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Estimation of Length or Height in Infants and Young Children Using Ulnar and Lower Leg Length with Dual-energy X-ray Absorptiometry Validation

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Estimation of length or height in infants and young children using ulnar and lower leg length with dual-energy X-ray absorptiometry validation

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Abstract

AIM—We compared the accuracy and reproducibility of using ulnar and lower leg length measurements to predict length and height in infants and children aged 0–6 years.

METHOD—Length/height and ulnar and lower leg length were measured in 352 healthy preterm and term-born children (16 males, 185 females). Ulna length was measured as the distance between the proximal olecranon process and the distal styloid process of the ulna. Tibia length was measured as the distance from the proximal aspect of the medial condyle and the most distal aspect of the medial malleolus of the tibia using a segmometer. Length measurements were taken using an infant length board in children less than 24 months of age, whereas a portable stadiometer was used to measure height in older children. Equations were developed using ulnar and lower leg length and age. Intra- and inter-examiner variability (n=167) was calculated, and dual-energy X-ray absorptiometry scans (n=126) were used to determine accuracy of limb lengths.

Results—Ulnar and lower leg length explained over 95% of the variability in length/height in term infants and children, but less in preterm infants (R²=0.80–0.87). In preterm infants, the limits of agreement (LOA) for males were −2.44 to 2.44cm and −2.88 to 2.88cm for the ulna and lower leg respectively, whereas the LOA for females were −1.90 to 1.90cm and −1.87 to 1.87cm respectively. In older children, the LOA for males were −5.53 to 4.48cm and −5.59 to 4.62cm for the ulna and lower leg respectively, whereas the LOA for females were −5.57 to 5.01cm and −6.02 to 5.02cm respectively. Intra- and inter-examiner variability was low for all measurements in both sexes and age groups.

INTERPRETATION—Length and height measurements using infant length board or stadiometer are reproducible. Because of the wide limits of agreement, estimation of length and height in children using ulnar and lower leg length is not an acceptable alternative to traditional methods.
The American Academy of Pediatrics recommends frequent length measurements during the first 18 months of a child’s life. In infants and children, length and height measurements are used in the determination of weight status, \(^1\) and measurements of stature are important in monitoring the growth and development of children. Therefore, accurate and reproducible measurements are important in preventing the misdiagnosis of several medical conditions.

Frequent measurements of length are made in preterm infants and accurate monitoring is important as changes are small. Because preterm infants are sensitive to over-stimulation, a less invasive method for estimating length would be beneficial. Length and height measurements are also used in the estimation of pulmonary function and inaccurate measurements can lead to misdiagnoses. In children who are unable to have their height measured using standard measures, ulnar length measurements may provide an alternative method. Ulnar length measurements have been used to predict pulmonary function \(^2\) and height \(^3\) in children aged between 5 and 19 years. Our study expands on the findings reported by Gauld et al. \(^3\) to include infants and children from birth to 5 years of age.

Data describing the accuracy of current length measurement methods in children vary and are inconclusive. Some studies have determined that when a proper technique is utilized the infant length board measurement is reliable and repeatable. \(^4,5\) However, other studies have reported the amount of error that exists between different examiners when using an infant length board measurement is large. \(^6,7\) and this has warranted the investigation of alternative length and height estimation methods. Heel-to-knee height has been used in the estimation of height in children with cerebral palsy. \(^8,9\) Additionally, a prediction equation using ulna length and age to determine height has been created for children between 5 and 19 years of age; \(^3\) however, no study has focused exclusively on children younger than 6 years of age using ulna measurements. A chart has been developed that expresses predicted segmental bone lengths as a percentage of sitting height in children as young as 2 years of age, \(^10\) but whether this relates to total body length or height is unknown.

Large epidemiological studies currently assess infant length using a supine length board and a child’s height using a portable stadiometer. One problem is that many of these visits take place in participants’ homes and the amount of equipment required for these visits can be overwhelming. The primary purpose of this study was to compare the accuracy and reproducibility of using ulnar and lower leg length to create prediction equations for length and height in infants and children aged 0 to 5 years. With this measurement technique, only a segmometer would be required. Other goals of this study were to determine if the reproducibility of limb measurements would be better than the reproducibility of infant length board and stadiometer measurements, and to determine whether the limb length measurements correlated with bone measurements using dual-energy X-ray absorptiometry (DXA).

**METHOD**

**Study population**

A convenience sample of healthy children from 0 and 5 years of age was recruited from communities surrounding South Dakota State University (Brookings, SD) and the University
of Utah (Salt Lake City, UT). Preterm infants were recruited from neonatal intensive care units located in Avera McKennan Hospital and University Health Center in Sioux Falls, SD and University Hospital at the University of Utah in Salt Lake City, UT, and were inpatients at the time of study. Parents of the infants and children were asked to provide informed consent and completed a brief questionnaire regarding the medical history and racial background of their child. Medical history questionnaires were reviewed for the presence of conditions that could affect growth; none of the children was excluded.

**Anthropometric measurements**

An individual with several years of experience in anthropometric measurements provided training at each of the sites. Examiners taking the measurements were instructed on the correct use of the measuring devices as well as patient positioning. In addition to the training on measurement technique, examiners were trained on palpation skills and the necessary anatomy to complete study visits.

Three individuals were trained and obtained all of the measurements at the two study locations. Measurements taken in preterm and term infants and all children were taken by the same two individuals. Measurements of length or height, ulna length, and lower leg length were all taken in triplicate and rounded to the nearest 0.1cm. In a subsample of children \( n = 167 \), all measurements were taken by two examiners to determine inter-examiner variability of the measurements. Children younger than 24 months had their length measured using a portable infantometer (SECA, Hanover, MD) and children 24 months and older had their height measured using a portable stadiometer (SECA, Hanover, MD). Ulna measurements were taken on the right arm with the child either lying supine or sitting, depending on their developmental stage. A small mark was made on the distal styloid process and the proximal olecranon process of the ulna. After completion of the measurements by the first examiner, the location of the marks was verified by the second examiner and adjusted as necessary. A Segmometer 4 (Rosscraft Surrey, BC, Canada) was used to measure the distance between these two points. Lower leg length was measured on the child’s right leg while lying in a supine position with the knee flexed at a 90 degree angle and the ankle dorsiflexed at a 90 degree angle. Reference marks were placed at the most proximal aspect of the medial condyle and the most distal aspect of the medial malleolus of the tibia. The same segmometer device used for ulna length measurements was used to measure lower leg length.

**Dual-energy X-ray absorptiometry**

DXA scans of the children’s forearm and lower leg were performed on a subset of children \( n = 126 \) to determine the relationship between segmometer measurements and the true length of the children’s bones. This measurement was important in determining if the measures obtained with the segmometer were an accurate representation of the child’s actual bone length. As the DXA scans involved the use of X-rays, the parent or legal guardian of each child was made aware of the potential risks of participation in the DXA portion of the study and asked to give their consent. This procedure has an estimated effective dose of 1mRem. The effective dose is within the negligible individual risk limit of 1mRem that has been established by the National Council for Radiation Protection and below the maximum.
acceptable effective dose allowed in children from medical research (single whole body
dose of 300mRem or annual whole body dose of 500mRem). High-definition intervertebral
assessment imaging, which is typically used in lumbar spine assessment, was used to capture
the images. Once the images were obtained, markers were placed at the distal ulnar styloid
process and the proximal olecranon process of the ulna and the distal medial malleolus and
proximal medial condyle of the tibia (Fig. 1). APEX software, version 3.3 (Hologic Inc.,
Bedford, MA, USA) was used to measure the distance between these markers and calculated
bone length.

Statistical analysis

Analyses were performed separately for neonatal preterm infants and term infants up to 5
years of age. We first evaluated the repeatability and reproducibility of the segmometer
measurements and the height measurement. For determination of intra-examiner
repeatability, the individual sets of measurements from examiner 1 were used (n=325). For
determination of inter-examiner reproducibility, the subset of 167 children who had two sets
of measurements taken was used. The Bland–Altman method\textsuperscript{11} was used to determine the
repeatability of the height, ulna length, and lower leg length measurements. Within
participant standard deviation (SD\textsubscript{w}) was calculated as the square root of residual mean
square obtained using one-way analysis of variance with participant as the factor variable.
Using the SD\textsubscript{w}, repeatability coefficients were calculated for each of the three measurements
as $1.96 \sqrt{2*SD_{w}}$.

Next, the accuracy of the segmometer measurements was evaluated by calculating the 95% limits of agreement (LOA) for ulna and tibia length measured by segmometer versus DXA\textsuperscript{11}. Limits of agreement were calculated as the mean difference and the 1.96 standard
deviations of the difference. Bland–Altman Plots were used to evaluate the relationship
between measured and predicted values across a range of measurements.

To evaluate the utility of segmometer-based measurement of ulna and tibia length as
surrogates for body length and height measurement, prediction equations were developed
using the coefficients from fractional polynomial regression models using age and either
ulna length or lower leg length as predictors. Fractional polynomial regression was used to
model the nonlinear relationship between length/height and age. The prediction equations
were developed using a random sample of one half of the participants (sample 1) and then
tested using the other half of participants (sample 2). Differences ($d$) between measured
height and height predicted using the fractional polynomial regression model were
calculated and means and standard deviations of the differences were obtained using sample
2 data. Limits of agreement were calculated as $\bar{d} \pm (1.96 * SD_{d})$ for equations where $\bar{d}$
was not related to the mean. If $d$ varied according to the mean, residuals (difference between
measured and predicted values($\hat{D}$)) were calculated,\textsuperscript{11} and absolute values of the residuals
were regressed on the average of measured and predicted values. From this regression
model, predicted residual values ($\hat{R}$) were obtained, and the 95% levels of agreement were
calculated as $\hat{D} \pm 1.96 \sqrt{\frac{\pi}{2} * \hat{R}}$. Bland–Altman Plots were used to evaluate the relationship
between measured and predicted values across a range of measurements.
The study was approved by the human participants review boards at South Dakota State University and University of Utah. Written informed consent was obtained from the parent or legal guardian of all participants before any study visits took place or measurements were obtained.

RESULTS

A total of 352 children distributed across the age ranges (preterm infants 7 to 70 days of age, \( n = 27 \); 0–0.9 years, \( n = 60 \); 1–2 years, \( n = 63 \); 2–2.9 years, \( n = 57 \); 3–3.9 years, \( n = 63 \); 4–4.9 years, \( n = 50 \); 5–5.9 years, \( n = 32 \)) participated in the study. Measurements were obtained by two examiners in 167 of 358 infants and children (age range of 0 to 5.9 years) and DXA ulna and tibia length measurements were obtained in 126 infants and children (age range of 0 to 5.9 years).

In term infants and children, measurements of length, height, ulna length, and lower leg length were repeatable within examiner and between examiners (Table I). In preterm infants, the results were similar with a high level of repeatability and reproducibility being exhibited within and between examiners (Table I). Bland–Altman plots including both preterm neonates and children confirmed that intra- and inter-examiner variability was independent of length/height, ulna length, and lower leg length (data not shown).

When comparing DXA and segmometer measurements, the segmometer measurement overestimated ulna length and lower leg length in term infants and older children as well as preterm infants (Table II). Bland–Altman plots of the difference between segmometer and DXA measurements are given in Figure 2. In preterm infants, the segmometer overestimated ulna length by 1.46cm and lower leg length by 2.24cm. The 95% LOA were 0.75 to 2.16cm for ulnar length and 1.31 to 3.18cm for lower leg length in preterm infants.

Preterm infants

Prediction equations were developed from fractional polynomial regression models including ulna or lower leg length, gestational age, and the natural log of gestational age (Table III). No direction-specific bias was observed for the difference between measured and predicted length based on the prediction equation using either ulnar or lower leg lengths; all equations explained between 80% and 87% of the variability in height measurements. The 95% LOA for measured-predicted length based on ulna length were −2.44 to 2.44cm and −1.90 to 1.90cm for males and females respectively. The difference in measured and predicted length was independent of the mean measurement. The 95% LOA for measured-predicted length based on lower leg length were −2.88 to 2.88cm and −1.87 to 1.87cm for males and females respectively. The difference between measured and predicted lengths for both equations was independent of the mean measurement in both sexes.

Term infants and children

Similar to preterm infants, prediction equations were developed from fractional polynomial regression models and included ulna or lower leg length, age, and the product of age and natural log of age (age*\( \log \)Age); see Table IV). No direction-specific bias was observed for the difference between measured and predicted height using any of the prediction equations.
and equations explained between 97% and 98% of the variability in height measurements. The 95% LOA for measured-predicted height based on ulna length were −5.53 to 4.48cm and −5.57 to 5.01cm for males and females respectively. For measured-predicted height based on lower leg length, the 95% LOA for males and females were −5.59 to 4.62cm and −6.02 to 5.02cm respectively. The difference between measured and predicted lengths and heights based on ulna length and lower leg length was independent of the mean length/height (Fig. 3).

DISCUSSION

Measurements taken using a segmometer were highly related to those obtained using DXA; however, a bias was observed with segmometer measurements over-estimating the DXA measurements. This is likely to be due to the inclusion of soft tissue when using a segmometer as opposed to a direct bone measurement. In situations where a direction-specific bias is occurring within a measurement, a correction factor is recommended.\(^\text{11}\) This correction factor would typically be the mean difference between the measurements and in the case of this study would range from 1.46cm for the ulna of preterm infants up to 2.57cm for the lower leg of term infants and children. These findings are important because they indicate that if a correction factor is applied, the use of a segmometer in obtaining bone length measurements in infants and children is effective. Additionally, validation of the technique used to obtain measurements using the segmometer was an important objective of this study and our findings support its use.

Measurements of length/height, ulna length, and lower leg length were highly repeatable at all ages. While our study indicates that the repeatability coefficients did not vary between preterm infants and children, it is important to consider that the range in length is narrower and the mean length is smaller in preterm infants. As the overall measurement size is smaller in preterm infants, the repeatability coefficient represents a greater percentage of the measurement indicating a potentially greater variability. This is likely to be caused by the small size of preterm infants that makes the measurement more difficult.

In preterm infants, the \(R^2\) values for the prediction equations were low in comparison to previous studies and our data in term infants and children; however, our LOA were small enough that the equations may still have some utility in clinical practice if other means of measurement are not possible. The lower \(R^2\) value seen in these equations could be a combination of smaller bone size, but the small sample and narrow range in values may also have played a role. Inaccuracies in measuring length in preterm infants with the infant length board also could have decreased the association. For research purposes, the LOA were too wide to allow for generalizability of results in large epidemiological studies. Individuals designing these studies should continue the use of infant length boards and portable stadiometers that had relatively low levels of variability (±0.45cm and ±0.27cm respectively).

While previous studies have created prediction equations for estimating stature based on segmental body lengths,\(^2,12–14\) our study is the first to do this in infants and children less than 6 years of age. Our \(R^2\) values for prediction equations ranged from 0.97 to 0.98 in term
infants and children, and are similar to those obtained by Gauld et al.\textsuperscript{2} (0.94–0.98) but higher than other studies that used segmental DXA measurements in height prediction.\textsuperscript{12,14}

Based on the $R^2$ statistics, all prediction equations for term infants and children adequately predicted mean height and length. From a clinical perspective, however, the actual range of values that the prediction would be expected to deviate from the mean is important. To address this, the 95% LOA were calculated to determine how many centimeters above or below the actual measurement the predicted values could fall. In preterm infants, the 95% LOA were less than 3cm and this may be acceptable in situations where measuring length using traditional methods is either unsafe or impossible. Clinicians and researchers must decide whether this is an acceptable value in their practice. Limits of agreement were somewhat higher in older children ranging from –6.02 to 5.02cm for all equations. These findings indicate that the equation may not necessarily be suitable for use in most clinical and research situations. One important consideration when looking at LOA is that they are only estimates of agreement between methods. As a result they are sensitive to sample size and, therefore, we must consider that the sample in this study was relatively small, especially for preterm infants.

One limitation is the potential measurement bias created by not removing reference marks between examiners. It was determined that removing marks from the child might cause discomfort and therefore the initial mark was verified and adjusted as deemed necessary by the second examiner. Another limitation is the small number of individuals who performed the measurements. In a clinical or large research setting, more individuals may be taking the measurements and greater variability between observers may occur. Finally, we are uncertain whether the reliability of these measurements would be similar if they were taken in children who were unable to have their height or length measured using normal methods because of an illness or disability.

In conclusion, measurement of ulna and lower leg length with a segmometer is repeatable as shown by low repeatability coefficients. While the repeatability of all measures was acceptable, the range of predicted values was beyond what we consider to be clinically acceptable in term infants and children. In the preterm infants the range of predicted values was nearer to the actual measurement; however, discretion must be used on the part of researchers and practitioners as to whether or not the equations are adequate.

**Acknowledgments**

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ABBREVIATIONS

**DXA**  Dual-energy X-ray absorptiometry

**LOA**  Limits of agreement

REFERENCES


What this paper adds

- Measurement of ulna and lower leg length with a segmometer is reproducible and accurate based on DXA validation.
- The range of predicted values for height and length were beyond what we consider to be clinically acceptable in term infants and children.
- In the preterm infants the range of predicted values was nearer to the actual measurement.
Figure 1.
High-definition intervertebral assessment images of the ulna and tibia with markers placed at the distal styloid and proximal olecranon processes of the ulna and the distal medial malleolus and the most proximal point of the tibia.
Figure 2.
(a) Bland–Altman plot of the difference between ulna length measured by segmometer and dual-energy X-ray absorptiometry (DXA). (b) Bland-Altman plot of the difference between tibia length measured by segmometer and DXA.
Figure 3.
(a) Bland–Altman plot of the difference between predicted and measured height in term infants and children using the ulna length equation. Reference lines represent the 95% limits of agreement for the respective sexes. (b) Bland–Altman plot of the difference between predicted and measured height in term infants and children using the tibia length equation. Reference lines represent the 95% limits of agreement for the respective sexes.
Table I

Variability within and between examiners

<table>
<thead>
<tr>
<th></th>
<th>Preterm infants (n=27)</th>
<th>Term infants and older children (n=325)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repeatability coefficient (cm)</td>
<td>95% Limits of agreement</td>
</tr>
<tr>
<td>Height</td>
<td>0.86</td>
<td>−0.57, 0.57</td>
</tr>
<tr>
<td>Ulna</td>
<td>0.78</td>
<td>−0.62, 0.50</td>
</tr>
<tr>
<td>Lower Leg</td>
<td>0.72</td>
<td>−0.68, 0.52</td>
</tr>
</tbody>
</table>

Repeatability coefficient, variability within participant by the same examiner.
**Table II**

Mean difference and 95% limits of agreement (LOA) between segmometer and dual-energy X-ray absorptiometry measurements

<table>
<thead>
<tr>
<th></th>
<th>Preterm infants (n=11)</th>
<th>Term infants and older children (n=167)</th>
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<tbody>
<tr>
<td></td>
<td>Mean difference</td>
<td>95% LOA</td>
</tr>
<tr>
<td>Ulna</td>
<td>1.46</td>
<td>0.75, 2.16</td>
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<tr>
<td>Lower leg</td>
<td>2.24</td>
<td>1.31, 3.18</td>
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</table>
### Table III

Regression equations for length in preterm infants

<table>
<thead>
<tr>
<th></th>
<th>Prediction equation</th>
<th>$R^2$</th>
<th>95% LOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males ($n=13$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulna</td>
<td>Ulna(2.15) − GA(12.35) + lnAge(434.88) − 1081.25</td>
<td>0.87</td>
<td>−2.44, 2.44</td>
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<tr>
<td>Lower Leg</td>
<td>Tibia(2.09) − GA(13.40) + lnAge(472.69) − 1180.73</td>
<td>0.81</td>
<td>−2.88, 2.88</td>
</tr>
<tr>
<td>Females ($n=14$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulna</td>
<td>Ulna(0.48) − GA(13.64) + lnAge(528.02) − 1358.61</td>
<td>0.80</td>
<td>−1.90, 1.90</td>
</tr>
<tr>
<td>Lower Leg</td>
<td>Tibia(0.42) − GA(14.19) + lnAge(549.66) − 1415.96</td>
<td>0.81</td>
<td>−1.87, 1.87</td>
</tr>
</tbody>
</table>

GA, gestational age; LOA, limits of agreement.
Table IV

Regression equations for length and height in term infants and children

<table>
<thead>
<tr>
<th></th>
<th>Prediction equation</th>
<th>$R^2$</th>
<th>95% LOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males (n=154)</td>
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<tr>
<td>Ulna</td>
<td>Ulna(3.64) + Age(9.76) − Age*logAge(2.9) + 23.86</td>
<td>0.98</td>
<td>−5.53, 4.48</td>
</tr>
<tr>
<td>Lower Leg</td>
<td>Tibia(2.52) + Age(8.49) − Age*logAge(2.82) + 32.49</td>
<td>0.98</td>
<td>−5.59, 4.62</td>
</tr>
<tr>
<td>Females (n=171)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulna</td>
<td>Ulna(3.04) + Age(11.98) − Age*logAge(3.53) + 27.45</td>
<td>0.97</td>
<td>−5.57, 5.01</td>
</tr>
<tr>
<td>Lower Leg</td>
<td>Tibia(1.96) + Age(12.29) − Age*logAge(4.04) + 34.73</td>
<td>0.98</td>
<td>−6.02, 5.02</td>
</tr>
</tbody>
</table>

LOA, limits of agreement.