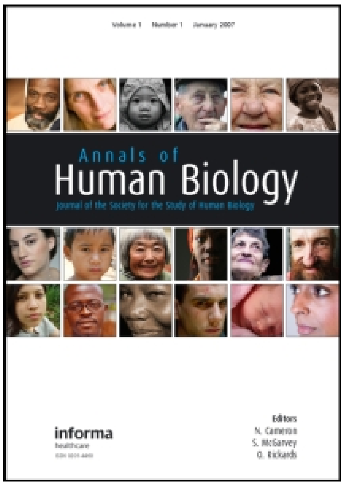

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ORIGINAL ARTICLE

The effect of body shape on weight-for-height and mid-upper arm circumference based case definitions of acute malnutrition in Ethiopian children

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Abstract

Background: Nutritional anthropometry surveys from Somalia and Ethiopia have reported that standard weight-for-height *z*-score (WHZ) and mid-upper arm circumference (MUAC) case definitions return different estimates of the prevalence of acute malnutrition in pastoralist livelihood zones but similar estimates of the prevalence of acute malnutrition in the agrarian livelihood zones. A study undertaken in Somalia to investigate this finding reported that children from pastoralist livelihood zones tended to have longer limbs and lower SSRs than children from agrarian livelihood zones.

Aim: The present study investigated the relationship between weight-for-height and body shape and the relationship between MUAC and body shape in different populations of Ethiopian children.

Subjects and methods: Six cross-sectional nutritional anthropometry surveys were undertaken. The combined survey datasets form the study sample. Data sources were grouped according to the livelihood zone from which data originated (either *settled agrarian* or *semi-nomadic pastoralist*). Case definitions of acute malnutrition using WHZ calculated using the NCHS and WHO reference populations and MUAC uncorrected for age or height were used. The SSR was used as an index of body shape. The association between body shape and the different case definitions of acute malnutrition were investigated using standard statistical techniques.

Results: Weight-for-height and MUAC case definitions yielded similar estimates of the prevalence of acute malnutrition in agrarian children but different estimates of the prevalence of acute malnutrition in pastoralist children. These populations also exhibit different SSRs. The SSR is an important predictor of weight-for-height. The SSR is a poor predictor of MUAC.

Conclusion: WHZ and WHZ case status in children are associated with body shape and may overestimate the prevalence of acute malnutrition in some populations. Consideration should be given

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as to whether WHZ should be replaced by MUAC for the purposes of estimating the prevalence of acute malnutrition.

Keywords: *Malnutrition, prevalence, weight-for-height, mid-upper arm circumference, body shape*

Introduction

Mid-upper arm circumference (MUAC) has recently been endorsed by the World Health Organization (WHO), the World Food Programme (WFP), the United Nations System Standing Committee on Nutrition (SCN), and the United Nations Children's Fund (UNICEF) as a suitable tool for diagnosing severe acute malnutrition (wasting) and deciding admission into therapeutic feeding programmes (United Nations System Standing Committee on Nutrition 2007). There are several practical and theoretical advantages of using MUAC rather than weight-for-height based anthropometric indices of nutritional status (Myatt et al. 2006). Many agencies are beginning to move towards using MUAC as a basis for admitting children to both therapeutic and supplementary feeding programmes (Myatt et al. 2006; United Nations System Standing Committee on Nutrition 2007; World Food Programme 2007). Most agencies continue to use a weight-for-height based index, specifically the weight-for-height *z*-score (WHZ) calculated using the National Center for Health Statistics (NCHS) reference population, when undertaking surveys to estimate the prevalence of acute malnutrition in a population (Hamill et al. 1979; Boelaert et al. 1995). Some agencies are planning to use WHZ calculated using the WHO Child Growth Standards for this for this purpose (WHO Multi-centre Growth Reference Study Group 2006, de Onis et al. 2006). The use of WHZ for prevalence estimation and MUAC for programme admission is likely to be problematic if the different indicators give very different estimates of the prevalence and immediate need (i.e. the number of children in a population meeting programme admission criteria). They are known to do this in some African populations, throughout the Indian Subcontinent, and in some Hispanic populations (World Health Organization 1995, de Onis 1993; Martorell et al. 1987; Malina et al. 1987; Zavaleta and Malina 1982; Eveleth and Tanner 1990). It may be preferable, therefore, to use a single case definition of acute malnutrition for both purposes. Before this can be done, however, research is required to better understand the likely consequences of changing from a weight-for-height based case definition of acute malnutrition to a MUAC based case definition of acute malnutrition.

In November 2005, a survey undertaken in rural areas of Belete Weyne district of Somalia by Save the Children (UK) found that standard WHZ and MUAC based case definitions returned different estimates of the prevalence of acute malnutrition in *pastoralist* and *agro-pastoralist* livelihood zones but similar estimates of the prevalence of global acute malnutrition in the *riverine–agrarian* livelihood zone (Myatt 2006). A small study undertaken to investigate this finding found that children from the pastoralist and agro-pastoral livelihood zones tended to have longer limbs and lower SSR than children from the riverine–agrarian livelihood zone (Myatt 2006). The worsening security situation in Somalia meant that plans for a further study were abandoned. In March 2006, it was decided to undertake the planned study in Ethiopia. In May 2006, the Emergency Nutrition Co-ordinating Unit (ENCU) of the Government of Ethiopia, funded by the United Nations Children's Fund (UNICEF) with personnel and logistics support provided by Save the Children (UK) and CONCERN Worldwide, initiated a study to investigate the relationship between WHZ and body shape and the relationship between MUAC and body shape in different populations. This report presents the results of this study.

Methods

Data sources

A retrospective analysis of data from 58 nutritional anthropometry surveys undertaken in Ethiopia and areas of Kenya bordering Ethiopia between September 1994 and July 2006 examined the estimates of the prevalence of global acute malnutrition returned by standard WHZ and MUAC based case definitions. The results of this analysis informed the location of the surveys used to collect the data presented in this report. Six cross-sectional nutritional anthropometry surveys of conventional design were undertaken (Boelaert et al. 1995). The six survey datasets, when combined, form the study sample. For the purposes of data analysis, data sources were grouped according to the agro-ecological or livelihood zone from which the data originated (either *settled agrarian* or *semi-nomadic pastoralist*). Table I describes these data sources.

Eligibility criteria

The surveys used the following eligibility criteria: (age ≥24 months AND age ≤59 months) OR (height ≥85 cm AND height ≤110 cm). This differs from the eligibility criteria commonly used in nutritional anthropometry surveys: (age ≥6 months AND age ≤59 months) OR (height ≥65 cm AND height ≤110 cm).

This restricted eligibility criteria was used because it simplified data collection and because measurements of supine length, rather than standing height, are used in younger children (Hamill et al. 1979; Boelaert et al. 1995; World Health Organization 1995; de Onis et al. 2006; WHO Multi-centre Growth Reference Study Group 2006).

Table I. Data sources used in the study.

Region	Zones	Woreda(s)	Agro-ecological (livelihood) zone	Ethnicity	Group*	Date of survey	Sample size†
Somali	Fik	Fik Hamaro Segeg Duhun	Fik‡	Somali	Pastoralist	Sep. 2006	506
Somali	Liben	Moyale Hudet	Moyale-Wayamo‡	Somali	Pastoralist	Sep. 2006	526
Somali	Liben Afder	Dolo Ado Dolo Bay Barrey	Filtu-Dolo‡	Somali	Pastoralist	Nov. 2006	530
Afar	Zone 4	Teru	Teru‡	Afar	Pastoralist	Nov. 2006	578
Afar	Zone 4	Yalu	Teru‡	Afar	Pastoralist	Nov. 2006	601
Amhara	North Wollo	Gubalafto	Agricultural§	Amhara	Agrarian	Jan. 2007	1481

*Grouping used for the purposes of analysis.
†$n = 1481$ for the agrarian group, $n = 2741$ for the pastoralist group.
‡Semi-nomadic pastoralism with mixed herds of camel, goats, sheep, and cattle.
§Mixed agro-ecological/livelihood zones were present in the survey population: Dega (highland: barley/wheat/beans/peas: belg rains only); Wina Dega (mid-highland: barley/wheat/beans/peas: belg and meher rains); Kolla (lowland: sorghum/teff: belg and meher rains).

Measurement

Measurement procedures followed, as far as was feasible, best practice (Boelaert et al. 1995; Schilg and Hulse 1997; Disaster Prevention and Preparedness Commission 2002). Age was determined by reference to official documents (e.g. birth certificates, 'road to health' cards, vaccination records) or by maternal report when official documents were unavailable. Weight was measured to the nearest 0.1 kg using Salter™ 25 kg by 100 g mechanical hanging scales using standard methods (Boelaert et al. 1995). Each scale was checked on a daily basis against a known 10 kg weight (Boelaert et al. 1995). Scales were set to zero prior to each measurement (Boelaert et al. 1995). All children were weighed with light clothing and without shoes following guidelines issued by Disaster Prevention and Preparedness Commission of the Government of Ethiopia (Disaster Prevention and Preparedness Commission 2002). Standing height was measured to the nearest 0.1 cm using portable height boards of standard construction using standard methods (Boelaert et al. 1995). Sitting height was measured to the nearest 0.1 cm using portable height boards of standard construction placed on tables. Children were measured with the backs of the knees resting on the edge of the table, thighs horizontal, back straight, buttocks and scapula against the height board, hands on their knees, looking straight ahead and breathing normally (Schilg and Hulse 1997). This deviates from best practice in that the feet were not supported and the measurement was not routinely taken when the child had exhaled fully (Schilg and Hulse 1997). MUAC was measured on the limp left arm to the nearest 0.1 cm using UNICEF insertion tapes (Boelaert et al. 1995). The presence of bilateral pitting oedema was ascertained using standard methods (Boelaert et al. 1995). Survey staffing, data recording, and data-entry procedures followed standard practice (Boelaert et al. 1995).

Data management

WHZ values were calculated for each child in the study sample. WHZ was calculated using both the NCHS reference population and the WHO Child Growth Standard (Hamill et al. 1979, WHO Multi-centre Growth Reference Study Group 2006). WHZ calculated using the NCHS reference population was calculated using the *EpiNut* module of *EpiInfo v6.04d* (Hamill et al. 1979; Dean et al. 1995). This software is commonly used to calculate WHZ from nutritional anthropometry survey data. WHZ calculated using the WHO Child Growth Standard was calculated using the appropriate reference datasets and procedures recommended by the WHO and implemented in a purpose-written R script (Cole and Green 1992; Ihaka and Gentleman 1996; WHO Multi-centre Growth Reference Study Group 2006). After WHZ was calculated the following case definitions of acute malnutrition were applied:

$$\text{WHZ} < -2.00 \text{ z-scores;}$$
$$\text{MUAZ} < 125\text{mm.}$$

A sitting-to-standing height ratio (SSR) value was calculated for each child in the study sample. SSR is a height-based index of body shape:

$$\text{SSR} = \frac{\text{sitting height}}{\text{standing height}}$$

providing a measure of the relative length of trunk and legs (Norgan 1994; Salama et al. 2001). Smaller values of SSR indicate longer limbs and/or shorter trunks. Larger values of SSR indicate longer trunks and/or shorter limbs. When used with adults, SSR is known as the Cormic Index and is used to correct body mass index (BMI), a weight-for-height index used in adults, whenever between-population comparisons of prevalence or mean BMI are to be made (Norgan 1994; Salama et al. 2001). At present, weight-for-height indices and prevalence estimates based upon weight-for-height indices are not corrected for body shape when used with children (Cogill 2003).

Data analysis

Data were analysed using standard statistical techniques using the *R Language for Data Analysis and Graphics* (Ihaka and Gentleman 1996). Prevalence was estimated using the MUAC-based case definition and WHZ-based case definitions with WHZ calculated using both the NCHS reference population and the WHO Child Growth Standard (Hamill et al. 1979, WHO Multi-centre Growth Reference Study Group 2006). The detailed results presented in this report are for the MUAC-based case definition and the WHZ-based case definition calculated using the NCHS reference population.

Results

Figure 1 summarizes the results of a retrospective analysis of data from 58 nutritional anthropometry surveys undertaken in Ethiopia and areas of Kenya bordering Ethiopia

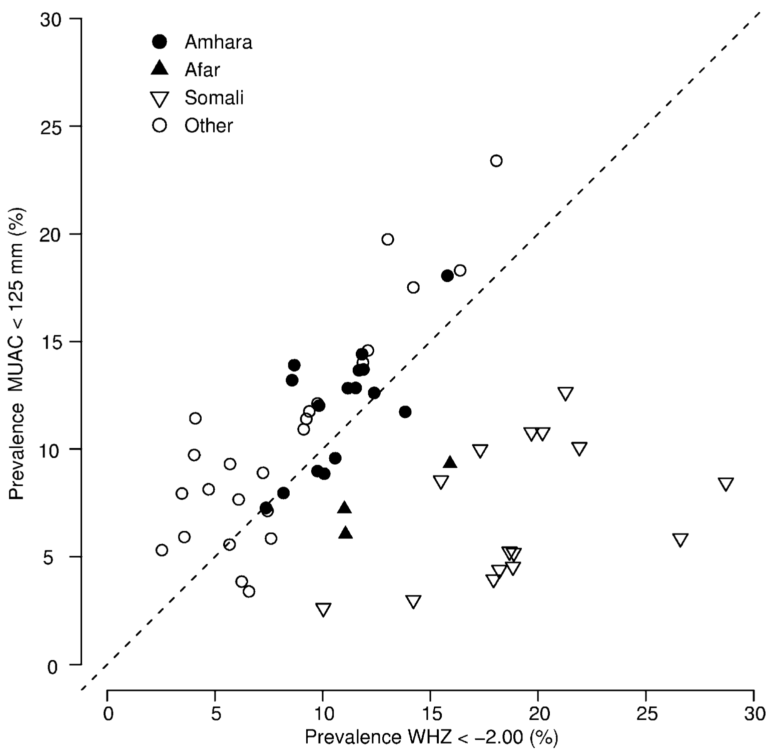


Figure 1. Comparison of prevalence estimates returned by standard WHZ and MUAC based case definitions in 58 nutritional anthropometry surveys.

between September 1994 and July 2006. The dashed 45° line on Figure 1 corresponds to perfect agreement between the prevalence estimates returned by the two indicators. This analysis revealed that WHZ and MUAC tended to return similar estimates of the prevalence of global acute malnutrition in Amhara (agrarian) populations but markedly different estimates of the prevalence of global acute malnutrition in Afar and Somali (pastoralist) populations. The results of this analysis informed the location of the surveys used to collect the data presented in this report.

Table II shows the prevalence of acute malnutrition found in each group in the study sample using the WHZ-based and MUAC-based case definitions. The two case definitions returned similar prevalence estimates in agrarian children ($p = 0.1416$). The WHZ-based case definition returned a significantly higher prevalence estimate than the MUAC-based case definition in pastoralist children ($p < 0.0001$). No cases of oedema were found in the study sample.

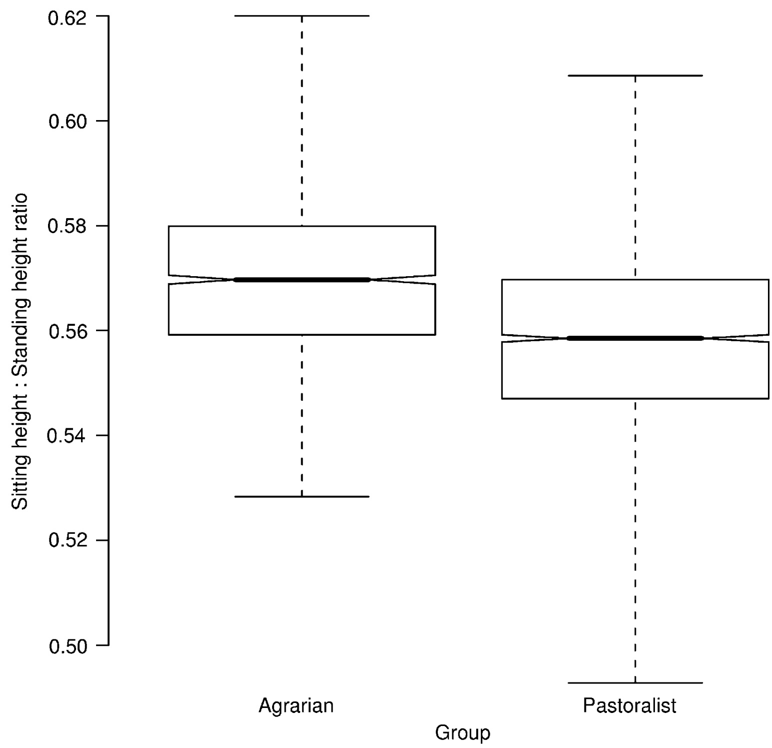
Figure 2 shows the distribution of SSR values in agrarian and pastoralist children. The distributions differ from each other with agrarian children tending to have significantly higher mean SSR values than pastoralist children (agrarian mean = 0.5698, pastoralist mean = 0.5585, $t = 22.73$, d.f. = 3372, $p < 0.0001$). In previous studies, body shape measured by SSR has been found to change with age, with the SSR declining shortly after birth until the onset of puberty (Eveleth and Tanner 1990). Differences in the ages of agrarian and pastoralist children may, therefore, explain the observed differences in mean SSR. The ages of children differed significantly between the two groups (Kruskal–Wallis $\chi^2 = 10.04$, d.f. = 1, p-value = 0.0015). This difference was, however, in the wrong direction to explain the observed differences in mean SSR: pastoralist children tended to be younger than agrarian children and this should have resulted in the pastoralist children having larger SSR values than the agrarian children if age were the only determinant of SSR. SSR was also associated with sex, with males tending to have slightly higher SSR values than females (male mean = 0.5635, female mean = 0.5613, $t = 4.2626$, d.f. = 4209, p-value < 0.0001). This association, with the same direction and similar magnitude of difference, was found in both groups of children. Multiple linear regression was used to assess the independent effects of age, sex, and group upon SSR. The results of this analysis are summarized in Table III. After adjusting for the effects of age and sex, SSR was independently associated with group, with agrarian children having significantly higher SSR values than pastoralist children ($t = 5.201$, d.f. = 4218, $p < 0.0001$).

Figure 3 shows the distribution of WHZ by group. WHZ was associated with group, with agrarian children tending to have higher WHZ values than pastoralist children (agrarian mean = −0.0603, pastoralist mean = −1.0278, $t = 18.02$, d.f. = 3273, $p < 0.0001$). WHZ was associated with SSR in both groups of children ($p < 0.0001$ for both groups). The strength of association was moderate in both groups of children ($r = 0.3357$ for agrarian children, $r = 0.3494$ for pastoralist children). WHZ was associated with age in both groups

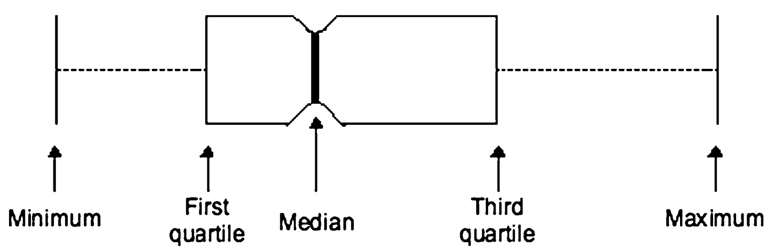
Table II. Prevalence by group and case definition.

Group	Case definition	*n*	Cases	Prevalence	Difference	95% CI for difference	*p*-value*
Agrarian	WHZ	1481	32	2.16%	0.81%	−0.18%; 1.80%	0.1416
	MUAC		44	2.97%			
Pastoralist	WHZ	2741	258	9.41%	8.32%	7.21%; 9.43%	<0.0001
	MUAC		30	1.09%			

*McNemar's chi-squared test for symmetry of rows and columns in a two-dimensional contingency table.



The box-plots used in this report show:



The notches about the medians in these plots correspond to:

$$\text{Median} \pm 1.58 \times \frac{\text{IQR}}{\sqrt{n}}$$

This yields an approximate 95% confidence interval for the difference in two medians: if the notches of two box-plots do not overlap this is ‘strong evidence’ that the two medians differ (Chambers et al. 1983).

Figure 2. Distribution of SSR in agrarian and pastoralist children.

of children ($p = 0.0008$ for agrarian children, $p < 0.0001$ for pastoralist children). WHZ was not associated with sex in either group of children. Multiple linear regression was used to assess the independent effects of SSR, age, and group on WHZ. The results of this analysis are summarized in Table IV. After adjusting for the effects of age and group, WHZ was independently associated with SSR ($t = 23.762$, d.f. $= 4218$, $p < 0.0001$).

Table III. Independent effects of age, sex, and group on SSR.

Model term	Regression coefficient	Standard error	p-value
Intercept	6.120×10^{-1}	1.079×10^{-3}	<0.0001
Age	-8.917×10^{-4}	2.173×10^{-5}	<0.0001
Sex†	-2.174×10^{-3}	4.179×10^{-4}	<0.0001
Group†	-1.219×10^{-2}	4.380×10^{-4}	<0.0001
Model R^2	0.3617		

†Sex and Group entered as dummy variables with males/agrarians as baselines.

Figure 4 shows the distribution of SSR by group by WHZ case status. SSR was associated with WHZ case status in both groups of children ($p = 0.0020$ for agrarian children, $p < 0.0001$ for pastoralist children). Multiple logistic regression was used to assess the independent effects of SSR and age on WHZ case status in each group of children. The results of this analysis are summarized in Table V. After adjusting for the effect of age, WHZ case status was independently associated with SSR in both groups of children ($p < 0.0001$).

MUAC was associated with height in both groups of children ($p < 0.0001$). MUAC was associated with age in both groups of children ($p < 0.0001$). Such associations were expected since the MUAC case definition uses uncorrected MUAC values rather than MUAC values corrected for height or age. MUAC was associated with SSR in both groups of children ($p < 0.0001$ for both groups). The strengths of the associations between MUAC and SSR were weak in both groups of children ($r = 0.1745$ for agrarian children, $r = 0.0951$

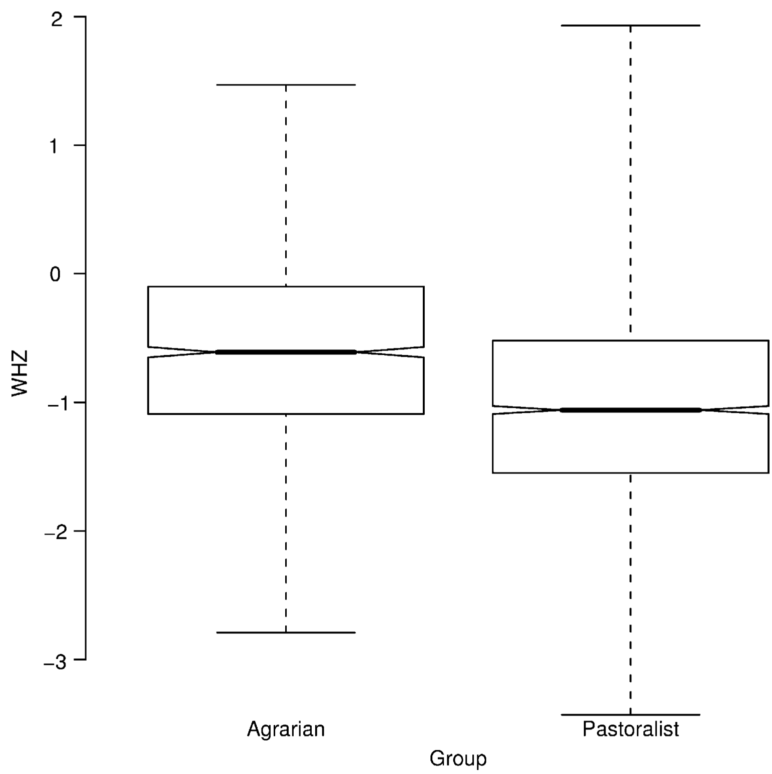


Figure 3. Distribution of WHZ (NCHS) in agrarian and pastoralist children.

Table IV. Independent effects of SSR, age, and group on WHZ (NCHS).

Model term	Regression coefficient	Standard error	p-value
Intercept	−11.7432	0.4879	<0.0001
SSR	18.8536	0.7934	<0.0001
Age	0.0086	0.0013	<0.0001
Group*	−0.2031	0.0246	<0.0001
Model R^2	0.1872		

*Group entered as dummy variables with agrarians as baseline.

for pastoralist children). Figure 5 shows the distribution of SSR by group by MUAC case status (i.e. MUAC < 125 mm). SSR was not associated with MUAC case status in either group of children ($p = 0.7735$ for agrarian children, $p = 0.9442$ for pastoralist children).

The analysis presented here was repeated using WHZ calculated using the WHO Growth Standards. The results of this analysis were almost identical to the analysis performed using WHZ calculated using the NCHS reference population.

Discussion

The associations between WHZ, and WHZ case status, and body shape were investigated using both WHZ calculated using the NCHS reference population and the WHO Growth Standards. The NCHS reference is the *de facto* standard used in nutritional anthropometry

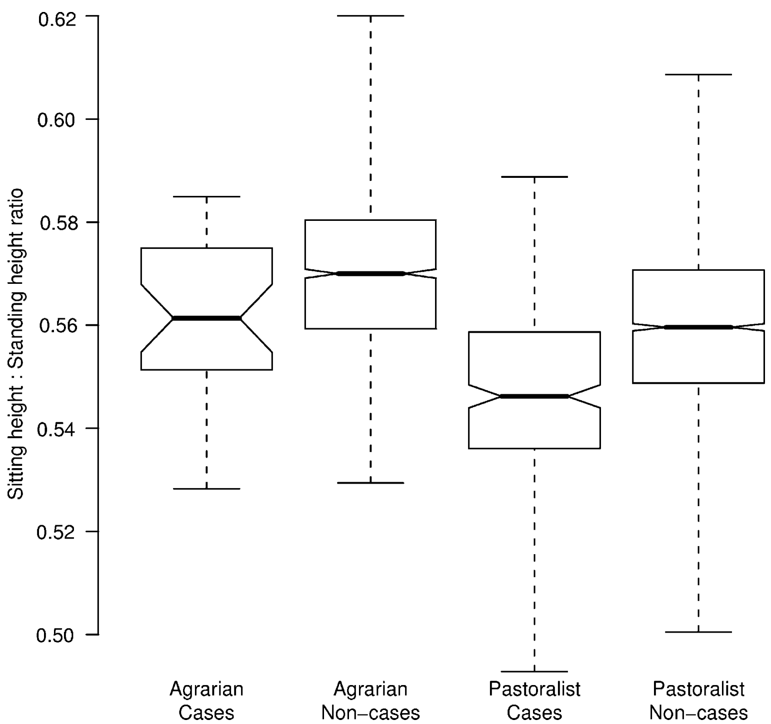


Figure 4. Distribution of SSR by group by WHZ case status.

Table V. Independent effects of SSR and age on WHZ case status in each group.

Model term	Odds ratio	95% CI	*p*-value
Agrarians			
SSR*	0.47	0.34%; 0.65%	<0.0001
Age†	0.92	0.88%; 0.96%	<0.0001
Pastoralists			
SSR*	0.56	0.52%; 0.62%	<0.0001
Age†	0.96	0.95%; 0.98%	<0.0001

*Odds ratio is for each percentage point increase (e.g. from 0.55 to 0.56) in SSR.
†Odds ratio is for each month increase in reported age (e.g. from 48 months to 49 months)

surveys and, in many programmes in developmental and emergency settings, for deciding admission into therapeutic and supplementary feeding programs. The WHO Growth Standards are currently being promoted as a superior replacement for the NCHS reference for these purposes (WHO Multi-centre Growth Reference Study Group 2006). The claim to superiority of the WHO Growth Standards is, in large part, based upon the distinction between *norm-referencing* and *criterion-referencing*. This distinction is the basis behind the use of the terms 'reference' and 'standard' to describe the two different growth curves although these terms have tended to be used interchangeably in the literature, including the principal document describing the WHO Growth Standards (WHO Multi-centre Growth Reference Study Group 2006). The NCHS reference is norm-referenced with growth curves derived from a large representative sample drawn from the US population (Hamill et al. 1979). The

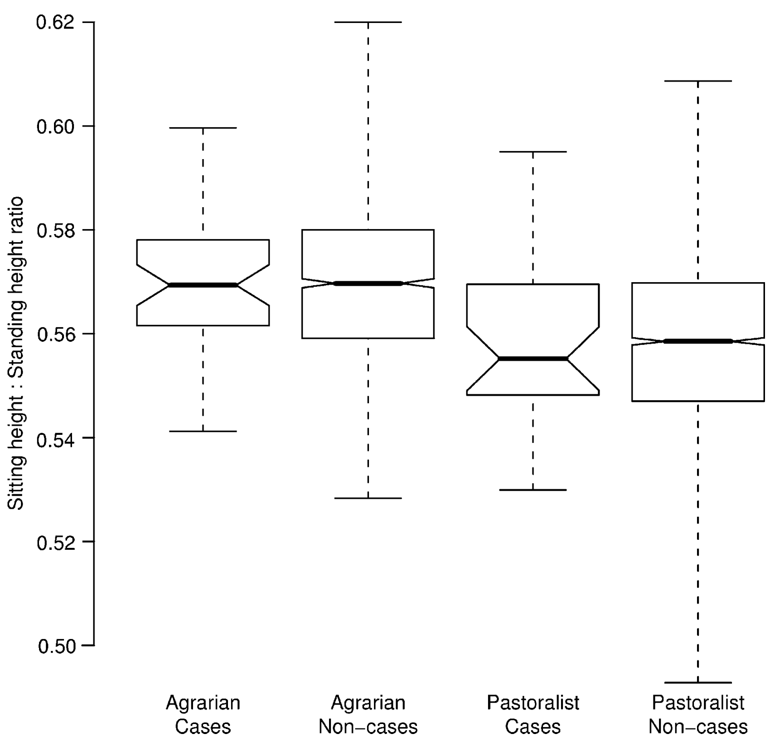


Figure 5. Distribution of SSR by group by MUAC case status.

WHO Growth Standards are criterion-referenced with growth curves derived from multi-centre samples of children meeting a stringent set of eligibility criteria that define them as living in 'conditions favourable to growth' (WHO Multi-centre Growth Reference Study Group 2006). The WHO Growth Standards are, therefore, designed to represent *ideal growth* under the assumption that 'children the world over grow similarly when their health and care needs are met' (WHO Multi-centre Growth Reference Study Group 2006). It is important to note, however, that the NCHS reference has long been considered as a standard derived from a representative sample of children living in conditions favourable to growth and that this was the principal reason why the NCHS reference was adopted as an international 'reference standard' (Cogill 2003).

Much can be made of the details of the differences between the NCHS reference and the WHO Growth Standards but such a discussion would miss the fact that an indicator designed to represent ideal growth may not be ideal for the purpose of identifying children, or populations, requiring emergency nutrition interventions (Pelletier et al. 1983; Pelletier 1994; Myatt 2006). The primary aim of most anthropometric surveys is to identify populations in need of emergency nutrition interventions. The primary aim of interventions treating acute malnutrition is to prevent mortality. In this context, the most useful case definition will be one that can identify individuals who are at high risk of dying if they remain untreated but would be likely to survive if treated in an appropriate nutrition support programme (Myatt 2006). This realization has led a number of workers to argue that the utility of case definitions for malnutrition are defined more by their ability to reflect mortality risk than their ability to reflect ideal growth (Sommer and Lowenstein 1975; Chen et al. 1980; Bairagi et al. 1985; Alam et al. 1989; Briend et al. 1986; Briend and Zimicki 1986; Heywood 1986; Briend et al. 1987; Vella et al. 1994; Pelletier 1994; Myatt 2006). Studies examining the prognostic or predictive value (i.e. of predicting death) of various anthropometric indicators have consistently reported weight-for-height to be the least effective predictor of mortality and that, at high specificities, MUAC is superior to both height-for-age and weight-for-age (Pelletier 1994; Myatt et al. 2006). In terms of indicators that are practical to collect in developmental and emergency settings, MUAC has the best claim to being a 'standard' of nutrition-associated mortality risk (Pelletier 1994; Myatt et al. 2006).

WHZ and WHZ case status were associated with body shape in both groups of children regardless of whether the NCHS reference population or the WHO Growth Standard were used to calculate WHZ. This leads the standard WHZ case definition to *overestimate* (i.e. compared to MUAC) the prevalence of acute malnutrition in populations with lower SSR body shapes. The use of case definitions based upon the WHZ index are likely to produce biased estimates of prevalence and need, particularly in pastoralist populations, unless WHZ is corrected for body shape. This correction is, however, difficult and time-consuming and is unlikely to be practical to perform in the majority of survey contexts (Cogill 2003). This would not be a great problem if the SSR values observed in the pastoralist group in the study reported here represented international extremes. Figure 6 plots sex-combined SSR by age reported from African, Chinese, European, and Mexican populations (Karlberg et al. 1976; Faulhaber 1976; Zhang 1977; Prader and Budliger 1977; Waaler 1983; Hernandez et al. 1985; Eiben and Pantó 1986; Zhang and Huang 1988; Gerver 1988; Martorell et al. 1988; Eveleth and Tanner 1990). The SSR values observed in the Ethiopian pastoralist children in the study sample appear to be no more extreme than 'well-off' urban Nigerians and African–Americans (Eveleth and Tanner 1990). This suggest that WHZ may produce biased estimates of prevalence and need in some African populations. In the study reported here, this bias was present and similar in both magnitude

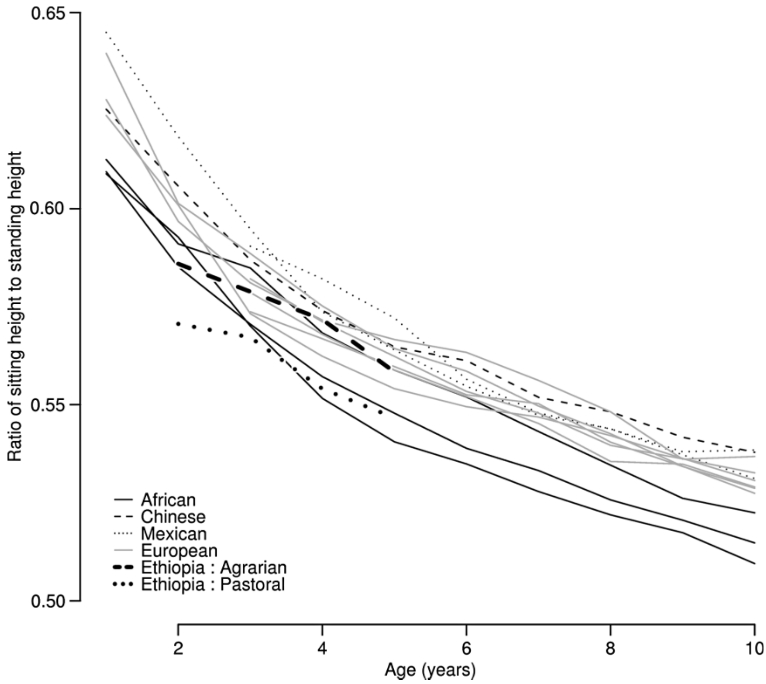


Figure 6. Sex-combined SSR by age reported from African, Chinese, European, and Mexican populations.

and direction regardless of whether the NCHS reference population or the WHO Growth Standard were used to calculate WHZ. This suggests that the problem may be general to the use of weight-for-height references/standards that are not locally derived. An alternative to correcting WHZ for body shape would be to use locally derived standards. Local standards are, however, likely to be both expensive and time-consuming to produce.

MUAC is also associated with body shape in both groups although the strength of association is weak. No effect of body shape on the MUAC case status using the standard MUAC case definition was detected in this study.

It is a long-standing observation that body shape varies with climate with SSR tending to be lower in populations from areas with higher mean temperatures (Roberts 1953; Schreider 1975; Katzmarzyk and Leonard 1998; Taylor-Weale and Vinicius 2008). The reason for this is believed to be thermoregulatory since SSR is strongly associated with the ratio of body surface area to mass (Schreider 1975). Daytime high temperatures for Amhara Region (agrarian group) range between 16°C and 30°C, daytime high temperatures for Afar Region (pastoralist group) range between 35°C and 50°C, and daytime high temperatures for Somali Region (pastoralist group) range between 27°C and 40°C. There is a possibility, therefore, that the observed differences in body shape between the two study groups are due to differences in climate although the effect of climate on body shape is thought to be modulated by diet (Katzmarzyk and Leonard 1998; Taylor-Weale and Vinicius 2008). Secular changes in body shape, exhibited as increases in leg length relative to trunk length, have been reported from different parts of the world (Tanner et al. 1982; Ohyama et al. 1987; Takamura et al. 1988; Leung et al. 1996; Bogin et al. 2002; Sanna and Palmas 2003). The rapidity of these changes suggests that they are due to environmental factors such as improved nutrition rather than changes in climate. Pastoralist diets tend to contain higher proportions of milk than agrarian diets (Lindtjørn et al. 1993; Fujita et al. 2004). Milk contains energy, protein, calcium, micronutrients, and insulin-like growth factor-I (IGF-I) all of which are known to facilitate bone growth (Wiley 2005). In particular, IGF-I is associated with growth in bone length and plasma levels of IGF-I are know to increase in response to milk intake (Cameron 2002; Heaney et al. 1999). In Japan, secular changes in body shape, exhibited as increases in leg length relative to trunk length, occurred after the addition of milk into school feeding programmes in the 1950s (Tanner et al. 1982; Takahashi 1984; Ohyama et al. 1987; Takamura et al. 1988). It is possible, therefore, that the differences in body shape between the two study groups are due, in part, to higher milk consumption in the pastoralist group.

It should be noted that long-leggedness may be advantageous to pastoralists. Physical models of walking and running predict that longer legs allow faster *natural* walking and running speeds (i.e. the walking and running speeds requiring the minimum expenditure of energy) than shorter legs (Alexander 1996). Faster natural walking and running speeds allow larger ranges with similar energy expenditures. Afar and Somali pastoralists herd on foot without dogs or horses. The ability to walk long distances efficiently may facilitate access to wider grazing ranges and allow (e.g.) larger herds to be maintained. This may lead to the development of a *virtuous circle* as illustrated in Figure 7. In such a virtuous circle, 'momentum' could be checked by exogenous factors such as drought, livestock disease, and competition for grazing land or endogenous factors limiting limb length. Both Afar and Somali pastoralists practice polygyny and the association between wealth and child survival predicted by such a virtuous circle may bestow a considerable reproductive advantage upon long-legged individuals.

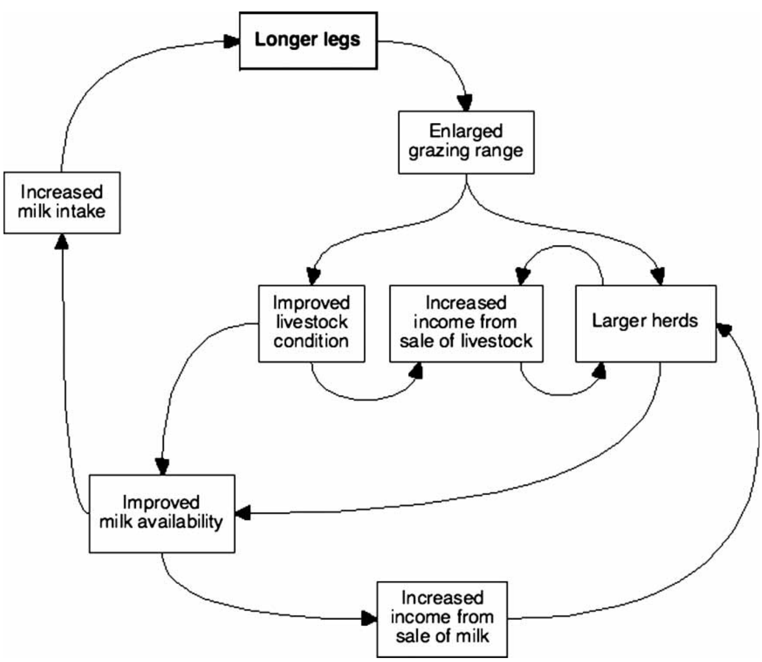


Figure 7. A virtuous circle associated with long-leggedness in pastoralists.

Conclusion

WHZ and WHZ case status in children are associated with body shape and may overestimate the prevalence of acute malnutrition in some populations. This problem cannot be fixed by switching from the NCHS reference population to the WHO Growth Standard. Consideration should be given as to whether WHZ should be replaced by MUAC for the purposes of estimating the prevalence of acute malnutrition.

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