Midupper arm circumference and weight-for-length z scores have different associations with body composition: evidence from a cohort of Ethiopian infants¹–³

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ABAΣTRACT

Background: A midupper arm circumference (MUAC) <115 mm and weight-for-height z score (WHZ) or weight-for-length z score (WLZ) less than −3, all of which are recommended to identify severe wasting in children, often identify different children. The reasons behind this poor agreement are not well understood.

Objective: We investigated the association between these 2 anthropometric indexes and body composition to help understand why they identify different children as wasted.

Design: We analyzed weight, length, MUAC, fat-mass (FM), and fat-free mass (FFM) data from 2470 measurements from 595 healthy Ethiopian infants obtained at birth and at 1.5, 2.5, 3.5, 4.5, and 6 mo of age. We derived WLZs by using 2006 WHO growth standards. We derived length-adjusted FM and FFM values as unexplained residuals after regressing each FM and FFM against length. We used a correlation analysis to assess associations between length, FFM, and FM (adjusted and nonadjusted for length) and the MUAC and WLZ and a multivariable regression analysis to assess the independent variability of length and length-adjusted FM and FFM with either the MUAC or the WLZ as the outcome.

Results: At all ages, length showed consistently strong positive correlations with the MUAC but not with the WLZ. Adjustment for length reduced observed correlation coefficients of FM and FFM with the MUAC but increased those for the WLZ. At all ages, both length-adjusted FM and FFM showed an independent association with the WLZ and MUAC with higher regression coefficients for the WLZ. Conversely, length showed greater regression coefficients for the MUAC. At all ages, the MUAC was shown to be more influenced than was the WLZ by the FM variability relative to the FFM variability.

Conclusions: The MUAC and WLZ have different associations with body composition, and length influences these associations differently. Our results suggest that the WLZ is a good marker of tissue masses independent of length. The MUAC acts more as a composite index of poor growth indexing jointly tissue masses and length. This trial was registered at www.controlled-trials.com as ISRCTN46718296.


Keywords: body composition, fat-free mass, fat mass, height, infants, length, midupper arm circumference, nutritional status, weight-for-height, weight-for-length

INTRODUCTION

Acute malnutrition is a serious concern worldwide, especially during the first 1000 d of life, which is a crucial period of development (1). Global estimates indicate that wasting, which is a type of acute malnutrition characterized by acute mass loss (2), affects 52 million children aged <5 y, including 8.5 million infants aged <6 mo (henceforth referred to as infants), and accounts for 11.5% of their total deaths (1, 3). Moreover, severe wasting affects 19 million of these children and accounts for 7.8% of their total deaths (1). Beyond its short-term impact on survival and health, this wasting burden has long-lasting consequences for both individuals and societies (4).

The WHO/UNICEF joint statement for the identification of severe wasting in children aged 6–59 mo (henceforth referred to as children) recommends the use of the following 2 different anthropometric indicators: a midupper arm circumference (MUAC)⁴ and weight-for-height z score (WHZ) with cutoffs <115 mm and less than −3, respectively (5, 6). However, data have shown poor agreement between these 2 indicators because they often identify different children as severely wasted (7, 8). Furthermore, each indicator predicts mortality risk in children differently with the MUAC predicting it better than the WHZ does (9–11). Among the reasons suggested that might explain this...
poor agreement is that low MUAC values are more likely to identify children as wasted who are either girls, younger, or have lower heights (7).

To understand why the MUAC and WHZ identify different children as malnourished, it would be helpful to know how each anthropometric index relates to body composition (12). Most studies have been unable to address this issue because they either have lacked body-composition information or have inferred it from anthropometric measures (13); although see Jensen et al. (14), Rolland-Cachera et al. (15), and Chomtho et al. (16).

This issue is of particular interest in infants, which is an age group for whom there is uncertainty over the use and interpretation of anthropometric data, because the current guidelines are based on weak evidence. Therefore, this issue has been identified as a research priority (6).

With the use of data from a study of healthy infants from Ethiopia (17), we aimed to investigate the association between the 2 anthropometric indexes and body composition with adjustment for the influence of length, age, and sex.

METHODS

Study population

We analyzed data from a birth cohort study in Jimma, Ethiopia, that was used to develop reference growth data of body composition in infants (www.controlled-trials.com; ISRCTN46718296). The study was described in detail elsewhere (17). Briefly, 595 infants without congenital malformations and with birth weight ≥1500 g were recruited at birth (9 children had a gestational age <37 wk) from women who delivered at Jimma University Specialized Hospital. Within 48 h after birth, anthropometric and body-composition data were collected. Infants returned for additional examinations at 1.5, 2.5, 3.5, 4.5, and 6 mo of age, although not all infants attended every visit (n = 436, 444, 446, 415, and 441 for each visit, respectively).

Measurements

Briefly, gestational age was estimated ≤48 h after birth by a physical examination according to the New Ballard Score (18). Length was measured to the nearest 0.1 cm by using a SECA 416 Infantometer (SECA). The MUAC was measured to the nearest 0.2 cm by using a standard measuring tape. The length and the MUAC, in the same arm, were obtained in duplicate, and the average was used for analysis. Weight and body density (Db) were measured by using the PEA POD (COSMED USA) air-displacement plethysmography device specifically developed for infants (19). Air-displacement plethysmography is considered a fast, safe, precise, and accurate densitometric technique to assess body composition in neonates and infants (20, 21). The technique, which has been validated in this population, estimates fat mass (FM) and fat-free mass (FFM) as described previously (17). Briefly, by using a 2-component model of body composition (FM and FFM), the FM percentage was calculated by using the measured Db with the assumption of a constant FM density (DFFM) of 0.9007 g/mL and an FFM density (DFFM) range from 1.063 g/mL at birth to 1.067 g/mL at 6 mo of age as outlined by Fomon et al. (22). The FM percentage was obtained by solving Siri’s modified equation for the FM percentage (23) as proposed by Lohman (24) as follows:

\[
\text{FM percentage} = \left( \frac{C1}{D^{1/8}} - C2 \right) \times 100
\]

(1)

\[
C1 = \frac{(D_{\text{FFM}} \times D_{\text{FM}})}{D_{\text{FFM}} - D_{\text{FM}}}
\]

(2)

\[
C2 = \frac{D_{\text{FM}}}{D_{\text{FFM}} - D_{\text{FM}}}
\]

(3)

FM in kilograms was obtained by multiplying weight by the FM percentage, and FFM was determined as the difference between weight and FFM.

Data handling

To adjust anthropometric measures for age and sex, we converted anthropometric data to the following z scores: MUAC-for-age, weight-for-age, weight-for-length, length-for-age, and BMI-for-age on the basis of 2006 WHO Child Growth Standards (25) by using the WHO igrowup_stata macro (http://www.who.int/childgrowth/software/en/).

Data included for analysis

A set of 2519 infant measurements, with complete data of the MUAC, weight-for-length z score (WLZ), and body composition, were available for analysis. Of these, we removed 37 measurements from the analysis because they presented negative FM values (36 measurements at birth and one measurement at 1.5 mo of age). We removed an additional 12 infant measurement points identified as either outliers (9 outliers) after the use of the BACON algorithm (26), which is a tool for the outlier detection of related variables (i.e., weight, length, MUAC, and body density) or that were flagged as biological implausible anthropometric values (4 flags) by using WHO cleaning criteria for anthropometric data (2). We used a final sample of 2470 infant measurement points (98.1% of the original) for this analysis.

Conceptual approach to body composition

It has been well established that tissue masses, representing body composition, reflect both the effects of body size and growth and of nutritional status. For instance, studies in older age groups have shown that height is positively associated with both FFM and FM (27–29), whereas much of the variability in FFM and FM is also independent of height. These associations are expected in any age group; hence, nutritional status can be assessed either in absolute terms (e.g., kilograms of FFM and FM) or after adjusting for the influence of body size (i.e., length or height).

The influence of body size on body composition is conceptualized in Figure 1, where the body is treated as a cylinder, the length of which represents that of the body. The cylinder volume
is proportional to the mass (assuming a given density of body tissues), and 2 cylinders can be taken into account that reflect FFM and FM. There is a close association between length and FFM because muscle mass scales with limb length. A key role of FM is to provide energy for the FFM during chronic energy deficiency. Because a larger FFM requires a larger FM to secure the energy availability for any given duration of energy deficiency and FFM scales with length, FM is also expected to scale with length. A preliminary analysis confirmed that length was significantly associated with FM at every age ($P < 0.05$), and this association remained evident even after adjusting for FFM, which had a much weaker association with FM than length did (data not shown). Once FFM and FM were adjusted for the influence of length, cylinder volumes reflected the nutritional status independent of body size.

To operationalize this approach in our analysis, we adopted a modified version of a method known as unexplained residuals (30, 31) to generate length-independent body-composition variables. With stratification by sex and age at visit, we first regressed FFM against length to obtain length-adjusted FFM residuals (henceforth referred to as length-adjusted FFM), which we standardized by dividing by the SD of residuals. We used a similar approach to obtain length-adjusted FM residuals (henceforth referred to as length-adjusted FM). Our approach rendered the values of length-adjusted body-composition components equivalent to $z$ score units, each of which were statistically independent of length and of each other (Supplemental Table 1), and also specific to age and sex.

**Statistical analysis**

First, we aimed to understand the crude association between each anthropometric index and FFM and FM in infancy by addressing the influence of length on these associations. For this aim, we used a Spearman correlation analysis to assess associations between length, FFM, and FM (adjusted and nonadjusted for length) and the MUAC and WLZ.

Second, we aimed to understand how much of the variability of the MUAC or WLZ might be explained by the independent variability of length and each length-adjusted body-composition component. For this aim, we used a multivariable regression analysis with either the MUAC or WLZ as the outcome.

We reported standardized regression coefficients, which indicated how many SD units of the outcome were associated with the change in one SD unit in the predictor. This approach facilitated the comparison of regression coefficients between predictors both within and between regression models. Within models, we also expressed the standardized regression coefficients as ratios (i.e., the length-adjusted FM standardized regression coefficient divided by the length-adjusted FFM standardized regression coefficient). This method gave a simple indication, with the predictive quality of any given model held constant, of the relative success with which length-adjusted FM and FFM predicted the outcome.

Our analysis treated the data as cross-sectional and stratified analyses by the age at visit to better match anthropometric assessments of infants in field conditions. All statistical analyses were done with Stata software (Stata Statistical Software: release 12, 2011; StataCorp LP).

**Ethics statement**

The Jimma University Ethical Review Committee granted ethical permission (reference RPO/56/2001), and the Danish National Committee on Health Research Ethics provided consultative approval. Details on the ethical approval are provided elsewhere (17).

**RESULTS**

**Infant characteristics**

Table 1 summarizes infant characteristics stratified by age. Although the number of infants measured was different at each visit, the percentage of male infants remained between 48.1% and 50.9%. As expected, most anthropometric and body-composition mean values were generally greater at older ages. As previously reported (17), early growth prioritized the fat accumulation. Mean WLZs and mean weight-for-age and BMI-for-age $z$ scores were lower than WHO standards at birth but increased with age. Conversely, length-for-age mean $z$ score values were slightly below the WHO standard at birth, temporarily increased, and declined again.

**Influence of length on the association between anthropometric measures and body composition**

Table 2 shows the correlations between body composition (adjusted and nonadjusted for length) and anthropometric indicators. At all ages, length showed a strong positive association with the MUAC, whereas it showed a negative association with the WLZ from birth to 2.5 mo of age and no association thereafter.

For body-composition data, we observed 2 sets of patterns in the correlation analysis. First, at most ages, the MUAC showed significantly stronger correlations with nonadjusted FFM and FM than did the WLZ. However, an adjustment for length reversed this pattern. Second, correlations of the MUAC with length-adjusted body-composition components were consistently and significantly smaller at all ages than were those observed for nonadjusted FFM or FM. We observed the opposite for the WLZ. Thus, the WLZ and MUAC have different associations with body composition. Furthermore, these associations are influenced differently by body size.
TABLE 1
Infant characteristics by age of measurement

<table>
<thead>
<tr>
<th>Age, mo</th>
<th>Birth (n = 528)</th>
<th>1.5 mo (n = 402)</th>
<th>2.5 mo (n = 414)</th>
<th>3.5 mo (n = 413)</th>
<th>4.5 mo (n = 368)</th>
<th>6 mo (n = 345)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, mo</td>
<td>0.02 ± 0.01²</td>
<td>1.55 ± 0.12</td>
<td>2.47 ± 0.13</td>
<td>3.41 ± 0.15</td>
<td>4.36 ± 0.17</td>
<td>6.06 ± 0.40</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>3.09 ± 0.38</td>
<td>4.71 ± 0.64</td>
<td>5.55 ± 0.74</td>
<td>6.25 ± 0.83</td>
<td>6.76 ± 0.91</td>
<td>7.39 ± 0.90</td>
</tr>
<tr>
<td>Length, cm</td>
<td>49.3 ± 1.80</td>
<td>56.0 ± 2.31</td>
<td>59.1 ± 2.41</td>
<td>61.5 ± 2.37</td>
<td>63.5 ± 2.48</td>
<td>66.0 ± 2.49</td>
</tr>
<tr>
<td>Weight-for-age z score</td>
<td>−0.42 ± 0.83</td>
<td>−0.40 ± 1.06</td>
<td>−0.30 ± 1.11</td>
<td>−0.24 ± 1.12</td>
<td>−0.24 ± 1.16</td>
<td>−0.33 ± 1.10</td>
</tr>
<tr>
<td>Length-for-age z score</td>
<td>−0.15 ± 0.95</td>
<td>−0.11 ± 1.13</td>
<td>−0.01 ± 1.15</td>
<td>−0.05 ± 1.11</td>
<td>−0.10 ± 1.12</td>
<td>−0.35 ± 1.13</td>
</tr>
<tr>
<td>Weight-for-length z score</td>
<td>−0.62 ± 0.92</td>
<td>−0.49 ± 1.00</td>
<td>−0.41 ± 1.01</td>
<td>−0.28 ± 1.08</td>
<td>−0.24 ± 1.11</td>
<td>−0.17 ± 1.09</td>
</tr>
<tr>
<td>BMJ-for-age z score</td>
<td>−0.53 ± 0.98</td>
<td>−0.36 ± 1.03</td>
<td>−0.31 ± 0.98</td>
<td>−0.20 ± 1.05</td>
<td>−0.16 ± 1.08</td>
<td>−0.06 ± 1.08</td>
</tr>
<tr>
<td>BMI, mm</td>
<td>101 ± 7.42</td>
<td>119 ± 10.7</td>
<td>128 ± 11.2</td>
<td>134 ± 11.4</td>
<td>137 ± 11.5</td>
<td>138 ± 11.6</td>
</tr>
<tr>
<td>MUAC, mm</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>MUAC-for-age z score</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Body density, g/L</td>
<td>1.05 ± 0.01</td>
<td>1.02 ± 0.01</td>
<td>1.01 ± 0.01</td>
<td>1.01 ± 0.01</td>
<td>1.02 ± 0.01</td>
<td>1.02 ± 0.01</td>
</tr>
<tr>
<td>Fat-free mass, kg</td>
<td>2.84 ± 0.31</td>
<td>3.68 ± 0.42</td>
<td>4.11 ± 0.47</td>
<td>4.49 ± 0.50</td>
<td>4.84 ± 0.55</td>
<td>5.36 ± 0.56</td>
</tr>
<tr>
<td>Fat mass, kg</td>
<td>0.24 ± 0.15</td>
<td>0.14 ± 0.33</td>
<td>1.45 ± 0.42</td>
<td>1.75 ± 0.49</td>
<td>1.92 ± 0.57</td>
<td>2.03 ± 0.62</td>
</tr>
<tr>
<td>Fat-free mass index, kg/m²</td>
<td>11.7 ± 0.89</td>
<td>11.7 ± 0.92</td>
<td>11.7 ± 0.93</td>
<td>11.8 ± 0.96</td>
<td>12.0 ± 0.98</td>
<td>12.3 ± 1.01</td>
</tr>
<tr>
<td>Fat mass index, kg/m²</td>
<td>0.99 ± 0.57</td>
<td>3.27 ± 0.94</td>
<td>4.11 ± 1.07</td>
<td>4.59 ± 1.17</td>
<td>4.73 ± 1.28</td>
<td>4.64 ± 1.34</td>
</tr>
<tr>
<td>Male sex, n (%)</td>
<td>259 (49.1)</td>
<td>197 (49.0)</td>
<td>202 (48.8)</td>
<td>210 (50.9)</td>
<td>184 (50.0)</td>
<td>166 (48.1)</td>
</tr>
<tr>
<td>Preterm, n (%)</td>
<td>9 (1.70)</td>
<td>6 (1.49)</td>
<td>4 (0.97)</td>
<td>5 (1.21)</td>
<td>7 (1.90)</td>
<td>8 (2.32)</td>
</tr>
</tbody>
</table>

1z Score values were calculated on the basis of 2006 WHO Growth Standards. MUAC, midupper arm circumference.

 Associates of length-adjusted body composition and anthropometric indicators

The ability of length-adjusted body composition to explain the variability in the MUAC or WLZ was analyzed by using a multivariable regression analysis stratified by the age at visit as described in Figures 2 and 3, Table 3, and in more detail in Supplemental Table 2.

Figure 2 illustrates standardized regression coefficients. At all ages, both length-adjusted body-composition components showed independent positive associations with the MUAC and WLZ. In addition, the standardized regression coefficients were, at most times, greater for the WLZ than for the MUAC. Conversely, the findings for length were more variable. Length showed a negative association with the WLZ from birth to 2.5 mo of age and a positive association at later ages, whereas for the MUAC, length showed a positive association at all ages. The absolute values of standardized regression coefficients of length were greater for the MUAC than for the WLZ.

Table 3 shows coefficients of determination for the MUAC and WLZ stratified by the age at visit. The regression model, at all ages, explained >97% of the WLZ variability but only 59–74% of the MUAC variability. The removal of length from the model reduced the coefficient of determination much more for the MUAC than for the WLZ.

We evaluated the relative contributions of each length-adjusted body-composition component to the MUAC and WLZ variability

TABLE 2
Correlations between length, FFM, length-adjusted FFM, FM, and length-adjusted FM with anthropometric indexes at different ages

<table>
<thead>
<tr>
<th>Index and age</th>
<th>Length</th>
<th>FFM</th>
<th>Length-adjusted FFM</th>
<th>FM</th>
<th>Length-adjusted FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight-for-length z score</td>
<td>Birth (n = 528)</td>
<td>−0.20²,³</td>
<td>0.39²,⁴</td>
<td>0.82²,³</td>
<td>0.42²,⁴</td>
</tr>
<tr>
<td>1.5 mo (n = 402)</td>
<td>−0.25²,³</td>
<td>0.28²,⁴</td>
<td>0.69²,³</td>
<td>0.39²,⁴</td>
<td>0.66²,³</td>
</tr>
<tr>
<td>2.5 mo (n = 414)</td>
<td>−0.14²,³</td>
<td>0.32²,⁴</td>
<td>0.62²,³</td>
<td>0.48²,⁴</td>
<td>0.69²,³</td>
</tr>
<tr>
<td>3.5 mo (n = 413)</td>
<td>0.03³</td>
<td>0.42²,⁴</td>
<td>0.66²,³</td>
<td>0.61²,³</td>
<td>0.74²,³</td>
</tr>
<tr>
<td>4.5 mo (n = 368)</td>
<td>0.05³</td>
<td>0.42²,⁴</td>
<td>0.56²,³</td>
<td>0.70²,³</td>
<td>0.76²,³</td>
</tr>
<tr>
<td>6 mo (n = 345)</td>
<td>0.00³</td>
<td>0.36²,⁴</td>
<td>0.53²,³</td>
<td>0.73²,³</td>
<td>0.76²,³</td>
</tr>
<tr>
<td>Midupper arm circumference</td>
<td>Birth (n = 528)</td>
<td>0.45²</td>
<td>0.60²,⁴</td>
<td>0.40²</td>
<td>0.56²,⁴</td>
</tr>
<tr>
<td>1.5 mo (n = 402)</td>
<td>0.57²</td>
<td>0.68²,⁴</td>
<td>0.39²</td>
<td>0.73²,⁴</td>
<td>0.46²</td>
</tr>
<tr>
<td>2.5 mo (n = 414)</td>
<td>0.50²</td>
<td>0.61²,⁴</td>
<td>0.34²</td>
<td>0.70²,⁴</td>
<td>0.47²</td>
</tr>
<tr>
<td>3.5 mo (n = 413)</td>
<td>0.45²</td>
<td>0.54²,⁴</td>
<td>0.32²</td>
<td>0.73²,⁴</td>
<td>0.54²</td>
</tr>
<tr>
<td>4.5 mo (n = 368)</td>
<td>0.45²</td>
<td>0.55²,⁴</td>
<td>0.31²</td>
<td>0.74²,⁴</td>
<td>0.57²</td>
</tr>
<tr>
<td>6 mo (n = 345)</td>
<td>0.38²</td>
<td>0.47²,⁴</td>
<td>0.33²</td>
<td>0.72²,⁴</td>
<td>0.60²</td>
</tr>
</tbody>
</table>

1z Score values were calculated on the basis of 2006 WHO growth standards. Length-adjusted values were calculated by regressing, separately by the age at measurement and sex, FFM or FM on length, FFM, fat-free mass; FM, fat mass.
²Correlation value is different from zero (P < 0.05).
³Correlation value is different from that observed for the MUAC (P < 0.05).
⁴Correlation value is different from that observed for its length-adjusted counterpart (P < 0.05).
by calculating the ratio of their regression coefficients (Supplemental Table 2, Figure 3). This ratio gave an indication of the relative degree to which the variability in each anthropometric index was explained more by either the FM or FFM variability. First, at all ages, the MUAC was more strongly associated with the FM variability than with the FFM variability. Second, at all ages, the MUAC had a stronger association with the FM variability than did the WLZ. Finally, for both anthropometric outcomes, the association with the FM variability relative to that with the FFM variability strengthened with age.

**DISCUSSION**

To our knowledge, this is the first study to show contrasting associations of the MUAC and WLZ with body size and composition during infancy, which is a period of the life course when nutritional status is a key predictor of survival in undernourished populations. Although our analysis was conducted in a healthy population, it sheds new light on the components of nutritional status that are indexed by the 2 most-widely used anthropometric outcomes in public health nutrition. Furthermore, this approach may help to understand why the 2 markers identify different children as wasted and why, in undernourished populations, the 2 indexes have differing ability to predict mortality.

First, we showed that length-adjusted body-composition components had consistently stronger associations with the WLZ than with the MUAC. This means that the WLZ is a better overall anthropometric marker than the MUAC is of relative tissue masses. Second, we observed that the contribution of length to the association between anthropometric measures and body composition differed between the WLZ and MUAC. Length explained the greater variability in the MUAC than in the WLZ, which suggested that the MUAC is a stronger marker of growth than is the WLZ. Finally, although its overall association with tissue masses was weaker, the MUAC was more strongly associated than was the WLZ with the variability in adiposity relative to the variability in FFM.

Most previous studies have considered whether anthropometric indexes can predict body-composition components (e.g., FFM, FM, or regional FFM) (14, 16). We undertook the reverse analysis to understand which body-composition components explained the variability in anthropometric indexes and, hence, to understand the different functional implications of the MUAC and WLZ. Nonetheless, despite age and methodologic differences, some findings were common to both approaches. For instance, a stronger association of the MUAC with FM than with FFM was also shown in 3-y-old children from Sweden (14) and in healthy and sick 9-y-old children from the United Kingdom (16). In the current study, we have shown that this scenario applies also to infants even after adjustment for length. Equivalent findings for the WLZ were weaker.

Our findings contradict the previous suggestion that the MUAC measures body-composition components more directly than does the WLZ (7, 32). This contradiction was unlikely to be explained by the younger age of our sample but could have been attributed to the importance of adjusting for length in the analysis as was previously
recommended for older children (16). Furthermore, because of the narrow age ranges at each measurement visit in our study, our analysis provides good evidence that, in infants, the confounding effect of length in these associations is independent of age.

A crucial issue in public health nutrition is to identify and use the most-sensitive marker of malnutrition to minimize mortality risk and prevent functional penalties. It has been generally accepted that a low MUAC values predict mortality better than low WLZ values do (9, 10, 14). Consequently, there is a growing trend to equate the MUAC's association with FFM with that of greater risk of dying (7, 33); (9, 10, 14). Thus, the use of a low MUAC has been suggested for identifying infants at high risk of death to receive treatment because of the current absence of better evidence (32). Likewise, the use of a low MUAC-only criterion for selecting children that will receive treatment (7). This prospect raises the possibility that the association between the MUAC and survival may not be constant across populations.

These debates cannot be resolved without measuring body composition and anthropometric measures in malnourished populations, and our current analyses apply only to healthy infants and not necessarily to older age groups. Nevertheless, our current analyses generate the hypothesis that the WLZ and MUAC differ in their ability to index growth vs. nutritional status. We suggest that, although the WLZ may act as the best marker of tissue masses independent of growth status, the MUAC may represent a more-composite index of poor growth by jointly indexing stunting and wasting (including low adiposity). Therefore, our analyses may provide an important framework for investigating these associations further. Currently, the limited understanding of why the MUAC predicts mortality better than the WLZ does in malnourished populations hinders the development of public health interventions that could maximize survival rates.

In conclusion, our results indicate that, in healthy infants, the MUAC variability and the WLZ variability reflect the nutritional status differently. Note that programs that provide care for severe acute malnutrition that previously identified severely wasted children by using a low-WHZ criterion are increasingly adopting a low MUAC-only criterion for selecting children that will receive treatment (7). Likewise, the use of a low MUAC has been suggested for identifying infants at high risk of death to receive treatment because of the current absence of better evidence (32). An improved understanding of the contrasting associations of the

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### Table 3

<table>
<thead>
<tr>
<th>Outcome and age</th>
<th>Adjusted $r^2$, %</th>
<th>Difference, %</th>
<th>Log-likelihood ratio test, $^a$ chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight-for-length $z$ score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth ($n = 528$)</td>
<td>97.7</td>
<td>93.5</td>
<td>4.2</td>
</tr>
<tr>
<td>1.5 mo ($n = 402$)</td>
<td>97.7</td>
<td>93.0</td>
<td>4.7</td>
</tr>
<tr>
<td>2.5 mo ($n = 414$)</td>
<td>98.2</td>
<td>97.3</td>
<td>0.9</td>
</tr>
<tr>
<td>3.5 mo ($n = 413$)</td>
<td>97.8</td>
<td>97.8</td>
<td>0.0</td>
</tr>
<tr>
<td>4.5 mo ($n = 368$)</td>
<td>98.0</td>
<td>96.9</td>
<td>1.1</td>
</tr>
<tr>
<td>6 mo ($n = 345$)</td>
<td>98.6</td>
<td>98.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Midupper arm circumference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth ($n = 528$)</td>
<td>59.3</td>
<td>37.1</td>
<td>22.2</td>
</tr>
<tr>
<td>1.5 mo ($n = 402$)</td>
<td>73.4</td>
<td>37.8</td>
<td>35.6</td>
</tr>
<tr>
<td>2.5 mo ($n = 414$)</td>
<td>72.0</td>
<td>38.6</td>
<td>33.4</td>
</tr>
<tr>
<td>3.5 mo ($n = 413$)</td>
<td>69.4</td>
<td>44.8</td>
<td>24.6</td>
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<tr>
<td>4.5 mo ($n = 368$)</td>
<td>74.1</td>
<td>48.9</td>
<td>25.2</td>
</tr>
<tr>
<td>6 mo ($n = 345$)</td>
<td>70.4</td>
<td>51.7</td>
<td>18.7</td>
</tr>
</tbody>
</table>

---

$^a$Analyses were stratified by the age at visit. The full regression model included length, length-adjusted fat mass, length-adjusted fat-free mass, male sex, and age. Adjusted $r^2$ is the coefficient of determination adjusted for the number of variables included in the model.

$^2P < 0.05.$
WLZ and MUAC with growth and body-composition outcomes in malnourished populations is likely to stimulate the development of interventions that can minimize mortality risk and functional penalties of malnutrition in early life.

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The authors’ responsibilities were as follows—CSG-E and JCKW: designed the analysis; CSG-E: analyzed the data, wrote the manuscript, and had primary responsibility for the final content of the manuscript; BA, GSA, and WO: contributed to the analysis; CSG-E: contributed to the manuscript revisions; and all authors: read and approved the final manuscript. None of the authors reported a conflict of interest related to the study.

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