Public Health Nutrition: 23(3), 538–543 doi:10.1017/S1368980019002520

Short Communication

Comparison of anthropometric indicators to predict mortality in a population-based prospective study of children under 5 years in Niger

Kieran S O'Brien[1,2], Abdou Amza[3], Boubacar Kadri[3], Beido Nassirou[3], Sun Y Cotter[1], Nicole E Stoller[1], Sheila K West[4], Robin L Bailey[5], Travis C Porco[1,6,7], Jeremy D Keenan[1,6], Thomas M Lietman[1,6,7] and Catherine E Oldenburg[1,7,]*
[1]Francis I. Proctor Foundation, University of California San Francisco, 513 Parnassus Avenue, S334, San Francisco, CA 94143, USA: [2]Division of Epidemiology, School of Public Health, University of California, Berkeley, CA, USA: [3]Programme FSS/Université Abdou Moumouni de Niamey, Programme National de Santé Oculaire, Niamey, Niger: [4]Dana Center for Preventive Ophthalmology, Wilmer Eye Institute, Johns Hopkins University, Baltimore, MD, USA: [5]Clinical Research Unit, Department of Infectious and Tropical Diseases, London School of Hygiene & Tropical Medicine, London, UK: [6]Department of Ophthalmology, University of California San Francisco, San Francisco, CA, USA: [7]Department of Epidemiology & Biostatistics, University of California San Francisco, San Francisco, CA, USA

Submitted 8 November 2018: Final revision received 21 April 2019: Accepted 21 May 2019: First published online 9 September 2019

Abstract
Objective: In the present study, we aimed to compare anthropometric indicators as predictors of mortality in a community-based setting.
Design: We conducted a population-based longitudinal study nested in a cluster-randomized trial. We assessed weight, height and mid-upper arm circumference (MUAC) on children 12 months after the trial began and used the trial's annual census and monitoring visits to assess mortality over 2 years.
Setting: Niger.
Participants: Children aged 6–60 months during the study.
Results: Of 1023 children included in the study at baseline, height-for-age *Z*-score, weight-for-age *Z*-score, weight-for-height *Z*-score and MUAC classified 777 (76·0 %), 630 (61·6 %), 131 (12·9 %) and eighty (7·8 %) children as moderately to severely malnourished, respectively. Over the 2-year study period, fifty-eight children (5·7 %) died. MUAC had the greatest AUC (0·68, 95 % CI 0·61, 0·75) and had the strongest association with mortality in this sample (hazard ratio = 2·21, 95 % CI 1·26, 3·89, $P = 0·006$).
Conclusions: MUAC appears to be a better predictor of mortality than other anthropometric indicators in this community-based, high-malnutrition setting in Niger.

Keywords
Malnutrition
Anthropometry
Mortality
Niger

Community-based screening and treatment of acute malnutrition can reduce malnutrition-related hospitalization and mortality[1,2]. The risk of mortality for children with a weight-for-height *Z*-score (WHZ) of <–3 or a mid-upper arm circumference (MUAC) of <115 mm is substantially elevated compared with children with higher scores[2]. The WHO uses these cut-offs in addition to the presence of nutritional oedema to identify children with severe acute malnutrition (SAM)[3].

Practitioners in clinic-based settings use both MUAC and WHZ to identify children with SAM for admission to nutritional programmes. MUAC is more suitable for community-based programmes[4,5], which typically use MUAC alone to screen for SAM. WHZ requires weight and height measurement and comparison to reference standards, whereas MUAC relies on a single, independent measurement. WHZ is also associated with body shape and might result in inaccurate estimates of the prevalence of malnutrition in certain populations[6,7]. MUAC is thus simpler, less expensive and more acceptable to children and practitioners in community settings than WHZ, while being both an accurate and a reliable indicator of malnutrition[5].

*Corresponding author: Email catherine.oldenburg@ucsf.edu

MUAC has been shown to be a better predictor of near-term mortality than WHZ in children in both clinic- and community-based settings[8–15]. Increasingly, studies have explored the use of MUAC alone to identify children for admission to nutritional programmes[5,11,16]. Despite identifying the most at-risk children, using MUAC < 115 mm as the only anthropometric criterion for admission might miss children who would benefit from treatment[13,17]. MUAC and WHZ tend to have poor agreement and identify different subsets of children[8,13,17–20]. In addition, much of the available evidence for MUAC's ability to identify children at risk for mortality is from clinical studies and as such is subject to selection bias related in part to health-care-seeking behaviours[8,12–15]. The effectiveness of using MUAC to efficiently identify malnourished children and reduce mortality relies on MUAC being an adequate indicator for mortality in multiple settings.

Here, we aimed to compare anthropometric indicators as predictors of mortality over 2 years in a population-based cohort of children nested in a cluster-randomized trachoma trial in Niger[21–23].

Methods

Study setting

The current secondary analysis was part of the Partnership for the Rapid Elimination of Trachoma (PRET; clinicaltrials.gov NCT00792922)[24]. The multicentre, cluster-randomized PRET trial took place in the Gambia, Niger and Tanzania; the present study uses data from the Niger site. Eligibility criteria for participation in the Niger trial have been reported elsewhere[21,25]. Briefly, the trial included forty-eight communities with populations between 250 and 600 people in six Centres de Santé Intégrés in the Matameye district and excluded communities with a prevalence of trachoma of less than 10 % among children younger than 72 months.

Study design and participants

The PRET trial randomized communities to four arms: (i) annual treatment, standard (80 %) coverage; (ii) annual treatment, enhanced (≥90 %) coverage; (iii) biannual treatment, standard (80 %) coverage; and (iv) biannual treatment, enhanced (≥90 %) coverage. Treatment was a single directly observed dose of oral azithromycin (20 mg/kg of body weight up to a maximum dose of 1 g). An annual census was conducted to collect data on demographics and vital status and to assess treatment coverage over the 3-year study period. Biannual study visits were conducted to monitor trachoma prevalence and collect data on secondary outcomes. The design of the parent trial has been reported previously[21,25].

The baseline visit for the present study corresponds to the PRET trial's 12-month study visit. The present study includes children 6–60 months old who completed anthropometric assessments during the baseline visit from the twenty-four communities randomized to annual or biannual treatment at 80 % coverage. A random sample of sixty-two children aged 6–60 months per community was generated from prior census data in order to include at least fifty children per community. If a community had fewer than sixty-two children, all children were selected.

Trained study personnel collected data on demographics and anthropometry, including length or height, weight and MUAC. Study personnel measured recumbent length in children younger than 24 months and standing height in children aged 24 months or older. Length and height were recorded to the nearest 0·1 cm and were assessed using a Schorrboard (Schorr Productions, Olney, MD, USA). Children were weighed standing or in the arms of a caregiver. Weight was recorded to the nearest 0·1 kg using a Seca 874 scale (Seca GmbH & Co. KG, Hamburg, Germany). MUAC was measured to the nearest 1 mm using a tape developed by Johns Hopkins University (Baltimore, MD, USA)[26]. All measurements were conducted three times and the median value was used for analysis. Study personnel referred children with MUAC < 115 mm or illness to the local health post.

Variables

The outcome for the present study is death as recorded on any census or monitoring visit from baseline to 2 years after enrolment, which corresponds to the PRET trial's 36-month visit. Children were classified as died during this period or alive at the final study visit. Children who moved during the study period or had an unknown status at the final study visit were classified as lost to follow-up.

The predictors in the present study are height-for-age *Z*-score (HAZ), weight-for-age *Z*-score (WAZ), WHZ and MUAC. HAZ, WAZ and WHZ were calculated according to the 2006 WHO Child Growth Standards using the zscore06 package in the statistical software package Stata version 14.2[27]. Anthropometric indicators were dichotomized into moderately to severely malnourished or not. Children with *Z*-scores < -2 or MUAC < 125 mm were classified as malnourished. We used moderate to severe malnutrition rather than SAM for categorization because, as both SAM and mortality are rare events, this sample contained too few cases of both for analysis.

Covariates were chosen *a priori* and included age at the time of the baseline visit in months, sex and randomization arm.

Statistical methods

Characteristics of the study population at baseline were compared by final study visit status (died, alive, moved/unknown) using Fisher's exact test for categorical variables or ANOVA for continuous variables. We constructed Venn diagrams to display the numbers of children classified by each combination of anthropometric indicators of malnutrition. Receiver-operating characteristic curves were

https://doi.org/10.1017/S1368980019002520 Published online by Cambridge University Press

constructed to compare the ability of each anthropometric indicator to predict mortality at different cut-off points. AUC were calculated and compared using a χ^2 test.

To examine the association between each predictor and mortality, we used generalized estimating equations to estimate hazard ratios. Models used a binomial distribution with a complementary log–log link, assumed an exchangeable working correlation, accounted for clustering by community and estimated robust SE. Unadjusted models included the predictor in question as the sole covariate. Adjusted models included age, sex and randomization arm as covariates. All models included an indicator for study visit interval to account for censoring between study visits. Analyses were conducted using Stata version 14.2 and figures were developed in R version 3.5.2.

Results

In May 2011, 1375 children aged 6–60 months were randomly selected from twenty-four communities included in the PRET-Niger trial and 1023 (74·4 %) participated in the study visit (Fig. 1). Table 1 displays baseline characteristics. Among children in the final sample, 47·1 % were female and the mean age was 36·9 months. HAZ, WAZ, WHZ and MUAC classified 777 (76·0 %), 630 (61·6 %), 131 (12·9 %) and eighty (7·8 %) children as malnourished, respectively. Fifty-two children (5·1 %) were classified as malnourished by all indicators (Fig. 2). Overall, fifty-eight children (5·7 %) died over the 2-year study period and 181 children (17·7 %) moved out of the study area or had an unknown status by the time of the final study visit. No significant differences were identified when comparing baseline characteristics by status (died, alive, moved/unknown) at the final study visit. By anthropometric indicator, deaths included 5·9 % (46/777) of those classified as malnourished by HAZ, 6·8 % (43/630) by WAZ, 9·9 % (13/131) by WHZ and 16·3 % (13/80) by MUAC.

Figure 3 shows receiver-operating characteristic curves for HAZ, WAZ, WHZ and MUAC. Table 2 summarizes the AUC for each anthropometric indicator. MUAC had the largest AUC (0·68, 95 % CI 0·61, 0·75), followed by WHZ and WAZ which had similar AUC (0·64, 95 % CI 0·57, 0·72 and 0·63, 95 % CI 0·55, 0·71, respectively).

Table 3 presents the population average relative hazard of mortality in children with and without malnutrition as predicted by HAZ, WAZ, WHZ and MUAC. The adjusted hazard of mortality over 2 years among children with MUAC < 125 mm was 2·21 times the hazard among children with MUAC ≥ 125 mm across communities in the present study (95 % CI 1·26, 3·89, P = 0·006). The comparison of mortality by nutritional status was not statistically significant for the other anthropometric indicators, although the magnitude of the association for the comparison with WAZ was the second largest (adjusted hazard ratio = 1·75, 95 % CI 0·96, 3·19, P = 0·07).

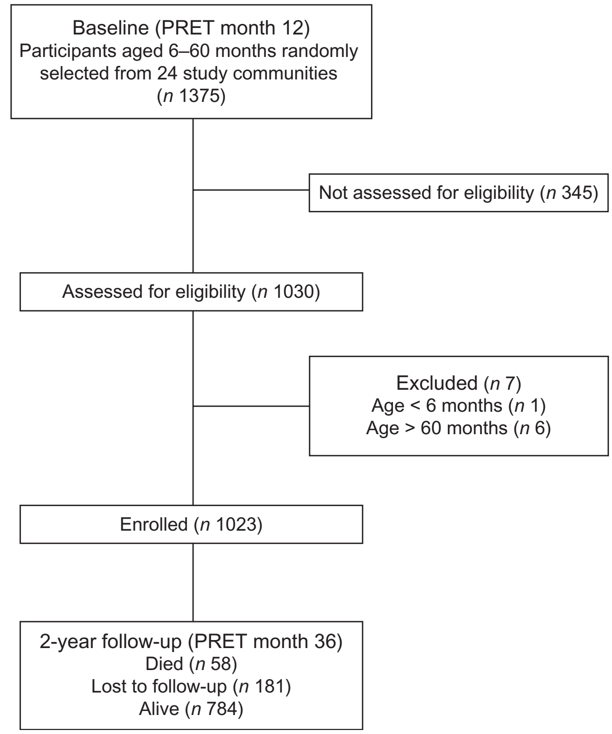

Fig. 1 Flow diagram of participants in the current secondary analysis of the PRET-Niger trial (PRET, Partnership for the Rapid Elimination of Trachoma)

Table 1 Baseline characteristics of the study population of children aged 6–60 months, PRET-Niger trial*

Characteristic	*n* or mean	% or SD
Female	482	47·1
Male	541	52·9
Age (months), mean and SD	36·9	14·5
Annual	482	47·1
Biannual	541	52·9
HAZ†, mean and SD	−3·1	2·0
WAZ, mean and SD	−2·4	1·3
WHZ‡, mean and SD	−0·8	1·2
MUAC (mm), mean and SD	142·0	12·2
HAZ ≥ −2	245	24·0
HAZ < −2	777	76·0
WAZ ≥ −2	393	38·4
WAZ < −2	630	61·6
WHZ ≥ −2	887	87·1
WHZ < −2	131	12·9
MUAC ≥ 125 mm	943	92·2
MUAC < 125 mm	80	7·8
Total *N*	1023	–

PRET, Partnership for the Rapid Elimination of Trachoma; HAZ, height-for-age *Z*-score; WAZ, weight-for-age *Z*-score; WHZ, weight-for-height *Z*-score; MUAC, mid-upper arm circumference.
*Percentages may not sum to 100 % due to rounding.
†Missing HAZ: *n* 1.
‡Missing WHZ: *n* 5.

Discussion

In the current population-based prospective study, we found that MUAC was the strongest predictor of mortality. Our results are consistent with previous similar studies in

https://doi.org/10.1017/S1368980019002520 Published online by Cambridge University Press

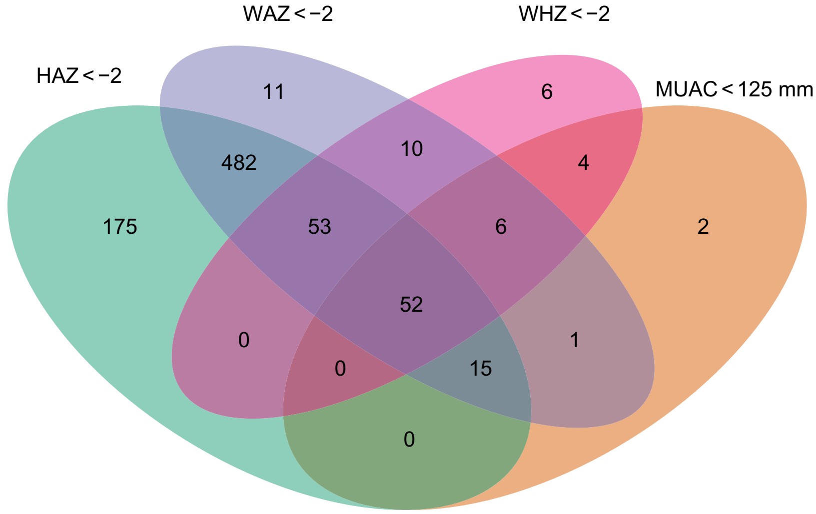

Fig. 2 Venn diagram showing the number of children aged 6–60 months classified as acutely malnourished by different anthropometric indicators in the PRET-Niger trial (HAZ, height-for-age *Z*-score; WAZ, weight-for-age *Z*-score; WHZ, weight-for-height *Z*-score; MUAC, mid-upper arm circumference; PRET, Partnership for the Rapid Elimination of Trachoma)

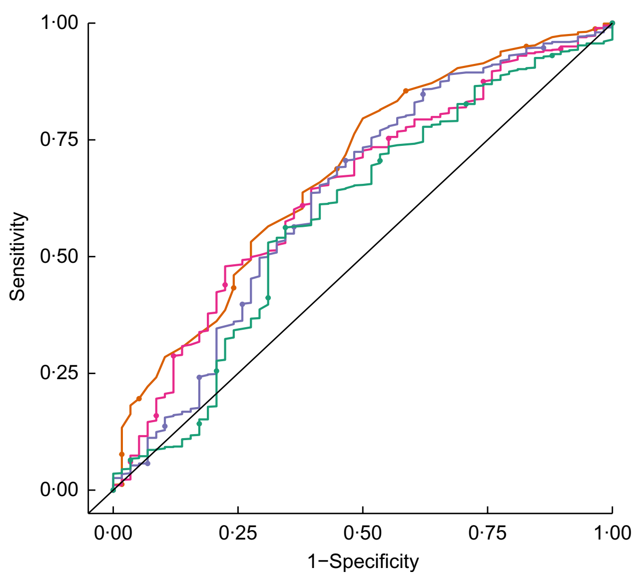

Fig. 3 Receiver-operating characteristic curves comparing the accuracy of different anthropometric indicators (─●─, height-for-age *Z*-score; ─●─, weight-for-age *Z*-score; ─●─, weight-for-height *Z*-score; ─●─, mid-upper arm circumference) in predicting mortality over 2 years among children aged 6–60 months in the PRET-Niger trial. — represents the line of no discrimination (PRET, Partnership for the Rapid Elimination of Trachoma)

Table 2 Comparison of areas under the receiver-operating characteristic curves of different anthropometric indicators* for predicting mortality over 2 years among children aged 6–60 months in the PRET-Niger trial

Model	AUC	95 % CI
HAZ	0·59	0·51, 0·67
WAZ	0·63	0·55, 0·71
WHZ	0·64	0·57, 0·72
MUAC	0·68	0·61, 0·75

PRET, Partnership for the Rapid Elimination of Trachoma; HAZ, height-for-age *Z*-score; WAZ, weight-for-age *Z*-score; WHZ, weight-for-height *Z*-score; MUAC, mid-upper arm circumference.
**P* value for the test of the null hypothesis that the four AUC are equal = 0·01.

community- and clinic-based settings. Population-based studies in South Asia and West Africa have demonstrated MUAC's strong association with mortality[16,28–30]. Several studies have shown that MUAC is a better predictor of mortality than WHZ[8,10,12,13,15,31,32], including other longitudinal studies conducted in community settings[9,11,21,33,34]. Studies examining multiple indicators suggest that WAZ is the second-most sensitive predictor of mortality[31,33,34] with one recent study concluding that a combination of WAZ and MUAC identifies the majority of near-term deaths associated with malnutrition[20].

In the present study, we found that HAZ, WAZ, WHZ and MUAC identified different subgroups of children as malnourished, with some overlap. Discordance in children identified with MUAC alone *v.* MUAC and/or WHZ as the criterion for admission to nutritional programmes for SAM has also been shown in other studies[17,18,35]. In our study, a larger proportion of children identified as moderately to severely malnourished by MUAC died compared with those identified by all other indicators. For community-based screening programmes, MUAC is more efficient than WHZ- or even WAZ-based screening, both of which require more complex measurements and calculation of *Z*-scores. Our results indicate that although use of MUAC alone will miss some children with malnutrition who may be at risk of mortality, at the community level MUAC identifies a large proportion of these children. Given the relative ease of the use of MUAC for mass screening programmes, these results support its continued use.

Table 3 Relative hazard of mortality over 2 years in children aged 6–60 months by nutritional status* in the PRET-Niger trial

Model	Unadjusted HR	95 % CI	*P* value	Adjusted HR†	95 % CI	*P* value
HAZ	1·20	0·61, 2·35	0·60	1·52	0·76, 3·05	0·24
WAZ	1·82	1·00, 3·31	0·05	1·75	0·96, 3·19	0·07
WHZ	2·25	1·34, 3·78	0·002	1·38	0·85, 2·27	0·20
MUAC	3·76	2·00, 7·07	<0·001	2·21	1·26, 3·89	0·006

PRET, Partnership for the Rapid Elimination of Trachoma; HR, hazard ratio; HAZ, height-for-age *Z*-score; WAZ, weight-for-age *Z*-score; WHZ, weight-for-height *Z*-score; MUAC, mid-upper arm circumference.
*Acute malnutrition defined as HAZ < −2, WAZ < −2, WHZ < −2 or MUAC < 125 mm.
†Adjusted for treatment arm, baseline age and sex.

Strengths of the present study include the use of a population-based sample, which provides evidence representative of the community as a whole. The prospective design also enabled us to examine mortality over a 2-year period, providing longer-term evidence than prior studies. In addition, we minimized the risk of misclassification by using standardized data collection as part of a randomized controlled trial and used triplicate measurements of anthropometric indicators to ensure repeatability. Limitations include the sample size, which was too small to examine moderate acute malnutrition and SAM separately, as there was only a single child identified with SAM. Prior work suggests that 46–80 % of deaths among malnourished children occur among mild to moderate malnutrition[36] and some have suggested using higher MUAC cut-offs for screening[13,19]. Another potential limitation is generalizability. The study was conducted in a trachoma-endemic, high-mortality setting in Niger, and it may not be possible to generalize results to other settings with different patterns of malnutrition, infectious disease and child mortality. In addition, loss to follow-up was 18 %. Although the population of children who moved or had unknown status at follow-up was similar to those who were alive, differential loss to follow-up could lead to selection bias. Finally, relatively few baseline covariates were measured, and we cannot rule out the possibility of bias due to residual confounding.

In the present study of pre-school children in a trachoma-endemic region of Niger, we found that MUAC was a better predictor of mortality than other anthropometric indicators. These results support the use of MUAC in screening for acute malnutrition, as MUAC alone may identify more children at risk for mortality than other indicators in similar West African settings.

Acknowledgements

Acknowledgements: The authors would like to thank the Data and Safety Monitoring Committee, including Douglas Jabs, MD, MBA (chair); Antoinette Darville, MD; Maureen Maguire, PhD; and Grace Saguti, MD, who were generous with their time and advice before and during the study. The authors thank Kurt Dreger, who designed and maintained the database, and the team in Niger at Programme National de Santé Oculaire who helped implement the study. *Financial support:* This work was supported by the Bill and Melinda Gates Foundation (grant number 48027); the National Institutes of Health (grant numbers NIH/NEI K23 EYO19881-01 and NIH/NCRR/OD UCSF-CTSI KL2 RR024130); Research to Prevent Blindness; That Man May See; the Harper-Inglis Trust; and the Peierls Foundation. The funders had no role in the design, analysis or writing of this article. *Conflict of interest:* None. *Authorship:* K.S.O. formulated the research question, analysed the data and contributed to the writing of this article. A.A., B.K., B.N., S.Y.C., N.E.S., S.K.W., R.L.B., T.C.P., J.D.K. and T.M.L. designed and implemented the original trial and contributed to the writing of this article. C.E.O. formulated the research question and contributed to the writing of this article. *Ethics of human subject participation:* This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the University of California San Francisco Committee for Human Research and the Comité d'Ethique du Niger (the Ethical Committee of Niger). Verbal informed consent was obtained from all subjects. Verbal consent was witnessed and formally recorded.

References

1. Collins S, Dent N, Binns P *et al.* (2006) Management of severe acute malnutrition in children. *Lancet* **368**, 1992–2000.
2. Collins S, Sadler K, Dent N *et al.* (2006) Key issues in the success of community-based management of severe malnutrition. *Food Nutr Bull* **27**, 3 Suppl., S49–S82.
3. World Health Organization & UNICEF (2009) *WHO Child Growth Standards and the Identification of Severe Acute Malnutrition in Infants and Children: A Joint Statement by the World Health Organization and the United Nations Children's Fund*. Geneva: WHO.
4. Velzeboer MI, Selwyn BJ, Sargent IF *et al.* (1983) The use of arm circumference in simplified screening for acute malnutrition by minimally trained health workers. *J Trop Pediatr* **29**, 159–166.
5. Myatt M, Khara T & Collins S (2006) A review of methods to detect cases of severely malnourished children in the community for their admission into community-based therapeutic care programs. *Food Nutr Bull* **27**, 3 Suppl., S7–S23.
6. Myatt M, Duffield A, Seal A *et al.* (2009) The effect of body shape on weight-for-height and mid-upper arm circumference based case definitions of acute malnutrition in Ethiopian children. *Ann Hum Biol* **36**, 5–20.

https://doi.org/10.1017/S1368980019002520 Published online by Cambridge University Press

7. Post CL & Victora CG (2001) The low prevalence of weight-for-height deficits in Brazilian children is related to body proportions. *J Nutr* **131**, 1290–1296.
8. Berkley J, Mwangi I, Griffiths K *et al.* (2005) Assessment of severe malnutrition among hospitalized children in rural Kenya: comparison of weight for height and mid upper arm circumference. *JAMA* **294**, 591–597.
9. Briend A, Maire B, Fontaine O *et al.* (2012) Mid-upper arm circumference and weight-for-height to identify high-risk malnourished under-five children. *Matern Child Nutr* **8**, 130–133.
10. Mwangome MK, Fegan G, Fulford T *et al.* (2012) Mid-upper arm circumference at age of routine infant vaccination to identify infants at elevated risk of death: a retrospective cohort study in the Gambia. *Bull World Health Organ* **90**, 887–894.
11. Ali E, Zachariah R, Shams Z *et al.* (2013) Is mid-upper arm circumference alone sufficient for deciding admission to a nutritional programme for childhood severe acute malnutrition in Bangladesh? *Trans R Soc Trop Med Hyg* **107**, 319–323.
12. Aguayo VM, Aneja S, Badgaiyan N *et al.* (2015) Mid upper-arm circumference is an effective tool to identify infants and young children with severe acute malnutrition in India. *Public Health Nutr* **18**, 3244–3248.
13. Grellety E, Krause LK, Shams Eldin M *et al.* (2015) Comparison of weight-for-height and mid-upper arm circumference (MUAC) in a therapeutic feeding programme in South Sudan: is MUAC alone a sufficient criterion for admission of children at high risk of mortality? *Public Health Nutr* **18**, 2575–2581.
14. Sachdeva S, Dewan P, Shah D *et al.* (2016) Mid-upper arm circumference *v.* weight-for-height *Z*-score for predicting mortality in hospitalized children under 5 years of age. *Public Health Nutr* **19**, 2513–2520.
15. Chiabi A, Mbanga C, Mah E *et al.* (2017) Weight-for-height Z score and mid-upper arm circumference as predictors of mortality in children with severe acute malnutrition. *J Trop Pediatr* **63**, 260–266.
16. Goossens S, Bekele Y, Yun O *et al.* (2012) Mid-upper arm circumference based nutrition programming: evidence for a new approach in regions with high burden of acute malnutrition. *PLoS One* **7**, e49320.
17. Isanaka S, Guesdon B, Labar AS *et al.* (2015) Comparison of clinical characteristics and treatment outcomes of children selected for treatment of severe acute malnutrition using mid upper arm circumference and/or weight-for-height Z-score. *PLoS One* **10**, e0137606.
18. Tadesse AW, Tadesse E, Berhane Y *et al.* (2017) Comparison of mid-upper arm circumference and weight-for-height to diagnose severe acute malnutrition: a study in Southern Ethiopia. *Nutrients* **9**, 267.
19. Laillou A, Prak S, de Groot R *et al.* (2014) Optimal screening of children with acute malnutrition requires a change in current WHO guidelines as MUAC and WHZ identify different patient groups. *PLoS One* **9**, e101159.
20. Myatt M, Khara T, Dolan C *et al.* (2019) Improving screening for malnourished children at high risk of death: a study of children aged 6–59 months in rural Senegal. *Public Health Nutr* **22**, 862–871.
21. Amza A, Kadri B, Nassirou B *et al.* (2017) A cluster-randomized trial to assess the efficacy of targeting trachoma treatment to children. *Clin Infect Dis* **64**, 743–750.
22. Amza A, Kadri B, Nassirou B *et al.* (2013) A cluster-randomized controlled trial evaluating the effects of mass azithromycin treatment on growth and nutrition in Niger. *Am J Trop Med Hyg* **88**, 138–143.
23. Amza A, Yu SN, Kadri B *et al.* (2014) Does mass azithromycin distribution impact child growth and nutrition in Niger? A cluster-randomized trial. *PLoS Negl Trop Dis* **8**, e3128.
24. Stare D, Harding-Esch E, Munoz B *et al.* (2011) Design and baseline data of a randomized trial to evaluate coverage and frequency of mass treatment with azithromycin: the Partnership for Rapid Elimination of Trachoma (PRET) in Tanzania and The Gambia. *Ophthalmic Epidemiol* **18**, 20–29.
25. Amza A, Kadri B, Nassirou B *et al.* (2012) Community risk factors for ocular chlamydia infection in Niger: pre-treatment results from a cluster-randomized trachoma trial. *PLoS Negl Trop Dis* **6**, e1586.
26. Labrique AB, Christian P, Klemm RDW *et al.* (2011) A cluster-randomized, placebo-controlled, maternal vitamin A or β-carotene supplementation trial in Bangladesh: design and methods. *Trials* **12**, 102.
27. Leroy J (2011) *ZSCORE06: Stata module to calculate anthropometric z-scores using the 2006 WHO Child Growth Standards. Statistical Software Components S457279*. Chestnut Hill, MA: Boston College Department of Economics.
28. Briend A, Wojtyniak B Rowland MG (1987) Arm circumference and other factors in children at high risk of death in rural Bangladesh. *Lancet* **2**, 725–728.
29. West KP Jr, Pokhrel RP, Katz J *et al.* (1991) Efficacy of vitamin A in reducing preschool child mortality in Nepal. *Lancet* **338**, 67–71.
30. Taneja S, Rongsen-Chandola T, Mohan SB *et al.* (2018) Mid upper arm circumference as a predictor of risk of mortality in children in a low resource setting in India. *PLoS One* **13**, e0197832.
31. Bairagi R (1981) On validity of some anthropometric indicators as predictors of mortality. *Am J Clin Nutr* **34**, 2592–2594.
32. Van den Broeck J, Eeckels R & Massa G (1996) Validity of single-weight measurements to predict current malnutrition and mortality in children. *J Nutr* **126**, 113–120.
33. Alam N, Wojtyniak B & Rahaman MM (1989) Anthropometric indicators and risk of death. *Am J Clin Nutr* **49**, 884–888.
34. Vella V, Tomkins A, Ndiku J *et al.* (1994) Anthropometry as a predictor for mortality among Ugandan children, allowing for socio-economic variables. *Eur J Clin Nutr* **48**, 189–197.
35. Bern C & Nathanail L (1995) Is mid-upper-arm circumference a useful tool for screening in emergency settings? *Lancet* **345**, 631–633.
36. Pelletier DL (1994) The relationship between child anthropometry and mortality in developing countries: implications for policy, programs and future research. *J Nutr* **124**, 10 Suppl., 2047S–2081S.

Public Health Nutrition