Chapter 78
Use of Segmental Lengths for the Assessment of Growth in Children with Cerebral Palsy

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Abstract Measurement of height or recumbent length is essential for the assessment of linear growth in children. Children with cerebral palsy (CP) often grow poorly and assessment of growth in this population is further complicated by two main difficulties. Firstly, children may have joint contractures, muscular weakness, scoliosis, and/or involuntary movements that make standing or lying straight difficult, if not impossible. Hence, accurate and reliable measures of height or recumbent length are not always attainable in this population. Secondly, as a result of atypical growth patterns, generally accepted reference charts for typically developing children may not be appropriate for use in children with CP. Due to these difficulties segmental lengths such as knee height, tibial length or upper arm length are frequently used as alternatives. These measures are all reliable and valid alternative measures for height in children with CP. They have been recommended for inclusion in the routine growth assessment of this group when accurate or reliable direct measurements of height or recumbent length are difficult or not possible (Spender et al. 1989; White and Ekvall 1993; Chumlea 1994; Stevenson 1995; Gauld et al. 2004). Segmental lengths can be compared directly with growth charts developed from data collected from children with normal growth or children with CP (Spender et al. 1989; White and Ekvall 1993; Stevenson et al. 2006). Alternatively, they may be used to estimate height using published equations, thus enabling comparison with height-for-age reference charts developed from typically developing children or children with CP (CDC 2000; Stevenson et al. 2006; WHO 2006; Day et al. 2007).

Abbreviations

A	Age
BMI	Body Mass Index
CDC	Center for Disease Control and Prevention
CP	Cerebral Palsy

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CV	Coefficient of Variation
GMFCS	Gross Motor Function Classification System
NAGCPP	North American Growth in Cerebral Palsy Project
RMSE	Root Mean Square of the Error
SEE	Standard Error of the Estimate
TE	Technical Error
WHO	World Health Organisation

78.1 Introduction

Physical growth is a fundamental aspect of health and an indicator of physical wellbeing in children. Abnormal growth may occur for a number of reasons and may be indicative of illness or chronic inadequate nutrient intake (Stevenson et al. 2006). Physical growth and development in children have been assessed for many years using classic anthropometric measurements. These include measures of height or supine length, weight and other simple measures (WHO Expert Committee on Physical Status 1995). In typically developing individuals, assessment of linear growth is relatively straightforward where values for recumbent length or height can be compared to a growth reference or standard (CDC 2000; WHO 2006). Measures of length or height are also frequently used with measures of body weight to assess body proportions through use the body mass index (BMI) or weight-for-height growth charts (WHO Expert Committee on Physical Status 1995). Other applications include calculation of predicted energy requirements using published formulae (Schofield 1985); and prediction of reference ranges for the assessment of pulmonary function and glomerular filtration rate (Gauld et al. 2004).

Growth and nutritional status of children and adolescents with CP have been the subject of numerous investigations over the past 50 years (Tobis et al. 1961; Spender et al. 1989; Stevenson et al. 1994; Krick et al. 1996; Stevenson et al. 2006; Day et al. 2007). In general, children with CP are shorter and lighter than their typically developing peers (Krick et al. 1996; Stevenson et al. 2006; Day et al. 2007). The largest study, to date, of the growth parameters of children and adolescents with CP was based on retrospective data relating to height and weight obtained from the patient records of 24,920 children and adolescents with CP aged 2–20 years (Day et al. 2007). A combination of cross-sectional and longitudinal data was included, totalling 141,961 different observations. The 10th, 50th and 90th percentile curves for height, weight and BMI were determined by age, sex, and five levels of functional ability. This study was the first to develop growth curves for children with CP stratified by gross motor skills and feeding ability (Day et al. 2007).

Height and weight percentile curves for the highest functioning groups (i.e. group 1: walks well alone for at least 6 m and balances well) approximated those of the general population. Trends for lower weight and height for age were apparent for the lower functional groups and deviated further from those of the general population with increasing functional impairment. Interestingly, in the lowest functioning groups (groups 4 and 5), the presence of a feeding tube was associated with greater height and weight (Day et al. 2007). The most significant limitation of this study was that the methods utilised to measure height were of unknown validity and reliability in this population. The authors acknowledge this limitation and conclude that the height curves presented for children with significant motor impairment (i.e. groups 3, 4 and 5) should be viewed with some caution.

Table 78.1 Key facts about the use of segmental lengths in children with cerebral palsy

Measurement of height or recumbent length in children with cerebral palsy may be difficult and sometimes impossible.
Segmental lengths are frequently used as alternative measures to height or length in children with cerebral palsy for the assessment of growth.
Commonly used segmental lengths in children with cerebral palsy are knee height, upper arm length and tibial length.
The landmarks for segmental lengths may be difficult to identify. Training and practice is required to develop skill and competence in their measurement.
All measurements should be taken twice and on the left hand side of the body. The average of the two measurements should be used.
Upper arm length and knee height should be measured using specialised equipment. Knee height should be measured using a sliding calliper or anthropometer. Upper arm length should be measured with an anthropometer or Vernier callipers, depending on the size of the child.
Tibial length can be measured accurately using steel or plastic measuring tapes.

This table describes some key facts related to the use of segmental lengths in children with cerebral palsy including those measures commonly used, equipment required and basic concepts

78.2 Difficulties with Conventional Assessment of Height or Length in Children with CP

Direct measurement of recumbent length or height may be inaccurate, unreliable and frequently impossible in children and adolescents with physical disabilities, such as cerebral palsy (CP), due to joint contractures, muscular weakness, scoliosis, involuntary movements or poor cooperation. Difficulty obtaining conventional measures of height or recumbent length have been reported in 53% of children with CP participating in a study of growth parameters (Spender et al. 1989); furthermore, reliable measurements of either recumbent length or height were unable to be obtained in 52% of a clinical population of children with CP (Stevenson 1995). In this study, the population in which a reliable measure of length or height was possible was those of the younger children with less severe motor impairment than the larger clinic population; suggesting that difficulties with obtaining direct measures of height or recumbent length in children with CP increase with increasing age and severity of motor impairment (Stevenson 1995). In order to overcome these difficulties, various segmental lengths including upper arm length, ulna length, forearm length, knee height and lower leg (tibial) length have been identified as potential alternatives or proxy measures in different populations. Key facts regarding the use of segmental lengths in children with CP are included in Table 78.1. To be clinically useful as a proxy measure for recumbent length or height in the population of interest, the measure must be (1) measurable in the population (2) reproducible (3) highly correlated with recumbent length or height and (4) able to be compared to a growth reference.

78.3 Use of Segmental Lengths in Children with Cerebral Palsy

Knee height, lower leg length and upper arm length have all been shown to be both reproducible and clinically useful as proxy measures for height or recumbent length in children and adolescents with CP (Spender et al. 1989; Chumlea 1994; Stevenson 1995; Hogan 1999; Bell and Davies 2006). In typically developing children, correlations between height and knee height, upper arm length and tibial length are very high (r = 0.97, 0.98 and 0.98, respectively) (Spender et al. 1989; Chumlea

Table 78.2 Reliability of segmental lengths in children with cerebral palsy

	Intra-observer error $N = 307$		Inter-observer error $N = 18$	
	TE (cm)	CV (%)	TE (cm)	CV (%)
Upper arm length[a]	0.27	1.07	0.52	2.32
Tibial length[b]	0.28	1.04	0.33	1.31
Knee height[a]	0.22	0.61	0.29	0.89

This table shows reliability data for measurements of segmental lengths in children with CP. All data presented here were obtained as part of the North American Growth in Cerebral Palsy Project

[a]Published data (Stevenson et al. 2006)

[b]Previously unpublished data. TE indicates the technical error = $\sqrt{\Sigma d^2/2n}$, where d = difference between paired measures on n subjects, CV is the coefficient of variation = 100 × (TE/mean of measures taken)

1994; Gauld et al. 2004). In children with CP, correlations between height or recumbent length and knee height, upper arm length and tibial length are similarly high ($r = 0.98$, 0.97, and 0.97, respectively, $p < 0.05$) (Stevenson 1995). In addition, knee height has been found to correlate significantly with recumbent length in a group of wheel chair dependent children, adolescents and adults with CP ($r = 0.88$, $p < 0.05$) (Hogan 1999).

78.4 Reliability

Reliability of anthropometric data may be expressed in many ways. Two commonly utilised statistics are the technical error of the measurement (TE) and the coefficient of variation (CV). The TE is calculated as $\sqrt{(\Sigma d^2/2n)}$, in which d is the difference between the same measure on the same child done by the same observer (intraobserver observer) or different observers (interobserver error) (Cameron 1986). The TE will be greater for measures of larger magnitude. For example, the TE for measurements of height will be greater than the TE for measurements of knee height due to the magnitude of the measure itself. The CV is the TE of measurement divided by the overall mean of all subjects for the particular variable under study. It is a measure of relative variability, i.e., variation relative to the overall magnitude of the measure (Malina et al. 1973).

Acceptable levels of intra- and inter-observer repeatability have been reported for measures of knee height, upper arm length and tibial length, when conducted by trained observers, in children with CP, as shown in Table 78.2 (Stevenson et al. 2006). The data reported here were obtained as part of the North American Growth in Cerebral Palsy Project (NAGCPP). This was a multicentre study that investigated the growth, body fat stores and physical development of children with moderate to severe CP (Gross Motor Function Classification System (GMFCS) Levels III–V). Data were collected across six different sites throughout the United States and Canada. Values reported for TE and CV for segmental lengths were similar to those obtained for measurement of height in typically developing children from the National Health Examination Survey cycle II. This large scale study reported TE and CV for height measured by the same observer (TE = 0.68 cm, CV = 0.42) and different observers (TE = 0.49 cm, CV = 0.30) (Malina et al. 1973).

78.5 Interpretation of Segmental Lengths

78.5.1 Use of Growth Charts for Segmental Lengths

The interpretation of anthropometric data is facilitated by comparison to a growth reference and/or to earlier measurements from the same child. Reference charts for lower leg length, upper arm length, knee height, and ulna length have been developed for healthy typically developing children and can be used to assess the linear growth of children with CP and other physical disabilities (Spender et al. 1989; White and Ekvall 1993; Gauld et al. 2004). For example, growth charts for upper arm length and tibial length were developed by Spender and colleagues using data obtained from 1,298 typically developing children (Snyder et al. 1977; Spender et al. 1989). These growth charts have not been commercialised and are not readily available in most clinical settings.

Growth charts for knee height have been developed from data collected specifically from children with CP as part of the NAGCPP (Stevenson et al. 2006). These charts, and additional charts for tibial length and upper arm length for boys and girls, are the first charts to allow clinicians to make comparisons with segmental length measurements obtained from a group of children with CP (Appendix 1–6). They were developed from data collected from 156 boys and 114 girls aged 2–18 years. All children were diagnosed with CP and classified as having moderate to severe motor impairment (GMFCS levels III–V only). The reference curves were estimated using the LMS method (Cole and Green 1992) Some key facts regarding the NAGCPP are included in Table 78.3.

78.5.2 Equations to Predict Height from Segmental Lengths

An alternative to direct comparisons with growth charts for segmental lengths is to predict height from the segmental length measure using published equations. Formulae have been developed from data collected from healthy, typically developing individuals to predict height from segmental lengths in different ethnic groups (Chumlea 1994; Cheng et al. 1998; Gauld et al. 2004) and from data collected specifically from children with CP (Stevenson 1995). These allow comparisons of predicted height with standard height-for-age growth references or standards for typically developing children (CDC 2000; WHO 2006) and children with CP (Day et al. 2007).

Equations to predict height from ulna, forearm, tibial and lower leg lengths have been developed from a large dataset of 2,343 healthy, typically developing Australian school children and adolescents aged 5–19 years as shown in Table 78.4 (Gauld et al. 2004). In addition, prediction equations for height from radius, humerus, tibia and ulna lengths have been developed from measurements conducted in a group of 3,647 healthy, typically developing Chinese elementary, middle and high school children and adolescents aged 3–18 years (Table 78.5) (Cheng et al. 1998). However, the largest data set to date from which equations to predict height have been developed was collected from 1960 to 1970 in cycles I, II and III of the United States National Health Examination Survey (Table 78.6) (Chumlea 1994). These surveys included nationally representative samples of free living United States civilian adults (cycle I, $n = 5{,}414$), children aged 6–11 years (cycle II, $n = 7{,}087$) and adolescents aged 12–18 years (cycle III, $n = 6{,}734$). Equations were developed by age, sex and ethnicity (Caucasian and African-American). Population specific equations have been developed to predict height from knee height, upper arm length and tibial length from data obtained from a group of 172 children with CP aged 2–12 years, 48% of which were non-ambulatory (Stevenson 1995) and are included in Table 78.7. Available reference data for measurements of segmental lengths are summarised in Table 78.8.

Table 78.3 Key Facts of the North American Growth in Cerebral Palsy Project

Study Design	The North American Growth in Cerebral Palsy Project (NAGCPP) was a multicentre, region based study established in 1996.
Location	Six regional geographic locations throughout the United States and Canada
Aims	The long term goal of NAGCPP was to optimise the growth, nutrition, functional outcome and overall quality of life in children with CP by: 1. Defining expected growth patterns 2. Determining the nutritional, endocrinological, neurological and physical factors that influence growth, and 3. Determining how growth affects function, general health status, cognitive and motor development, family stress, health care use, morbidity and mortality.
Eligibility	All children with CP between the ages of 2 and 18 years residing in the designated geographical regions and classified as Gross Motor Function Classification Levels III, IV or V were eligible to participate.
Participants	235 children participated. Average age was 9.7 ± 4.6 years. 59% were male GMFCS Levels were: III – 56; IV – 55; V – 122
Measures	• Anthropometry: weight, head circumference, length, upper arm length, tibial length, knee height, calf circumference, mid-arm circumference, triceps skinfold thickness, calf skinfold thickness, subscapular skinfold thickness • Child Health Questionnaire • Medical history • Feeding abilities • Cognitive functioning • Health care use • General health

This table describes some of the key features of the North American Growth in Cerebral Palsy Project (NAGCPP) (Liptak et al. 2001)

Table 78.4 Equations to estimate height from segmental lengths in typically developing children and adolescents

Segmental measure	Estimation equation (cm)	RMSE
Males		
Ulna length	Height = (4.605 × UL) + (1.308 × A) + 28.003	3.896
Forearm length	Height = (2.904 × FL) + (1.193 × A) + 20.432	3.556
Tibial length	Height = (2.758 × TL) + (1.717 × A) + 21.818	3.791
Lower leg length	Height = (2.423 × LL) + (1.327 × A) +21.818	3.062
Females		
Ulna length	Height = (4.459 ×UL) + (1.315 × A) + 31.485	3.785
Forearm length	Height = (2.908 × FL) + (1.147 × A) + 21.167	3.344
Tibial length	Height = (2.771 × TL) + (1.457 × A) + 37.748	3.383
Lower leg length	Height = (2.473 × LL) + (1.187 × A) + 21.151	2.717

Equations to estimate height from measurements of segmental lengths obtained from 2,343 healthy, typically developing Australian school children and adolescents aged 5–19 years (Gauld et al. 2004)
UL ulna length, *A* age, *FL* forearm length, *TL* tibial length, *LL* lower leg length, *RMSE* root mean square of the error

Table 78.5 Equations to estimate height from segmental lengths in typically developing Chinese children and adolescents

Segmental measure	Estimation equation (cm)
Radius length	Height = 40.45 + (4.45 × A) – (0.28 × Sex) + (4.15 × RL)
Humerus length	Height = 31.15 + (1.48 × A) + (0.30 × Sex) + (3.52 × HL)
Tibia length	Height = 41.05 + (1.64 × A) + (0.84 × Sex) + (2.55 × TL)
Ulna length	Height = 30.35 + (1.29 × A) + (0.77 × Sex) + (4.32 × UL)

Equations to estimate height from measurements of segmental lengths obtained from a group of 3,647 health, typically developing Chinese elementary, middle and high school students aged three – 18 years (Cheng et al. 1998). Sex = 0 for girls and 1 for boys
RL radius length, *HL* humerus length, *TL* tibia length, *UL* ulna length, *A* age

Table 78.6 Equations to estimate height from knee height in typically developing children and adolescents (6–18 years)

Group	Estimation equation (cm)	RMSE	SEE (cm)
Caucasian boys	Height = 40.54 + (2.22 × KH)	4.16	4.21
African-American boys	Height = 39.60 + (2.18 × KH)	4.44	4.58
Caucasian girls	Height = 43.21 + (2.15 × KH)	3.84	3.90
African-American girls	Height = 46.59 + (2.02 × KH)	4.25	4.29

Equations to estimate height from measurement of knee height developed from data collected from 13,821 children and adolescents in the United States (Chumlea 1994)
RMSE root mean squared of the error, *SEE* standard error of the estimate, *KH* knee height

Table 78.7 Equations to predict height from segmental lengths in children with cerebral palsy (under 12 years of age)

Segmental measure	Prediction equation (cm)	SEE (cm)
Upper-arm length	Height = (4.35 × UAL) + 21.8	±1.7
Tibial length	Height = (3.26 × TL) + 30.8	±1.4
Knee height	Height = (2.69 × KH) + 24.2	±1.1

Equations to predicted height from segmental lengths obtained from 172 children with cerebral palsy aged 2–12 years (Stevenson 1995)
UAL Upper-arm length, *TL* tibial length, *KH* knee height, *SEE* standard error of the estimate

Table 78.8 Key features of reference data for measurements of segmental lengths

Author	Population	Growth charts developed for	Prediction equations developed for
Cheng et al. (1998)	*N* = 3,647 Healthy, typically developing Chinese children and adolescents Aged 3–18 years		Radius length Humerus length Tibia length Ulna length
Chumlea (1994)	*N* = 13,821 Typically developing children and adolescents aged 6–18 years from cycles II and III of the United States National Health Examination Survey		Knee height

(continued)

Table 78.8 (continued)

Author	Population	Growth charts developed for	Prediction equations developed for
Gauld et al. (2004)	*N* = 2,343 Healthy, typically developing Australian children and adolescents 5–19 years of age	Ulna length	Radius length Humerus length Tibia length Ulna lengths Knee height
Spender et al. (1989)	*N* = 1,298 Typically developing United States children and adolescents (Snyder et al. 1977)	Upper arm length Tibial length	
Stevenson et al. (2006)	*N* = 273 North American children with Cerebral Palsy (GMFCS III–V) Aged 2–19 years	Knee height Tibial length Upper arm length	
Stevenson (1995)	*N* = 172 North American children with Cerebral Palsy (GMFCS III–V) Aged 2–12 years 48% non-ambulatory		Knee height Tibial length Upper arm length
White and Ekvall (1993)	*N* = 1,298 Typically developing United States children (Snyder et al. 1977)	Knee height	

This table shows key information relating to currently available reference data for segmental lengths in various populations. Included in the table are: descriptions of the populations in which measurements have been conducted (sample size, nationality, diagnosis of cerebral palsy), as well as identification of datasets used to develop growth charts for segmental lengths and equations to estimate height from segmental lengths

GMFCS Gross Motor Function Classification System

78.5.3 Evaluation of Prediction Equations

The accuracy of equations to predict height from segmental lengths in individuals with CP has been evaluated (Spender et al. 1989; Hogan 1999; Bell and Davies 2006). The ability of the Chumlea equations (Chumlea 1994) and the Stevenson equation (Stevenson 1995) to predict height from knee height was investigated in a group of 17 ambulatory children with CP (Gross Motor Function Classification System I and II) and 20 typically developing children (Bell and Davies 2006). At the population level, the Stevenson (1995) equation performed best with height predicted to within, on an average, 0.4% of measured height. Again, at the population level, the Chumlea equation also performed well with height predicted to within 1%; however, the bias in predicted height using the Chumlea equation increased with increasing height. Importantly, whilst the mean bias produced by the equations may have been acceptable, the limits of agreement for both equations remained relatively large. As a result, at the individual level height predicted by the Stevenson equation can vary by as much as 12.7 cm (10%) below to 11.8 cm (9%) above actual measured height for children with CP and 10.9 cm (9%) below to 12.3 cm (10%) above that for typically developing children. Thus the equations may be accurate at the group level; however, they may lead to unacceptable error for any one individual and caution should be exercised when using these equations in that way. Johnson and Ferrara (Johnson and Ferrara 1991) also found equations derived from healthy typically developing individuals to predict height from knee height were not sufficiently accurate for use in a group of adolescents with CP (Table 78.7 and 78.8).

These studies highlight the long known and well accepted concern relating to the application of equations to populations from which they were not derived. Equations to predict height or recumbent length from segmental lengths assume a strong relationship between the segmental length and height or recumbent length. Due to the heterogeneous nature of CP and known alterations in growth patterns, it is unlikely that this relationship is constant between children with different types and severities of motor impairment, let alone in children with CP and typically developing children (Krick et al. 1996; Stevenson et al. 2006; Day et al. 2007). Obviously, the Stevenson (1995) equations were derived from a group of children with CP where measurement of recumbent length or height was possible. The appropriateness of applying these equations to ambulatory children with CP has been confirmed (Bell and Davies 2006). Caution should be exercised when using these equations in children with more severe motor impairments where measures of height or recumbent length are not possible, such as those with severe scoliosis and contractures, the precise group for whom an alternative assessment of linear growth is necessary. The validity of prediction equations for use in these populations may never be determined since direct measurement of height or length is not possible. For these children it would be more appropriate to use growth charts for knee height, upper arm length or tibial length to assess linear growth, thereby avoiding any of the potential error associated with prediction equations.

78.5.4 Choice of Segmental Length in Individuals with CP

When an accurate measure of height or recumbent length is difficult, or impossible, the choice of alternative measure is likely to be determined by the resources available and the abilities of the child. To be accurate and reliable, both upper arm length and knee height require specialised measuring equipment (anthropometer or knee height calliper), whereas, tibial length can be measured using a flexible measuring tape (Spender et al. 1989; Rogerson et al. 2000). Of the three alternatives, the landmarks for knee height are the easiest to identify and indeed knee height has been found to be the most reproducible (Stevenson 1995). Since measurement of tibial length does not require specialised equipment, is not impacted on by knee and ankle contractures and the landmarks are relatively easy to palpate in lean individuals, it may be the most suitable alternative measure for height in children with CP. It is important to note however, that training of observers is required to ensure reliable and accurate results.

78.6 Practical Methods and Techniques

Detailed methods for the measurement of knee height, upper arm length and tibial length are described below (refer to Table 78.9). By convention, all anthropometric measures for the assessment of growth in children should be conducted on the left hand side of the body and in duplicate with the mean of the two measurements used for interpretation and analysis (WHO Expert Committee on Physical Status 1995). Where duplicates are not within an acceptable level of accuracy a third measurement may be taken and the mean of the two closest measurements used. In children with CP with marked asymmetry, investigators have conducted measurements on the less impaired side (Stevenson 1995; Bell and Davies 2006).

Table 78.9 Measurement of segmental lengths

Segmental measure	Equipment required	Distance of measurement
Upper arm length	Anthropometer or Vernier calliper in smaller children (Spender 1989)	From the acromium process to the head of the radius (Cameron 1986)
Tibial length	Flexible tape measure or Anthropometer (Stevenson 1995)	From the superomedial edge of the tibia to the inferior edge of the medial malleolus (Stevenson 1995)
Knee height	Anthropometer or Knee height calliper (Rogerson 2000)	From the heel to the anterior surface of the thigh over the femoral condyles (Cameron 1986)

This table describes the equipment required for measurement of different segmental lengths as well as the distance to be measured

Fig. 78.1 Measurement of knee height in a child with CP in the supine position. Measurement of knee height in the recumbent position requires two observers. Care must be taken to ensure that the child's knee and ankle should both be held at 90° angles

78.6.1 Knee Height

Knee height is the distance from the heel to the anterior surface of the thigh over the femoral condyles. Both the knee and ankle must be flexed at 90° angles with the subtabular joint in neutral. This can be achieved in one of two ways:

(a) The child may be seated upright with feet flat on the floor and both the knee and ankle joints flexed at 90° angles. In this instance, the measurement is taken as the distance from the floor, or foot rest, to the anterior surface of the thigh just proximal to the patella. The shaft of the caliper should be held parallel to the tibia and gentle pressure applied to the blades of the caliper to blanch the skin and compress the tissue (Chumlea 1994).

(b) Recumbent knee height is measured with both the knee and ankle held at 90° angles while the child is in a supine position (see Fig. 78.1). One of the blades of the calliper or anthropometer should be positioned under the heel of the left foot and the other placed over the anterior surface of the thigh above the femoral condyles, just proximal to the patella. Once again, the shaft of the calliper is held parallel to the shaft of the tibia and gentle pressure is applied to the blades of the calliper to compress the tissue (Stevenson 1995).

Fig. 78.2 Measurement of upper arm length in a child with CP. For children who are unable to sit independently, adequate positioning for measurement of upper arm length may be best achieved with the child lying on their right side

Accurate and reliable measurements of knee height may be difficult to achieve in children with contracture of the soleus resulting in equinovarus deformity or in children with a proximally displaced patella. Knee height should be measured using a sliding calliper or anthropometer, as accuracy is impaired when using a flexible measuring tape. Values for knee height collected using a flexible tape measure have been found to be on average 1.3 cm greater than those conducted using specialised equipment in a group of 56 non-ambulatory adults with developmental disabilities ($p < 0.001$) (Rogerson et al. 2000).

78.6.2 Upper Arm Length or Humerus Length

Upper arm length is the distance from the acromion process to the head of the radius (Cameron 1986) (see Fig. 78.2). The measurement should be made when the child is upright (either seated or standing) with their back to the observer, arms relaxed and vertical and the elbow flexed to 90°. This position can be difficult to achieve in children with physical disabilities who are unable to sit independently. The landmarks can be challenging to identify, and the measure requires significant practice to develop competence. Upper arm length should be measured with an anthropometer or may be measured with Vernier callipers in smaller children. Steel and plastic measuring tapes should

Fig. 78.3 Landmarks for the measurement of tibial length in a CP in the supine position. Landmarks for measurements of segmental lengths should be identified and marked prior to the measurement being taken

Fig. 78.4 Measurement of tibial length in a child with CP in the supine position. Adequate positioning for measurement of tibial length may be achieved with the child in a supine position with their left leg held so that the medial aspect of the tibia faces upwards

be avoided when measuring upper arm length as accuracy is impaired with their use (Spender et al. 1989). In children with CP, measurements of upper arm length obtained using steel and plastic measuring tapes have been found to be on average 1.03 cm (±0.2 cm) and 1.1 cm (±0.25 cm) greater than those obtained using an anthropometer (Spender et al. 1989).

78.6.3 Tibial Length

Tibial length is the distance from the superomedial edge of the tibia to the inferior edge of the medial malleolus (Stevenson 1995). The measurement should be conducted with the child in a seated position facing the observer with the left ankle or calf resting on the right knee so that the medial aspect of the tibia faces upwards (see Figs. 78.3 and 78.4) (Cameron 1986).

78.7 Applications to Other Areas of Health and Disease

Segmental lengths have proven to be clinically useful in other populations of children with physical disabilities such as Duchenne muscular dystrophy and myelomeningocele. The use of segmental lengths (ulna length, forearm length, tibial length, lower leg length) was investigated in a group of 20 children with Duchenne muscular dystrophy between 7 and 19 years of age, 17 of whom were wheelchair dependant (Gauld et al. 2004). Adequate positioning was not attainable for forearm and lower leg length measures in children with wrist or ankle deformities. Measurement of tibial length was difficult in children with equinovarus deformities of the ankle. Ulna length measurements were possible in all children and were not affected by wrist contracture; however, reliability was not reported. The usefulness of forearm length, ulna length, and arm span in children with idiopathic scoliosis and children with Duchenne muscular dystrophy was evaluated by Miller and colleagues (Miller and Koreska 1992). They concluded that for children who were unable to stand and who had proximal upper extremity contractures, height should be calculated from measurement of forearm segment. If there are finger or wrist contractures, height can be calculated from measurement of ulna length.

Arm span measurements are frequently used for the assessment of linear growth in children with myelomeningocele; however it is difficult to obtain accurate and reliable measurements in children with high level spinal lesions (Belt-Niedbala et al. 1986). For this reason other upper limb measurements have been proposed as alternatives including upper arm length, forearm length and total arm length, for use in this population (Belt-Niedbala et al. 1986). These measures have been shown to correlate significantly with recumbent length in a group of 44 children with myelomeningocele between three and 12 years of age ($r = 0.96$, 0.95 and 0.85, respectively), suggesting that these may be suitable proxy measures for linear growth in this population. Equations to predict height from segmental lengths are yet to be evaluated in children with myelomeningocele.

78.8 Clinical Usefulness of Measures of Body Height or Body Segments

Assessment of physical growth is an important aspect of routine health care maintenance for all children and is used by physicians primarily (1) as a screen for general endocrine and medical integrity and health and (2) as a marker of nutritional status (Stevenson 1996). For the assessment of physical growth *per se*, direct comparison of the segmental measure with its corresponding growth reference is recommended (Spender et al. 1989; White and Ekvall 1993; Gauld et al. 2004; Stevenson et al. 2006). This will avoid any potential error associated with the use of prediction equations. There is growing evidence that children with CP have different growth patterns as compared to typically developing children and that growth patterns in this population are influenced by both nutritional factors as well as factors related to the severity of CP (frequently referred to as non-nutritional factors) (Stevenson et al. 1994; Day et al. 2007). Due to the influence of non-nutritional factors on growth in this group, even well-nourished children with CP should not be expected to exhibit the same growth patterns as the general paediatric population. One major issue facing clinicians who treat children with CP is determining whether a child who is growing poorly according to a growth reference, is actually growing as expected for a child with CP, or whether a potentially treatable medical problem, such as malnutrition, is present that is limiting growth.

Most readily available growth references or growth standards have been derived from the general paediatric population and application to children with growth disorders may be problematic. In recognition of the requirement for diagnosis specific reference data, specialised growth charts have been developed for children with CP, as previously discussed (Krick et al. 1996; Stevenson et al. 2006; Day et al. 2007). These charts are not necessarily reflective of the "optimal growth" of well-nourished children as they were derived from populations with potentially high degrees of undernutrition. As a result they should be viewed with some caution. They do allow comparisons of the growth of individuals with CP with other large groups of children with CP; however they should by no means be used to determine "ideal" growth in this population.

78.9 Use of Segmental Lengths in the Assessment of Nutritional Status in Children with CP

For the evaluation of nutritional status in the clinical setting, measures of length or height are frequently used in combination with measures of body weight. Indices have been developed to provide simple estimates of body size, in both children and adults, and also to infer levels of body fatness (Benn 1971). Those most commonly utilised indices are weight-for-height (i.e. weight/height^1) and the BMI (weight/height^2). The BMI is the index which removes the most influence of height on weight and is highly correlated with skinfold thicknesses and total body fatness in typically developing children (Mei et al. 2002). As a result, BMI cut points to identify overweight, obesity and underweight in children and adolescents have been determined and are commonly utilised in clinical settings (WHO Expert Committee on Physical Status 1995; Cole et al. 2000, 2007). Use of these cut points in children with CP is problematic for a number of reasons. Firstly, the prediction of height from segmental lengths in children where this is necessary, introduces potential error associated with the prediction equation. Secondly, the BMI may not be a sensitive measure of body fatness in children and adolescents who are particularly short for their age or who have an unusual body composition. For example, a wheel chair dependent child with CP may have a low BMI but may in fact have a high level of body fatness in comparison to a typically developing child. In this instance, limitations in physical activity participation would result in a reduction in lean body mass and a subsequent increase in the proportion of body fat. Use of the BMI and other weight for height indices as indicators of adiposity in children with CP is an area that requires further investigation (Table 78.9).

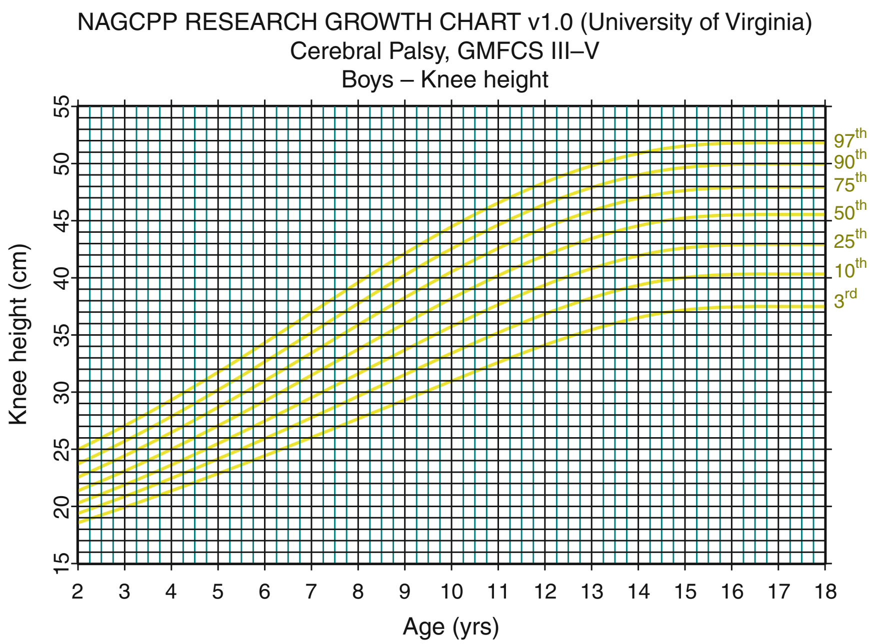
The inclusion of a more direct measure of body fat when assessing the nutritional status of children with CP will allow for more accurate identification of poorly nourished children. Measures such as skinfold thicknesses are frequently utilised in this group; however, they do require specialised equipment and adequate training to be performed accurately and reliably. Further research is required to determine the most appropriate methods for the assessment of nutritional status in children with CP, in the clinical setting, and to establish links between nutritional status and health related outcomes in this group; with a view to establishing standards that reflect "ideal" patterns of growth for this population.

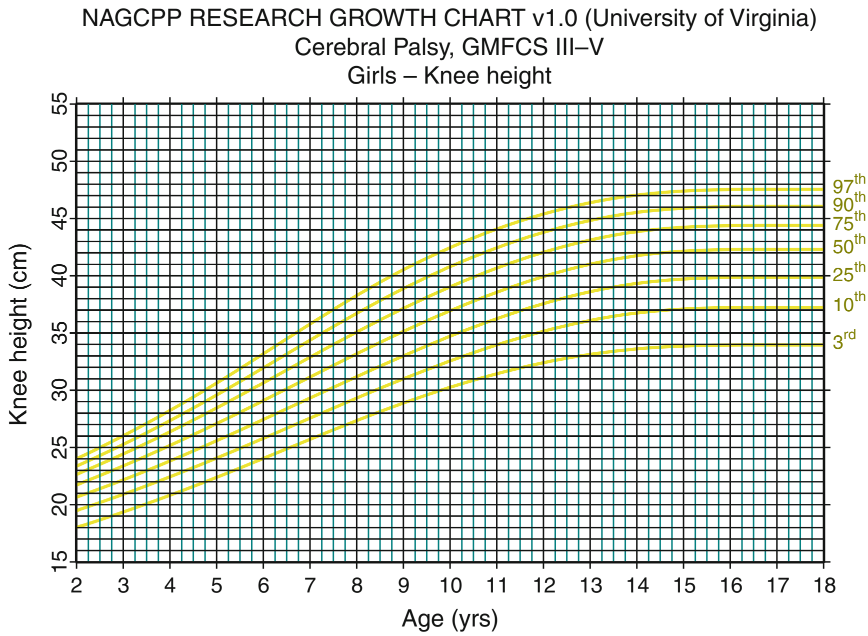
Summary Points

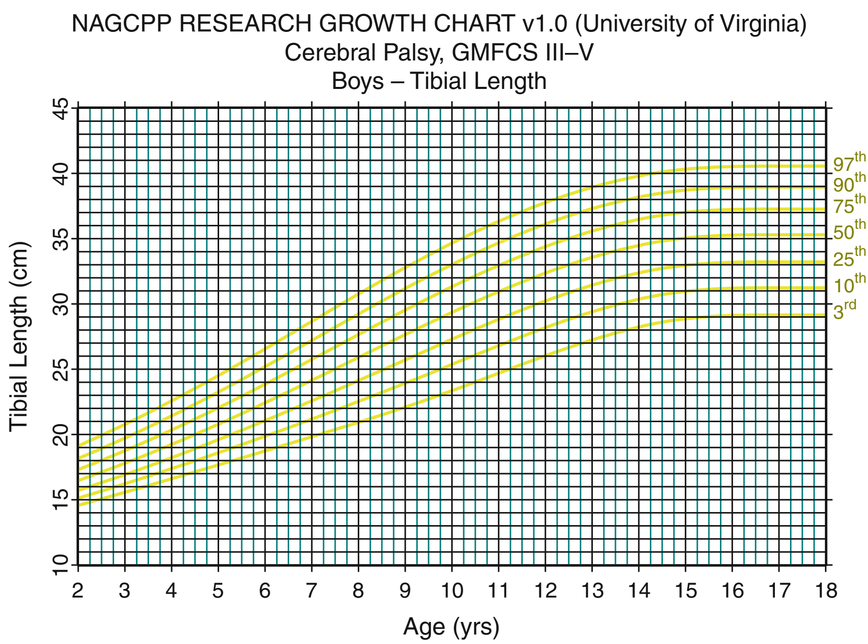
- Measurement of height or recumbent length in children with CP may be difficult and sometimes impossible due to joint contractures, muscular weakness, scoliosis, involuntary movements and poor cooperation.

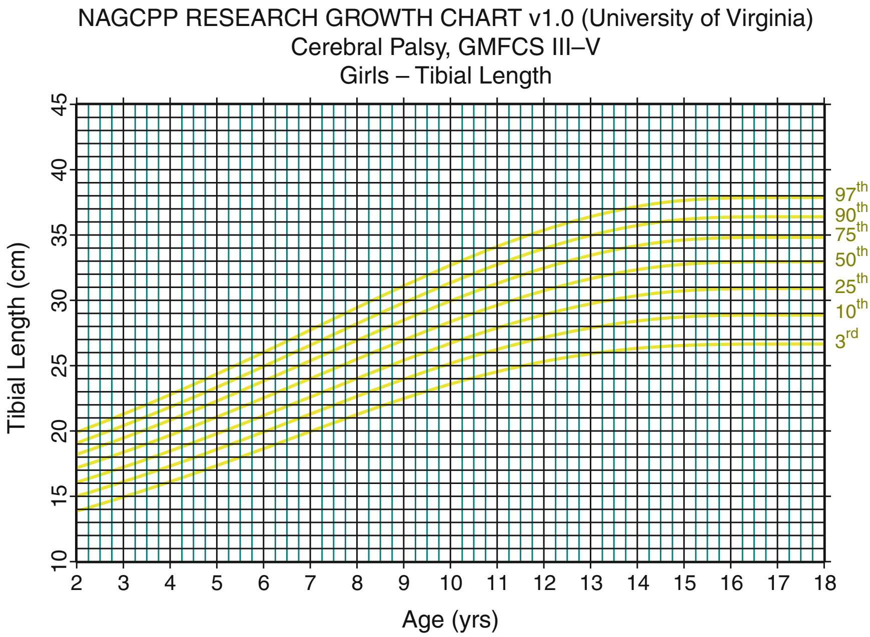
- Correlations between height or recumbent length and knee height, upper arm length and tibial length are high in both typically developing children and children with CP.
- Knee height, lower leg length and upper arm length have been shown to be both reproducible and clinically useful as alternative measures for height or recumbent length in children with CP.
- Reference charts for lower leg length, upper arm length, knee height, and ulna length have been developed from data obtained from typically developing children.
- Reference charts for knee height, tibial length, and upper arm length have been developed from data obtained from children with CP.
- Height can be predicted from knee height, upper arm length or tibial length in children with cerebral palsy to facilitate comparison with standard height-for-age growth charts.
- Population specific equations to predict height from knee height perform better in children with cerebral palsy than equations developed from typically developing children.
- Whilst knee height is the most reproducible proxy measure and the landmarks are easily identified, it may be difficult or impossible to obtain an accurate measurement in some children with severe contractures of the lower limb, as the distance to be measured crosses two joints.
- Upper arm length and knee height should always be measured using either an anthropometer or a knee height calliper. Tibial length can be measured using a flexible measuring tape.

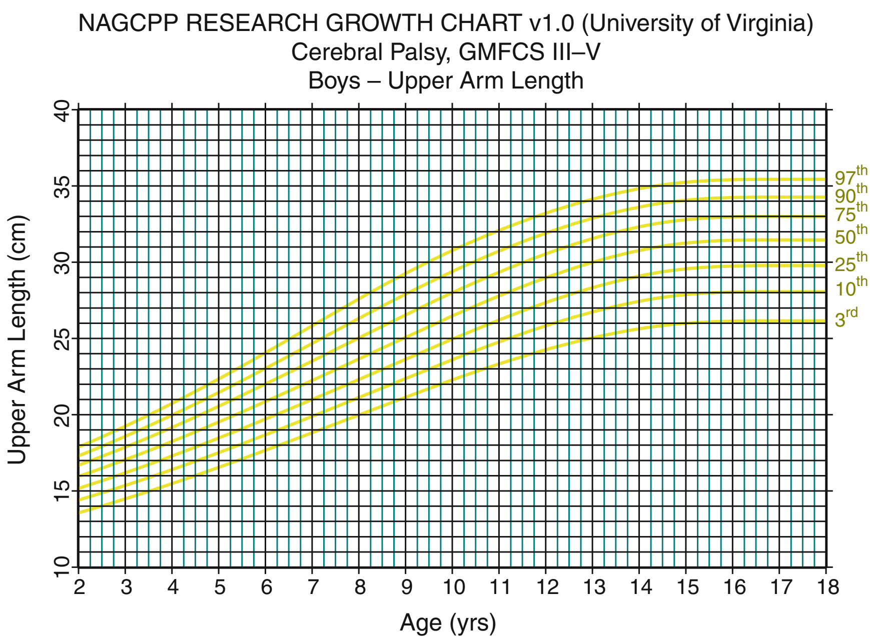
Appendix

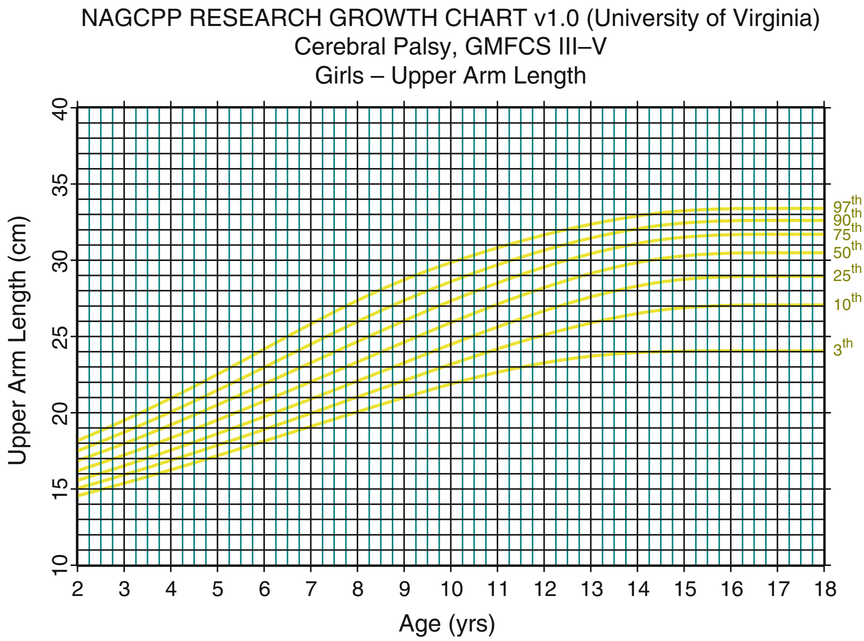



NAGCPP RESEARCH GROWTH CHART v1.0 (University of Virginia)
Cerebral Palsy, GMFCS III–V
Girls – Knee height
Knee height (cm)
Age (yrs)
97th
90th
75th
50th
25th
10th
3rd


NAGCPP RESEARCH GROWTH CHART v1.0 (University of Virginia)
Cerebral Palsy, GMFCS III–V
Boys – Tibial Length
Tibial Length (cm)
Age (yrs)
97th
90th
75th
50th
25th
10th
3rd


NAGCPP RESEARCH GROWTH CHART v1.0 (University of Virginia)
Cerebral Palsy, GMFCS III–V
Girls – Tibial Length
Tibial Length (cm)
10
15
20
25
30
35
40
45
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Age (yrs)
97th
90th
75th
50th
25th
10th
3rd


NAGCPP RESEARCH GROWTH CHART v1.0 (University of Virginia)
Cerebral Palsy, GMFCS III–V
Boys – Upper Arm Length
Upper Arm Length (cm)
10
15
20
25
30
35
40
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Age (yrs)
97th
90th
75th
50th
25th
10th
3rd



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