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ORIGINAL ARTICLE

Mid-upper-arm-circumference and mid-upper-arm circumference *z*-score: the best predictor of mortality?

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BACKGROUND/OBJECTIVE: Mid-upper-arm circumference (MUAC) is a simple method of assessing nutritional status in children above 6 months of age. In 2007 World Health Organization (WHO) introduced a MUAC *z*-score for children above 3 months of age. We evaluated whether MUAC or MUAC *z*-score had the best ability to identify children with high short-term mortality risk in Guinea-Bissau.

SUBJECTS/METHODS: The Bandim Health Project visits children 3-monthly until 3 years of age. MUAC is measured and deaths are registered. We studied a high-mortality cohort of children born in 1995–96 and a lower mortality cohort of children born in 2005–06. The prognostic ability of MUAC and MUAC *z*-score to predict mortality within 1 and 3 months after the MUAC assessment were compared by area under the receiver operating characteristic curve, sensitivity and positive predictive value.

RESULTS: Compared with MUAC *z*-score, MUAC identified as malnourished more girls than boys (prevalence ratio (PR) = 1.74 (1.52;2.01)) and more children aged 6–11 months than children aged 12–35 months (1.59 (1.38;1.82)). There was no difference in the prognostic ability of MUAC and MUAC *z*-score to predict mortality for children aged 6–35 months. The prognostic ability was higher when mortality was lower. MUAC performed well in the youngest infants.

CONCLUSION: In the age group 6–35 months, MUAC and MUAC *z*-score had the same prognostic ability to predict short-term mortality. As MUAC is easier to use in field settings, there is no need to use MUAC *z*-score to identify children with a high-mortality risk.

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Keywords: anthropometry; child mortality; child nutrition disorders/mortality; predictive value of tests

INTRODUCTION

Nutritional status in children has often been assessed by *z*-scores for weight-for-height, weight-for-age and height-for-age. These methods require exact information about age, and scales and measuring boards, which may be difficult to use in fields settings. Mid-upper-arm circumference (MUAC) is a cheap and simple way to access nutritional status, and a recent study showed that it performed as well as weight-for-height in predicting mortality.[1] As MUAC has been regarded independent of age and sex among 1–4 year-old children,[2] fixed common cutoff values has been used to detect malnutrition in this age group.[3] This assumption was later questioned, which led to the development of sex-specific MUAC-for-age *z*-scores.[4]

In 2006–07 WHO introduced a new set of child growth standards based on The WHO Multicentre Growth Reference Study, including a MUAC-for-age *z*-score for children older than 3 months of age.[5,6] To our knowledge there has been no evaluation of the association between the new MUAC *z*-scores and mortality.

In this study, we aimed to evaluate whether MUAC or MUAC *z*-score had the best ability to identify children at high risk of subsequent death. Taking advantage of a long-lasting health and demographic surveillance system in Guinea-Bissau, we examined a cohort from 1995–96 with high mortality and a cohort from 2005–06 with lower mortality.

MATERIALS AND METHODS

Setting

The Bandim Health Project is based in Bissau, the capital of Guinea-Bissau and runs a health and demographic surveillance system. All houses in the study area are visited every month to register new pregnancies and deliveries, and children are visited every third month until 3 years of age. At the trimonthly visits, vaccination status and other health information are registered and MUAC is measured if the child is found at home. This routine data collection formed the basis for the present study.

Participants

We analyzed two cohorts of children: (a) children less than 3 years of age who were born in 1995–96 and lived in the study area between 1 January 1995 and 6 June 1998, when a civil war broke out in Guinea-Bissau; (b) a similar group of children 10 years later, that is children who were born in 2005–06 and lived in the study area between 1 January 2005 and 30 June 2008.

Cutoffs

The recommended cutoffs for MUAC are valid from 6 months of age. We defined MUAC $\leqslant$115 mm as severe malnutrition[7] and MUAC $\leqslant$125 mm as malnutrition.[8] Similarly, we defined MUAC *z*-scores $\leqslant -3$ SD as severe malnutrition and MUAC *z*-score $\leqslant -2$ SD as malnutrition.[9]

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Contributors: PA and AR supervised the data collection. CBS, PA and ABF designed the study. AA, JR and HR did the statistical analysis, and JR wrote the first draft of the paper. All authors contributed to and approved the final version of the paper.
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STATISTICS

MUAC *z*-scores were calculated using the *WHO Child Growth Standards igrowup_standard.ado* macro for *STATA*. No MUAC *z*-score exist for children younger than 90 days. *Z*-scores below -5 SD were not calculated by the program, but were afterwards set to -5 SD.

As the recommendation for MUAC cutoffs are not valid for children younger than 6 months of age, and no MUAC *z*-score is available for children younger than 90 days, the comparison of MUAC and MUAC *z*-scores were primarily conducted for children age 6–35 months.

To assess whether MUAC and MUAC *z*-score classified children similarly, we compared the percentage classified differently (discordant) for the two methods (for example, MUAC >125 mm and MUAC *z*-score $\leqslant -2$ SD; or MUAC $\leqslant 125$ mm and MUAC *z*-score > -2 SD). Similarly, we compared discordance between young children (6–11 month) and older children ($\geqslant 12$ months).

For the two cohorts we calculated the mortality rate (MR) for the children with at least one MUAC measurement. The children were considered at risk from the first MUAC measurement and were followed until 3 years of age, date of death, date of moving or end of follow-up, whichever came first. We only considered the prognostic ability of MUAC and MUAC *z*-score within 90 and 30 days after measurement. Time at risk was therefore stopped 90 or 30 days after a MUAC measurement and started again at the next MUAC measurement. In the 1995–96 cohort there were 174 deaths among children who had not had their MUAC measured. In the 2005–06 cohort there were 121 deaths without MUAC measurement.

Sensitivity and specificity of MUAC can be explained as follows: sensitivity is the proportion of children who died who were below the MUAC cutoff. Specificity is the proportion of surviving children who were above the MUAC cutoff. For a given marker, the receiver operating characteristic (ROC) curve is a plot of sensitivity and specificity for each cutoff. The area under the ROC curve (AUC) is an index of the marker's ability to discriminate between true positives and true negatives. We used AUC to evaluate the overall prognostic ability to detect short-term mortality of MUAC and MUAC *z*-score. To calculate an overall age-adjusted AUC for MUAC, we obtained a linear prediction, called the risk index, from a Cox-model with age as underlying time and the repeated MUAC measurements as a linear time-varying covariate. The risksetROC package in the statistical software R[10] was used to calculate AUC based on the risk index as prognostic marker. AUC for MUAC *z*-score was calculated similarly.

To take censoring into account, the sensitivity and specificity for a specific MUAC or MUAC *z*-score cutoff was calculated from the R-package survivalROC.[10] Overall sensitivity and specificity was estimated from a sample containing several observations from the same child, one for each MUAC measurement.

Confidence intervals for AUC and sensitivity were obtained by bootstrapping. AUC and sensitivity was estimated from each of the 200 bootstrap replacement samples and the confidence limits were taken as the 2.5 and 97.5% percentiles.

We furthermore conducted the analyses of AUC and sensitivity stratified by age groups 3–5, 6–11 and 12–35 months. The positive predictive value (PPV) can be explained as follows: among children classified as malnourished, the PPV is the proportion of children who dies. To compare sensitivity and PPV we used the 5% lowest values for both MUAC and MUAC *z*-score to get the same proportion of children below the cutoff. The lowest 5% values correspond to a MUAC of 126 mm for children older than 90 days. The age groups 12–23 and 24–35 months were combined as mortality was very low in the latter group, especially in 2005–06.

RESULTS

In the 1995–96 cohort, 4366 children had a total of 33 158 visits. Visits with missing questionnaires ($n=20$), implausible dates on the questionnaire ($n=7$), children not at home ($n=8$ 986) or children turned 3 years of age ($n=127$) were excluded, leaving 24 018 observations for 4141 children. There were 225 deaths from a total follow-up time of 5064 person-years of observation (PYO) (MR = 44.4 per 1000 PYO). In the 2005–06 cohort, 7248 children were followed through 51 877 visits. At 12 274 visits the child was not at home and at 772 visits the child had turned 3 years. Excluding these resulted in 38 831 observations for 6757 children. There were 138 deaths from a total follow-up time of 8783 PYO (MR = 15.7 per 1000 PYO). MRs according to age and sex are given in Table 1. Mean MUAC was 141.4 mm in 1995–96 and 144.5 mm in 2005–06, the difference adjusted for age and ethnicity being 2.6 mm (95% CI: 2.4;2.8).

Prevalence of malnutrition

Using 125 mm as cutoff for MUAC, the overall prevalence of malnutrition was 5.0% in 1995–96 and 2.8% in 2005–06 (Table 2). Using -2 SD as cutoff for MUAC *z*-score, the prevalence of malnutrition was 4.8 and 2.5% in the two cohorts. The prevalence of severe malnutrition was identical for MUAC ($\leqslant 115$ mm) and MUAC *z*-score ($\leqslant -3$ SD) with 1.2% in 1996–96 and 0.5% in 2005–06. The prevalence of malnutrition according to age and sex is illustrated in Figure 1.

MUAC classified more girls and young children as malnourished compared with MUAC *z*-score (Figure 1 and Supplementary Table 1). We denoted a child discordant if it was classified differently by MUAC and MUAC *z*-score. The prevalence of discordant children was 74% higher for girls than boys (PR = 1.74 (1.52;2.01)) and 59% higher for young children aged 6–11 months than older children aged 12–35 months (PR = 1.59 (1.38;1.82)). In other words,

Table 1. Mortality rates per 1000 PYO (deaths/PYO) according to age at MUAC measurement and sex for children from 0–35 months

Age at MUAC measurement (in months)	*1995–96 Cohort*		*2005–06 Cohort*	
	Boys	*Girls*	*Boys*	*Girls*
0–2	62.5 (19/304)	52.4 (16/305)	24.8 (13/523)	33.4 (17/509)
3–5	46.4 (14/302)	67.5 (19/282)	28.0 (14/501)	23.4 (12/513)
6–11	50.4 (29/575)	56.9 (32/563)	17.4 (17/974)	16.4 (16/976)
12–23	39.7 (39/983)	40.6 (38/936)	14.3 (24/1674)	9.0 (15/1661)
24–35	29.8 (12/403)	17.0 (7/412)	6.9 (5/726)	6.9 (5/724)
6–35	40.8 (80/1961)	40.3 (77/1911)	13.6 (46/3375)	10.7 (36/3362)
0–35	44.0 (113/2566)	44.8 (112/2498)	16.6 (73/4399)	14.8 (65/4384)

Abbreviations: MUAC, mid-upper-arm circumference; PYO, person-years of observation.

Table 2. Children aged 6–35 months: prevalence of malnutrition, mortality within 90 days, mortality risk ratio, sensitivity and specificity as well as AUC for MUAC and MUAC *z*-score for different cutoffs within 90 days of follow-up in Guinea-Bissau in 1995–96 and 2005–06

1995–96 Cohort						*2005–06 Cohort*					
MUAC			*MUAC z-score*			*MUAC*			*MUAC z-score*		
Cutoff	*Above*	*Below*	*Cutoff*	*Above*	*Below*	*Cutoff*	*Above*	*Below*	*Cutoff*	*Above*	*Below*
Prevalence of malnutrition											
115	18181 (98.8%)	216 (1.2%)	−3 SD	18 186 (98.9%)	211 (1.2%)	115	30 021 (99.5%)	144 (0.5%)	−3 SD	30 018 (99.5%)	147 (0.5%)
125	17482 (95.0%)	915 (5.0%)	−2 SD	17 514 (95.2%)	883 (4.8%)	125	29 330 (97.2)	835 (2.8%)	−2 SD	29 409 (97.5%)	756 (2.5%)
Deaths/PYO (rate/100 PYO)											
115	139/3827 (3.6)	18/44 (40.5)	−3 SD	137/3829 (3.6)	20/43 (46.7)	115	64/6705 (1.0)	18/32 (56.8)	−3 SD	61/6705 (0.9)	21/32 (66.5)
125	116/3677 (3.2)	41/194 (21.1)	−2 SD	117/3686 (3.2)	40/185 (21.6)	125	53/6545 (0.8)	29/192 (15.1)	−2 SD	54/6566 (0.8)	28/170 (16.4)
Sensitivity/specificity											
115	0.10/0.99		−3 SD	0.12/0.99		115	0.21/1.00		−3 SD	0.25/1.00	
Boys	0.07/0.99		Boys	0.08/0.99		Boys	0.15/1.00		Boys	0.25/1.00	
Girls	0.14/0.99		Girls	0.15/0.99		Girl	0.28/0.99		Girls	0.24/1.00	
125	0.25/0.95		−2 SD	0.25/0.95		125	0.34/0.97		−2 SD	0.33/0.98	
Boys	0.21/0.96		Boys	0.25/0.95		Boys	0.32/0.98		Boys	0.30/0.97	
Girls	0.29/0.94		Girls	0.24/0.96		Girls	0.34/0.97		Girls	0.33/0.98	
AUC (95% CI)	0.70 (0.64;0.75)[a]			0.69 (0.63;0.73)[a]			0.80 (0.74;0.85)[b]			0.80 (0.74;0.85)[b]	
Boys	0.68 (0.60;0.75)[a]			0.68 (0.60;0.74)[a]			0.80 (0.71;0.86)[b]			0.80 (0.72;0.85)[b]	
Girls	0.72 (0.65;0.78)[a]			0.70 (0.63;0.77)[a]			0.81 (0.72;0.88)[b]			0.81 (0.72;0.81)[b]	

Abbreviations: AUC, area under the curve; CI, confidence interval; MUAC, mid-upper-arm circumference; PYO, person-years of observation. [a]AUC: MUAC95-MUAC *z*-score95 = 0.017 (−0.007;0.031); boys 0.013 (−0.020;0.028); girls 0.007 (−0.006;0.038). [b]AUC: MUAC05-MUAC *z*-score05 = −0.008 (−0.022;0.011); boys 0.006 (−0.011;0.022); girls −0.011 (−0.034;0.023).

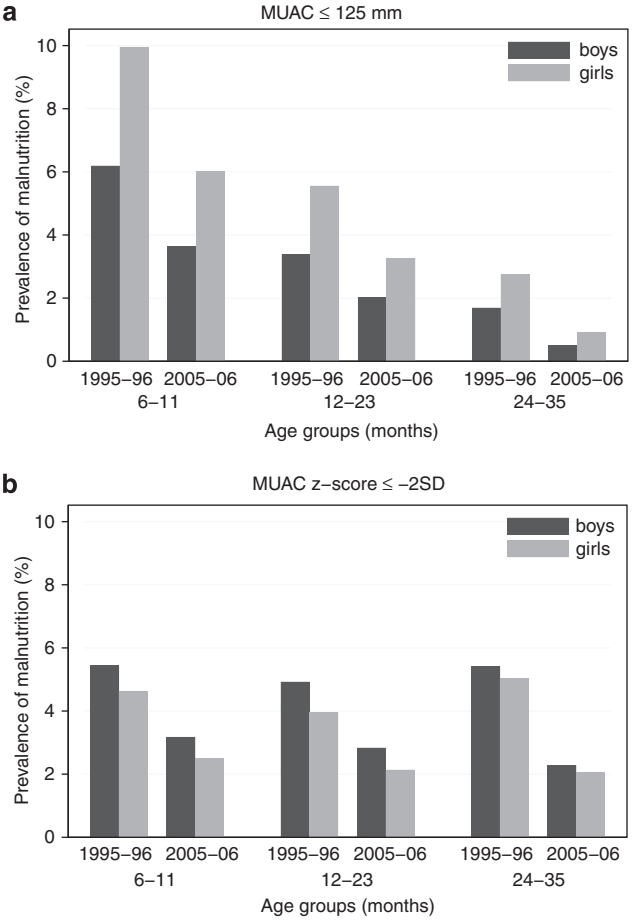

Figure 1. (**a**, **b**) Prevalence of malnutrition defined as MUAC⩽125 mm or MUAC *z*-score⩽2 SD for children aged 6–35 months in 1995–96 and 2005–06.

these differences mean that the two indices classified different children as malnourished or 'at risk'. The differences were larger in 2005–06 than in 1995–96 (data not shown).

Prognostic ability of MUAC and MUAC z-score

There were no statistical significant differences in the MRs for children with a MUAC or MUAC *z*-score below the cutoff when 90 days of follow-up were used. Similarly, there were no significant differences in sensitivity (Table 2). Using MUAC, sensitivity was generally higher for girls than boys. For mortality within 30 days, sensitivity for the severe malnutrition cutoff was the same for MUAC and MUAC *z*-score (18% in 1995–96 and 25% in 2005–06). Sensitivity of the malnutrition cutoff was 29% for MUAC and 32% for MUAC *z*-score in 1995–96, whereas it was 35% for both measures in 2005–06 (Table 3).

The AUCs presented in Table 2 were adjusted for age. AUC was similar for MUAC and MUAC *z*-score. AUC was significantly larger in 2005–06 compared with 1995–96 for both MUAC (difference: 0.10 (0.03;0.18)) and for MUAC *z*-score (difference: 0.12 (0.05;0.19)). Thus, the prognostic ability was better in 2005–06 compared with 1995–96.

Sensitivity for mortality within 30 days was significantly higher for girls than boys (Table 3). Comparing mortality within 30 days to mortality within 90 days of measurement, AUC was higher for girls in 1995–96 (difference for MUAC: 0.11 (0.04;0.16); difference for MUAC *z*-score: 0.11 (0.05;0.18)), whereas there was no difference for boys (Table 3). AUC also tended to be higher for girls in 2005–06 (difference for MUAC: 0.05 (−0.08;0.15); difference for MUAC *z*-score: 0.04 (−0.11;0.16)), whereas it may have been lower for boys (difference for MUAC: −0.05 (−0.23;0.08); difference for MUAC *z*-score: −0.06 (−0.24;0.07)).

Prognostic ability of MUAC and MUAC z-score according to age and sex

Figure 2 shows no difference between MUAC and MUAC *z*-score evaluated by AUC in either by sex or age groups with 90 days of follow-up. Similarly, Figure 3 and Supplementary Figure 1 show no

Table 3. Children aged 6–35 months: prevalence of malnutrition, mortality within 30 days, mortality risk ratio, sensitivity and specificity as well as AUC for MUAC and MUAC *z*-score for different cutoffs within 30 days of follow-up in Guinea-Bissau in 1995–96 and 2005–06

1995–96 Cohort						*2005–06 Cohort*					
MUAC			*MUAC z-score*			*MUAC*			*MUAC z-score*		
Cutoff	*Above*	*Below*	*Cutoff*	*Above*	*Below*	*Cutoff*	*Above*	*Below*	*CutOff*	*Above*	*Below*
Prevalence of malnutrition											
115	18181 (98.8%)	216 (1.2%)	−3 SD	18186 (98.9%)	211 (1.2%)	115	30021 (99.5%)	144 (0.5%)	−3 SD	30018 (99.5%)	147 (0.5%)
125	17482 (95.0%)	915 (5.0%)	−2 SD	17514 (95.2%)	883 (4.8%)	125	29330 (97.2)	835 (2.8%)	−2 SD	29409 (97.5%)	756 (2.5%)
Deaths/PYO (rate/100 PYO)											
115	50/1452 (3.4)	11/17 (63.8)	−3 SD	50/1452 (3.4)	11/17 (66.0)	115	15/2418 (0.6)	5/11 (43.5)	−3 SD	15/2418 (0.6)	5/12 (42.9)
125	43/1396 (3.1)	18/74 (24.5)	−2 SD	41/1399 (2.9)	20/70 (28.4)	125	13/2362 (0.6)	7/68 (10.3)	−2 SD	13/2368 (0.5)	7/61 (11.4)
Sensitivity/specificity											
115	0.18/0.99		−3 SD	0.18/0.99		115	0.25/1.00		−3 SD	0.25/1.00	
Boys	0.09/0.99		Boys	0.09/0.99		Boys	0.17/1.00		Boys	0.25/0.99	
Girls	0.28/0.99		Girls	0.28/0.99		Girls	0.37/0.99		Girls	0.25/1.00	
125	0.29/0.95		−2 SD	0.32/0.95		125	0.35/0.97		−2 SD	0.35/0.98	
Boys	0.18/0.96		Boys	0.24/0.95		Boys	0.25/0.98		Boys	0.25/0.97	
Girls	0.42/0.94		Girls	0.42/0.96		Girls	0.35/0.97		Girls	0.35/0.98	
AUC (95% CI)	0.76 (0.69;0.82)			0.75 (0.68;0.82)			0.80 (0.63;0.89)			0.79 (0.61;0.89)	
Boys	0.69 (0.58;0.80)			0.68 (0.58;0.78)			0.75 (0.53;0.89)			0.74 (0.53;0.89)	
Girls	0.83 (0.74;0.89)			0.81 (0.73;0.89)			0.86 (0.70;0.97)			0.85 (0.65;0.97)	

Abbreviations: AUC, area under the curve; CI, confidence interval; MUAC, mid-upper-arm circumference; PYO, person-years of observation.

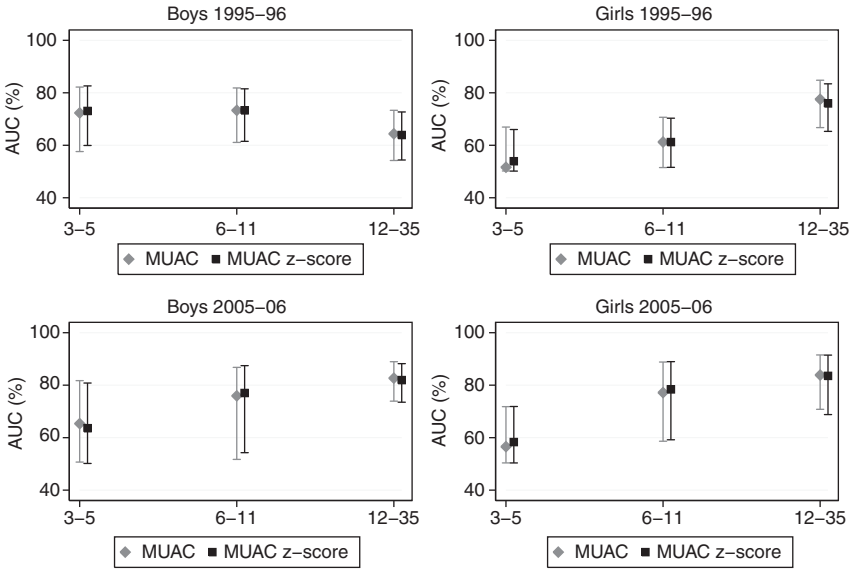

Figure 2. AUC for children aged 3–35 months for MUAC and MUAC *z*-scores ability to predict mortality within 90 days.

difference in sensitivity and PPV for the lowest 5% of MUAC and MUAC *z*-score with 90 days of follow-up.

Figures 2 and 3 indicate that in 1995–96 the prognostic ability and sensitivity were stronger for the infant boys than the older boys. Among the infants the prognostic ability was clearly better for boys than for girls. The opposite pattern was seen for the girls and in the age group 12–35 months the prognostic ability was better for girls than for boys. In 2005–06 the prognostic ability and sensitivity got stronger with age for both sexes.

Prognostic ability of MUAC and MUAC z-score for the youngest infants

As indicated in Figures 2 and 3 and the supplementary Figure, both MUAC and MUAC *z*-score performed reasonably well for the 3–5-month-old boys. No MUAC *z*-score is available for the age group 0–2 months. AUC for MUAC was higher in the age group 0–2 months compared with 3–5 months. In 1995–96 AUC was 0.75 (0.65–0.84) for 0–2 months and 0.62 (0.52–0.72) for 3–5 months. In 2005–06 AUC was 0.70 (0.57–0.80) for 0–2 months and 0.61 (0.51–0.75) for 3–5 months.

DISCUSSION

Main observations

For children aged 6–35 months there were no significant differences in the prevalence of malnutrition and severe malnutrition using MUAC and MUAC *z*-score. As expected because girls are slightly smaller than boys of the same age, MUAC classified more

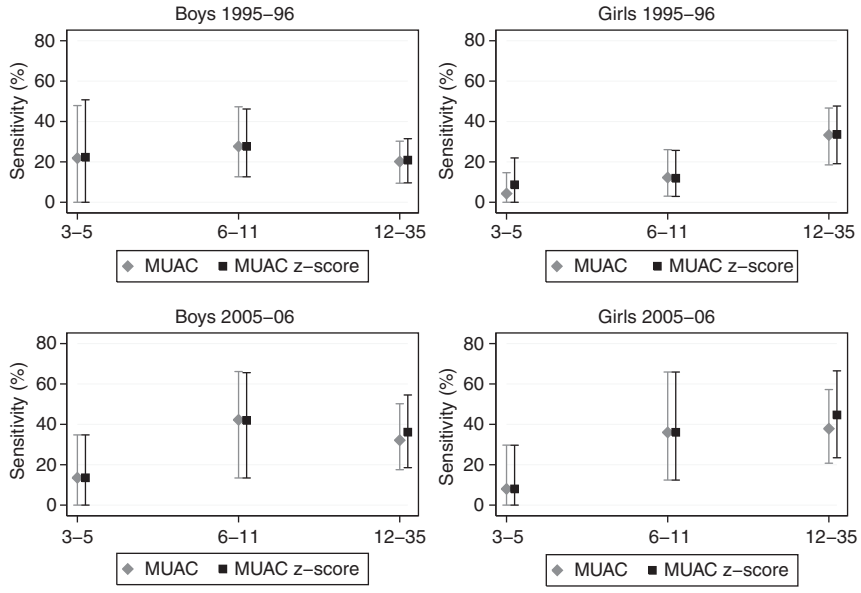

Figure 3. Sensitivity for children aged 3–35 months below the 5th percentile of MUAC and MUAC *z*-score in predicting mortality within 90 days.

girls and young children as moderately malnourished compared with MUAC *z*-score. Measured by the age-adjusted AUC, the overall and sex-specific prognostic ability of MUAC *z*-score was not better than MUAC. The prognostic ability for children aged 6–35 months was better in 2005–06 in the period with lower mortality than in 1995–96 with higher mortality. Overall sensitivity was low; the highest sensitivity (34%) with a 90 days follow-up was observed for the moderate MUAC cutoff in 2005–06.

There were no differences in AUC, sensitivity and PPV between MUAC and MUAC *z*-score for boys and girls in different age groups. Both MUAC and MUAC *z*-scores performed less well in 3–5 month-old girls. MUAC performed for children less than 3 months old as well as in older children. Hence, MUAC may perform an important role in identifying children at high risk of subsequent death also in this age group.

Strength and weaknesses

A strength of this study is the continued field-based prospective data collection allowing an unbiased investigation of the association between MUAC and mortality. A limitation is that children were not visited at specified ages, but at rounds of visits with a 3 months interval. Another potential limitation is that the study is based on data from an urban African area and availability of care and risk of death may differ in rural areas or in other geographical settings.

Consistency with previous observations

The prognostic ability of MUAC *z*-score has not been evaluated previously, but in previous studies MUAC has been corrected for age. In a large meta analysis of the relation between nutritional status and mortality, Pelletier[11] reported that simple arm circumference was superior to arm circumference corrected by age, in all studies except one. This superiority has often been attributed to age confounding, MUAC identifying more young children and young children having a higher mortality.[11] We found that MUAC identified more young children and girls as malnourished, but MUAC and MUAC *z*-score had the same sensitivity. Evaluated by AUC, MUAC performed similarly as MUAC *z*-score in predicting mortality.

Interpretations

We found no overall difference in the performance of MUAC and MUAC *z*-score as predictors for mortality. We found that MUAC classified more girls and young children as malnourished, AUC and sensitivity varied across period, sex and age groups (Figures 2 and 3), and the short-term prognostic ability was better for girls than boys. The relative advantage of MUAC or MUAC *z*-score might therefore vary for different cutoffs and between populations with different mortality patterns. On the basis of the present study MUAC can be used for all age groups. As the *z*-score is more difficult to use it may not be optimal for screening.

Implications

The measurement of MUAC only requires a measuring tape, and versions exist with different colors making it possible for people with little education to use it. MUAC *z*-score, on the other hand, requires exact information on age and the use of a chart. It therefore requires better educated health workers and leaves more room for errors. On the basis of this study, we see no need to use MUAC *z*-score instead of MUAC to identify children at high risk of dying.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Supplementary Information accompanies the paper on European Journal of Clinical Nutrition website (http://www.nature.com/ejcn)