7.3	9.1	11.5
1: 8	**20**	-0.5934	6.0274	0.17925	3.8	4.4	5.1	6.0	7.3	9.0	11.5
1: 9	**21**	-0.6066	5.9972	0.17966	3.8	4.3	5.1	6.0	7.3	9.0	11.5
1:10	**22**	-0.6196	5.9706	0.18006	3.7	4.3	5.0	6.0	7.2	9.0	11.5
1:11	**23**	-0.6324	5.9470	0.18046	3.7	4.3	5.0	5.9	7.2	9.0	11.5
2: 0	**24**	-0.6449	5.9258	0.18085	3.7	4.3	5.0	5.9	7.2	8.9	11.6

Table 63 Subscapular skinfold-for-age for boys, age in years and months (continued)

					Z-scores (subscapular skinfold in mm)						
Year: Month	**Month**	**L**	**M**	**S**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
2: 1	**25**	-0.6573	5.9067	0.18124	3.7	4.3	5.0	5.9	7.2	8.9	11.6
2: 2	**26**	-0.6695	5.8891	0.18162	3.7	4.3	5.0	5.9	7.1	8.9	11.6
2: 3	**27**	-0.6816	5.8729	0.18199	3.7	4.2	4.9	5.9	7.1	8.9	11.6
2: 4	**28**	-0.6935	5.8576	0.18237	3.7	4.2	4.9	5.9	7.1	8.9	11.7
2: 5	**29**	-0.7053	5.8431	0.18273	3.7	4.2	4.9	5.8	7.1	8.9	11.7
2: 6	**30**	-0.7169	5.8290	0.18309	3.7	4.2	4.9	5.8	7.1	8.9	11.7
2: 7	**31**	-0.7283	5.8150	0.18345	3.7	4.2	4.9	5.8	7.1	8.9	11.7
2: 8	**32**	-0.7397	5.8011	0.18381	3.7	4.2	4.9	5.8	7.1	8.9	11.8
2: 9	**33**	-0.7509	5.7870	0.18416	3.6	4.2	4.9	5.8	7.1	8.9	11.8
2:10	**34**	-0.7620	5.7727	0.18450	3.6	4.2	4.9	5.8	7.0	8.9	11.8
2:11	**35**	-0.7730	5.7580	0.18485	3.6	4.2	4.8	5.8	7.0	8.9	11.9
3: 0	**36**	-0.7839	5.7430	0.18519	3.6	4.1	4.8	5.7	7.0	8.9	11.9
3: 1	**37**	-0.7947	5.7278	0.18552	3.6	4.1	4.8	5.7	7.0	8.9	11.9
3: 2	**38**	-0.8054	5.7125	0.18585	3.6	4.1	4.8	5.7	7.0	8.9	12.0
3: 3	**39**	-0.8159	5.6971	0.18618	3.6	4.1	4.8	5.7	7.0	8.9	12.0
3: 4	**40**	-0.8264	5.6815	0.18651	3.6	4.1	4.8	5.7	7.0	8.9	12.0
3: 5	**41**	-0.8368	5.6658	0.18684	3.6	4.1	4.8	5.7	6.9	8.9	12.1
3: 6	**42**	-0.8471	5.6500	0.18716	3.6	4.1	4.7	5.6	6.9	8.9	12.1
3: 7	**43**	-0.8574	5.6339	0.18748	3.6	4.1	4.7	5.6	6.9	8.9	12.1
3: 8	**44**	-0.8675	5.6174	0.18779	3.6	4.1	4.7	5.6	6.9	8.8	12.2
3: 9	**45**	-0.8775	5.6006	0.18811	3.5	4.0	4.7	5.6	6.9	8.8	12.2
3:10	**46**	-0.8875	5.5834	0.18842	3.5	4.0	4.7	5.6	6.9	8.8	12.2
3:11	**47**	-0.8974	5.5659	0.18873	3.5	4.0	4.7	5.6	6.8	8.8	12.3
4: 0	**48**	-0.9073	5.5482	0.18903	3.5	4.0	4.7	5.5	6.8	8.8	12.3

Table 63 Subscapular skinfold-for-age for boys, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (subscapular skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	**49**	-0.9170	5.5303	0.18934	3.5	4.0	4.6	5.5	6.8	8.8	12.3
4: 2	**50**	-0.9267	5.5125	0.18964	3.5	4.0	4.6	5.5	6.8	8.8	12.4
4: 3	**51**	-0.9363	5.4948	0.18994	3.5	4.0	4.6	5.5	6.8	8.8	12.4
4: 4	**52**	-0.9459	5.4774	0.19024	3.5	4.0	4.6	5.5	6.8	8.8	12.4
4: 5	**53**	-0.9554	5.4606	0.19053	3.5	3.9	4.6	5.5	6.7	8.8	12.5
4: 6	**54**	-0.9648	5.4443	0.19083	3.5	3.9	4.6	5.4	6.7	8.8	12.5
4: 7	**55**	-0.9742	5.4288	0.19112	3.4	3.9	4.6	5.4	6.7	8.8	12.6
4: 8	**56**	-0.9835	5.4140	0.19141	3.4	3.9	4.5	5.4	6.7	8.8	12.6
4: 9	**57**	-0.9928	5.4000	0.19170	3.4	3.9	4.5	5.4	6.7	8.7	12.7
4:10	**58**	-1.0020	5.3868	0.19199	3.4	3.9	4.5	5.4	6.7	8.7	12.7
4:11	**59**	-1.0111	5.3744	0.19227	3.4	3.9	4.5	5.4	6.7	8.7	12.8
5: 0	**60**	-1.0202	5.3628	0.19255	3.4	3.9	4.5	5.4	6.6	8.7	12.8

6.3 Subscapular skinfold-for-age for girls

Steps similar to those used to construct the subscapular skinfold-for-age growth curves for boys were followed to fit the subscapular skinfold-for-age growth curves for girls.

6.3.1 Sample size

There were a total of 10 934 subscapular skinfold observations for girls. The longitudinal and cross-sectional sample sizes by visit and age are presented in Tables 64 and 65. The measurement of subscapular skinfold started at 3 months of age (de Onis et al., 2004b).

Table 64 Longitudinal sample sizes for subscapular skinfold-for-age for girls

Visit	**5**	**6**	**7**	**8**	**9**	**10**
Age	**3 mo**	**4 mo**	**5 mo**	**6 mo**	**7 mo**	**8 mo**
N	446	443	447	445	444	440
Visit	**11**	**12**	**13**	**14**	**15**	**16**
Age	**9 mo**	**10 mo**	**11 mo**	**12 mo**	**14 mo**	**16 mo**
N	444	443	440	448	445	441
Visit	**17**	**18**	**19**	**20**		
Age	**18 mo**	**20 mo**	**22 mo**	**24 mo**		
N	444	443	433	447		

Table 65 Cross-sectional sample sizes for subscapular skinfold-for-age for girls

Age (mo)	**<18**	**18–20**	**21–23**	**24–26**	**27–29**	**30–32**	**33–35**
N	2	159	167	237	213	224	222
Age (mo)	**36–38**	**39–41**	**42–44**	**45–47**	**48–50**	**51–53**	**54–56**
N	217	233	246	205	219	196	229
Age (mo)	**57–59**	**60–62**	**63–65**	**66–68**	**69–71**	**>71**	
N	236	213	203	222	198	0	

6.3.2 Model selection and results

The model BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) was used as a starting point to search for the best value of the age-transformation power λ. Table 66 shows the global deviance for values of λ from 0.05 to 1. The minimum global deviance value was for λ 0.45 to 0.60, and λ=0.50 was selected to continue the search for the best model.

Table 66 Global deviance (GD) for models within the class BCPE(x=age$^{\lambda}$, df(μ)=9, df(σ)=4, df(ν)=4, τ=2) for subscapular skinfold-for-age for girls

λ	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
GD[a]	658.1	657.6	657.2	656.9	656.7	656.5	656.3	656.3	656.2	656.2
λ	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
GD[a]	656.2	656.2	656.3	656.4	656.5	656.7	657.1	657.5	658.1	659.0

[a] In excess of 36 000.

The search for the best df(μ) and df(σ) followed, fixing λ=0.50, ν=1 and τ=2. All possible combinations with df(μ) values ranging from 4 to 15 and df(σ) from 2 to 10 were considered and partial results are presented in Table 67. The fitted model that minimized *GAIC(3)* was that with df(μ)=5 and df(σ)=4 and it was thus selected for further evaluation.

Table 67 Goodness-of-fit summary for models using the BCPE distribution with fixed ν=1 and τ=2 for subscapular skinfold-for-age for girls

df(μ)	df(σ)	GD[a]	AIC[a]	GAIC(3)[a]	Total df
	2	2485.9	2497.9	2503.9	6
	3	2438.2	2452.2	2459.2	7
4	**4**	2433.0	2449.0	2457.0	8
	5	2432.3	2450.3	2459.3	9
	6	2431.6	2451.6	2461.6	10
	2	2477.0	2491.0	2498.0	7
	3	2430.9	2446.9	2454.9	8
5	**4**	2424.4	2442.4	2451.4	9
	5	2423.2	2443.2	2453.2	10
	6	2422.4	2444.4	2455.4	11
	2	2475.2	2491.2	2499.2	8
	3	2429.4	2447.4	2456.4	9
6	**4**	2422.5	2442.5	2452.5	10
	5	2421.2	2443.2	2454.2	11
	6	2420.4	2444.4	2456.4	12
	2	2474.2	2492.2	2501.2	9
	3	2428.5	2448.5	2458.5	10
7	**4**	2421.5	2443.5	2454.5	11
	5	2420.1	2444.1	2456.1	12
	6	2419.3	2445.3	2458.3	13
	2	2473.0	2493.0	2503.0	10
	3	2427.5	2449.5	2460.5	11
8	**4**	2420.4	2444.4	2456.4	12
	5	2419.1	2445.1	2458.1	13
	6	2418.2	2446.2	2460.2	14

GD, Global Deviance; AIC, Akaike Information Criterion;
GAIC(3), Generalized AIC with penalty equal to 3;
[a] In excess of 36 000.

Model 1: BCPE(x=age$^{0.50}$, df(μ)=5, df(σ)=4, ν=1, τ=2)

This model was inadequate with evidence of residual skewness in both the worm plots (Figure 79) and the Q-test results (Table 68). The worms presented U-shapes in all age groups and the Q-test results (Table 68) showed that all groups had absolute values of z3 higher than 2. Most of the age groups also presented absolute values of z4 higher than 2, indicating residual kurtosis. Both overall tests for skewness and kurtosis were significant (p-value < 0.01). No misfit was detected in the mean and the variance.

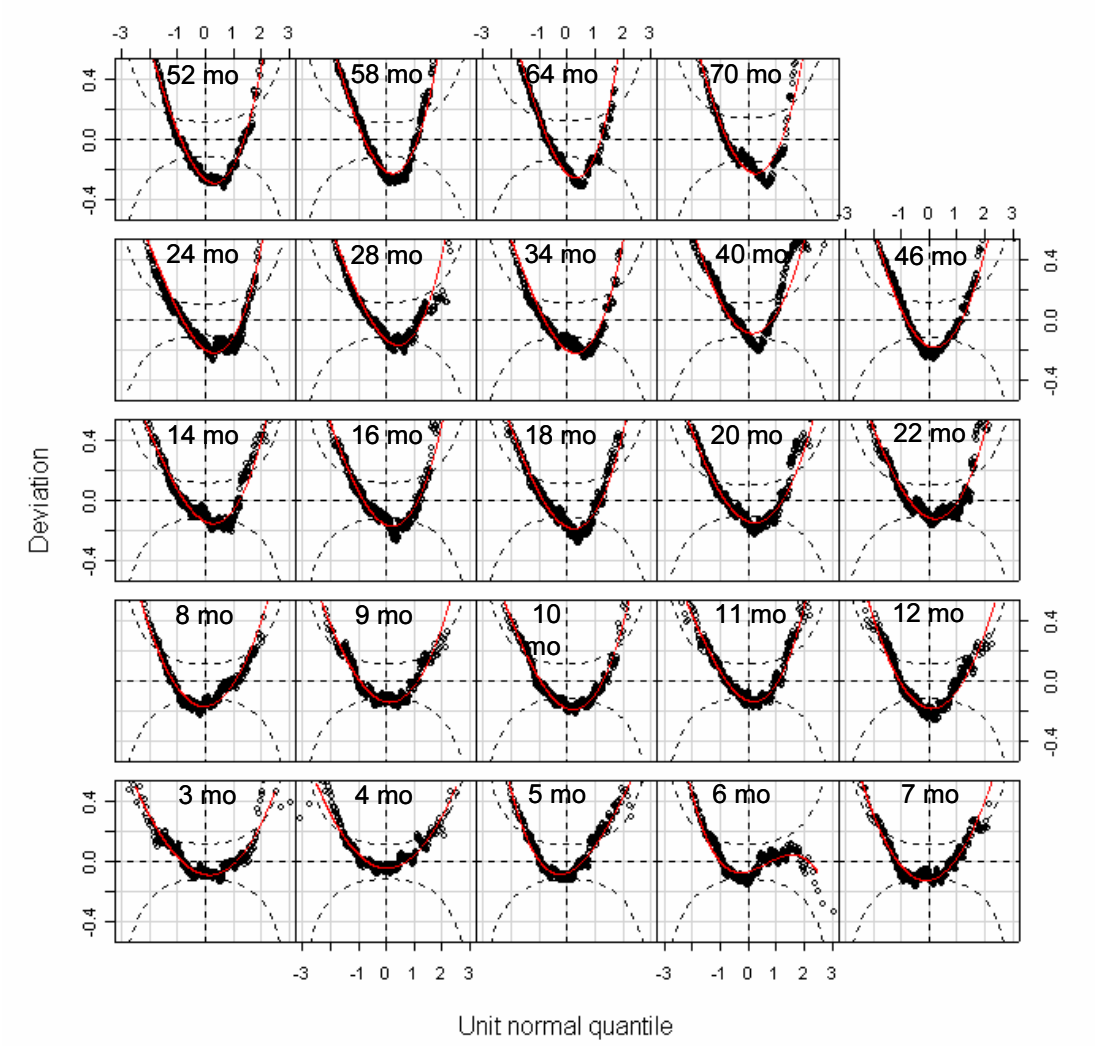


Figure 79 Worm plots of z-scores for Model 1 for subscapular skinfold-for-age for girls

Table 68 Q-test for z-scores from Model 1 [BCPE(x=age$^{0.50}$, df(μ)=5, df(σ)=4, ν=1, τ=2)] for subscapular skinfold-for-age for girls

Age (days)	Group	N	z1	z2	z3	z4
83 to 99	**3 mo**	439	0.0	-0.3	4.6	1.7
100 to 129	**4 mo**	443	1.0	0.1	4.2	1.1
130 to 159	**5 mo**	441	1.2	0.8	5.4	0.5
160 to 189	**6 mo**	441	0.2	-1.5	3.2	-3.6
190 to 219	**7 mo**	432	0.0	1.0	5.5	2.3
220 to 249	**8 mo**	435	-0.8	1.0	6.1	2.5
250 to 279	**9 mo**	437	-0.3	-0.1	5.9	2.8
280 to 309	**10 mo**	443	-1.1	-0.2	6.7	3.7
310 to 349	**11 mo**	476	0.4	0.5	7.2	4.0
350 to 379	**12 mo**	450	-1.0	-0.2	6.3	2.3
380 to 439	**14 mo**	442	0.0	-0.4	6.9	3.8
440 to 499	**16 mo**	443	0.1	0.3	7.7	4.2
500 to 559	**18 mo**	466	-0.4	0.1	7.7	4.2
560 to 619	**20 mo**	543	-0.3	-0.7	7.1	3.0
620 to 679	**22 mo**	538	0.7	0.1	7.6	4.2
680 to 749	**24 mo**	592	-0.6	0.0	9.7	6.4
750 to 929	**28 mo**	454	0.6	-1.2	8.8	6.2
930 to 1119	**34 mo**	466	-0.5	0.1	9.0	6.0
1120 to 1309	**40 mo**	470	1.7	0.0	7.5	3.2
1310 to 1499	**46 mo**	448	0.0	-0.5	7.9	3.6
1500 to 1689	**52 mo**	443	-1.5	-0.7	9.4	5.9
1690 to 1879	**58 mo**	487	0.3	1.1	9.9	5.6
1880 to 2069	**64 mo**	413	0.3	0.9	10.3	6.6
2070 to 2191	**70 mo**	292	0.1	-0.2	7.7	4.5
Overall Q stats		**10 934**	**12.1**	**10.5**	**1308.7**	**416.5**
degrees of freedom			**19.0**	**21.5**	**24.0**	**24.0**
p-value			**0.8814**	**0.9773**	**<0.01**	**<0.01**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

The next step involved fitting the parameter ν for skewness using the BCPE distribution with fixed parameter τ=2 and keeping the degrees of freedom for the μ and σ curves selected for Model 1. Table 69 shows the *GAIC(3)* values for various degrees of freedom for the ν curve.

Table 69 Goodness-of-fit summary for models BCPE(x=age$^{0.50}$, df(μ)=5, df(σ)=4, df(ν)=?, τ=2) for subscapular skinfold-for-age for girls

df(ν)	GD[a]	GAIC(3)[a]	Total df
1	694.6	724.6	10
2	668.3	701.3	11
3	665.3	701.3	12
4	664.0	703.0	13
5	663.2	705.3	14
6	662.6	707.6	15
7	661.9	709.9	16

GD, Global Deviance; GAIC(3), Generalized Akaike Information Criterion with penalty equal to 3;
[a] In excess of 36 000.

The smallest *GAIC(3)* value corresponded to df(ν)=2 or 3. Selecting df(ν)=2, a re-search for the best df(μ) and df(σ) was carried out and df(μ)=5 and df(σ)=4 was still the best choice. A re-search for the age transformation power λ using the model BCPE(x=age$^{0.50}$, df(μ)=5, df(σ)=4, df(ν)=2, τ=2) was carried out and it pointed to the value 0.15 as the best choice of λ (*GD*=36665.5). Using λ=0.15 and df(ν)=2, the best combination of df(μ) and df(σ) was sought. Partial results of this re-search are presented in Table 70.

Table 70 Goodness-of-fit summary for models using the BCPE distribution with λ=0.15, df(ν)=2 and τ=2 for subscapular skinfold-for-age for girls

df(μ)	df(σ)	GD[a]	AIC[a]	GAIC(3)[a]	Total df
	2	726.4	742.4	750.5	8
	3	678.7	696.7	705.7	9
4	**4**	669.7	689.7	699.7	10
	5	667.8	689.8	700.8	11
	6	667.1	691.1	703.1	12
	2	722.7	740.7	749.7	9
	3	674.3	694.3	704.3	10
5	**4**	665.5	687.5	698.5	11
	5	663.8	687.8	699.8	12
	6	663.2	689.2	702.2	13
	2	720.5	740.5	750.5	10
	3	672.5	694.5	705.5	11
6	**4**	663.9	687.9	699.9	12
	5	662.3	688.3	701.3	13
	6	661.6	689.6	703.6	14
	2	719.6	741.6	752.6	11
	3	671.1	695.1	707.1	12
7	**4**	662.5	688.5	701.5	13
	5	660.9	688.9	702.9	14
	6	660.3	690.3	705.4	15
	2	718.3	742.3	754.3	12
	3	669.8	695.8	708.8	13
8	**4**	661.3	689.3	703.3	14
	5	659.7	689.7	704.7	15
	6	659.2	691.2	707.2	16

GD, Global Deviance; AIC, Akaike Information Criterion;
GAIC(3), Generalized AIC with penalty equal to 3;
[a] In excess of 36 000.

The smallest *GAIC(3)* value was associated with df(μ)=5 and df(σ)=4 indicating no need for further updating the model.

Model 2: BCPE(x=age$^{0.15}$, df(μ)=5, df(σ)=4, df(ν)=2, τ=2)

Figure 80 shows the fit of parameters μ, σ and ν for Model 2 with their respective sample estimates, that is, the median for μ, the sample standard deviation of the Box-Cox transformed data for σ and Box-Cox transform power for ν.

Figures 81 and 82 show the distribution of differences between empirical values and fitted centiles for the longitudinal and cross-sectional samples, respectively. There was a non-random pattern only for

the 75th centile for ages between 3 and 24 months (Figure 81), the maximum difference between the empirical and the fitted centiles being less than 0.2 mm. There was no indication of systematic bias for ages between 24 and 71 months (Figure 82).

The worm plots for this model (Figure 83) show that adjustment for skewness was effective (no age groups presented U-shaped worms using Model 2). There were a few age groups with S-shaped worms but these were contained within the 95% confidence intervals, except for age groups 5 mo and 6 mo, which indicated remaining kurtosis. There was also a worm with slope at age group 28 mo, suggesting misfit of the variance but it was contained within the 95% confidence interval.

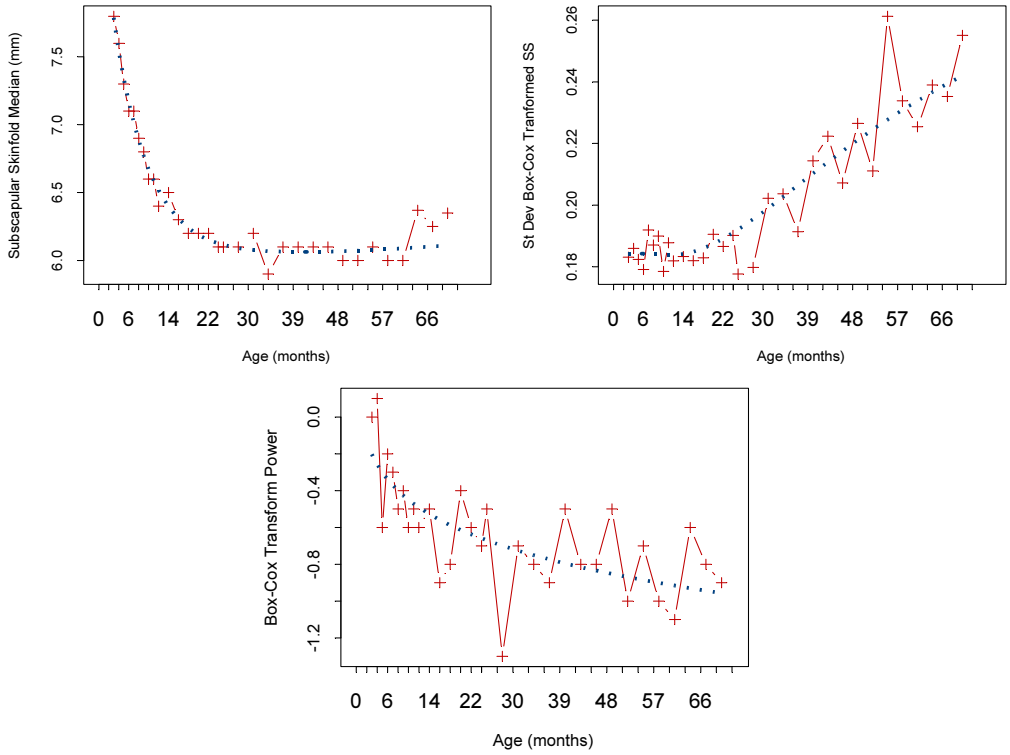


Figure 80 Fitting of the μ, σ, and ν curves of Model 2 for subscapular skinfold-for-age for girls from 3 to 71 months (dotted line) and their respective sample estimates (points with solid line)

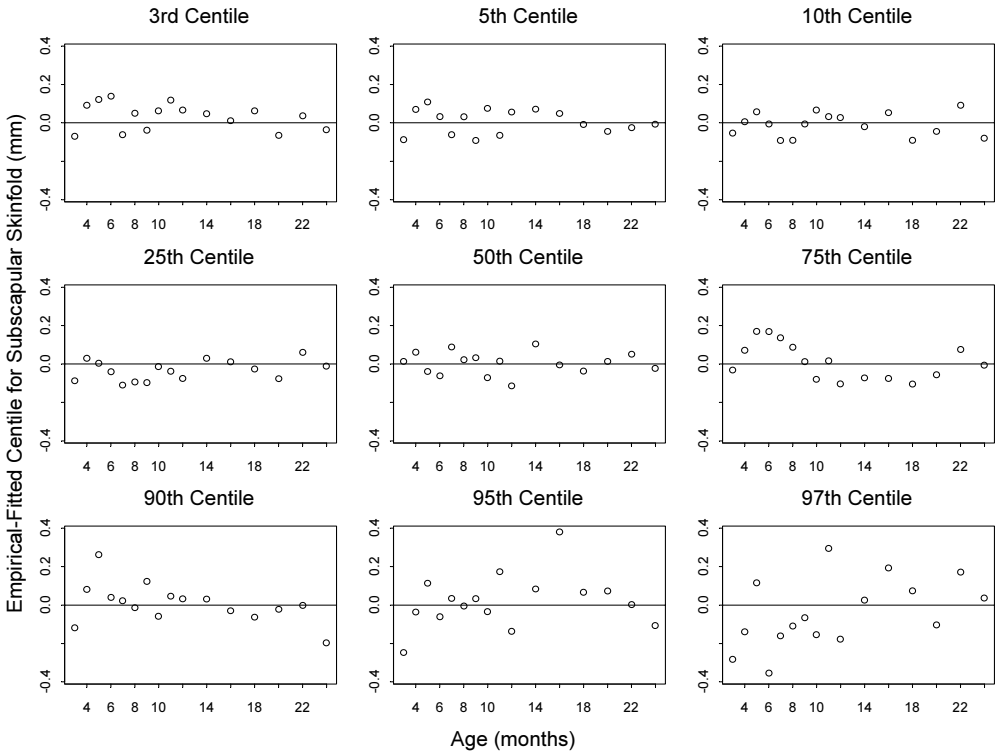


Figure 81 Centile residuals from fitting Model 2 for subscapular skinfold-for-age from 3 to 24 months for girls

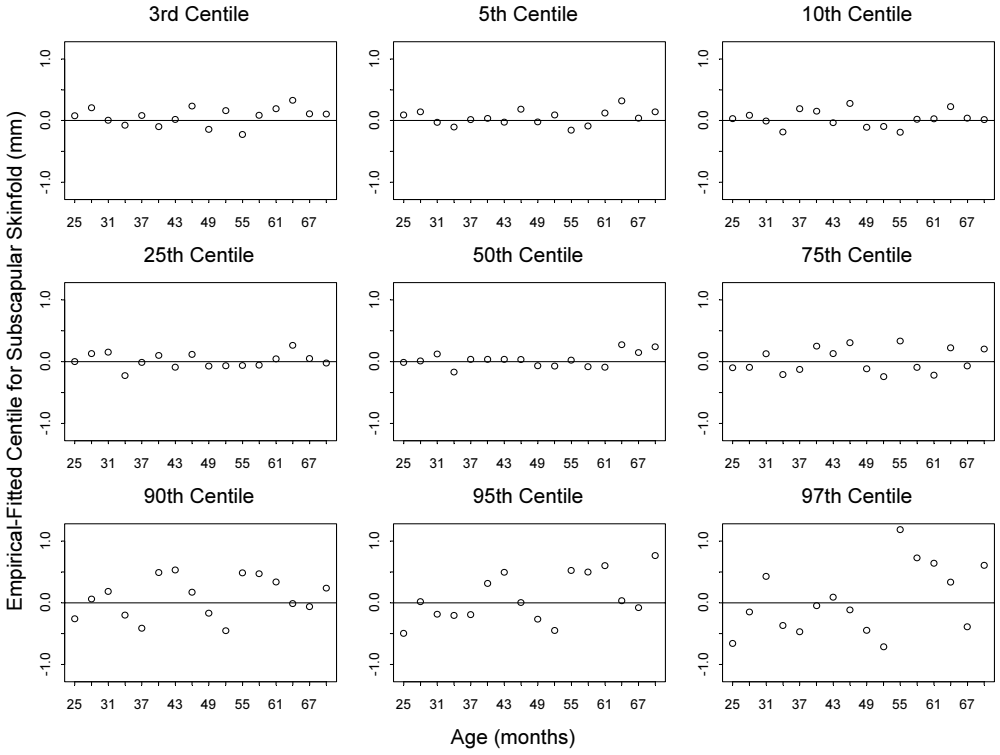


Figure 82 Centile residuals from fitting Model 2 for subscapular skinfold-for-age from 24 to 71 months for girls

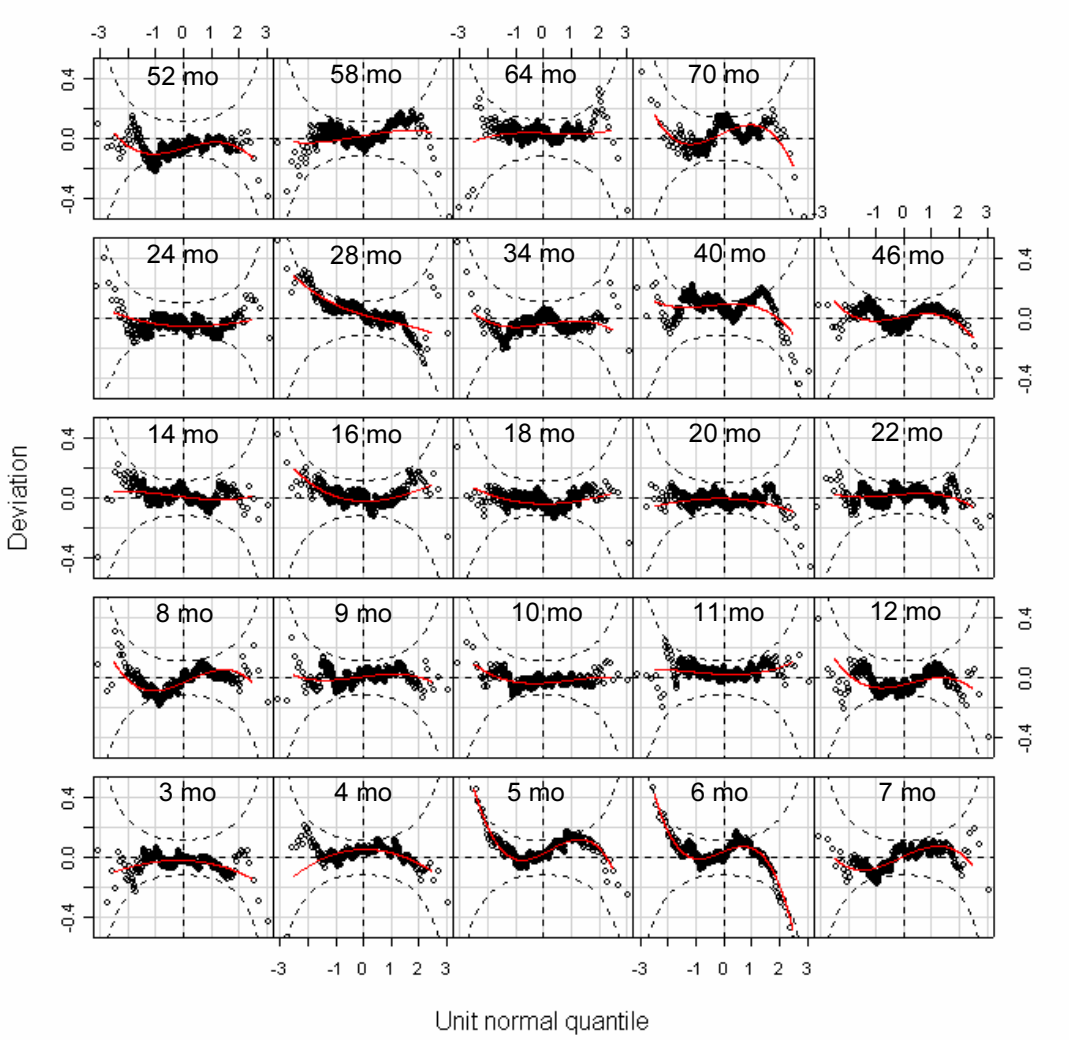


Figure 83 Worm plots of z-scores for Model 2 for subscapular skinfold-for-age for girls

The Q-test results from Model 2 are shown in Table 71. There were no indications of misfit of the mean or variance, as neither z1 nor z2 absolute values were larger than 2. There were also no age groups with z3 absolute values larger than 2 to indicate remaining skewness. Although only two age groups presented absolute values of z4 greater than 2, the overall test statistic for kurtosis had a significant p-value at the 5% level (< 0.01). Based on these results, a model adjusting for kurtosis (modelling τ) was sought to assess if increasing the model's complexity and compromising the consistency between the sexes and across indicators would be justifiable.

A summary of results from the search for the best df(τ) is found in Table 72. The model with df(τ)=6 corresponded to the smallest values of *GAIC(3)* and thus this model was selected for comparison with Model 2.

Figure 84 compares curves from Model 2 and the model BCPE(x=age$^{0.15}$, df(μ)=5, df(σ)=4, df(ν)=2, df(τ)=6). The curves for the two models overlap even at the outer tails of the distribution providing no justification for using a more the complex model. Thus, Model 2 was selected as the final one for constructing the subscapular skinfold-for-age standards for girls.

Table 71 Q-test for z-scores from Model 2 [BCPE(x=age$^{0.15}$, df(μ)=5 df(σ)=4, df(ν)=2, τ=2)] for subscapular skinfold-for-age for girls

Age (days)	Group	N	z1	z2	z3	z4
83 to 99	**3 mo**	439	-0.8	-0.2	-0.8	0.1
100 to 129	**4 mo**	443	0.6	0.2	-1.6	1.1
130 to 159	**5 mo**	441	1.1	0.1	1.2	-3.5
160 to 189	**6 mo**	441	0.6	-1.0	-0.5	-5.5
190 to 219	**7 mo**	432	0.1	1.1	-0.2	-1.5
220 to 249	**8 mo**	435	-0.6	1.1	0.7	-1.8
250 to 279	**9 mo**	437	0.1	0.0	-0.2	-0.4
280 to 309	**10 mo**	443	-0.7	0.0	0.6	-0.7
310 to 349	**11 mo**	476	0.7	0.1	0.5	0.2
350 to 379	**12 mo**	450	-0.8	0.2	0.6	-1.3
380 to 439	**14 mo**	442	0.2	-0.4	0.1	0.4
440 to 499	**16 mo**	443	0.1	-0.3	1.4	-0.1
500 to 559	**18 mo**	466	-0.6	0.0	0.8	0.0
560 to 619	**20 mo**	543	-0.5	-0.1	-0.6	0.3
620 to 679	**22 mo**	538	0.4	0.1	-0.4	-0.6
680 to 749	**24 mo**	592	-1.0	-0.1	0.6	0.0
750 to 929	**28 mo**	454	0.7	-1.9	0.7	-0.2
930 to 1119	**34 mo**	466	-0.9	0.2	0.1	-0.6
1120 to 1309	**40 mo**	470	1.7	-0.3	-0.6	-0.6
1310 to 1499	**46 mo**	448	0.1	-0.1	-0.1	-1.3
1500 to 1689	**52 mo**	443	-1.5	0.3	0.2	-1.2
1690 to 1879	**58 mo**	487	0.3	0.9	0.0	-0.1
1880 to 2069	**64 mo**	413	0.7	0.2	-0.2	0.7
2070 to 2191	**70 mo**	292	0.5	0.4	-0.3	-1.9
Overall Q stats		**10 934**	**13.6**	**8.7**	**10.7**	**60.2**
degrees of freedom			**19.0**	**21.5**	**22.0**	**24.0**
p-value			**0.8093**	**0.9934**	**0.9790**	**<0.01**

Note: Absolute values of z1, z2, z3 or z4 larger than 2 indicate misfit of, respectively, mean, variance, skewness or kurtosis.

Table 72 Goodness-of-fit summary for models BCPE(x=age$^{0.15}$, df(μ)=5, df(σ)=4, df(ν)=2, df(τ)=?) for subscapular skinfold-for-age for girls

df(τ)	GD[a]	GAIC(3)[a]	Total df
1	655.3	691.3	12
2	652.6	691.7	13
3	648.3	690.3	14
4	643.1	688.2	15
5	638.5	686.5	16
6	635.2	686.2	17
7	632.8	686.8	18

GD, Global Deviance; GAIC(3), Generalized Akaike Information Criterion with penalty equal to 3;
[a] In excess of 36 000.

Table 73 presents observed percentages with subscapular skinfolds below the fitted centiles. There was no detectable pattern of a systematic bias.

The model BCPE($x=age^{0.15}$, df(μ)=5, df(σ)=4, df(ν)=2, τ=2) was considered adequate and selected for constructing the subscapular skinfold-for-age growth curves for girls. It adjusts only for skewness, since there was no difference in the final curves when adjusting for kurtosis. The fitted centile curves and empirical centiles are shown in Figures 85 to 88.

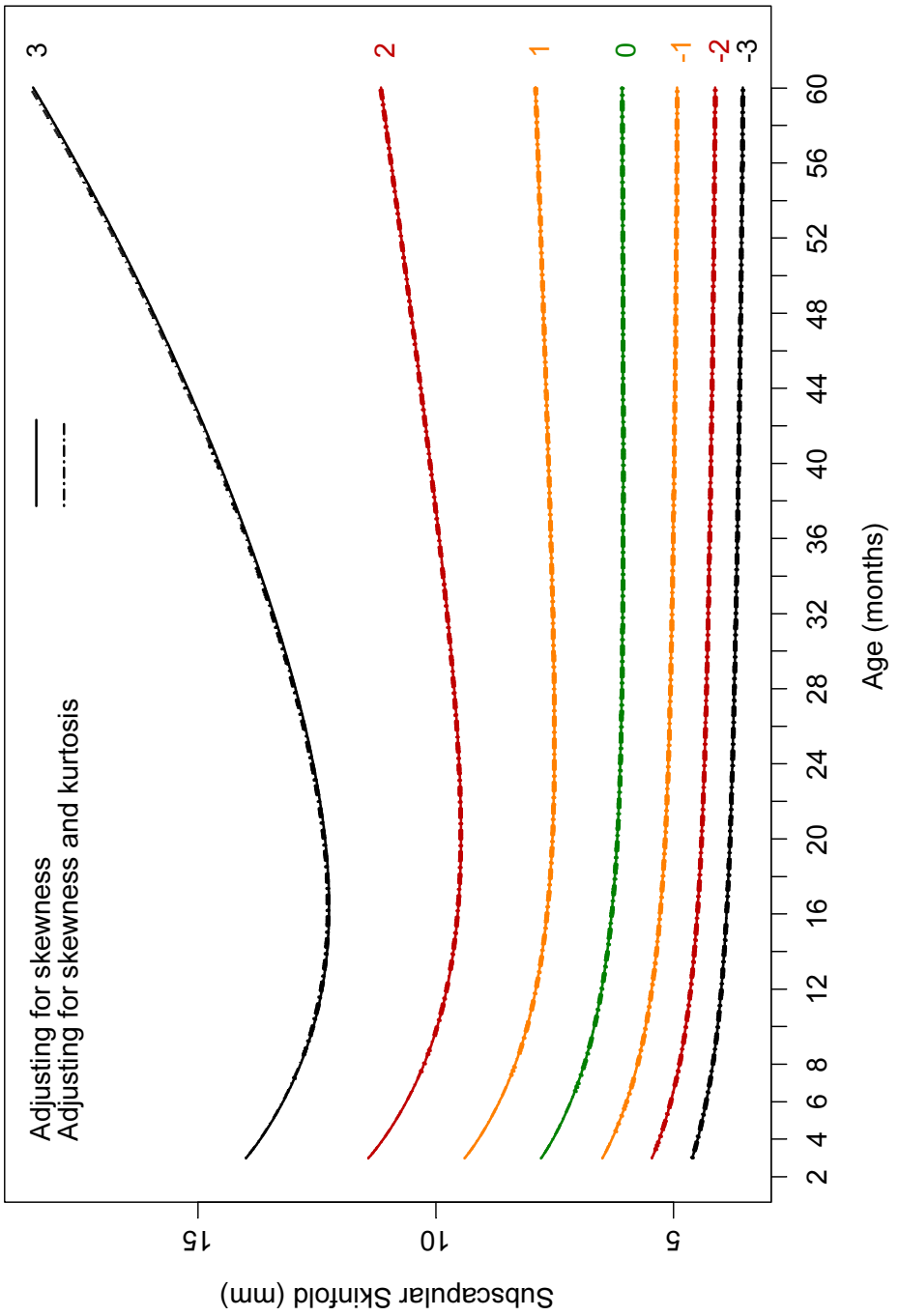


Figure 84 Comparison of the fitted growth curves using Model 2 (solid line) with the model adjusting for kurtosis (dashed line)

Table 73 Observed proportions of children with measurements below the fitted centiles from Model 2, subscapular skinfold-for-age for girls

Expected	3 mo	4 mo	5 mo	6 mo	7 mo	8 mo	9 mo	10 mo	11 mo
1	0.9	0.9	0.0	0.0	0.9	0.7	0.5	0.9	1.5
3	4.6	2.0	1.1	1.6	3.0	2.8	3.2	2.9	1.7
5	5.9	4.3	3.4	4.1	5.3	4.6	4.8	5.0	5.0
10	10.0	9.5	9.3	9.8	10.9	11.3	8.7	10.2	8.6
25	25.3	24.4	25.9	26.3	27.8	27.6	25.2	27.5	24.4
50	49.7	48.3	49.9	50.3	47.9	49.9	49.2	51.5	48.9
75	75.9	71.6	71.7	70.7	73.4	72.9	74.1	75.4	74.2
90	91.6	88.7	87.1	89.1	89.4	89.7	88.8	90.7	89.7
95	96.1	95.0	93.4	95.7	94.0	94.7	95.2	95.7	93.9
97	97.0	97.3	96.6	98.4	97.5	97.0	97.5	96.8	96.6
99	98.9	99.1	99.1	100.0	98.8	98.9	98.9	98.9	98.7
Expected	**12 mo**	**14 mo**	**16 mo**	**18 mo**	**20 mo**	**22 mo**	**24 mo**	**28 mo**	**34 mo**
1	1.8	0.7	0.7	1.1	1.3	0.7	0.7	0.7	0.9
3	2.7	2.3	1.8	3.0	2.6	3.3	4.1	1.8	3.6
5	5.1	4.1	4.1	5.6	4.4	5.4	6.4	2.6	6.9
10	10.0	10.6	9.5	10.3	10.9	10.8	11.0	8.8	11.4
25	26.2	24.0	24.6	26.2	24.1	25.7	27.0	22.7	26.8
50	53.8	45.7	50.8	51.7	48.8	48.5	52.5	48.0	48.7
75	75.6	75.8	75.6	77.9	75.9	74.3	77.7	75.6	77.5
90	89.1	89.8	90.1	90.3	90.4	90.1	91.2	90.1	91.0
95	95.1	94.8	94.4	94.2	94.7	94.4	95.6	96.3	95.5
97	97.6	96.4	95.5	96.6	97.2	96.1	97.0	98.5	97.0
99	98.9	99.1	98.9	98.7	99.3	98.9	98.8	99.1	99.1

Table 73 Observed proportions of children with measurements below the fitted centiles from Model 2, subscapular skinfold-for-age for girls (cont)

Expected	40 mo	46 mo	52 mo	58 mo	64 mo	70 mo	Overall
1	0.6	1.1	1.4	1.4	0.7	0.3	0.9
3	3.2	2.7	3.2	3.1	2.4	2.7	2.7
5	4.7	4.9	4.7	4.9	3.9	5.5	4.8
10	7.7	9.2	12.9	8.8	8.7	11.6	10.0
25	22.8	25.2	28.0	24.8	24.5	27.4	25.6
50	46.6	50.7	52.1	51.1	48.2	46.2	49.6
75	73.0	73.7	77.4	74.9	74.8	75.0	74.8
90	87.0	88.6	90.5	88.1	89.3	90.1	89.6
95	92.6	94.9	95.7	94.0	94.9	94.2	94.8
97	96.6	97.1	97.3	95.7	96.1	96.2	96.9
99	99.8	99.3	98.9	98.8	98.1	99.7	99.0

Note: Group labels correspond to the age intervals in Table 71.

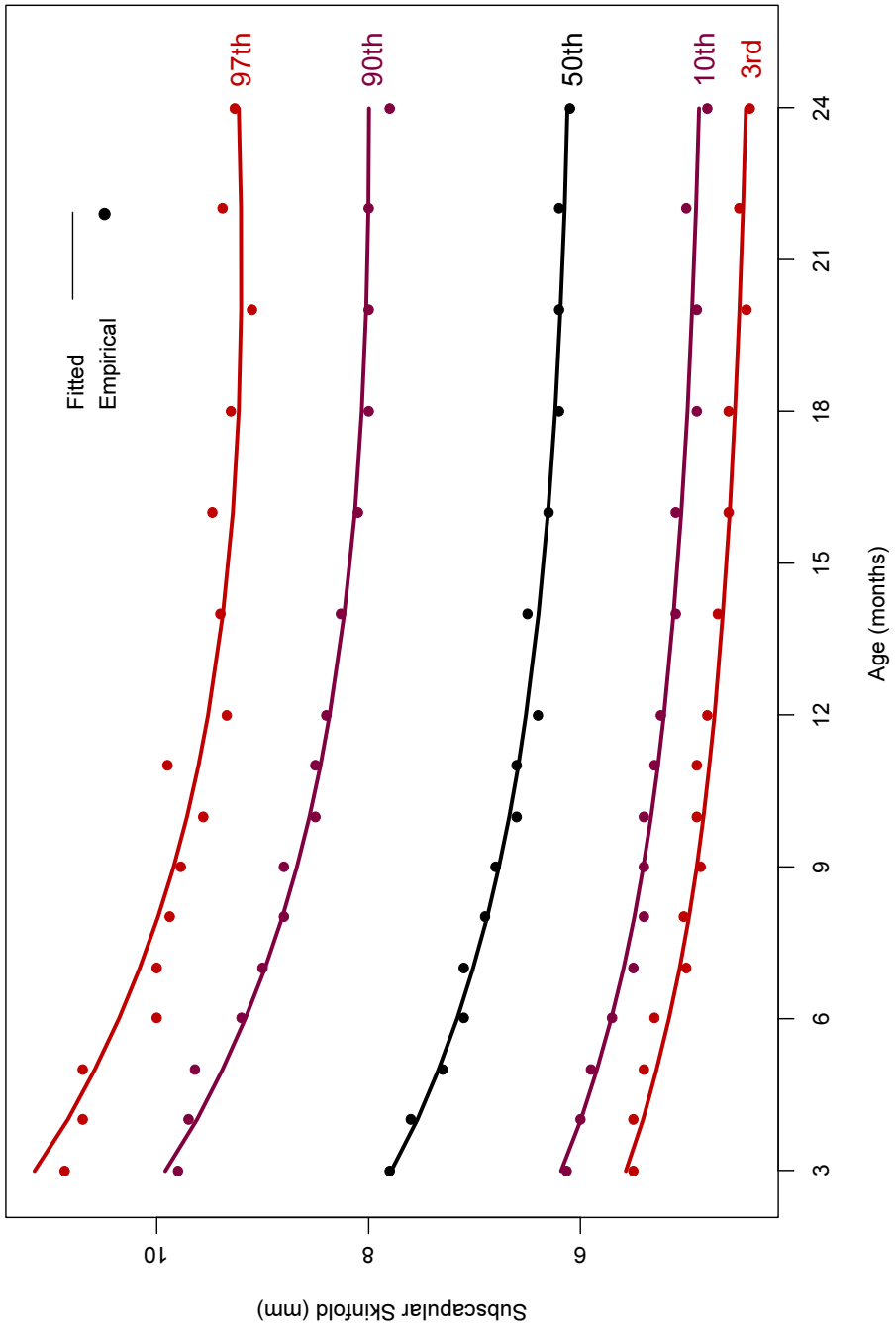


Figure 85 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: subscapular skinfold-for-age for girls from 3 to 24 months

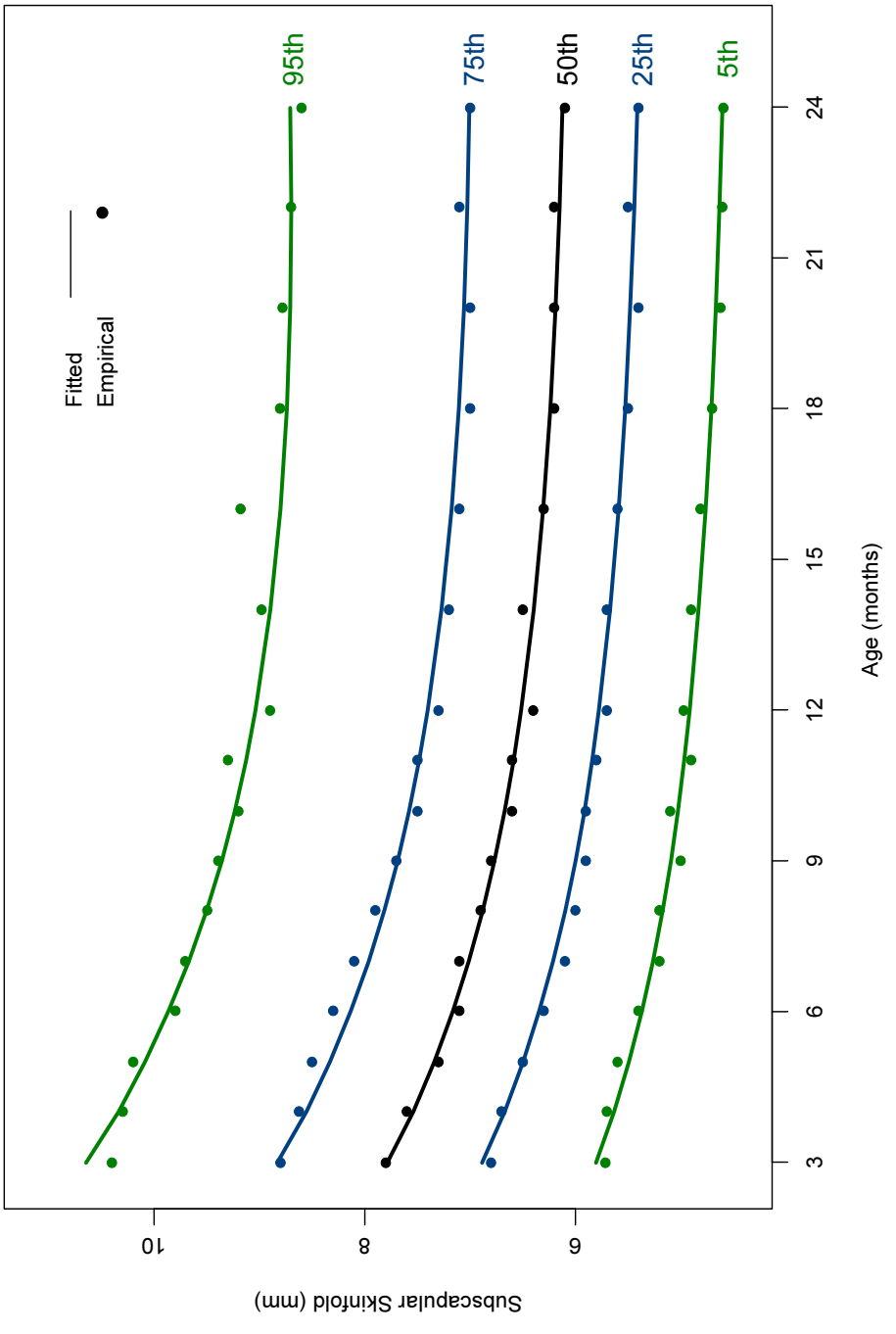


Figure 86 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: subscapular skinfold-for-age for girls from 3 to 24 months

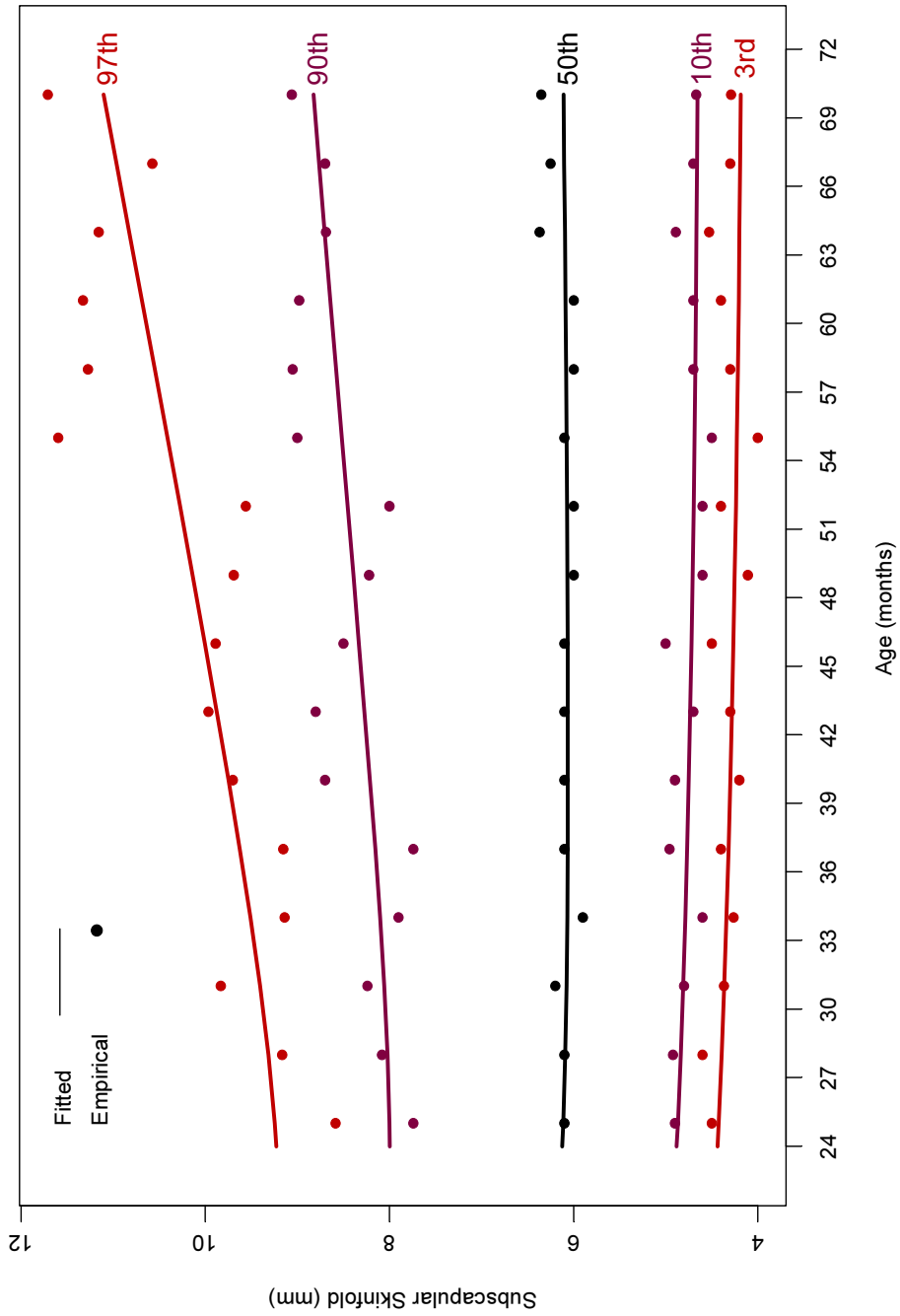


Figure 87 3rd, 10th, 50th, 90th, 97th smoothed centile curves and empirical values: subscapular skinfold-for-age for girls from 24 to 71 months

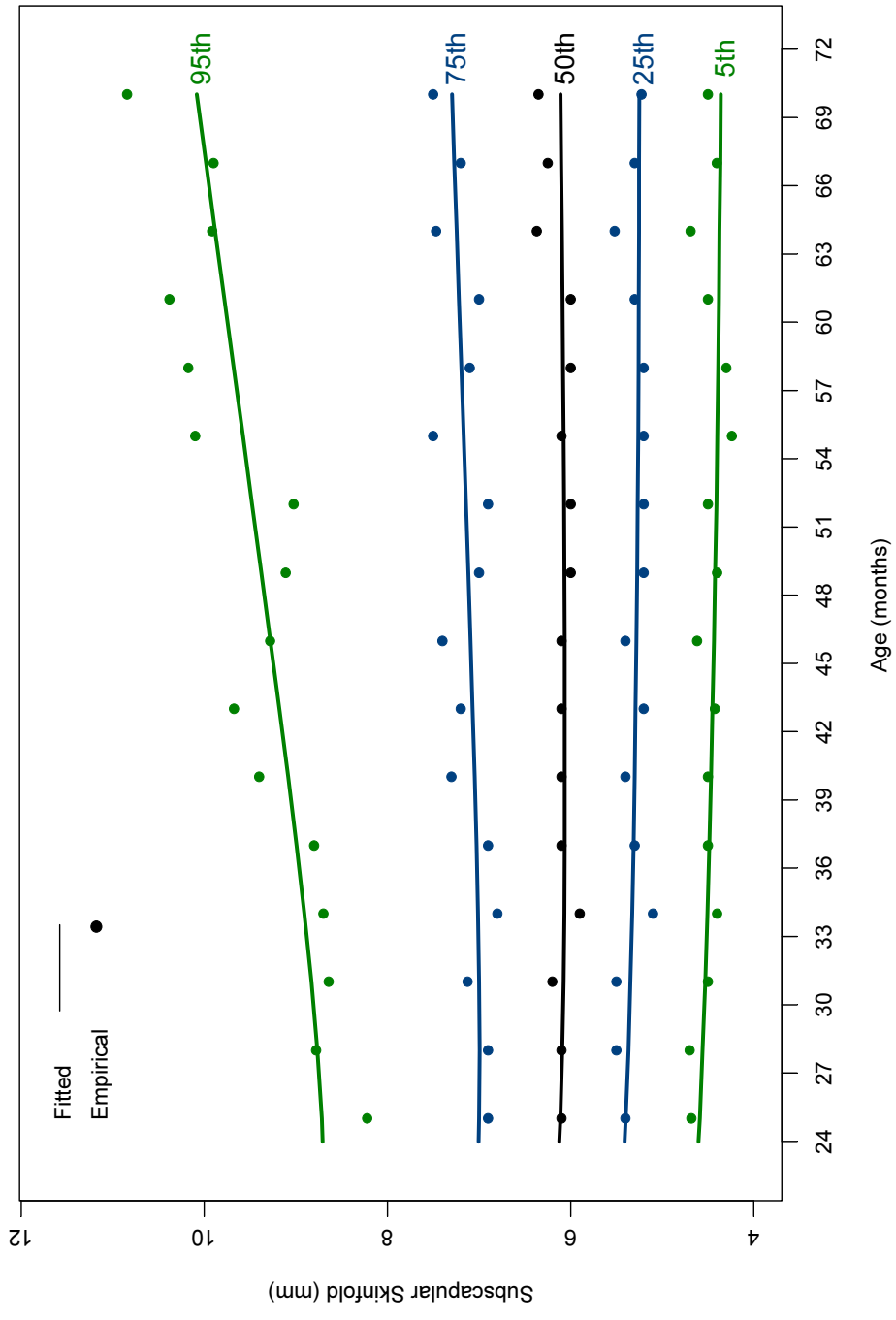


Figure 88 5th, 25th, 50th, 75th, 95th smoothed centile curves and empirical values: subscapular skinfold-for-age for girls from 24 to 71 months

6.2.3 WHO standards

This section presents the final WHO subscapular skinfold-for-age z-score and percentile charts (Figures 89 and 90) and table (Table 74) for girls.

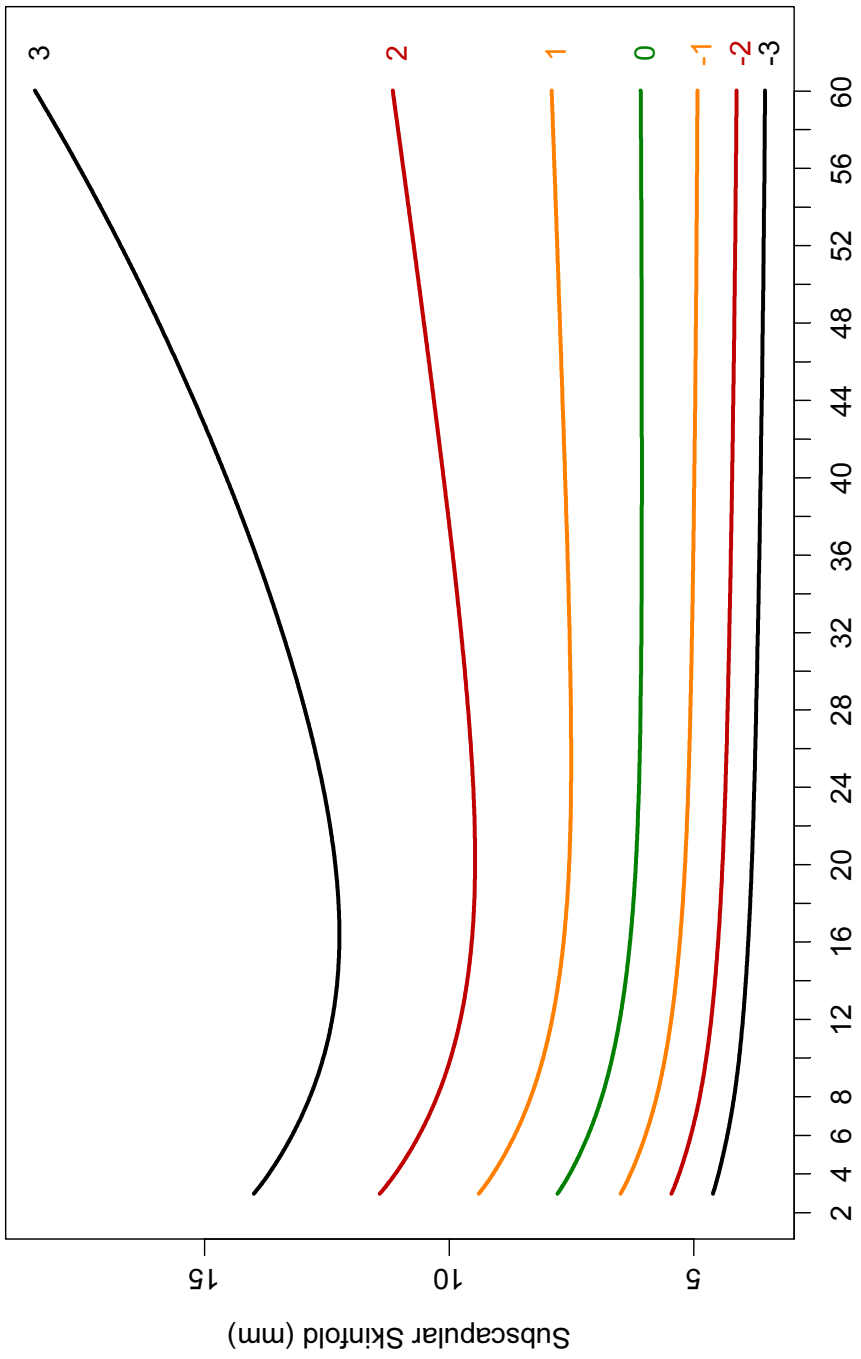


Figure 89 WHO subscapular skinfold-for-age z-scores for girls from 3 to 60 months

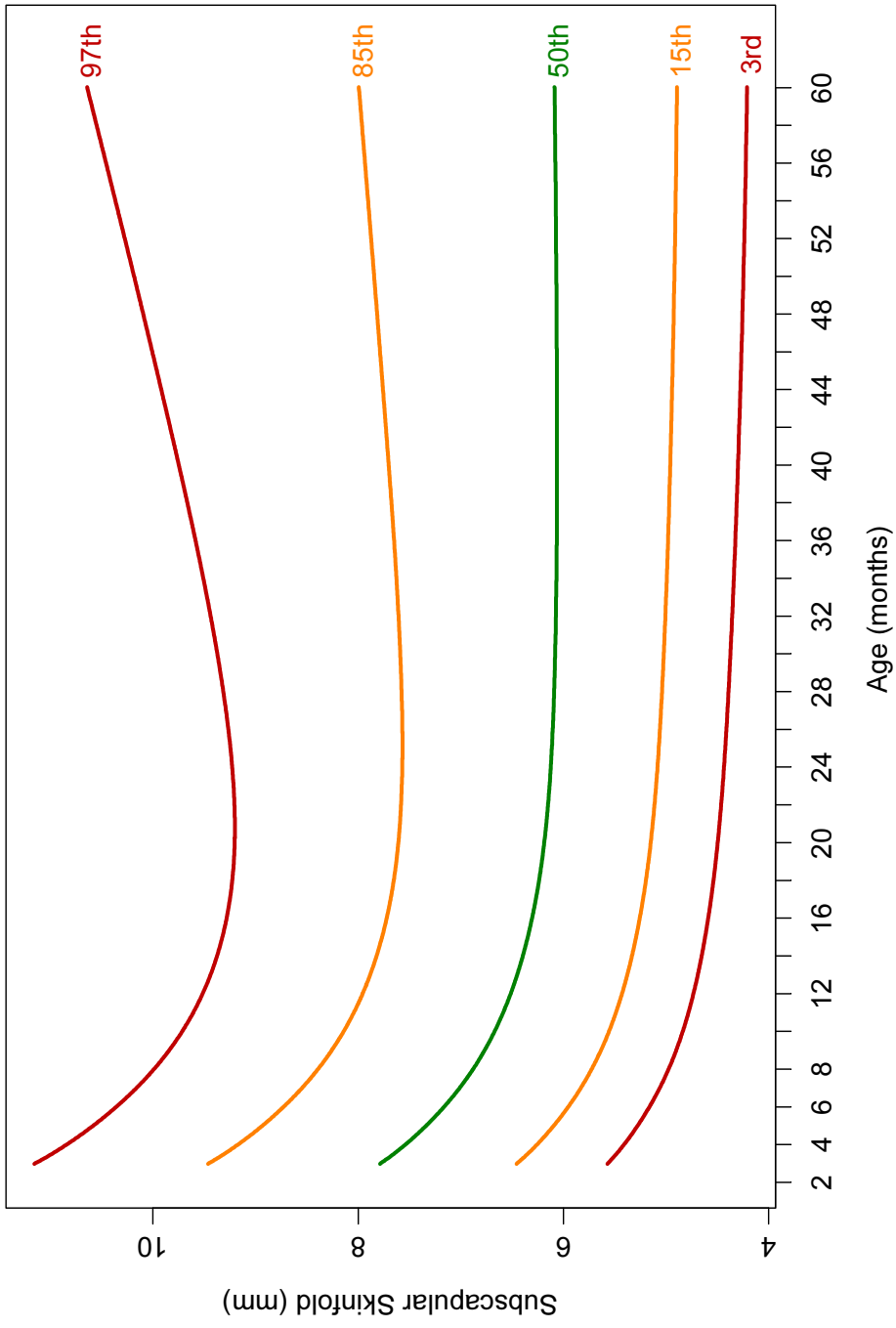


Figure 90 WHO subscapular skinfold-for-age percentiles for girls from 3 to 60 months

Table 74 Subscapular skinfold-for-age for girls, age in years and months

Year: Month	Month	L	M	S	Percentiles (subscapular skinfold in mm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
0: 3	**3**	-0.2026	7.7846	0.18428	5.2	5.6	5.8	6.5	6.9	7.8	8.8	9.5	10.6	11.2	12.2
0: 4	**4**	-0.2577	7.5405	0.18430	5.0	5.4	5.6	6.3	6.7	7.5	8.6	9.2	10.3	10.8	11.9
0: 5	**5**	-0.3020	7.3384	0.18428	4.9	5.3	5.5	6.1	6.5	7.3	8.3	8.9	10.1	10.6	11.6
0: 6	**6**	-0.3394	7.1637	0.18425	4.8	5.2	5.4	6.0	6.3	7.2	8.1	8.7	9.9	10.4	11.4
0: 7	**7**	-0.3718	7.0118	0.18421	4.7	5.1	5.3	5.8	6.2	7.0	8.0	8.5	9.7	10.2	11.2
0: 8	**8**	-0.4005	6.8807	0.18412	4.6	5.0	5.2	5.7	6.1	6.9	7.8	8.4	9.5	10.0	11.0
0: 9	**9**	-0.4263	6.7679	0.18399	4.6	4.9	5.1	5.6	6.0	6.8	7.7	8.3	9.4	9.8	10.9
0:10	**10**	-0.4498	6.6707	0.18387	4.5	4.8	5.0	5.6	5.9	6.7	7.6	8.1	9.2	9.7	10.7
0:11	**11**	-0.4713	6.5867	0.18381	4.5	4.8	5.0	5.5	5.8	6.6	7.5	8.0	9.1	9.6	10.6
1: 0	**12**	-0.4912	6.5138	0.18383	4.4	4.7	4.9	5.4	5.8	6.5	7.4	8.0	9.0	9.5	10.5
1: 1	**13**	-0.5098	6.4505	0.18394	4.4	4.7	4.9	5.4	5.7	6.5	7.3	7.9	9.0	9.4	10.5
1: 2	**14**	-0.5272	6.3955	0.18415	4.3	4.7	4.8	5.3	5.7	6.4	7.3	7.8	8.9	9.4	10.4
1: 3	**15**	-0.5435	6.3474	0.18446	4.3	4.6	4.8	5.3	5.6	6.3	7.2	7.8	8.8	9.3	10.3
1: 4	**16**	-0.5590	6.3055	0.18487	4.3	4.6	4.8	5.3	5.6	6.3	7.2	7.7	8.8	9.3	10.3
1: 5	**17**	-0.5736	6.2689	0.18538	4.3	4.6	4.7	5.2	5.6	6.3	7.1	7.7	8.8	9.2	10.3
1: 6	**18**	-0.5876	6.2373	0.18598	4.2	4.5	4.7	5.2	5.5	6.2	7.1	7.7	8.7	9.2	10.3
1: 7	**19**	-0.6009	6.2101	0.18666	4.2	4.5	4.7	5.2	5.5	6.2	7.1	7.6	8.7	9.2	10.3
1: 8	**20**	-0.6136	6.1868	0.18741	4.2	4.5	4.7	5.1	5.5	6.2	7.1	7.6	8.7	9.2	10.3
1: 9	**21**	-0.6257	6.1669	0.18823	4.2	4.5	4.6	5.1	5.5	6.2	7.0	7.6	8.7	9.2	10.3
1:10	**22**	-0.6374	6.1500	0.18911	4.2	4.5	4.6	5.1	5.4	6.2	7.0	7.6	8.7	9.2	10.3
1:11	**23**	-0.6487	6.1355	0.19005	4.2	4.4	4.6	5.1	5.4	6.1	7.0	7.6	8.7	9.2	10.3
2: 0	**24**	-0.6595	6.1232	0.19104	4.1	4.4	4.6	5.1	5.4	6.1	7.0	7.6	8.7	9.2	10.4

Table 74 Subscapular skinfold-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Percentiles (subscapular skinfold in mm)										
					1st	3rd	5th	15th	25th	50th	75th	85th	95th	97th	99th
2: 1	**25**	-0.6700	6.1129	0.19207	4.1	4.4	4.6	5.1	5.4	6.1	7.0	7.6	8.7	9.2	10.4
2: 2	**26**	-0.6801	6.1041	0.19315	4.1	4.4	4.6	5.1	5.4	6.1	7.0	7.6	8.7	9.3	10.4
2: 3	**27**	-0.6899	6.0968	0.19426	4.1	4.4	4.6	5.0	5.4	6.1	7.0	7.6	8.7	9.3	10.5
2: 4	**28**	-0.6994	6.0905	0.19540	4.1	4.4	4.6	5.0	5.4	6.1	7.0	7.6	8.8	9.3	10.5
2: 5	**29**	-0.7086	6.0851	0.19657	4.1	4.4	4.5	5.0	5.4	6.1	7.0	7.6	8.8	9.3	10.6
2: 6	**30**	-0.7175	6.0806	0.19776	4.1	4.4	4.5	5.0	5.4	6.1	7.0	7.6	8.8	9.4	10.6
2: 7	**31**	-0.7262	6.0766	0.19898	4.1	4.4	4.5	5.0	5.3	6.1	7.0	7.6	8.8	9.4	10.7
2: 8	**32**	-0.7347	6.0733	0.20021	4.1	4.4	4.5	5.0	5.3	6.1	7.0	7.6	8.9	9.4	10.7
2: 9	**33**	-0.7429	6.0705	0.20145	4.1	4.3	4.5	5.0	5.3	6.1	7.0	7.6	8.9	9.5	10.8
2:10	**34**	-0.7509	6.0683	0.20270	4.1	4.3	4.5	5.0	5.3	6.1	7.0	7.6	8.9	9.5	10.9
2:11	**35**	-0.7587	6.0665	0.20395	4.0	4.3	4.5	5.0	5.3	6.1	7.0	7.6	8.9	9.5	10.9
3: 0	**36**	-0.7664	6.0652	0.20521	4.0	4.3	4.5	5.0	5.3	6.1	7.0	7.7	9.0	9.6	11.0
3: 1	**37**	-0.7738	6.0643	0.20647	4.0	4.3	4.5	5.0	5.3	6.1	7.0	7.7	9.0	9.6	11.1
3: 2	**38**	-0.7811	6.0637	0.20773	4.0	4.3	4.5	5.0	5.3	6.1	7.0	7.7	9.0	9.7	11.1
3: 3	**39**	-0.7882	6.0633	0.20899	4.0	4.3	4.5	5.0	5.3	6.1	7.0	7.7	9.1	9.7	11.2
3: 4	**40**	-0.7952	6.0632	0.21024	4.0	4.3	4.5	5.0	5.3	6.1	7.0	7.7	9.1	9.7	11.3
3: 5	**41**	-0.8020	6.0632	0.21149	4.0	4.3	4.5	5.0	5.3	6.1	7.1	7.7	9.1	9.8	11.3
3: 6	**42**	-0.8087	6.0634	0.21273	4.0	4.3	4.5	4.9	5.3	6.1	7.1	7.7	9.1	9.8	11.4
3: 7	**43**	-0.8152	6.0637	0.21396	4.0	4.3	4.5	4.9	5.3	6.1	7.1	7.7	9.2	9.9	11.5
3: 8	**44**	-0.8217	6.0641	0.21518	4.0	4.3	4.4	4.9	5.3	6.1	7.1	7.8	9.2	9.9	11.6
3: 9	**45**	-0.8280	6.0647	0.21638	4.0	4.3	4.4	4.9	5.3	6.1	7.1	7.8	9.2	10.0	11.6
3:10	**46**	-0.8341	6.0653	0.21758	4.0	4.3	4.4	4.9	5.3	6.1	7.1	7.8	9.3	10.0	11.7
3:11	**47**	-0.8402	6.0661	0.21876	4.0	4.3	4.4	4.9	5.3	6.1	7.1	7.8	9.3	10.0	11.8
4: 0	**48**	-0.8462	6.0669	0.21993	4.0	4.3	4.4	4.9	5.3	6.1	7.1	7.8	9.3	10.1	11.9

Table 74 Subscapular skinfold-for-age for girls, age in years and months (continued)

					Percentiles (subscapular skinfold in mm)										
Year: Month	**Month**	**L**	**M**	**S**	**1st**	**3rd**	**5th**	**15th**	**25th**	**50th**	**75th**	**85th**	**95th**	**97th**	**99th**
4: 1	**49**	-0.8520	6.0679	0.22109	4.0	4.3	4.4	4.9	5.3	6.1	7.1	7.8	9.4	10.1	11.9
4: 2	**50**	-0.8578	6.0690	0.22223	4.0	4.2	4.4	4.9	5.3	6.1	7.1	7.8	9.4	10.2	12.0
4: 3	**51**	-0.8634	6.0703	0.22335	4.0	4.2	4.4	4.9	5.3	6.1	7.1	7.9	9.4	10.2	12.1
4: 4	**52**	-0.8690	6.0717	0.22447	3.9	4.2	4.4	4.9	5.3	6.1	7.1	7.9	9.5	10.3	12.2
4: 5	**53**	-0.8745	6.0732	0.22556	3.9	4.2	4.4	4.9	5.3	6.1	7.2	7.9	9.5	10.3	12.3
4: 6	**54**	-0.8799	6.0748	0.22664	3.9	4.2	4.4	4.9	5.3	6.1	7.2	7.9	9.5	10.4	12.3
4: 7	**55**	-0.8852	6.0765	0.22771	3.9	4.2	4.4	4.9	5.3	6.1	7.2	7.9	9.6	10.4	12.4
4: 8	**56**	-0.8904	6.0784	0.22876	3.9	4.2	4.4	4.9	5.3	6.1	7.2	7.9	9.6	10.5	12.5
4: 9	**57**	-0.8955	6.0803	0.22979	3.9	4.2	4.4	4.9	5.3	6.1	7.2	7.9	9.6	10.5	12.6
4:10	**58**	-0.9006	6.0823	0.23081	3.9	4.2	4.4	4.9	5.3	6.1	7.2	8.0	9.7	10.5	12.7
4:11	**59**	-0.9056	6.0844	0.23182	3.9	4.2	4.4	4.9	5.3	6.1	7.2	8.0	9.7	10.6	12.8
5: 0	**60**	-0.9105	6.0865	0.23280	3.9	4.2	4.4	4.9	5.3	6.1	7.2	8.0	9.7	10.6	12.8

Table 74 Subscapular skinfold-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (subscapular skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 3	**3**	-0.2026	7.7846	0.18428	4.6	5.5	6.5	7.8	9.4	11.4	14.0
0: 4	**4**	-0.2577	7.5405	0.18430	4.5	5.3	6.3	7.5	9.1	11.1	13.7
0: 5	**5**	-0.3020	7.3384	0.18428	4.4	5.2	6.1	7.3	8.9	10.8	13.4
0: 6	**6**	-0.3394	7.1637	0.18425	4.3	5.1	6.0	7.2	8.7	10.6	13.2
0: 7	**7**	-0.3718	7.0118	0.18421	4.2	5.0	5.9	7.0	8.5	10.4	13.0
0: 8	**8**	-0.4005	6.8807	0.18412	4.2	4.9	5.8	6.9	8.3	10.2	12.8
0: 9	**9**	-0.4263	6.7679	0.18399	4.1	4.8	5.7	6.8	8.2	10.1	12.7
0:10	**10**	-0.4498	6.6707	0.18387	4.1	4.7	5.6	6.7	8.1	10.0	12.6
0:11	**11**	-0.4713	6.5867	0.18381	4.0	4.7	5.5	6.6	8.0	9.9	12.5
1: 0	**12**	-0.4912	6.5138	0.18383	4.0	4.6	5.5	6.5	7.9	9.8	12.4
1: 1	**13**	-0.5098	6.4505	0.18394	4.0	4.6	5.4	6.5	7.8	9.7	12.3
1: 2	**14**	-0.5272	6.3955	0.18415	3.9	4.6	5.4	6.4	7.8	9.6	12.3
1: 3	**15**	-0.5435	6.3474	0.18446	3.9	4.5	5.3	6.3	7.7	9.6	12.3
1: 4	**16**	-0.5590	6.3055	0.18487	3.9	4.5	5.3	6.3	7.7	9.5	12.2
1: 5	**17**	-0.5736	6.2689	0.18538	3.9	4.5	5.3	6.3	7.6	9.5	12.2
1: 6	**18**	-0.5876	6.2373	0.18598	3.8	4.5	5.2	6.2	7.6	9.5	12.3
1: 7	**19**	-0.6009	6.2101	0.18666	3.8	4.4	5.2	6.2	7.6	9.5	12.3
1: 8	**20**	-0.6136	6.1868	0.18741	3.8	4.4	5.2	6.2	7.5	9.5	12.3
1: 9	**21**	-0.6257	6.1669	0.18823	3.8	4.4	5.2	6.2	7.5	9.5	12.4
1:10	**22**	-0.6374	6.1500	0.18911	3.8	4.4	5.1	6.2	7.5	9.5	12.4
1:11	**23**	-0.6487	6.1355	0.19005	3.8	4.4	5.1	6.1	7.5	9.5	12.5
2: 0	**24**	-0.6595	6.1232	0.19104	3.8	4.4	5.1	6.1	7.5	9.5	12.6

Table 74 Subscapular skinfold-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (subscapular skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
2: 1	**25**	-0.6700	6.1129	0.19207	3.8	4.3	5.1	6.1	7.5	9.5	12.7
2: 2	**26**	-0.6801	6.1041	0.19315	3.7	4.3	5.1	6.1	7.5	9.6	12.8
2: 3	**27**	-0.6899	6.0968	0.19426	3.7	4.3	5.1	6.1	7.5	9.6	12.8
2: 4	**28**	-0.6994	6.0905	0.19540	3.7	4.3	5.1	6.1	7.5	9.6	13.0
2: 5	**29**	-0.7086	6.0851	0.19657	3.7	4.3	5.1	6.1	7.5	9.6	13.1
2: 6	**30**	-0.7175	6.0806	0.19776	3.7	4.3	5.1	6.1	7.5	9.7	13.2
2: 7	**31**	-0.7262	6.0766	0.19898	3.7	4.3	5.0	6.1	7.5	9.7	13.3
2: 8	**32**	-0.7347	6.0733	0.20021	3.7	4.3	5.0	6.1	7.5	9.8	13.4
2: 9	**33**	-0.7429	6.0705	0.20145	3.7	4.3	5.0	6.1	7.6	9.8	13.5
2:10	**34**	-0.7509	6.0683	0.20270	3.7	4.3	5.0	6.1	7.6	9.8	13.7
2:11	**35**	-0.7587	6.0665	0.20395	3.7	4.3	5.0	6.1	7.6	9.9	13.8
3: 0	**36**	-0.7664	6.0652	0.20521	3.7	4.2	5.0	6.1	7.6	9.9	13.9
3: 1	**37**	-0.7738	6.0643	0.20647	3.7	4.2	5.0	6.1	7.6	10.0	14.1
3: 2	**38**	-0.7811	6.0637	0.20773	3.6	4.2	5.0	6.1	7.6	10.0	14.2
3: 3	**39**	-0.7882	6.0633	0.20899	3.6	4.2	5.0	6.1	7.6	10.1	14.4
3: 4	**40**	-0.7952	6.0632	0.21024	3.6	4.2	5.0	6.1	7.6	10.1	14.6
3: 5	**41**	-0.8020	6.0632	0.21149	3.6	4.2	5.0	6.1	7.6	10.2	14.7
3: 6	**42**	-0.8087	6.0634	0.21273	3.6	4.2	5.0	6.1	7.7	10.2	14.9
3: 7	**43**	-0.8152	6.0637	0.21396	3.6	4.2	5.0	6.1	7.7	10.3	15.0
3: 8	**44**	-0.8217	6.0641	0.21518	3.6	4.2	5.0	6.1	7.7	10.3	15.2
3: 9	**45**	-0.8280	6.0647	0.21638	3.6	4.2	5.0	6.1	7.7	10.4	15.4
3:10	**46**	-0.8341	6.0653	0.21758	3.6	4.2	5.0	6.1	7.7	10.4	15.6
3:11	**47**	-0.8402	6.0661	0.21876	3.6	4.2	5.0	6.1	7.7	10.5	15.7
4: 0	**48**	-0.8462	6.0669	0.21993	3.6	4.2	5.0	6.1	7.7	10.5	15.9

Table 74 Subscapular skinfold-for-age for girls, age in years and months (continued)

Year: Month	Month	L	M	S	Z-scores (subscapular skinfold in mm)						
					-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	**49**	-0.8520	6.0679	0.22109	3.6	4.2	5.0	6.1	7.8	10.6	16.1
4: 2	**50**	-0.8578	6.0690	0.22223	3.6	4.2	5.0	6.1	7.8	10.6	16.3
4: 3	**51**	-0.8634	6.0703	0.22335	3.6	4.2	4.9	6.1	7.8	10.7	16.5
4: 4	**52**	-0.8690	6.0717	0.22447	3.6	4.2	4.9	6.1	7.8	10.7	16.7
4: 5	**53**	-0.8745	6.0732	0.22556	3.6	4.2	4.9	6.1	7.8	10.8	16.9
4: 6	**54**	-0.8799	6.0748	0.22664	3.6	4.1	4.9	6.1	7.8	10.8	17.1
4: 7	**55**	-0.8852	6.0765	0.22771	3.6	4.1	4.9	6.1	7.8	10.9	17.3
4: 8	**56**	-0.8904	6.0784	0.22876	3.6	4.1	4.9	6.1	7.9	10.9	17.6
4: 9	**57**	-0.8955	6.0803	0.22979	3.6	4.1	4.9	6.1	7.9	11.0	17.8
4:10	**58**	-0.9006	6.0823	0.23081	3.6	4.1	4.9	6.1	7.9	11.0	18.0
4:11	**59**	-0.9056	6.0844	0.23182	3.5	4.1	4.9	6.1	7.9	11.1	18.2
5: 0	**60**	-0.9105	6.0865	0.23280	3.5	4.1	4.9	6.1	7.9	11.2	18.5

6.4 Comparisons between boys and girls

This section presents the subscapular skinfold-for-age z-score comparisons between boys and girls for the WHO standards (Figure 91).

6.3.1 WHO

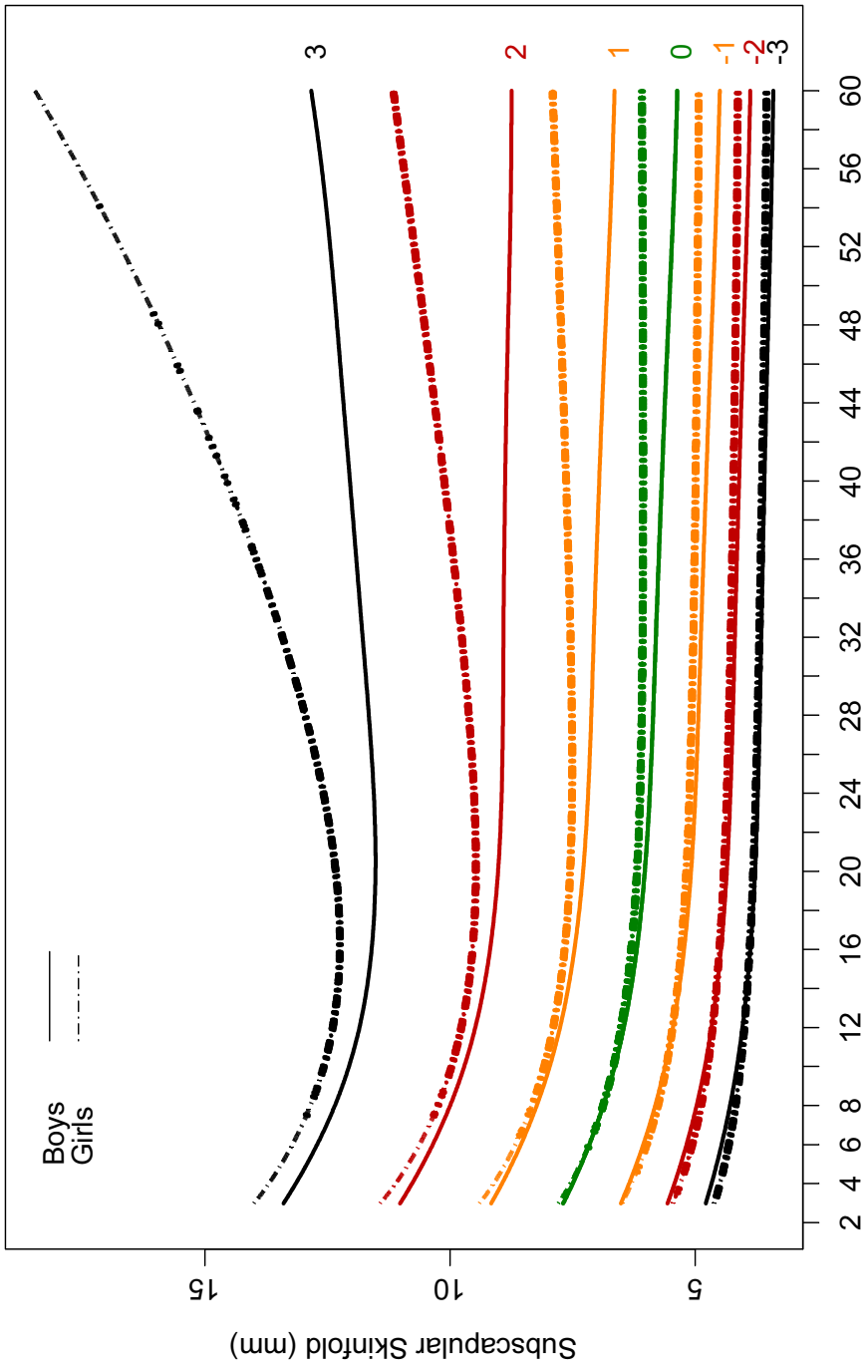


Figure 91 Comparison of boys' and girls' subscapular skinfold-for-age z-score

7. COMPUTATION OF CENTILES AND Z-SCORES FOR HEAD CIRCUMFERENCE-FOR-AGE, ARM CIRCUMFERENCE-FOR-AGE, TRICEPS SKINFOLD-FOR-AGE, SUBSCAPULAR SKINFOLD-FOR-AGE

The method used to construct the standards based on head circumference, arm circumference, skinfold thicknesses and age, generally relied on GAMLSS with the Box-Cox power exponential distribution (Rigby and Stasinopoulos, 2004). However, the final selected models simplified to the LMS model (Cole and Green, 1992) since none of the standards required adjustment for kurtosis. As a result, the computation of percentiles and z-scores for these standards uses formulae based on the LMS method. However, a restriction was imposed on all indicators to enable the derivation of percentiles only within the interval corresponding to z-scores between -3 and 3. The underlying reasoning is that percentiles beyond ±3 SD are invariant to changes in equivalent z-scores. The loss accruing to this restriction is small since the inclusion range corresponds to the 0.135th to 99.865th percentiles.

For all indicators, the tabulated fitted values of Box-Cox power, median and coefficient of variation corresponding to age *t* are denoted by *L(t)*, *M(t)* and *S(t)*, respectively.

Centiles and z-scores for head circumference-for-age

For this indicator, *L(t)* is equal to 1, simplifying the Box-Cox normal distribution used in the LMS method (Cole and Green, 1992) to the normal distribution. Therefore, differences between adjacent standard deviations (e.g. between 2 SD and 3 SD) were constant for a specific age but varied at different ages.

In this case, the centiles at age *t* can be estimated from:

$$C_{100\alpha}(t) = M(t)\left[1 + L(t)S(t)Z_\alpha\right]^{1/L(t)} = M(t)\left[1 + S(t)Z_\alpha\right]$$
$$= M(t) + StDev(t)Z_\alpha, \qquad -3 \le Z_\alpha \le 3$$

where Z_α is the normal equivalent deviate for tail area α, $C_{100\alpha}(t)$ is the 100α-th centile, and $StDev(t)$ is the standard deviation at age *t* (derived from multiplying $S(t)$ by $M(t)$).

The z-score for a measurement *y* at age *t* is computed as:

$$z_{ind} = \frac{\left[y / M(t)\right]^{L(t)} - 1}{S(t)L(t)} = \frac{y - M(t)}{StDev(t)}$$

Centiles and z-scores for arm circumference-for-age, triceps skinfold-for-age and subscapular skinfold-for-age

These indicators presented right-skewed distributions as did the weight-related indicators (WHO Multicentre Growth Reference Study Group, 2006d). When modelled correctly, right skewness in data has the effect of making distances between positive z-scores increase progressively the farther away they are from the median, while distances between negative z-scores decrease progressively. The LMS method fits skewed data adequately by using a Box-Cox normal distribution, which follows the empirical data closely. The drawback, however, is that the outer tails of the distribution are highly affected by extreme data points even if only very few (e.g. less than 1%). A restricted application of the LMS method as the one used for the construction of the WHO weight-related indicators (WHO Multicentre Growth Reference Study Group, 2006d) was used, limiting the Box-Cox normal distribution to the interval corresponding to z-scores where empirical data were available (i.e. between -3 SD and 3 SD). Beyond these limits, the standard deviation at each age was fixed to the distance between ±2 SD and ±3 SD, respectively. This approach avoids making assumptions about the distribution of data beyond the limits of the observed values.

As a result of this adjustment, the z-score distribution can depart slightly from normality in the extreme tails (beyond ±3 SD), although the expected practical impact is minimal.

The centiles were calculated as follows:

$$C_{100\alpha}(t) = M(t)\left[1 + L(t)S(t)Z_{\alpha}\right]^{1/L(t)}, \qquad -3 \le Z_{\alpha} \le 3$$

The following procedure is recommended to calculate a z-score for an individual child with measurement *y* at age *t*:

1. Calculate

$$z_{ind} = \frac{\left[y / M(t)\right]^{L(t)} - 1}{S(t)L(t)}$$

2. Compute the final z-score $\left(z^{*}_{ind}\right)$ of the child for that indicator as:

$$z^{*}_{ind} = \begin{cases} z_{ind} & if \quad |z_{ind}| \le 3 \\ 3 + \left(\dfrac{y - SD3pos}{SD23pos}\right) & if \quad z_{ind} > 3 \\ -3 + \left(\dfrac{y - SD3neg}{SD23neg}\right) & if \quad z_{ind} < -3 \end{cases}$$

where

$SD3pos$ is the cut-off 3 SD calculated at t by the LMS method:

$$SD3pos = M(t)\left[1 + L(t) * S(t) * (3)\right]^{1/L(t)};$$

$SD3neg$ is the cut-off -3 SD calculated at t by the LMS method:

$$SD3neg = M(t)\left[1 + L(t) * S(t) * (-3)\right]^{1/L(t)};$$

$SD23pos$ is the difference between the cut-offs 3 SD and 2 SD calculated at t by the LMS method:

$$SD23pos = M(t)\left[1 + L(t) * S(t) * (3)\right]^{1/L(t)} - M(t)\left[1 + L(t) * S(t) * (2)\right]^{1/L(t)};$$

and $SD23neg$ is the difference between the cut-offs -2 SD and -3 SD calculated at t by the LMS method:

$$SD23neg = M(t)\left[1 + L(t) * S(t) * (-2)\right]^{1/L(t)} - M(t)\left[1 + L(t) * S(t) * (-3)\right]^{1/L(t)}$$

To illustrate the procedure, an example with arm circumference-for-age for boys is provided below and displayed in Figure 92.

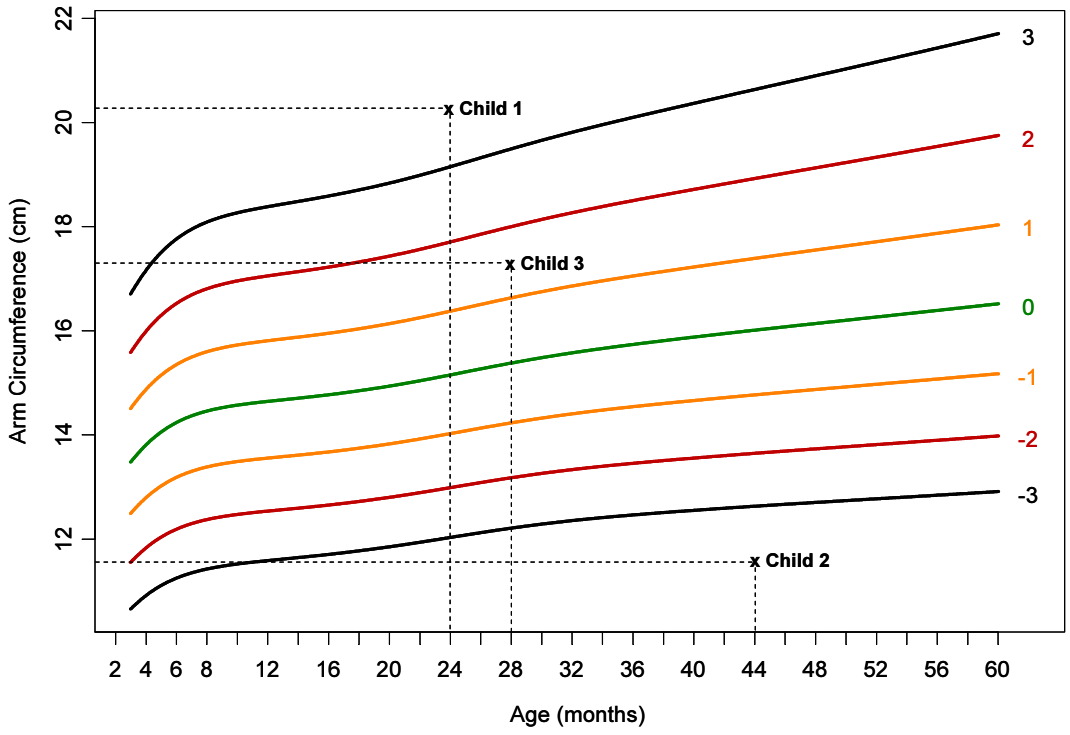


Figure 92 Examples of children ranked according to the WHO arm circumference-for-age standards

Child 1: 24 month-old boy with arm circumference=20.3 cm.

L=-0.0643; M=15.1536; S=0.07746;

$$z_{ind} = \frac{\left[20.3/15.1536\right]^{(-0.0643)} - 1}{0.07746 * (-0.0643)} = 3.74 \quad \textbf{>3}$$

$$SD3pos = 15.1536 * \left[1 + (-0.0643) * 0.07746 * (3)\right]^{1/(-0.0643)} = 19.15$$
$$SD2pos = 15.1536 * \left[1 + (-0.0643) * 0.07746 * (2)\right]^{1/(-0.0643)} = 17.71$$
$$SD23pos = 19.15 - 17.71 = 1.44$$
$$\Rightarrow \quad z^*_{ind} = 3 + \left(\frac{20.3 - 19.15}{1.44}\right) = 3.80$$

Child 2: 44 month-old boy with arm circumference=11.5 cm.

L=-0.2730; M=16.0124; S=0.08166;

$$z_{ind} = \frac{\left[11.5/16.0124\right]^{(-0.2730)} - 1}{0.08166 * (-0.2730)} = -4.24 \quad \textbf{<-3}$$

$$SD2neg = 16.0124 * \left[1 + (-0.2730) * 0.08166 * (-2)\right]^{1/(-0.2730)} = 13.65$$
$$SD3neg = 16.0124 * \left[1 + (-0.2730) * 0.08166 * (-3)\right]^{1/(-0.2730)} = 12.63$$
$$SD23neg = 13.65 - 12.63 = 1.02$$
$$\Rightarrow \quad z^*_{ind} = -3 + \left(\frac{11.5 - 12.63}{1.02}\right) = -4.11$$

Child 3: 28 month-old boy with arm circumference=17.4 cm.

L=-0.1132; M=15.3808; S=0.07794;

$$z_{ind} = \frac{\left[17.4/15.3808\right]^{(-0.1132)} - 1}{0.07794 * (-0.1132)} = 1.57 \quad \textbf{≥-3 and ≤3} \quad \textbf{(LMS z-score)}$$

8. CONCLUSION

The goal of the MGRS was to describe the growth of healthy children. Well-defined criteria were applied in the study design to achieve this aim (de Onis et al., 2004b). The sample used for the construction of the growth standards for the head and arm circumferences and the skinfold thicknesses was the same one used for the construction of the standards based on length or height, weight and age (WHO Multicentre Growth Reference Study Group, 2006d, 2006g).

The construction of the child growth curves followed a careful, methodical process. Rigorous methods of data collection, standardized across sites, were followed during the entire study. Sound procedures for data management and cleaning were applied (Onyango et al., 2004). As a result, the anthropometric data available for analysis were of the highest possible quality. The selection of the best statistical approach to construct the standards followed a broad consultative process that included a thorough review of 30 available methods. State-of-the-art statistical methodologies were then employed to generate the standards (Borghi et al., 2006).

The Box-Cox-power-exponential (BCPE) method (Rigby and Stasinopoulos, 2004), with curve smoothing by cubic splines, was selected as the approach for constructing the growth curves. The BCPE accommodates various kinds of distributions, from normal to skewed or kurtotic, as necessary. There was wide variability in the degrees of freedom required for the cubic splines to achieve the best models. Except for head circumference-for-age, which followed a normal distribution, all other standards required the modelling of skewness but not kurtosis. A set of diagnostic tools was used to detect possible biases in estimated percentile or z-score curves. These included examining patterns of differences between empirical and fitted centiles, and comparing observed and expected proportions of children with measurements below selected percentile curves. Percentile and z-score curves for boys and girls were generated for head circumference-for-age (0–60 months), arm circumference-for-age (3–60 months), triceps skinfold-for-age and subscapular skinfold-for-age (3–60 months). Appendix A summarizes the specifications of the BCPE models for each of the standards.

Overall, concordance between smoothed curves and empirical centiles was free of bias in both the median range and the tails, indicating that the resulting curves are an adequate description of the true growth of healthy children. The average absolute difference between smoothed and empirical centiles was 0.091 cm for boys' and girls' head circumference-for-age (Figures 5-8 and 15-18); 0.102 cm and 0.098 cm for boys' and girls' arm circumference-for-age, respectively (Figures 27-30 and 38-41); 0.152 mm and 0.146 mm for boys' and girls' triceps skinfold-for-age, respectively (Figures 50-53 and 61-64); and 0.101 mm and 0.136 mm for boys' and girls' subscapular skinfold-for-age, respectively (Figures 73-76 and 85-88). Taking the sign into account, the average differences are close to zero: 0.031 cm and 0.022 cm for boys' and girls' head circumference-for-age, respectively; 0.004 cm and -0.003 cm for boys' and girls' arm circumference-for-age, respectively; 0.024 mm and 0.028 mm for boys' and girls' triceps skinfold-for-age, respectively; and 0.018 mm and 0.024 mm for boys' and girls' subscapular skinfold-for-age, respectively. These results indicate lack of bias in the fit between smoothed and empirical percentiles.

As was done for the construction of the first set of standards (WHO Multicentre Growth Reference Study Group, 2006d), a restricted application of the LMS method was used for the construction of the indicators arm circumference-for-age and skinfold thicknesses, limiting the Box-Cox normal distribution to the interval corresponding to z-scores where empirical data were available (i.e. between -3 SD and 3 SD). Beyond these limits, the standard deviation was fixed to the distance between ±2 SD and ±3 SD, respectively. This approach avoids making assumptions about the distribution of the data beyond the limits of the actual data (e.g. the 3 SD corresponds to the 99.9th percentile).

All four indicators presented in this report are a new addition to the previously available set of indicators in the NCHS/WHO reference. Head circumference-for-age is often used in clinical settings as part of health screening for potential developmental or neurological disabilities in infants and young children (WHO, 1995). Very small and very large circumferences are both indicative of health or developmental risk. Arm circumference-for-age is used as an alternative indicator of nutritional status when the collection of length/height and weight measurements is difficult, as happens in emergency humanitarian situations due to famine or refugee crises (WHO, 1995). Triceps and subscapular skinfold measurements assess the thickness of subcutaneous tissue and reflect fatness primarily. The skinfold indicators are thus a useful addition to the battery of growth standards for assessing childhood obesity.

The WHO Child Growth Standards provide a technically robust set of tool for assessing the well-being of infants and young children. They were derived from children who were raised in environments that minimized constraints to growth such as poor diets and infection. In addition, their mothers followed healthy practices such as breastfeeding their children and not smoking during and after pregnancy. The standards depict normal early childhood growth under optimal environmental conditions and can be used to assess children everywhere, regardless of ethnicity, socioeconomic status and type of feeding. Together, three new elements — a *prescriptive* approach that moves beyond the development of growth references towards a standard, inclusion of children from around the world, and links between physical growth and motor development — provide a solid instrument for helping to assess the health and nutritional needs of the world's children.

9. BIBLIOGRAPHY

Bhandari N, Bahl R, Taneja S, de Onis M, Bhan MK (2002). Growth performance of affluent Indian children is similar to that in developed countries. *Bulletin of the World Health Organization,* 80:189–195.

Borghi E, de Onis M, Garza C, Van den Broeck J, Frongillo EA, Grummer-Strawn L, van Buuren S, Pan H, Molinari L, Martorell R, Onyango AW, Martines JC for the WHO Multicentre Growth Reference Study Group (2006). Construction of the World Health Organization child growth standards: selection of methods for attained growth curves. *Statistics in Medicine*, 25:247–265.

Cole TJ, Green PJ (1992). Smoothing reference centile curves: the LMS method and penalized likelihood. *Statistics in Medicine*, 11:1305–1319.

de Onis M, Habicht JP (1996). Anthropometric reference data for international use: recommendations from a World Health Organization Expert Committee. *American Journal of Clinical Nutrition*, 64:650–658.

de Onis M, Yip R (1996). The WHO growth chart: historical considerations and current scientific issues. *Bibliotheca Nutritio et Dieta*, 53:74–89.

de Onis M, Garza C, Victora CG, Bhan MK, Norum KR, eds (2004a). WHO Multicentre Growth Reference Study (MGRS): Rationale, planning and implementation. *Food and Nutrition Bulletin*, 25(Suppl 1):S1–S89.

de Onis M, Garza C, Victora CG, Onyango AW, Frongillo EA, Martines J, for the WHO Multicentre Growth Reference Study Group (2004b). The WHO Multicentre Growth Reference Study: planning, study design and methodology. *Food and Nutrition Bulletin*, 25(Suppl 1):S15–S26.

de Onis M, Onyango AW, Van den Broeck J, Chumlea WC, Martorell R, for the WHO Multicentre Growth Reference Study Group (2004c). Measurement and standardization protocols for anthropometry used in the construction of a new international growth reference. *Food and Nutrition Bulletin*, 25(Suppl 1):S27–S36.

Garza C, de Onis M, for the WHO Multicentre Growth Reference Study Group (2004). Rationale for developing a new international growth reference. *Food and Nutrition Bulletin*, 25(Suppl 1):S5–S14.

Mohamed AJ, Onyango AW, de Onis M, Prakash N, Mabry RM, Alasfoor DH (2004). Socioeconomic predictors of unconstrained child growth in Muscat, Oman. *Eastern Mediterranean Health Journal*, 10:295–302.

Onyango AW, Pinol AJ, de Onis M, for the WHO Multicentre Growth Reference Study Group (2004). Managing data for a multicountry longitudinal study: Experience from the WHO Multicentre Growth Reference Study. *Food and Nutrition Bulletin*, 25 Suppl 1:S46–S52.

Owusu WB, Lartey A, de Onis M, Onyango AW, Frongillo EA (2004). Factors associated with unconstrained growth among affluent Ghanaian children. *Acta Paediatrica*, 93:1115–1119.

Rigby RA, Stasinopoulos DM (2004). Smooth centile curves for skew and kurtotic data modelled using the Box-Cox power exponential distribution. *Statistics in Medicine*, 23:3053–3076.

Royston P, Wright EM (2000). Goodness-of-fit statistics for age-specific reference intervals. *Statistics in Medicine*, 19:2943–2962.

Stasinopoulos DM, Rigby RA, Akantziliotou C (2004). Instructions on how to use the GAMLSS package in R. Technical Report 02/04. London: STORM Research Centre, London Metropolitan University.

van Buuren S, Fredriks M (2001). Worm plot. A simple diagnostic device for modelling growth reference curves. *Statistics in Medicine*, 20:1259–1277.

WHO. Physical status: the use and interpretation of anthropometry (1995). Report of a WHO Expert Committee. *World Health Organ Tech Rep Ser*; 854:161–262.

WHO Multicentre Growth Reference Study Group (2006a). Assessment of differences in linear growth among populations in the WHO Multicentre Growth Reference Study. *Acta Paediatric*, Suppl 450:56–65.

WHO Multicentre Growth Reference Study Group (2006b). Breastfeeding in the WHO Multicentre Growth Reference Study. *Acta Paediatrica*, Suppl 450:16–26.

WHO Multicentre Growth Reference Study Group (2006c). WHO Motor Development Study: Windows of achievement for six gross motor development milestones. *Acta Paediatrica*, Suppl 450:86–95.

WHO Multicentre Growth Reference Study Group (2006d). WHO Child Growth Standards: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: Methods and development. Geneva: World Health Organization; pp 312.

WHO Multicentre Growth Reference Study Group (2006e). Enrolment and baseline characteristics in the WHO Multicentre Growth Reference Study. *Acta Paediatrica*, Suppl 450:7–15.

WHO Multicentre Growth Reference Study Group (2006f). Reliability of anthropometric measurements in the WHO Multicentre Growth Reference Study. *Acta Paediatrica*, Suppl 450:38–46.

WHO Multicentre Growth Reference Study Group (2006g). WHO Child Growth Standards based on length/height, weight and age. *Acta Paediatrica*, Suppl 450:76–85.

WHO Working Group on Infant Growth (1994). An evaluation of infant growth. Geneva: World Health Organization.

Appendix A. Model specifications of the WHO child growth standards

Table A1 Degrees of freedom for fitting the parameters of the Box-Cox-power exponential (BCPE) distribution for the models with the best fit to generate standards based on age, head circumference, arm circumference, triceps skinfold and subscapular skinfold in children 0–60 months of age

Standards	Sex	λ[a]	df(μ)[b]	df(σ)[c]	df(ν)[d]	τ[e]
Head circumference, 0–60 mo	Boys	0.20	9	5	0[f]	2
	Girls	0.20	9	2	0[f]	2
Arm circumference, 3–60 mo	Boys	0.35	7	4	2	2
	Girls	0.35	8	4	1	2
Triceps skinfold, 3–60 mo	Boys	0.30	7	5	2	2
	Girls	0.15	7	5	3	2
Subscapular skinfold, 3–60 mo	Boys	0.65	6	2	2	2
	Girls	0.15	5	4	2	2

[a] Age transformation power.
[b] Degrees of freedom for the cubic splines fitting the median (μ).
[c] Degrees of freedom for the cubic splines fitting the coefficient of variation (σ).
[d] Degrees of freedom for the cubic splines fitting the Box-Cox transformation power (ν).
[e] Parameter related to the kurtosis fixed (τ=2).
[f] ν=1: Normal distribution.