Reference ranges for midupper arm circumference, upper arm muscle area, and upper arm fat area in US children and adolescents aged 1–20 y$^{1,2}$

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**ABSTRACT**

**Background:** Midupper arm circumference (MUAC) has long been used in anthropometric assessments of nutritional status in field settings, especially in emergency situations, but percentile ranges for healthy, well-nourished children are currently unavailable.

**Objective:** We developed reference curves for MUAC and derived measures of arm muscle area (AMA) and arm fat area (AFA) on the basis of the population used in the current CDC body mass index growth index charts.

**Design:** We analyzed cross-sectional MUAC and triceps (triceps skinfold thickness) data from 32,952 US children aged 1–20 y. Generalized additive models for location, scale, and shape were used to calculate semiparametric smoothed percentiles and $L$, $M$, and $S$ coefficients needed for $z$-score estimation by age and sex. Equations were developed with the use of the height-for-age $z$ score (HAZ) to adjust for the associations of stature with upper arm measures.

**Results:** MUAC increased with age steadily throughout the growing period. For children $<$5 y old, lower percentile ranges varied markedly across age and sex such that the single cutoff ($<11.5$ or $12.5$ cm) for field screening of acute malnutrition did not track along the same percentile. AFA and AMA growth patterns exhibited sex-specific trends including multiple distinct age-related inflections that were more pronounced in males for AFA-for-age than in females. HAZ and age were substantially and independently related with all arm measures.

**Conclusions:** The new reference percentile ranges for midupper arm measures for healthy children provide a useful nutritional assessment tool in a wide variety of settings. Height status (HAZ) to adjust for the associations of stature with upper arm measures.

**Keywords:** arm, nutritional assessment, percentiles, references, stature

**INTRODUCTION**

The assessment of anthropometric measures is a rapid, safe, inexpensive, and effective method to screen for malnutrition in children (1). In most settings, measurements of height and weight are sufficient for nutritional status assessment. The measurement of midupper arm circumference (MUAC)$^6$ has been used in field settings to rapidly identify young children with undernutrition who are at elevated risk of near-term mortality, especially under emergency situations such as famine or refugee crises (2). MUAC, together with the triceps skinfold thickness (TSFT) can be used to estimate skeletal muscle and subcutaneous fat stores (3).

Recently, the Academy of Nutrition and Dietetics consensus report on the nutritional assessment of critically ill children recommended the use of MUAC to assess nutritional status in bedbound children when measurements of weight and length or height were not feasible (4). However, only limited reference data for MUAC are available for children $>5$ y of age, and these data were not established with the use of contemporary statistical approaches that provide smoothed reference percentiles (3).

In children aged 2–20 y, the CDC 2000 BMI reference percentiles are most commonly used to screen for underweight, overweight, and obesity. The CDC 2000 BMI charts were based on $>32,600$ observations of children throughout the United States that were measured between 1963 and 1994; children $\geq6$ y of age who were measured between 1988 and 1994 were excluded because of the rising prevalence of obesity (5). More recently, Addo and Himes (6) published references for skinfold thicknesses at TSFT and subscapular skinfold thickness (SSFT) sites to aid in the interpretation of subcutaneous fat measures.

$^1$The authors reported no funding received for this study.

$^2$Supplemental Tables 1 and 2 are available from the “Online Supporting Material” link in the online posting of the article and from the same link in the online table of contents at http://ajcn.nutrition.org.

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$^6$Abbreviations used: AFA, arm fat area; AMA, arm muscle area; GAMLSS, generalized additive models for location, scale, and shape; HAZ, height-for-age $z$ score; MUAC, midupper arm circumference; SSFT, subscapular skinfold thickness; TSFT, triceps skinfold thickness.

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with the use of a nearly identical set of children who were not exposed to the more obesogenic environment of the previous decades. In the current study, we present reference ranges for MUAC, upper arm muscle area (AMA), and upper arm fat area (AFA) from the same individuals for use in a nutritional status assessment.

METHODS

Data sources and participant measures

We analyzed pooled anthropometric data from the following 5 US cross-sectional national surveys from 1963 through 1994: the National Health Examination Surveys (cycles II and III) and 3 NHANESs (NHANES I–III). The NHANES was approved by the Ethics Review Board of the National Center for Health Statistics, and informed consent was obtained for all participants (parents and guardians for minors). The current report was based on MUAC and 2 derived measures of midupper AMA and AFA.

All anthropometric measures were obtained according to standardized protocols (7) and by highly trained technicians (8). Standing height was measured to the nearest 0.1 cm with the use of a stadiometer. MUAC was measured to the nearest 0.1 cm on the right arm midway between the acromion and olecranon processes of the ulna with the use of a steel or fiberglass tape over the survey 5 cycles (8), and TSFT was measured to the nearest 0.2 or 0.5 mm depending on the survey. We are not aware of equations to convert Lange caliper (Lange) measures to Holtain caliper (Holtain Inc.) measures, and therefore, we conducted 2 statistical analyses to assess potential differences. Because 2 different calipers were used across the 5 surveys (8). First, in a subset of children aged 2–5 y, TSFT was measured with the use of a Holtain caliper in 4010 cases and with a Lange caliper in 5177 cases. In a pooled linear regression with TSFT (transformed to normality), the potential differences were considered generally minimal because the upper arm area (AA) (3, 9) was derived as

\[
AA = \left(\pi \div 4 \right) \times D^2
\]

where \( D \) is the arm diameter, which was calculated as

\[
MUAC \div \pi
\]

AFA was calculated as

\[
AFA (\text{mm}^2) = AA - AMA
\]

Data exclusions

The analytic study sample was selected to be comparable to published national references, namely, the CDC 2000 charts and 2010 skinfold-thickness curves (5, 6). In addition, observations with missing TSFT (for deriving upper AFA and upper AMA), sex, and unascertainable age were excluded. Only a small proportion of cases were excluded; our total sample was 32,952 cases compared with a sample size of \( \sim 33,000 \) cases that were used in the creation of the CDC 2000 BMI curves (5) and the 32,800 individuals used in the curves for TSFT and SSFT (6). To be consistent with the CDC 2000 BMI charts (5), children \( \geq 6 \) y of age were excluded from the NHANES III as were data from the Hispanic HANES (1982–1984) [Mexican Americans (residing in 5 Southwestern United States: Texas, Colorado, New Mexico, Arizona, and California); Cuban Americans (in Miami-Dade County, Florida); and Puerto Ricans (in New York, New Jersey, and Connecticut)]. MUAC measurements of 3 participants were flagged as being potential outliers per Tukey’s far-outside rule of \( \sim \pm 5 \) SDs (10) in sex-specific distributions but were left in the data pool for developing the reference curves.

Statistical analysis

All analyses were conducted with the use of R 3.2.0 software (The R Foundation for Statistical Computing), STATA 14 software (StataCorp LP), and SAS 9.4 software (SAS Institute Inc.). We developed MUAC-for-age, AFA-for-age, and AMA-for-age curves with the use of GAMLSS (11). The method used a semi-parametric maximum likelihood to estimate smoothed growth curves that could be summarized by the median (\( M \)), generalized CV (\( S \)), and Box-Cox power for skew (\( L \)) while concurrently accounting for kurtosis (\( T \)). The technique also used locally weighted splines to smooth across age to obtain final fitted objective functions that were used to calculate percentiles. To address potential end-effects artifacts that were associated with smoothed growth-curve modeling, we included participants aged 1.0 to 24.0 y to establish the fitted function for generating the age- and sex-specific smoothed reference ranges and LMS variables for ages 1.0–20 y for MUAC, AFA, and AMA.

We used a large variety of statistical and visual diagnostic tools to guide the choice of our final GAMLSS. These tools included worm plots, residual, Owen D-trend plots, as well as an examination of the percentile of smoothed curves that were superimposed on the empirical data. Intracluster variance
because of NHANES survey-design effects (primary sampling units and strata) as were derived with the use of the sandwich estimator that ranged from 1.6% to 1.7% (weighted analyses resulted in a very minute intraclass correlation coefficient). Thus, only sampling weights were accounted for in the new reference percentile calculations.

Height-for-age adjustment and prediction equations

The independent effects of height status on upper arm measures (circumference, muscle area, and fat area) as children grow were accounted for with the use of linear regressions with Taylor series variance estimation (12). SDs (z scores) were first calculated for the 3 arm measures with the use of the age-sex specific LMS coefficients that were generated from our final GAMLSS. Height-for-age z scores (HAZs) were calculated with the use of the CDC 2000 charts for participants aged 2–20 y and with the use of the WHO 2006 growth reference data for subjects <2 y of age (13, 14).

In survey linear regressions, age, age squared, HAZ, and 2 interactions (HAZ × age; HAZ × age squared) were used as predictors and were regressed against arm z scores as outcome variables. Several regression diagnostics were used to judge the overall model fit and were shown to be acceptable. An evaluation of adjusted arm z scores indicated adequate adjustment especially for children in the top and lower 15th HAZ percentiles. Prediction equations were developed separately for males and females on the basis of the regressions used to study associations between the HAZ and age with each of the arm z scores and were generated with the use of 500 bootstrap (15) replications.

RESULTS

The 5 US national survey databases used in generating the new percentile curves for MUAC and derived measures of midupper AMA and AFA are shown in Table 1. Participant age ranged from 1.0 to 20.0 y, and a total of 32,952 MUAC and TSFT measurements (from 16,715 males and 16,237 females) were used.

Crude rank correlations in MUAC, skinfold thickness (TSFT and SSFT), and height were generally positive and moderately high for both males and females (Table 2). Both derived arm measures (AMA and AFA) were correlated with skinfold thickness. Across all ages, AFA had stronger correlations with skinfold thicknesses than did AMA.

### TABLE 1
Analytic data sources

<table>
<thead>
<tr>
<th>Survey, year</th>
<th>Age range, y</th>
<th>Sample size, n</th>
</tr>
</thead>
<tbody>
<tr>
<td>NHANES III, 1988–94</td>
<td>2.00–5.92</td>
<td>4010</td>
</tr>
<tr>
<td>NHANES II, 1976–80</td>
<td>2.00–20.00</td>
<td>7355</td>
</tr>
<tr>
<td>NHANES I, 1971–74</td>
<td>1.00–20.00</td>
<td>7700</td>
</tr>
<tr>
<td>NHANES III, 1966–70</td>
<td>12.00–18.08</td>
<td>6768</td>
</tr>
<tr>
<td>NHANES II, 1963–65</td>
<td>6.00–12.08</td>
<td>7119</td>
</tr>
<tr>
<td>Total</td>
<td>1.0–20.00</td>
<td>32,952</td>
</tr>
</tbody>
</table>

1 Analyzed arm measures included midupper arm circumference and derived arm muscle area and arm fat area that were determined with the use of triceps skinfold thickness.

2 NHES, National Health Examination Survey.

### TABLE 2
Intercorrelation in anthropometric measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>BMI</th>
<th>Height</th>
<th>TSFT</th>
<th>SSFT</th>
<th>AMA</th>
<th>AFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MUAC</td>
<td>0.86</td>
<td>0.89</td>
<td>0.23</td>
<td>0.61</td>
<td>0.96</td>
<td>0.66</td>
</tr>
<tr>
<td>BMI</td>
<td>—</td>
<td>0.66</td>
<td>0.37</td>
<td>0.74</td>
<td>0.78</td>
<td>0.71</td>
</tr>
<tr>
<td>Height</td>
<td>—</td>
<td>—</td>
<td>0.03</td>
<td>0.38</td>
<td>0.93</td>
<td>0.41</td>
</tr>
<tr>
<td>TSFT</td>
<td>—</td>
<td>—</td>
<td>0.57</td>
<td>0.00</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>SSFT</td>
<td>—</td>
<td>—</td>
<td>0.47</td>
<td>0.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMA</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AFA</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Female

<table>
<thead>
<tr>
<th>Measure</th>
<th>BMI</th>
<th>Height</th>
<th>TSFT</th>
<th>SSFT</th>
<th>AMA</th>
<th>AFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUAC</td>
<td>0.88</td>
<td>0.85</td>
<td>0.72</td>
<td>0.75</td>
<td>0.95</td>
<td>0.88</td>
</tr>
<tr>
<td>BMI</td>
<td>—</td>
<td>0.65</td>
<td>0.74</td>
<td>0.82</td>
<td>0.80</td>
<td>0.85</td>
</tr>
<tr>
<td>Height</td>
<td>—</td>
<td>—</td>
<td>0.46</td>
<td>0.50</td>
<td>0.88</td>
<td>0.66</td>
</tr>
<tr>
<td>TSFT</td>
<td>—</td>
<td>—</td>
<td>0.77</td>
<td>0.49</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>SSFT</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.61</td>
<td>0.82</td>
<td></td>
</tr>
</tbody>
</table>

1 AMA = (MUAC − p \times \text{triceps}^2) / 4 \pi. AFA (mm^2) = AA − AMA, where AA is the arm area calculated as AA = \pi \times D^2 (where D is the arm diameter calculated as MUAC / \pi). Spearman correlations were used. AFA, arm fat area; AMA, arm muscle area; MUAC, midupper arm circumference; SSFT, subscapular skinfold thickness; TSFT, triceps skinfold thickness.

2 TSFT was inversely correlated with AMA (r = −0.0048) but is shown as 0.00 because it was rounded to 2 decimal places.

Age- and sex-specific smoothed percentiles and corresponding LMS variables for MUAC, AMA, and AFA are shown in Tables 3–5 as well as in corresponding Figures 1–3. Estimates are presented at half-year ages from 1 to 20 y (monthly estimates are available in Supplemental Table 1). The positive associations between these arm measures and height are shown in Table 2. Consequently, even within an age group, differences in MUACs, e.g., were biased by the height of the child. Regression equations for the prediction of MUAC, AMA, and AFA with age and height accounted for are presented for each sex in Table 6.

Sex differences in patterns of growth

There was a steady increase with age for all upper arm measures with the exception of AFA—for-age in males, which had multiple distinct age-related inflections (data not shown). In males, AFA was characterized by a slight decline in the median AFA in childhood between ages 2 and 6 y, age-related increases from ages 6–11.5 y, slower gains from 12 to 15 y of age, and a faster age-related increase from 16 to 20 y of age. In contrast, females exhibited gradual age-related increases between 2 and 6 y of age and more-intense increases from 6.5 to 20 y of age. AMA had no marked sex differences in age-related trends until age 12 y. After age 12 y, males had much greater age-related increases in AMA than did females of similar age.

Comparisons with existing curves

The new curves were compared with 1981 norms (2) and showed similar overall growth patterns, but median estimates were systematically different (data not shown). MUAC-for-age medians were higher in the current data for males <12 y of age, but not thereafter, and for females, only subjects ≥9 y of age had higher MUACs relative to the 1981 data. Similar differences
were observed with AMA-for-age and AFA-for-age curves. The new median Multi-Centre Growth Study-for-age curves were also compared with the WHO Multi-Centre Growth Study 2006 standards (11) for children aged 2–5 y, showing strong similarities, but the new curves were ~1 cm higher (data not shown). The cutoffs used for acute-malnutrition screening (severe acute malnutrition: <11.5 cm; moderate acute malnutrition: 12.5 cm) corresponded to low z scores (range: −3.8 to −2.5) with the use of the new MUAC-for-age ranges, did not track along a single percentile, and varied markedly across age and sex (data not shown).

**DISCUSSION**

We present smoothed reference percentile curves for MUAC and derived measures of midupper AMA and AFA for healthy US children and adolescents aged 1–20 y. The new curves were derived from a large, nationally representative sample who were nearly identical to the sample used in constructing the CDC 2000 BMI charts (5) and the 2010 skinfold-thickness percentiles of Addo and Himes (6) and, thus, introduced no sampling issues for comparisons across measures. MUAC has been used in nutrition assessments for severe acute malnutrition (2, 16). It also

| TABLE 3 |
| MUAC-for-age LMS variables and percentiles¹ |

<table>
<thead>
<tr>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L</strong></td>
<td><strong>S</strong></td>
</tr>
<tr>
<td>3rd</td>
<td>5th</td>
</tr>
<tr>
<td>3rd</td>
<td>5th</td>
</tr>
</tbody>
</table>

¹Semiparametric GAMLS models with polynomial age splines were used to calculate all estimates. S denotes the generalized CV, L denotes the Box-Cox power transformation of the objective function for each growth curve, and M denotes the median. z Scores can be calculated with the use of the LMS coefficients that are specific to the nearest completed month or one-half year of age for a child or adolescent for each measured MUAC with the following expression: $z = \sqrt{(\text{MUAC} \times M/L)^2 - 1} \times S \times L$. Supplemental Table 1, with estimates for every 6 mo of age, shows the entire listing of LMS parameters and all percentiles (third through 97th). If the age (in mo) of the subject is available, a more precise age-in-month z-score estimate can be obtained with the use of the monthly data (provided in Supplemental Table 2 for estimates every 1 mo of age). MUAC, midupper arm circumference.
has practical applications in special populations such as amputees, persons with posture problems, and critically ill patients (4) has practical applications in special populations such as amputees, persons with posture problems, and critically ill patients (4) has practical applications in special populations such as amputees, persons with posture problems, and critically ill patients (4) has practical applications in special populations such as amputees, persons with posture problems, and critically ill patients (4) has practical applications in special populations such as amputees, persons with posture problems, and critically ill patients (4) has practical applications in special populations such as amputees, persons with posture problems, and critically ill patients (4) has practical applications in special populations such as amputees, persons with posture problems, and critically ill patients (4) has practical applications in special populations such as amputees, persons with 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posture problems, and critically ill patients (4)
to the nearest completed month or one-half year of age for a child or adolescent (Tables 3–5, Supplemental Table 1, Supplemental Table 2), \( z \) scores can be calculated that correspond to the published reference percentiles for each arm measurement (y) (i.e., MUAC, AMA, or AFA) with the expression

\[
z = \frac{(y - \mu)}{\sigma} = \frac{(y - \text{Mean})}{\text{SD}} = \frac{(y - \text{Midupper AFA, cm}^2)}{\text{SD}}
\]

with \( y \) as the arm measurement (y) (i.e., MUAC, AMA, or AFA), \( \mu \) as the mean, and \( \sigma \) as the standard deviation. The previously published 1981 norms for MUAC, muscle area, and fat area were based on a more limited earlier data set that consisted only of the measurements obtained in the NHANES I survey (1971–1974). Smoothing techniques were not applied, and sex-specific empirical percentiles were calculated for integer ages with age-specific sample sizes ranging from 91 to 230 individuals. Consequently, the reference ranges presented in the current article represent a significant improvement over what was previously available.

From ages 2–5 y, median values for the new MUAC curves for US children corresponded well with those published by the WHO Multi-Centre Growth Study (18). There was ~1-cm
difference between the 2 curves, which could have been due to rounding, differences in measurement techniques, or sample differences. Both curves were developed with the use of the GAMLSS technique. The striking similarity observed in the current study is in alignment with the long-described phenomenon that, in early life, the average growth of children with good nutrition is very similar regardless of geographic location (17, 19). In addition, the recommended WHO references for school-aged children and adolescents for BMI, height, and weight were based on National Center for Health Statistics/WHO 1977 data (20), which consisted of a subset of the sample used in the current study. Therefore, the new curves for MUAC, AMA, and AFA may be useful for practitioners and researchers around the world because they provide reference percentiles for well-nourished children up to age 20 y.

TSFT data were used to calculate AMA and AFA. For children 2–5 y of age, TSFTs were measured with the use of 2 different calipers (Lange caliper for the first 4 surveys, and Holtain caliper for the NHANES III 1988–94) (8). Although the available data indicated that the differences between the 2 calipers were systematic, they were also quite small (mean: 0.9 mm). Because of the limited age range involved, the relatively small impact on the results, and the unacceptability of alternative solutions (e.g., altering the sample by excluding cases at these ages or separate curves by caliper), it was decided to pool the available data and alert researchers to the issue, which potentially added to the robustness of the new references.

We observed complex nonlinear, age-dependent associations between the HAZ and each of the arm \( z \)-score measures (total explained variance: 5–18%) that varied across sex. These associations were consistent with previous data that showed associations between height and subcutaneous fat thicknesses, bone mass, and other body measures in children in the United States and elsewhere (21–24). In part, these associations were due to age-related growth in all of the outcomes but correlations beyond the age-adjusted \( z \) scores with height. On the basis of these associations, we developed prediction equations to account for stature effects on arm anthropometric measures, which may be important for nutritional assessment in populations with a high prevalence of stunted children or in populations in which well-nourished children are substantially shorter than the average height. At the other end of the nutrition spectrum, height-adjusted MUAC and AFA may be more sensitive than unadjusted measures of fatness have been in studies that were related to metabolic alterations that are associated with obesity. It was decided that height-adjustment equations were preferable to developing

a separate set of (arm-for-height) reference curves. We used the CDC 2000 reference data for HAZ calculations for ages 2–20 y and the WHO standards for breastfed children <2 y of age according to the recommendations (14) to enhance the generalizability of the new equations.

The new curves were based on MUAC and TSFT measures that were easily obtainable with inexpensive and portable field kits (i.e., a measuring tape and skinfold-thickness caliper). To reduce measurement errors, training is still required, although such training is not comparable to what would be required for more-advanced body-composition techniques such as dual-energy X-ray absorptiometry. The new curves were based on the same large, random sample used in other US national growth charts. These are high-quality data that were collected with the use of rigorous training and quality-assurance protocols. The very large sample size (~33,000) provided adequate statistical power for developing percentiles even at the extremes. The new curves are accompanied by multiple-regression equations for adjustments of age and height associations.

This work has limitations. We recognize that population ancestry is associated with different patterns of lean and adipose tissue accretions (25–27) although the actual importance of these patterns relative to anthropometric assessments of nutritional assessments has been little studied. We chose to present curves and age-adjustment equations on the basis of all the race-ethnicity groups that were represented in the surveys of US children. Investigators who are concerned about specific race-ethnicity differences should take them into consideration in the interpretation of their clinical or research applications relative to the new curves.

We did not account for any differences that resulted from the use of 2 different calipers to measure TSFTs of children aged 2–5 y across the surveys, and it was unclear how these caliper differences translated into any biases in AMA and AFA. Prenatal staging was not available for all 5 surveys, and thus, relative sexual maturation could not be included in the results. Finally, calculations of derived measures of upper AFAs and AMAs were based on the assumption that the upper arm, subcutaneous fat, lean tissue, and humerus are concentric circles and that TSFT was an accurate estimate of the annulus of fat in the model. We recognize that these assumptions were not strictly true. Nevertheless, the important issue is that, even with the inexact model, the derived measures were shown to be valid and useful estimates of lean mass and fat mass in the upper arm. For example, the upper AFA was strongly correlated (0.7–0.8) with the SSFTs (an independent measure of fatness) in the surveyed

**FIGURE 2** Muscle area–for-age percentiles for US children and adolescents aged 1–20 y.
children. However, it was beyond the scope of this work to determine how derived AMA and AFA relate to the overall body composition.

In conclusion, the new reference percentile ranges for MUAC, muscle area, and fat area for children and adolescents provide a useful nutritional-status assessment tool in a wide variety of settings. Attained height at a particular age has complex independent effects on arm measures irrespective of distributional ranking by age and sex. Prediction equations that account for these effects further extend the practical use of the new curves.

The authors’ responsibilities were as follows—OYA and BSZ: analyzed the data; and all authors: participated in the conceptual construct, manuscript write-up, interpretation and critical review of the manuscript for intellectual content, and read and approved of the final manuscript. None of the authors reported a conflict of interest related to the study.

**TABLE 6**

Prediction equations for height-for-age–adjusted arm z scores in children and adolescents aged 1–20 y

<table>
<thead>
<tr>
<th>Adjusted arm z score</th>
<th>Prediction equation</th>
<th>$R^2$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MUAC-for-age</td>
<td>$0.1412 + 0.5012 \times \text{HAZ} + 0.0222 \times \text{age} - 0.0026 \times \text{age}^2 - 0.0057 \times \text{HAZ} \times \text{age} - 0.0050 \times \text{age}^2 \times \text{HAZ}$</td>
<td>17.03</td>
</tr>
<tr>
<td>AMA-for-age</td>
<td>$0.1898 + 0.54703 \times \text{HAZ} + 0.0255 \times \text{age} - 0.0029 \times \text{age}^2 - 0.0050 \times \text{age}^2 \times \text{HAZ}$</td>
<td>17.80</td>
</tr>
<tr>
<td>AFA-for-age</td>
<td>$0.0267 + 0.3058 \times \text{HAZ} + 0.0076 \times \text{age} - 0.0009 \times \text{age}^2 - 0.0054 \times \text{HAZ} \times \text{age} - 0.0043 \times \text{age}^2 \times \text{HAZ}$</td>
<td>5.77</td>
</tr>
<tr>
<td><strong>Female</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MUAC-for-age</td>
<td>$0.1148 + 0.4718 \times \text{HAZ} + 0.0110 \times \text{age} - 0.0027 \times \text{age}^2 - 0.0167 \times \text{HAZ} \times \text{age} - 0.0058 \times \text{age}^2 \times \text{HAZ}$</td>
<td>14.02</td>
</tr>
<tr>
<td>AMA-for-age</td>
<td>$0.0906 + 0.4616 \times \text{HAZ} + 0.0053 \times \text{age} - 0.0033 \times \text{age}^2 - 0.0097 \times \text{HAZ} \times \text{age} - 0.0054 \times \text{age}^2 \times \text{HAZ}$</td>
<td>14.62</td>
</tr>
<tr>
<td>AFA-for-age</td>
<td>$0.0904 + 0.3356 \times \text{HAZ} + 0.0129 \times \text{age} - 0.0012 \times \text{age}^2 - 0.0103 \times \text{HAZ} \times \text{age} - 0.0048 \times \text{age}^2 \times \text{HAZ}$</td>
<td>6.70</td>
</tr>
</tbody>
</table>

1 Age was measured in years and was mean centered by sex. HAZs were calculated with the use of CDC (for individuals aged 2–20 y) and WHO (for individuals aged <2 y) reference data (13, 14). Prediction coefficients were derived from 500 bootstrap (15) replications. $R^2$ values were estimated from the base sample (i.e., nonbootstrapped). AFA, arm fat area; AMA, arm muscle area; HAZ, height-for-age z score; MUAC, midupper arm circumference.
REFERENCES


