Utilization of mid-upper arm circumference versus weight-for-height in nutritional rehabilitation programmes: a systematic review of evidence

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Abbreviations

CI	confidence interval
F-75	therapeutic milk used in stabilization phase of the treatment of SAM
F-100	therapeutic milk used in transition and recovery phases of the treatment of SAM
IQR	interquartile range
MUAC	mid-upper arm circumference
NCHS	National Center for Health Statistics
NGO	nongovernmental organization
OTP	outpatient treatment programme
PICO	Population, Intervention, Comparator and Outcomes
RCT	randomized controlled trial
RUTF	ready-to-use therapeutic food
SAM	severe acute malnutrition
SD	standard deviation
SFP	supplementary feeding programme
W/H	weight-for-height
WHM	W/H percentage of the median
WHO	World Health Organization
WHO-GS	World Health Organization Child Growth Standards
WHZ	weight-for-height z-score

Measurements

cm	centimetre
d	day
g	gram
kcal	kilocalorie
kg	kilogram
kJ	kilojoule
m	month
ml	millilitre
mm	millimetre
n	number
w	week

Abstract

Background
A low mid-upper arm circumference (MUAC) <115 mm is increasingly used as a stand-alone anthropometric admission criterion for nutritional rehabilitation of severely acute malnourished children, alongside a low weight-for-height z-score (WHZ) <-3. As these two indicators correlate poorly, we reviewed the evidence on the comparative outcomes of children with severe acute malnutrition (SAM) admitted to and discharged from nutritional rehabilitation programmes on the basis of either MUAC or WHZ. The utilization of bilateral pitting oedema as an independent indicator of SAM was out of the scope of our review.

Methods
We searched Medline, Embase, the CRD databases, the Cochrane Library and grey literature for evidence on mortality, recovery, treatment duration, costs, adverse events and population coverage when admission of SAM children was based on MUAC vs WHZ.

Findings
Eleven studies were included. Only one cohort study directly compared children with a MUAC <115 mm and those with WHZ <-3 at the start of the nutritional rehabilitation. It reported similar mortality rates in both groups, although different causalities might have been involved as a low MUAC was more associated with stunting, younger age, being a female and nutritional oedema than a low WHZ. Four studies admitted SAM children on the basis of MUAC only. The mortality risk was relatively low in three studies (≤2.1%). The mean standard deviation (±SD) recovery time ranged from 44±30 days to 50±26 days, and the daily MUAC gain from 0.17±0.16 mm to 0.51±0.3 mm. These findings were consistent with six additional studies where WHZ but not MUAC was the admission criterion. Overall, the increase in MUAC paralleled the daily weight gain, which ranged between 2.0 and 6.5 g/kg/day. One study reported a lower daily MUAC gain when children were younger and smaller, and in females. Two studies discharged children on the basis of MUAC (MUAC ≥124 mm only or MUAC ≥130 mm), but did not report on outcomes after discharge. The most appropriate MUAC cut-off for discharge is thus unknown. No study reported on costs, adverse effects or population coverage. No study assessed the outcomes of children with a low WHZ excluded from treatment because they did not fulfil the MUAC stand-alone admission criterion.

Conclusion
There are indications that MUAC could be used adequately as a stand-alone criterion for SAM children to be admitted to and discharged from nutritional rehabilitation programmes. However, the evidence base is currently insufficient. More data are particularly needed on the risks of children with a low WHZ not treated for SAM where MUAC is used as a stand-alone criterion. The extent to which factors such as age, sex and stunting affect the rehabilitation outcomes in children admitted with MUAC <115 mm must also be clarified. There are numerous nutritional programmes currently active worldwide and their thorough evaluation could generate such data in the short term.

This work was commissioned by the World Health Organization (WHO).

Authors declare that they have no conflict of interest.

Background and objective

In 1999, the World Health Organization (WHO) defined severe acute malnutrition (SAM) in 6–59 month old children as a weight-for-height z-score (WHZ) <-3 standard deviations (SD) (severe wasting) of a reference population, or the presence of bilateral pitting oedema (*1*). The reference population was the one collected by the United States National Center for Health Statistics (1978 NCHS reference) until the issue of the WHO 2006 Child Growth Standards (2006 WHO-GS) (*2*). In 2007, the United Nations agencies endorsed a low mid-upper arm circumference (MUAC) <110 mm as an independent diagnostic criterion for SAM, alongside a WHZ <-3 or nutritional oedema (*3*). The cut-off was recently increased to MUAC <115 mm because it was judged to better align with the WHZ <-3 classification under the 2006 WHO-GS (*2*). MUAC is judged to have operational advantages compared to WHZ: no reference table is needed as a single cut-off is applied independently of sex, age and height; only one measurement is required, with a simple and cheap arm strip; and the colored band can be easily used and interpreted by poorly educated community workers allowing its use in large community-based programmes (*4*). Since United Nations endorsement and because of its operational advantages, MUAC is increasingly used as a stand-alone admission criterion for nutritional rehabilitation in countries such as Bangladesh, Ethiopia and Pakistan.

However, MUAC-based and WHZ-based malnutrition diagnosis correlates poorly, a puzzling observation for two indicators of severe wasting. It was reported that only about 40% of children identified as SAM by one indicator is also diagnosed as such by the other (*2*). For example, among severely malnourished children hospitalized in rural Kenya, 65.1% (486/746) of the WHZ-based SAM cases also had an MUAC <115 mm, whereas 56.0% (489/873) of the MUAC-based SAM cases was also identified by WHZ (*5*). In that study, 42.9% (489/1140) of the SAM cases based on one indicator or the other was identified by both. The discrepancy between the two indicators can be even more extreme. Fernandez et al. reported that among 34 937 children between the ages of 6 and 59 months, from 39 nutritional surveys, 75% of the children with a WHZ <- 3 (2006 WHO-GS) was not identified by a MUAC <115 mm (*6*). Such discrepancy generates important programmatic challenges and confusion. On the one hand, relying on only one of these indicators may underdetect true acute malnutrition cases and result in missed opportunities of treating a severe condition. On the other hand, a strategy where the diagnosis of SAM can be based on either indicator could inflate programme volumes unduly, as it is unclear if children identified by one indicator and not by the other require standard nutritional rehabilitation.

A much related question concerns the choice of the anthropometric indicator for monitoring nutritional rehabilitation and deciding discharge. Until recently, SAM in children 6–59 months had been considered a condition systematically requiring inpatient treatment. The recommended anthropometric discharge criterion was then based on WHZ ≥-1 or a weight-for-height (W/H) ≥90% of the reference median (*1*). It has also been proposed that children be discharged based on percent weight gain (>15% of the weight at enrolment) (*2*). However, when admission to nutritional rehabilitation is based on MUAC alone, it might be practical to use MUAC also for monitoring the recovery, particularly in community-based programmes. Historical cohort studies from Bangladesh, Malawi and Uganda, for example, indicated that the mortality risk does not exceed 1/10 000/day if MUAC ≥125 mm (*4*). Consequently, it has been proposed that this cut-off could define nutrition recovery. However, outcomes of children discharged on the basis of MUAC only must be reviewed before issuing guidance.

In order to clarify these two important issues, we reviewed the evidence on the outcomes of SAM children admitted to and discharged from nutritional rehabilitation programmes on the basis of MUAC as a stand-alone criterion, compared to using WHZ. The utilization of bilateral pitting oedema as an independent indicator of SAM was out of the scope of our review. Our research questions are summarized in Table 1.

Table 1
Research questions

PICO criteria	
Population	SAM children aged >6 months, being admitted to inpatient or outpatient programmes of nutritional rehabilitation in low and middle income countries
Intervention	1. MUAC for SAM diagnosis[a] 2. MUAC for monitoring recovery and discharge
Comparator	1.WHZ for SAM diagnosis 2.WHZ for monitoring recovery and discharge
Outcomes	1. short-term mortality 2. recovery rate 3. time to recover 4. weight, MUAC, length gain 5. use of resources, costs 6. adverse effects 7. numbers treated, population coverage

[a] SAM is defined by a MUAC <110 mm when compared with WHZ <-3 according to the 1978 NCHS reference and a MUAC <115 mm when compared with WHZ <-3 according to the 2006 WHO reference.

Methods

We searched Medline via PubMed (http://www.ncbi.nlm.nih.gov), Embase (http://www.embase.com), the Cochrane Library (www.cochranelibrary.com) and the databases of the Centre for Reviews and Dissemination (www.crd.york.ac.uk). We also searched the Emergency Nutrition Network web site (http://ennonline.net/) for additional field reports and the MUAC community web site (http://tng.brixtonhealth.com/tracker).

We applied the following search strategy in Medline:

#1. (((arm OR midarm OR mid-arm) AND circumference) OR MUAC*)
#2. weight-for-height OR weight-for-length OR WHZ OR WHM OR WFH OR weight gain OR wast* OR wasting syndrome [mesh] OR emaciation [mesh] OR Malnutrition [Mesh] OR growth disorders [mesh] OR child nutrition disorders [mesh]
#3. (treatment OR therapeutic OR supplementary feeding) OR (rehabilitation OR discharge* OR cure*)
#4. infant [Mesh] OR child [Mesh]
#5. #1 AND #2 AND #3 AND #4
#6. editorial [ptyp] OR comment[ptyp] OR letter [ptyp]
#7. #5 NOT #6

The search strategy was adapted to fit each individual database. We searched for evidence up to July 2012. Although the research question initially included a comparison term with WHZ, our preliminary evidence search found virtually no such comparative studies. Therefore, we decided to include all original (observational or experimental) studies reporting on the use of MUAC for inclusion, monitoring or discharge from nutritional rehabilitation in children >6 months. We excluded editorials, letters or comments; studies including only children older than 60 months of age or children with chronic diseases; studies on the predictive power of MUAC for mortality at the population level; studies in developed countries; studies with a small sample size (n ≤30); and studies in languages other than English, French or Spanish.

We first screened titles and abstracts. All papers for which the title and/or abstract indicated that inclusion criteria could be fulfilled were retrieved and read in full. The selection process was applied by two independent researchers. In case of discrepancies, a third reviewer was consulted and the decision to include or exclude the paper was reached by consensus. Papers excluded at this second

step were listed with reasons for exclusion. References of included studies were also screened. Moreover, we contacted authors every time additional data or information were needed.

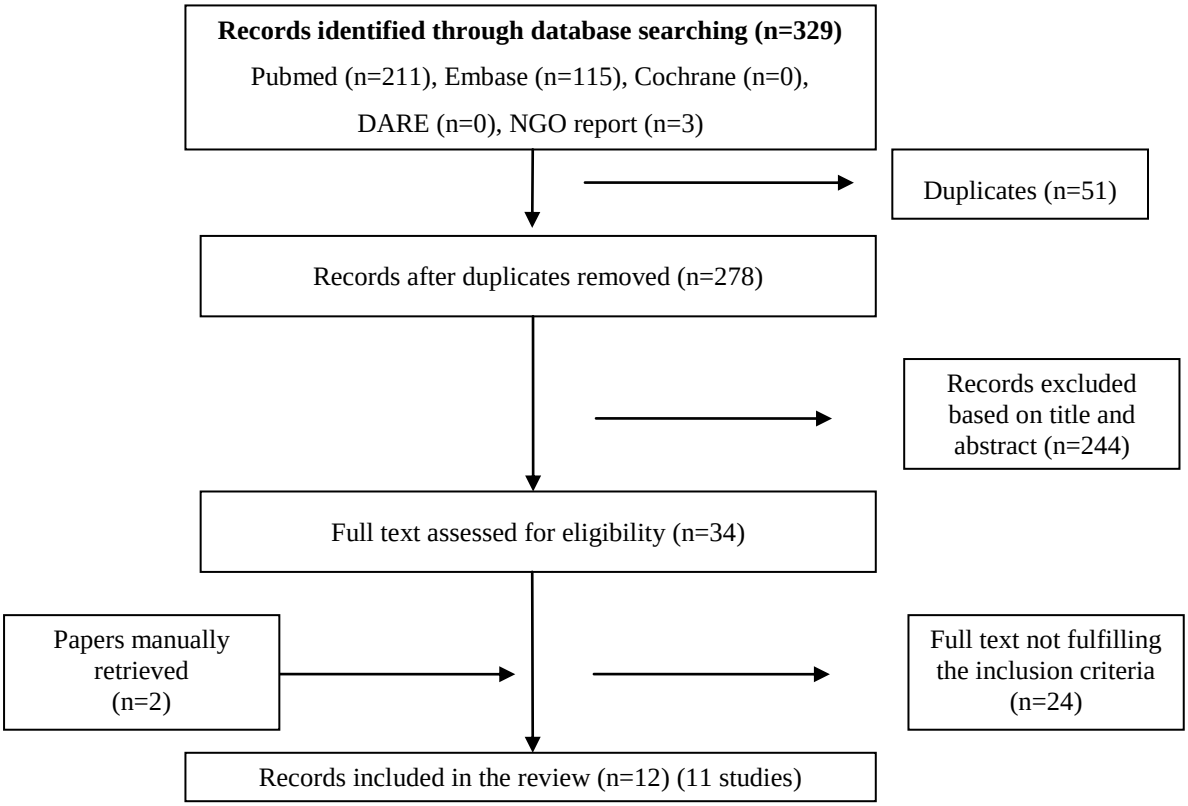
Quality appraisal of the selected studies was derived from the checklists of the Scottish Intercollegiate Guidelines Network (www.sign.ac.uk/methodology/checklists.html). We adjusted the existing checklist for cohort studies to fit case series, the main design of included studies. The selected quality criteria were: (i) adequate sampling of subjects (i.e. study not performed on a very specific subpopulation with limited external validity); (ii) management of missing values (% of incomplete data reported, % of loss-to-follow-up, participation bias assessed and discussed); (iii) quality of measurement (training of assessors and standardization of measurements reported, double measurements of anthropometry parameters, quality control procedures described); and (iv) appropriate statistical analysis. Each item was rated by two independent reviewers as: adequately addressed; moderately addressed; poorly addressed; or not reported.

Because of the great heterogeneity in the methods of studies included, no pooled estimates were generated.

Results

We retrieved 326 references from electronic databases, and three additional reports from nongovernmental organizations (NGOs) (*7*–*9*) (**Error! Reference source not found.**). Eventually, 12 papers reporting on 11 studies met the inclusion criteria. Two papers (Ciliberto et al. 2005 and Ciliberto et al. 2006) had a comparable study population (75% overlap) (personal communication of Mark Manary) (*10,11*). These two papers were, therefore, considered as a unique study. Five studies reported on the use of MUAC as a stand-alone criterion for admitting children in their nutritional rehabilitation programme (Table 2). The six other studies admitted children on the basis of a low WHZ, but reported on MUAC gain during nutritional rehabilitation (Table 3). Among the 11 studies included, 3 used cut-off for admission that did not correspond to the definition of SAM (MUAC < 120 mm in the study by Bekele et al. (*7*); MUAC <130 mm in the study by Nielsen et al. (*12*); WHZ <-2 in the study by Ciliberto et al. (*10*). However, outcomes of SAM children could be extracted from these three studies. Studies also presented great heterogeneity in terms of treatment provided and discharge criteria (Table 2). All studies, except one, took place in African countries and 5 of the 11 studies occurred in the same setting in Malawi and had a high proportion of oedematous malnutrition. The majority of studies treated uncomplicated cases of SAM in an outpatient programme setting.

Figure 1: Flow chart of review



We retrieved no randomized controlled trial (RCT) comparing outcomes of children admitted on the basis of a low WHZ vs a low MUAC. Only one observational study compared the mortality risk of hospitalized children according to their MUAC vs WHZ level (*5*). This study, conducted at Kilifi District Hospital in Kenya, collected prospectively data on 8190 children aged 12–59 months hospitalized over a period of 28 months. Among those, 3.3% was severely wasted by WHZ only (WHZ ≤-3 by 1978 NCHS reference), 4.7% by MUAC only (MUAC ≤115 mm), and 5.6% by both WHZ and MUAC. It is worth mentioning that the selection of patients was not done on the basis of nutritional criteria but on the need for hospital care. This explains the high proportion of participants with no low WHZ, no low MUAC and no bipedal oedema in the cohort. The mortality risk was quite similar for children presenting with a WHZ ≤-3 only or MUAC ≤115 mm only, peaking at 10.1% and 10.9%, respectively. The highest death rate was observed for children combining both indicators (25.4%). Unfortunately, no other outcomes were reported (authors have been contacted but the data were not available). Children diagnosed with a MUAC ≤115 mm presented more frequently signs of recent or current kwashiorkor, stunting, subcostal indrawing, and were more likely to be females and of younger age compared to those admitted with a WHZ ≤-3 (*5*). Bipedal oedema was present in 38.0% of children with a low MUAC vs 13.9% in those presenting with WHZ ≤-3 only.

Four other studies, including one unpublished, reported on outcomes of children diagnosed malnourished on the basis of MUAC only, without a comparison group of children admitted on the basis of WHZ (*4,7,12,13*). The mortality risk for SAM children was reported in three of the studies and was relatively low (≤2.1%), except for SAM children enrolled in a supplementary feeding programme (SFP) in Ethiopia (*4*). The mean recovery time (see the definition of discharge criteria in Table 2) went from 44.4±29.7 days (*13*) to 50.5±25.8 days (*7*) (Table 4). The mean (±SD) daily MUAC gain ranged from 0.17±0.16 mm d^{-1} in children admitted with a MUAC <110 mm and treated

in an SFP (*4*) to 0.51±0.3 mm d^{-1} in Burkina Faso (*7*). The value reported in the study in Guinea-Bissau (2.1 mm d^{-1}; 95% CI -1.29; 5.47) seems implausible and should be considered cautiously given the methodological weaknesses of that study (*12*). Two of the studies stratified the results by level of MUAC at admission (*7,12*). They showed that children admitted with a lower MUAC displayed a greater weight and MUAC daily gain. The study in Burkina Faso also reported an average change in WHZ between admission and discharge greater in children with a lower MUAC at admission (*7*). Also in that study, a lower MUAC at inclusion resulted in a greater mortality risk and required more often some inpatient care (*7*). Finally, these authors also stratified the outcomes by age (≤12 months vs >12 months), height (<67 cm vs ≥67 cm) and sex (*7*) (Table 5). The MUAC daily gain was higher in older and taller children, and in males.

Six additional studies were included as they reported on the MUAC gain during nutritional rehabilitation of SAM children, although the inclusion of these children in the programme had not been based on MUAC (Table 3) (*11,14–18*). Overall, MUAC increased from 0.2 to 0.4 mm d^{-1}, with no obvious differences between studies admitting children on the basis of MUAC or WHZ (nine studies in total) (Table 4). The increase in MUAC mirrored the daily weight gain, which ranged between 2.0 and 6.5 g/kg/day. Three of these studies also reported on WHZ change between admission and discharge, which ranged from 0.6 (*17*) to 1.27 (*18*) SD.

Only two studies used MUAC as a discharge criterion (*7,12*). The study in Burkina Faso where children were discharged on the basis of a MUAC ≥124 mm reported that the mean WHZ at exit was -1.7±0.9 (*7*). That study also compared the outcomes of malnourished children who were discharged from a community-based programme based on 15% weight gain and MUAC >110 mm (between April and December 2008) vs MUAC ≥124 mm only (between April and December 2009) (*7*). Globally, the time to recover for all children was shorter when using MUAC ≥124 mm (36.1±19.7 days) as a discharge criterion compared to 15% weight gain (52.5±25.4 days). Remarkably, the average length of stay to achieve >15% weight gain was longer for less malnourished children (48.0±23.0 days for children admitted with MUAC ≤114 mm and 55.1±26.0 days for children admitted with a MUAC between 115 mm and 119 mm). When the discharge criterion was switched to MUAC ≥124 mm, the average lengths of stay became 46.5±24.9 days and 32.5±16.3 days, respectively. Globally, default rates were 7.8% when 15% weight gain was used as a discharge criterion and 4.3% for those discharged based on MUAC, although this difference might be partly attributable to a change in retrieval strategies between the two observation periods (personal communication of Sylvie Goosens). The percentage of non-responders was 2.1% in the group that needed to attain a 15% weight gain compared to 1.5% in the group discharged at MUAC ≥124 mm. The other study in Guinea-Bissau used a MUAC ≥130 mm as a discharge criterion but did not report outcomes specifically for SAM children (*12*). Outcomes after discharge were not reported in these two studies.

We found no studies assessing the follow-up of children after discharge, i.e. whether the risk of relapse or longer-term mortality varied by the anthropometric indicator used for discharging children is unknown. We retrieved no study reporting on the other planned outcomes, i.e. costs, adverse events or population coverage.

Table 6 summarizes the quality appraisal for the selected studies. One consistent weakness was the lack of information on the reliability of measurements. In most studies, quality control and standardization of measurements was not described. The risk of selection bias and the plausible impact of missing values on results were also poorly addressed. Table 7 lists the studies excluded as well as the reasons for exclusion.

Discussion

Direct evidence for comparing treatment outcomes of SAM children diagnosed by MUAC vs WHZ is scarce. Only one study indirectly addressed the question (*5*). Unfortunately, lessons learnt from that study in a Kenyan hospital are limited for a number of reasons. First, MUAC or WHZ were not used for enrolling SAM children, but these two indicators were measured in sick, hospitalized children. It is thus impossible to extrapolate the results to a programme of nutritional rehabilitation of SAM children. As a matter of fact, children presenting a MUAC ≤115 mm but a WHZ >-3 had a profile significantly different from those identified on the basis of WHZ only. In particular, they suffered more often from kwashiorkor, were more stunted, younger, and more likely to be females. Second, only death rates were reported, and the other outcomes of nutritional rehabilitation of these complicated cases are unknown.

There is evidence from four studies (*4,7,12,13*) that children classified as SAM on the basis of a low MUAC respond to nutritional rehabilitation in terms of weight gain and MUAC gain, although the recovery rates were low in two of those studies (*4,12*). Children admitted with a lower MUAC displayed a greater daily gain in MUAC during the rehabilitation. There is also consistent evidence that MUAC increases during nutritional rehabilitation from studies that enrolled SAM children based on a low WHZ. No studies assessed the outcomes after nutritional rehabilitation when MUAC was used as the discharge criterion.

Our findings indicate that MUAC could be used adequately as a stand-alone criterion for the diagnosis, monitoring and discharge of SAM children. However, important pieces of evidence are still lacking before a strong recommendation for such use of MUAC can be formulated. First, the outcomes of children with a WHZ <-3 excluded from nutritional rehabilitation because their MUAC is ≥115 mm have not been studied. Just one study reported that mortality rates in children presenting with a WHZ ≤-3 only or MUAC ≤115 mm only were similar (*5*). However, that study included a cohort of hospitalized children, i.e. the admission was not based on anthropometric criteria. This evidence gap is worrying given the rapid extension of community-based programmes admitting children in nutritional rehabilitation on the basis of a low MUAC alone, and emphasizes the need for urgent studies and programme evaluation. Second, studies did not provide much data on factors interacting with the outcomes of the nutritional rehabilitation in children admitted on the basis of MUAC. In particular, young age, being a female and being stunted are factors that are independently associated with a low MUAC (*19*). One of the included studies also reported that, besides age, sex and stunting, bipedal oedema was also a factor more often observed in children with a low MUAC than in those with a low WHZ (*5*). Although these factors are expected to influence the pathological significance of a low MUAC and thus the progress and outcomes of nutritional rehabilitation, only the authors of the study in Burkina Faso stratified their results by age, sex and height upon enrolment (*7*). The mean MUAC and weight daily gain were lower, the treatment duration longer and the proportion of non-responders greater in younger and smaller children, and in females (Table 4). This might correspond to a suboptimal response in less severely acutely malnourished children, or be an indicator that the treatment is less effective or required in such children. Unfortunately, it is unclear how these three parameters interrelated as no multivariate analysis was performed. More data are needed to define if MUAC <115 mm alone can be applied to diagnose SAM indifferently in all children, or if the outcomes of the nutritional rehabilitation vary substantially according to the presence of other factors. Third, we retrieved no evidence on the best MUAC cut-off to be used. A same MUAC cut-off, either for defining SAM (MUAC <115 mm) or recovery (≥125 mm), translates in a different nutritional status according to age and sex (*20*), as illustrated in Figure 2. Whether using a higher MUAC cut-off (both for admission and discharge) in older children, and particularly in males, would be appropriate is unknown. Lastly, we also retrieved no evidence on the benefit of using MUAC vs WHZ in terms of population coverage or cost.

A 15% weight gain also has been recommended previously by WHO as a discharge criterion (*2*). However, the average time to achieve 15% weight gain was longer in less wasted children (MUAC >115 mm) compared to the most wasted ones, indicating a faster weight gain in those children more malnourished at enrolment (*7*). On the contrary, a MUAC-based discharge resulted in a longer average recovery time for the most severely wasted. Together, these observations provide indirect evidence that 15% weight gain is an inappropriate discharge criterion as it results in the more severely malnourished children getting the shortest treatment (*7*).

There were important limitations in the quality of the evidence that need to be highlighted: (i) no studies were specifically designed to compare outcomes of SAM children identified, monitored or discharged on the basis of MUAC vs WHZ; (ii) the sample sizes were relatively small in 4 of the 12 studies included; and (iii) precision and accuracy of anthropometric measurement were not addressed in most of the studies, albeit the contradictory evidence to date on whether more precision can be reached with MUAC or with WHZ (*21–23*). In addition, a third of the studies included was carried out in the same Malawian setting, with a majority of oedematous cases and a high prevalence of HIV infection, which might impact the external validity of our results to an unknown extent.

In conclusion, there are indications that MUAC could be used adequately as a stand-alone criterion for admitting to and discharging from nutritional rehabilitation SAM children. However, the evidence base is currently insufficient to make a strong recommendation in favour of using MUAC as a stand-alone criterion in programmes of nutritional rehabilitation. The most crucial evidence gap concerns the morbidity and mortality of children with WHZ <-3 receiving no treatment because their MUAC is ≥115 mm. The extent to which all children with MUAC <115 mm require standard nutritional rehabilitation is also unknown. There are numerous nutritional programmes currently active worldwide and their thorough evaluation could generate such data in the short term.

Table 1

Characteristics of studies reporting on outcomes in children with a low MUAC as a stand-alone diagnosis criterion of SAM

Reference	Country	Age (months)	Number	Design	Criteria for admission	Treatment	Discharge criteria
Berkley 2005 (*5*)	Kenya	12–59	8 190	Cohort	Clinical diagnosis of SAM	Inpatient care with F-75 and F-100	NR
Bekele 2009 (*7*)	Burkina Faso	6–59	30 130	Case series	MUAC <120 mm[a]	Outpatient care mainly, with RUTF (Plumpy Nut®) (500 kcal/packet) two packets if weight <8 kg, three if weight ≥8 kg. F-75 and F-100 are available for hospitalized children.	15% weight gain[b] MUAC ≥124 mm[c]
Nielsen 2004 (*12*)	Guinea-Bissau	6–59	247	Case series	MUAC <130 mm[d]	Outpatient care with a gruel made of millet, fresh eggs, fresh bananas, margarine and full-strength milk powder, providing 3.8 kJ/ml (8.7% of energy from proteins). Children received micronutrient tablets and flour mix in an amount of 6500–8700 kJ/d.	MUAC ≥130 mm
Defourny 2009 (*13*)	Niger	6–36	6 311	Case series	MUAC <110 mm	Outpatient care mainly, with RUTF (1000 kcal/d for children <8 kg and 1500 kcal/d for children ≥8 kg). Children with severe co-morbidities, nutritional oedema extending beyond the feet or a negative appetite test were admitted for inpatient care.	NR
Myatt 2006 (*4*)	Ethiopia	6–36	98	Case series	MUAC <110 mm and WHM >70% and no oedema	OTP = high intensity intervention (n=42). SFP = low intensity Intervention (n=56).	NR

NR = not reported

[a] Outcomes for children with MUAC ≤110 mm are reported.

[b] In 2008.

[c] In 2009.

[d] Outcomes for children with MUAC <115 mm are reported.

Table 2
Characteristics of studies included where MUAC was not an inclusion criterion but MUAC gain during rehabilitation was reported

Study	Country	Age (months)	Number	Design	Criteria for admission	Treatment	Discharge criteria
Amthor 2009 (14)	Malawi	6–60	826	Case series	WHM <70% and/or oedema and appetite	Outpatient, RUTF: 175 kcal/kg/d and 5.3 g protein/kg/d during 8 w	WHM ≥85%
Ciliberto 2005 (*10*), Ciliberto 2006 (*11*)[a]	Malawi	10–60	645	Non-randomized (stepped wedge design) controlled trial	WHZ <-2[b] and/or "mild" oedema and appetite	Second phase of treatment in inpatient therapy (n=113) vs home-based RUTF (175 kcal/kg/d and 5.3 g protein/kg/d during 8 w) after 1 w hospitalization (n= 532)	WHZ >-2
Linneman 2007 (*15*)	Malawi	6–60	2131	Case series	W/H <70% and/or oedema and appetite	Outpatient, RUTF: 175 kcal/kg/d and 5.3 g protein/kg/d during 8 w	WHM >85% and oedema resolved
Manary 2004 (*16*)	Malawi	>12	282	Non-randomized controlled comparative trial	WHZ <-3, no oedema, discharge hospital if infection control and appetite	Outpatient, RUTF, comparison three home-based diets. The first dietary group received RTUF in a quantity sufficient to meet their nutrient requirements for full catch-up growth (733 kJ/kg/d, 175 kcal/kg/d). The second group received a multivitamin/mineral fortified RTUF supplement providing 2090 kJ/d, about 33% (25–50%) of the daily energy requirement. The third group was given maize/soy flour.	WHZ >0
Oakley 2010 (*17*)	Malawi	6–59	1874	RCT, double blind	WHZ <-3 and/or oedema and appetite	Outpatient, RUTF containing 25% milk (n=954) vs 15% milk (n=929)	WHZ >-2 and no oedema at 8 w
Sullivan 1991 (*18*)	Gambia	6–36	22	Case series	WHM <75% and ≥4 loose stools/d for >2 w	Inpatient 3–4 w, 180 kcal/kg/d and 4 g protein/kg/d (w 1)	Gaining weight and no diarrhoea

[a] 75% overlap in population with oedema treated exclusively in outpatient (personal note from author).
[b] Outcomes for children with a WHZ <-3 are reported.

Table 3

Outcomes of SAM children diagnosed by MUAC or WHZ

Study	Admission					Recovery					Complications			
	Cut-off	Mean WHZ (SD)	Mean MUAC (mm)	N	Success rate	Mean duration (days)	Mean weight daily gain[a] (g/kg/d)	Mean WHZ discharge (SD)	Mean MUAC daily gain (mm/d)	Mean MUAC discharge (mm)	% only outpatient	% dead	% fail	% default
Berkley 2005 (*5*)	MUAC ≤115 mm	NR	NR	384	NR	NR	NR	NR	NR	NR	0	10.9	NR	NR
	WHZ ≤-3 only	NR	NR	267	NR	NR	NR	NR	NR	NR	0	10.1	NR	NR
	MUAC ≤115 mm and WHZ ≤-3	NR	NR	489	NR	NR	NR	NR	NR	NR	0	25.4	NR	NR
Bekele 2009 (*7*)	MUAC ≤110 mm	-3.5±0.9	104.6±6	7 589	86.0	50.5±25.8	6.5±7.0	-1.7±0.9	0.51±0.3	125.7±6.4	70.7	2.1	2.0	9.3
	110 mm <MUAC ≤114 mm	-3.3±0.8	113.2±1	6 666	91.3	47.4±25.6	6.5±3.3	-1.6±0.9	0.43±0.2	129.3±5.7	82.5	1.0	1.5	6.0
	114 mm <MUAC <120 mm	-3.1±0.8	117.3±1	15 875	92.7	47.0±27.3	4.9±4.5	-1.5±0.7	0.38±0.2	131.2±6.2	84.3	0.7	1.6	4.7
Nielsen 2004 (*12*)	MUAC <130 mm	-3.4±0.7	122.0±0.5	247	13.1[b]	48 (37; 72)[c]	4.0±0.5	NR	0.78±0.22	NR	100	0.8	NR	32.0
	MUAC <115 mm	NR	NR	NR	5.9[b]	NR	8.0±0.5	NR	2.1±1.7	NR	100 (?)	NR	NR	NR
Defourny 2009 (*13*)	MUAC <110 mm	NR	NR	6 311	90.0	44.4±29.7	5.1±4.6	NR	NR	NR	82.5	2.0	1.2	5.2
Myatt 2006 (*4*)	MUAC <110 mm treatment in OTP	NR	NR	42	NR	NR	4.3±2.4	NR	0.40±0.25[d]	NR	NR	0	NR	4.8
	MUAC <110 mm treatment in SFP	NR	NR	56	NR	NR	1.9±1.1	NR	0.17±0.16[e]	NR	NR	14.3	NR	3.6
Amthor 2009 (*14*)	WHM <70%	-1.4±1.3	120±12	826	93.7	NR	2.7±3.7	-0.5±2.7	0.2±0.3	NR	NR	0.9	1.8	3.6
Ciliberto 2005 (*10*)	WHZ <-2 home	-2.2±0.8	116±14	992	NR	NR	3.5±3.7	NR	0.32±0.4	NR	NR	3.0	NR	NR
Ciliberto 2006 (*11*)	WHZ <-2 inpatient	-2.5±0.9	116±15	186	NR	NR	2.0±6.9	NR	0.23±0.4	NR	NR	5.4	NR	NR
	WHZ <-3home	NR	NR	532	72.0[f]	NR	3.7±4.3[g]	NR	0.42±0.71	NR	NR	3.7	NR	NR
	WHZ <-3 inpatient	NR	NR	113	49.0[h]	NR	3.0±8.8	NR	0.28±0.4	NR	NR	6.2	NR	NR
Linneman 2007 (*15*)	WHM <70%	-1.5±1.4	120±14	2 131	89.0	NR	3.5±4.1	NR	0.2±0.4	NR	NR	1	3	7
Manary 2004 (*16*)[j]	WHZ <-3	-1.8±0.8	120±17	69	86.0	NR	5.2	NR	0.43	NR	NR	4	NR	10

Study	Admission				Recovery						Complications			
	Cut-off	Mean WHZ (SD)	Mean MUAC (mm)	N	Success rate	Mean duration (days)	Mean weight daily gain[a] (g/kg/d)	Mean WHZ discharge (SD)	Mean MUAC daily gain (mm/d)	Mean MUAC discharge (mm)	% only outpatient	% dead	% fail	% default
Oakley 2010[k] (*17*)	WHZ <-3	-2.1±1.2	121±13	1 874	82.0	NR	2.4±2.8	-1.5±1.1	0.2±0.3	NR	97	4	8	3
Sullivan 1991 (*18*)	WHM <75%	-3.97	108.4	22	NR	NR	NR	-2.70	0.03	114.8	NR	0	NR	NR

N = number of children; NR = not reported

[a] Weight and MUAC gain assessed at 4 weeks, except in Bekele 2009 (*7*) and Oakley 2010 (*17*) where it was assessed at 8 weeks.

[b] Recovery rate expressed in persons per 1000 person-days; 27 children still under treatment at the end of the study.

[c] Median and IQR range.

[d] Measured on 19 over 42.

[e] Measured on 24 over 56.

[f] Children reaching WHZ >-2 after 8 weeks of therapy.

[g] In the first four weeks of therapy.

[h] Children reaching WHZ >-2 after 8 weeks of therapy.

[i] Computed by us as only the main MUAC gain over 90 days was reported; average WHZ change was 1.61±0.86.

[j] We report here only the results of children receiving RUTF, the group who performed the best.

[k] We pooled the results of the two randomization groups.

Table 5

Influence of age, height, sex on outcomes of acutely malnourished children admitted by MUAC (*7*)

Variable	Cut-off variable	Sample size	Mortality (%)	Recovery (%)	Median time to recover (d) (IQR) (cured)	Mean weight gain (g/kg/d) ± SD (cured)	Mean MUAC gain (mm/d) ± SD (cured)	Other adverse effects
Age	≤12 m	13 210	1.2	90.4	49.9±27.0	5.1±3.2	0.38±0.23	Non-responder 2.1%, defaulter 5.7%
	>12 m ≤59	14 118	1.0	91.0	46.1±27.3	5.6±6.3	0.46±0.26	Non-responder 1.2%, defaulter 5.6%
Height	<67 cm	7 828	1.5	88.1	50.6±27.0	5.4±3.6	0.38±0.23	Non-responder 2.8%, defaulter 6.5%
	≥67 cm	22 302	1.0	91.6	47.0±26.0	5.4±5.4	0.44±0.26	Non-responder 1.3%, defaulter 6.1%
Sex	Female	15 356	1.0	90.5	49.1±27.4	5.1±4.6	0.40±0.2	Non-responder 2.0%, defaulter 6.1%
	Male	14 774	1.2	90.9	46.7±25.7	5.6±5.5	0.44±0.3	Non-responder 1.4%, defaulter 6.2%

Table 6

Quality appraisal of included studies

Study	Children selection	Reliability of measures			Statistical analysis	Missing data			Other comments
		Training of assessors	Double measurements	Quality control (methods)		MUAC assessed in all children	% drop-out	Effect drop-out assessed	
Berkley 2005 (*5*)	A	M	NR	NR	A	NR	NR	NR	Bipedal oedema present in 38% of children with MUAC ≤115 mm
Bekele 2010 (*7*)	M	A	NR	NR	A	A	6.2	NR	25% of children not included in the evaluation (missing height); 12% of children with MUAC <115 mm required hospitalization
Nielsen 2004 (*12*)	P	NR	NR	NR	A	M, not if absent from home	32	NR	
Defourny 2009 (*13*)	P	NR	NR	NR	NR	A	4.7	NR	
Myatt 2006 (*3*)	P	NR	NR	NR	NR	NR	4.8	NR	Oedema excluded, only children ≤75 cm, small sample size (n=42)
Amthor 2009 (*14*)	M	A	NR	NR	M, weight gain over 4 weeks (NR if after loss of oedema)	NR	3.6	NR	
Ciliberto 2005 (*10*) Ciliberto 2006 (*11*)	M	NR	NR	NR	A, weight gain over 4 weeks	NR	9.6	A	
Linneman 2007 (*15*)	M	A	NR	NR	A, weight gain over 4 weeks	A	7.4	A	
Manary 2004 (*16*)	M, only hospitalized children	NR	NR	NR	A	A	10	A	

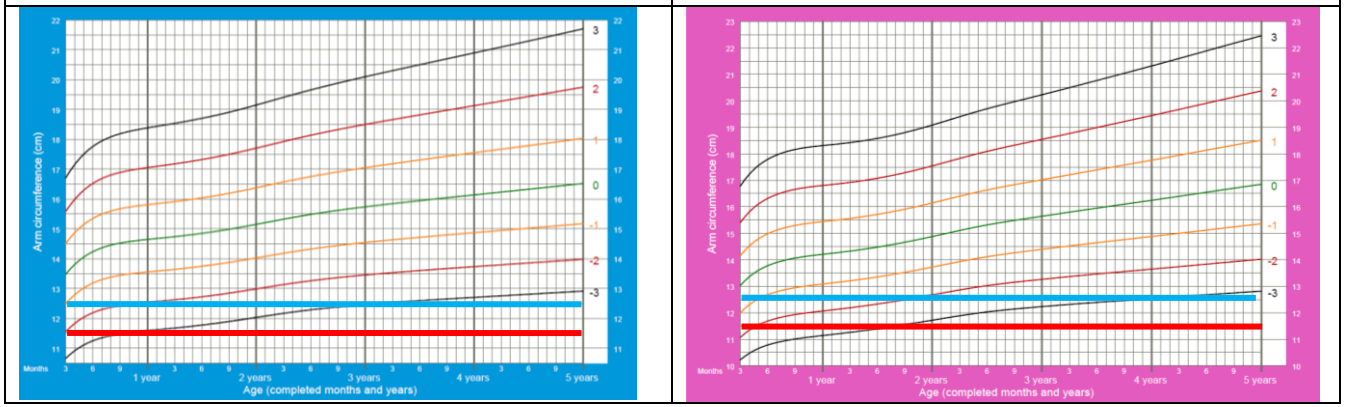
Oakley 2010 (*17*)	M	A	A	A	A	NR	3	M
Sullivan 1991 (*18*)	M, only hospitalized children	NR	NR	A	A	M	8.5	NR

A = Adequate; M = Moderate; P = Poor; NR = Not reported

Figure 1

Arm circumference according to age and sex

Males[1] **Females**[2]



Thick red line: MUAC = 115 mm; thick blue line: MUAC = 125 mm.
Source: WHO-GS 2006.

[1] http://www.who.int/childgrowth/standards/second_set/cht_acfa_boys_z_3_5.pdf.
[2] http://www.who.int/childgrowth/standards/second_set/cht_acfa_girls_z_3_5.pdf.

Table 7 **Studies excluded and reasons for exclusion**

	Study	Reason for exclusion
1.	Akinbami 2010 (*24*)	Children not included for severe malnutrition but for disease treatment in hospital; mortality results not presented by level of MUAC at entry; no results of nutritional rehabilitation reported.
2.	Beckett 2000 (*25*)	Included children with a length-for-age ≤1 SD and weight-for-length between -1 and -2 SD of the median of the WHO reference.
3.	Bejon 2008 (*26*)	Children not included for severe malnutrition but for disease treatment in hospital; focus on attributable fraction of death due to malnutrition with varying anthropometric indicators, no MUAC on follow-up reported.
4.	Blankhart 1977 (*27*)	No nutritional rehabilitation; MUAC compared to weight-for-age.
5.	Briend 1986 (*28*)	Validity of different nutritional indices and classifications for predicting the death of children with diarrhoea admitted to hospital; nutritional rehabilitation not reported.
6.	Cheek 1977 (*29*)	MUAC not used for admission or follow-up, small sample size.
7.	Chevalier 1996 (*30*)	MUAC not used for admission or follow-up
8.	Collins 2006 (*31*)	Position paper; no MUAC gain reported.
9.	Connor 2010 (*32*)	Included moderately malnourished children; selection based on WHZ; no MUAC gain reported.
10.	Doherty 1998 (*33*)	RCT testing three different regimens of zinc supplements in children with a WAM <60% and/or oedema, and proportion with a WHZ <-3 and/or a MUAC <110 mm is not reported.
11.	Dramaix 1993 (*34*)	Children not included for severe malnutrition but for disease treatment in hospital; nutritional rehabilitation not reported; no comparison of outcomes of WHZ-based SAM vs MUAC-based SAM reported.
12.	Erinoso 1993 (*35*)	Unclear MUAC cut-off (80%–70%–60% of what?); unusual therapeutic protocol (all had intensive nutritional support with high protein and energy-rich foods), very high lethality rates.
13.	Hossain 2009 (*36*)	Admission criteria based on W/H, MUAC or oedema but no details on the number and outcomes of children admitted based on MUAC.
14.	Isanaka 2011 (*37*)	Paper focused on the duration of untreated malnutrition.
15.	Kumar 1996 (*38*)	No use of MUAC for nutritional rehabilitation.
16.	Lagrone 2010 (*39*)	Only moderate acute malnutrition children included.
17.	Lapidus 2009, 2006 (*40,41*)	Children aged 6–59 months admitted with malnutrition (<80% W/H and/or MUAC <110 mm and/or presence of oedema; results on outcomes not provided for children selected on MUAC; no variations of MUAC during rehabilitation reported).
18.	Loewenstein 1973 (*42*)	Correlation between MUAC and weight-for-age z-scores (WAZ) or WHZ or weight for different countries.

	Study	Reason for exclusion
		Assessment of sensitivity and specificity of MUAC compared to WHZ was not possible.
19.	McDowell 1982 (*43*)	MUAC and W/H relative to clinical malnutrition.
20.	Manary 2008 (*44*)	General paper on management of acute malnutrition.
21.	Minetti 2009 (*45*)	Only comparison of NCHS and WHO 2006 standard references for W/H; no performance of MUAC.
22.	Ojo 2000 (*46*)	Population level; estimation of prevalence malnutrition by MUAC z-scores and WHZ; no comparison of anthropometric indicators; no nutritional intervention.
23.	O'Neill 2012 (*47*)	Predictive power of MUAC-for-age for mortality; no nutritional rehabilitation.
24.	Savadogo 2007 (*48*)	Inclusion at entry not clearly defined (children dichotomized in MUACAZ ≤-4.93 and MUCAZ >-4.93); no MUAC reported at entry; no MUAC gain reported.

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