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Use of Cutoffs for Mid-Upper Arm Circumference (MUAC) as an Indicator or Predictor of Nutritional and Health-Related Outcomes in Adolescents and Adults: A Systematic Review

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Abbreviations and Acronyms

ART	antiretroviral therapy
AUC	area under the receiver operating characteristic curve
BMI	body mass index
CMAM	Community-Based Management of Acute Malnutrition
DIH	drug-induced hepatotoxicity
FANTA	Food and Nutrition Technical Assistance III Project
HIV	human immunodeficiency virus
IMAI	Integrated Management of Adult Illness
IMCI	Integrated Management of Childhood Illness
LBW	low birth weight
MNA	mini-nutritional assessment
MUAC	mid-upper arm circumference
PLHIV	people living with HIV
TB	tuberculosis
WHO	World Health Organization
USAID	U.S. Agency for International Development

1 Introduction

The use of mid-upper arm circumference (MUAC) has improved the ability of front-line health workers to screen and assess for acute malnutrition among children by increasing the reach and enhancing the quality of Community-Based Management of Acute Malnutrition (CMAM) services (Collins et al. 2006, Brown et al. 2009). In 2009, the World Health Organization (WHO) and UNICEF published updated guidelines recommending a MUAC cutoff of <11.5 cm as one of three screening criteria for identifying and managing severe acute malnutrition in infants and children 6–60 months (WHO and UNICEF 2009). Although an earlier systematic review of the literature showed that children with MUAC measurements <11.0 cm had significantly elevated risk of mortality (Myatt et al. 2006), WHO and UNICEF recommended a slightly higher cutoff to increase sensitivity of the measure, while maintaining high specificity. Largely due to the guidance from WHO and UNICEF on a standardized cutoff, MUAC has become a widely used and successful diagnostic tool for screening children and determining eligibility for services to manage acute malnutrition (Brown et al. 2009, Nyirandutiye et al. 2011).

Increasingly, MUAC is also being used to assess nutritional status and determine eligibility for nutrition support among adolescents and adults in low-resource settings, especially among pregnant women and people living with HIV (PLHIV) who are eligible for antiretroviral therapy (ART) (Bahwere et al. 2011, Tumilowicz 2010, Ververs 2013). As with children, the use of MUAC among adolescents and adults offers the advantages of being a simple and relatively inexpensive measure that can be carried out at both community- and facility-based settings. Measurement of MUAC requires minimal equipment and calculations as compared to weight and height measurements for calculation of body mass index (BMI) (weight [in kg] / height [in meters]^2) or other anthropometric measurements, such as skinfold thicknesses.

Numerous studies have shown that MUAC correlates well with BMI in adult populations (Mazicioglu et al. 2010, Martin et al. 2009, Ferro-Luzzi and James 1996, Kaushik et al. 2007, Chakraborty et al. 2009, Collins 1996). However, globally recognized MUAC cutoffs have not been established to classify malnutrition among adolescents and adults. Many countries and programs have established their own MUAC cutoffs to determine eligibility for program services (Republic of Namibia Ministry of Health and Social Services and FANTA-2 2010, Federal Democratic Republic of Ethiopia Ministry of Health and FANTA 2008, FHI 360 and Uganda Regional Centre for Quality of Health Care 2008, Republic of Zambia Ministry of Health and FANTA 2011), but there is limited evidence supporting these cutoffs and it is not known whether the cutoffs are optimal. Patient monitoring guidelines provided by WHO for country adaptation to support the Integrated Management of Adult Illness (IMAI) do not include MUAC, in part because there is no guidance about what MUAC cutoff should trigger further action. In contrast, monitoring forms for Integrated Management of Childhood Illness (IMCI) do include MUAC because standard malnutrition cutoffs exist. Lack of a single, universally accepted, and widely accessible approach to diagnosing and documenting adult malnutrition has impeded accurate estimations of the human and financial burdens associated with prevention and treatment of malnutrition (White et al. 2012). Therefore, the establishment of standardized MUAC cutoffs for malnutrition among adolescents and adults could help expand the reach of community and treatment programs to identify adolescents and adults who are at increased risk of death or poor treatment outcomes due to acute malnutrition, as well as strengthen and harmonize programming in IMAI, HIV, and broader maternal health and nutrition.

This paper compiles and synthesizes currently available research on the association between low MUAC and measures of nutritional status and health-related outcomes among adolescents and adults. Our objective was to determine whether and what cutoffs for low MUAC have been associated with poor health outcomes in the following subpopulations: adolescents, adults, the elderly, and pregnant women.

2   Methods

2.1   Literature Search

We conducted a literature search of the Ovid Medline (1946 to March 2013), CAB Abstracts (1973 to March 2013), and Global Health (1973 to March 2013) electronic databases. Key search terms used were "mid upper arm circumference" or "MUAC" and "nutrition status" or "malnutrition." We also conducted a separate search using only the terms "mid upper arm circumference" or "MUAC" to include articles examining MUAC with all possible outcomes. We restricted our search to English-language articles. Reference lists of all included articles were manually searched for additional publications that may have been missed, including the reference list of a review article (Ververs et al. 2013) that was referred to us by one co-author (MD) and was published after the March 2013 cutoff date for our literature search.

2.2   Study Selection and Eligibility Criteria

Titles and abstracts of all search results were screened independently by two reviewers (KD and AT) to determine the relevance of each study. Abstracts that contained any measurement of MUAC, even if MUAC wasn't the primary focus of the study, were included. Full-text articles of potentially relevant abstracts were retrieved and screened according to the inclusion and exclusion criteria outlined in Table 1. Cases in which there was disagreement between the reviewers were resolved by discussion and consensus. In brief, only studies that explored a relationship between low MUAC (as defined by a cutoff) and another nutritional or health-related measure among adolescents and/or adults were included in this review.

Table 1. Summary of Study Inclusion and Exclusion Criteria

	Inclusion Criteria	Exclusion Criteria
Language	English language	Non-English language
Population	- Adolescents - Adults (men and women) - The elderly - Pregnant women - Lactating women (until 6 months postpartum) - Combinations of above	- Infants - Children - Individuals with chronic diseases (except HIV and TB): e.g., cystic fibrosis, acute lymphoblastic leukemia, hemodialysis, inflammatory bowel disease, cancer, stroke, Crohn's disease, cerebral palsy, type 2 diabetes - Critically ill patients
Setting	- All geographic locations - Community-dwelling - Long-term care facilities or nursing homes for the elderly	Intensive care unit or other inpatient hospital setting
MUAC measure	MUAC analyzed as binary or categorical variable using risk ratios, 95 percent confidence intervals, chi square tests, regression models, or sensitivity/specificity analyses	- MUAC analyzed as continuous variable - MUAC incorporated into a score - MUAC used to calculate arm muscle circumference
Outcome variables	Any measure of nutritional status or health-related outcome	Sociodemographic variables
Study design	- Cross-sectional (MUAC measured at same time point as outcome) - Longitudinal (MUAC measured at a point before assessment of outcome)	- Descriptive studies - Randomized control trials or systematic reviews of the effects of an intervention on MUAC

Studies that predominantly included infants and children under 10 years were excluded. Studies that included subjects ranging from young children to adolescents but did not present results by age were also excluded. Beyond that, we did not pre-specify age ranges for adolescents, adults, or the elderly, but relied on the studies themselves to define these populations. For example, if a study reported that it focused on adolescents, then we categorized that study as an adolescent study and recorded the age range defined by the authors. As such, different adolescent studies (or elderly studies) in our review may encompass slightly different age ranges. Furthermore, some of the studies of adults might include ages that extend into adolescent or elderly age ranges defined by other studies. Age ranges for each study, when stated by the authors, were recorded.

We excluded studies focused on individuals who were critically ill, were hospitalized, or had chronic debilitating diseases (other than HIV and tuberculosis [TB]) due to the distinct attributes of these populations and, therefore, the inability to generalize the results to the broader population of interest. Elderly people living in long-term care facilities or nursing homes were included.

All studies that assessed associations between MUAC (as a binary or categorical variable) and a health- or nutrition-related outcome using chi-square analyses, regression models, and/or sensitivity/specificity analyses were included. Studies that examined MUAC as a continuous measure or incorporated MUAC as part of a score or in the calculation of arm muscle circumference were excluded because these types of analyses cannot inform what cutoffs for low MUAC have been associated with poor outcomes.

In terms of outcomes, we included other indicators of nutritional status or any health-related outcomes but excluded sociodemographic measures, such as age, gender, or poverty indicators. Other indicators of nutritional status included anthropometric (e.g., BMI, weight gain, low birth weight [LBW] infants), biochemical (e.g., hemoglobin), or summary nutrition measures (e.g., mini-nutritional assessment [MNA]). Health-related outcomes included measures such as mortality, pregnancy outcomes, incidence of infections, or failure to initiate ART.

Study designs that would not lend significant insight into the promise of low MUAC as an indicator of malnutrition or poor health outcomes were excluded, such as studies comparing proportions of people with low MUAC between various demographic groups or against a reference population, and randomized controlled trials or systematic reviews that examined an intervention's effect on MUAC. Cross-sectional and longitudinal studies meeting the other study eligibility criteria were included.

2.3 Data Synthesis and Presentation

Full-text articles from all eligible abstracts were obtained. Study data were extracted by one reviewer (KD) using a standardized data collection form to record key data elements, including first author, date of publication, study location, study design, subject characteristics (sample size, age range or mean age, sex distribution, disease status, other special features), MUAC cutoff(s) analyzed, point during pregnancy when MUAC was measured (if relevant), and outcomes evaluated against the MUAC cutoff(s). Unadjusted risk ratios (odds ratios, relative risks, or hazard ratios comparing risk of poor outcome between low and normal MUAC) and 95 percent confidence intervals were extracted or, if possible, manually calculated from data presented in the articles. If unadjusted risk ratios were not available or calculable, adjusted risk ratios from multivariable regression models were recorded along with the variables that the models were adjusted for. In addition, for articles presenting information on diagnostic test accuracy of MUAC, we recorded sensitivity, specificity, positive predictive value, negative predictive value, and area under the receiver operating characteristic curve (AUC), to the extent this information was available.

After the initial data extraction, a second reviewer (AT) assessed the extracted information for any gaps or discrepancies. Both reviewers used the selection criteria listed in Table 1 to determine the final studies for inclusion.

For documentation purposes, detailed data from all eligible studies are tabulated by population type (adolescents, elderly, adults, pregnant women) in Supplemental Tables 1A–1D in Annex 1. Within each population type, the studies are organized by study design and then outcome.

Given that different study designs offer different insights into the value of low MUAC as a screening tool, our results are discussed in this paper by study design (cross-sectional vs. longitudinal). Within each study design, studies are presented by population type and outcome. In brief, cross-sectional studies (studies that measure MUAC and outcome at the same point in time) provide insight as to how closely low MUAC is associated with another measure of nutritional or clinical status at the time the MUAC is measured. This is useful if the purpose is to establish low MUAC (a relatively simpler and less expensive measure) as a surrogate marker for another (more complex) measure of nutritional or clinical status, which in turn is predictive of a poor future outcome. Longitudinal studies (studies in which MUAC is measured prior to development of an outcome) provide insight as to how well low MUAC itself predicts a future outcome. This type of study design can also be used to directly compare the predictive ability of low MUAC against other measures of malnutrition. Given the discrepancy in the literature regarding whether and how much MUAC measurements change during pregnancy (Ricalde et al. 1998, Lechtig 1988, Lopez et al. 2011, Dhar and Bhadra 2008, Assefa et al. 2012), we categorized studies on pregnant women in two ways: Studies that measured maternal MUAC during pregnancy and followed the women longitudinally for birth outcomes were classified as longitudinal, while studies that measured maternal MUAC upon labor or after delivery were classified as cross-sectional.

For visual presentation of the MUAC cutoffs used by different studies, we present bubble plots, with the bubble size proportional to the sample size of each study. To compare effect sizes among the two most frequently examined outcomes (BMI <18.5 and infant LBW, respectively), forest plots of risk ratios and 95 percent confidence intervals are shown. In most cases, risk ratios presented were based on the frequency of the outcome occurring in the group below the defined MUAC cutoff compared to the frequency of occurrence in the group above the defined MUAC cutoff. However, when multiple cutoffs were presented, the risk ratios presented in the forest plot represent the frequency of the outcome occurring in the lowest defined MUAC category compared to the reference category noted in a footnote.

Finally, in Supplemental Table 2, which appears in Annex1, we present data from studies that examined the diagnostic test accuracy of MUAC as a screening tool for various outcomes among adolescents and adults.

3   Results

Figure 1 displays the summary of our literature search and study selection process. The literature search yielded 827 potentially relevant abstracts that were screened, resulting in a total of 78 studies that were considered for data extraction. The full-text articles of these studies were retrieved, along with the review article published after the cutoff date for our literature search (Ververs et al. 2013). An additional 28 studies were identified from review of the reference lists of these papers. Of the total 107 full-text articles that underwent data extraction, 60 were subsequently excluded because they did not meet the eligibility requirements listed in Table 1. The remaining 47 studies are included in this systematic review.

Figure 1. Literature Search and Study Selection Process
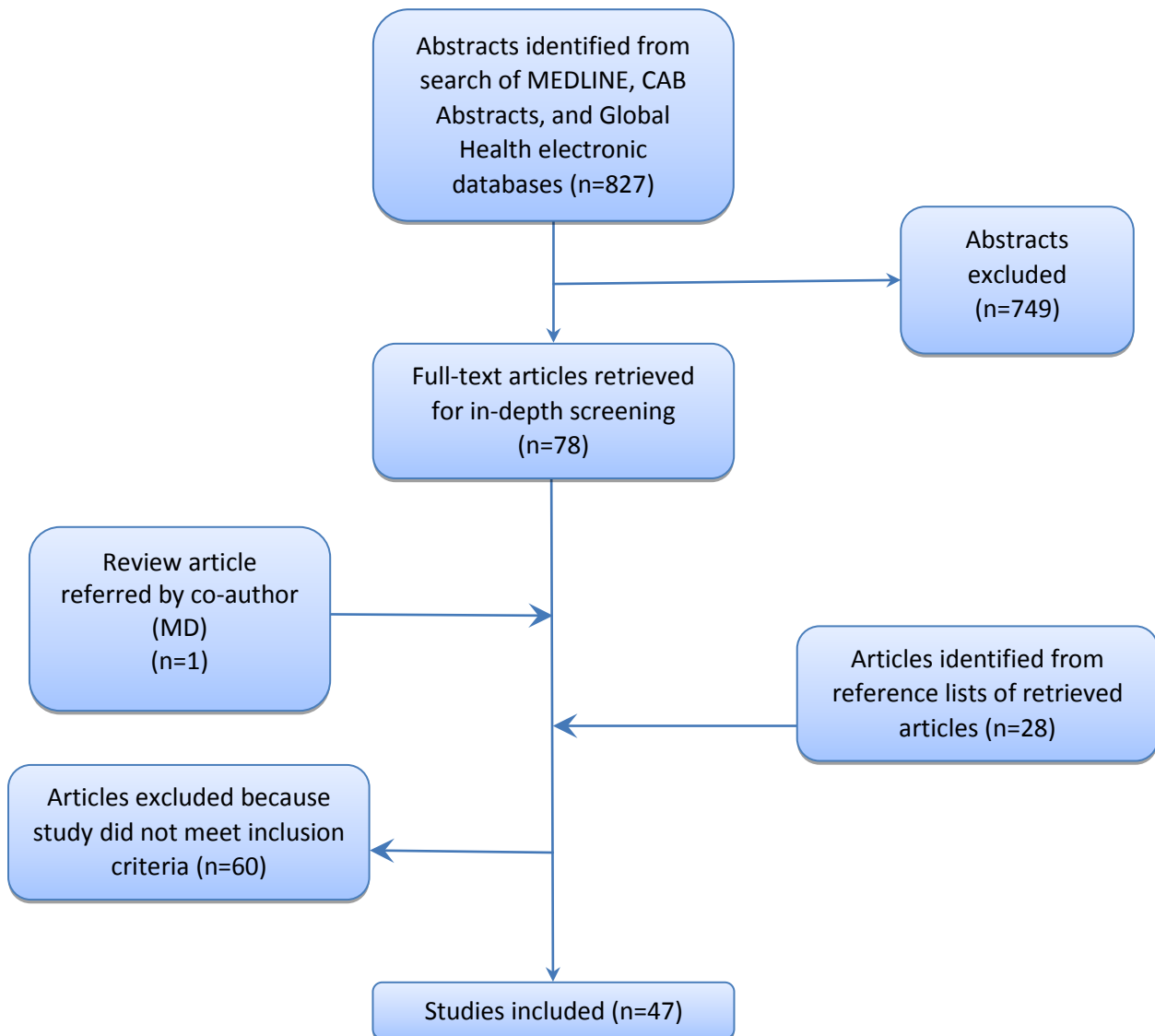
3.1   Cross-Sectional Studies

Nineteen cross-sectional studies met our study criteria: one on adolescents (Bulliyya et al. 2007), six on adults (Ferro-Luzzi and James 1996, Chakraborty et al. 2009, Bisai et al. 2009, Gartner et al. 2001, Singla et al. 2010, Lemmer et al. 2011), one on the elderly (Tsai et al. 2010), and 11 on pregnant women (Dhar and Bhadra 2008, Elshibly and Schmalisch 2008, Janjua et al. 2009, Ogbonna et al. 2007, Ojha and Malla 2007, Osman et al. 1995, Sen et al. 2010, Begum et al. 2003, Charles et al. 2010, Verhoeff et al. 1999, Libombo et al. 1994) (Supplemental Tables 1A-1D in Annex 1 and Figure 2). Overall, the cutoffs chosen for low MUAC were relatively consistent among adult populations (ranging from 20 cm to 24 cm) and slightly more variable among studies on pregnant women (ranging from 20.0 cm to 28.9 cm).

3.1.1   Adolescents

The only study of adolescents we identified was conducted in India among nearly 2,000 adolescent girls (11–19 years) not attending school (Bulliyya et al. 2007), the vast majority (97 percent) of whom were anemic. The authors reported significantly lower mean hemoglobin levels in those with low MUAC (<22 cm) than those with MUAC ≥22 cm.

3.1.2   Adults

Four (Ferro-Luzzi and James 1996, Chakraborty et al. 2009, Bisai et al. 2009, Gartner et al. 2001) of the six adult studies examined the association between low MUAC and BMI <18.5 and found statistically significant unadjusted odds ratios ranging from 13.9 (Gartner et al. 2001) to 28.8 (Ferro-Luzzi and James 1996) (Figure 2). All four studies used a MUAC cutoff of 23 cm, although two studies included 23 cm in the low category (i.e., MUAC ≤23 cm) (Chakraborty et al. 2009, Bisai et al. 2009), while the other two did not (i.e., MUAC <23 cm) (Ferro-Luzzi and James 1996, Gartner et al. 2001). In addition, Ferro-Luzzi and James (1996) analyzed a lower cutoff for women (<22 cm) and found an equally strong association with BMI <18.5 (odds ratio=21.2).

Chakraborty et al. further examined the association between categories of MUAC (≤23.0, 23.1–24.9, ≥25.0) and several other outcomes, including BMI as a continuous measure. A MUAC ≤23 cm was significantly associated with an increased proportion of men reporting illness and lost work days compared to those with MUAC ≥25 cm. However, these measures of morbidity were not different between those with MUAC in the middle range (23.1–24.9 cm) and those with MUAC ≥25 cm. Two studies (Singla et al. 2010, Lemmer et al. 2011) used a case comparison design to examine the association between low MUAC and poor health-related outcomes. Singla et al. (2010) found significantly higher proportions of patients with low MUAC (<20 cm) among 175 TB-treated patients with anti-TB drug-induced hepatotoxicity (DIH) compared to 428 TB-treated patients without anti-TB DIH. In a smaller study, Lemmer et al. (2011) found no difference in proportions of patients with low MUAC (≤24.3 for men, ≤23.2 for women) among HIV patients with and without cardiomyopathy.

3.1.3   The Elderly

Tsai et al. was the only cross-sectional study we found on the elderly. The authors reported a significant association between low MUAC (<23.5 for men, <22.0 for women) and the MNA, which is a tool commonly used for screening and classifying nutritional status of the elderly. The MNA classification is based on 18 questions/assessments in four areas: anthropometrics (measures of BMI, MUAC, and calf circumference), dietary intake, global indicators, and self-perception of nutritional and health status.

Figure 2. MUAC Cutoffs for Cross-Sectional Studies, Organized by Population and Outcome
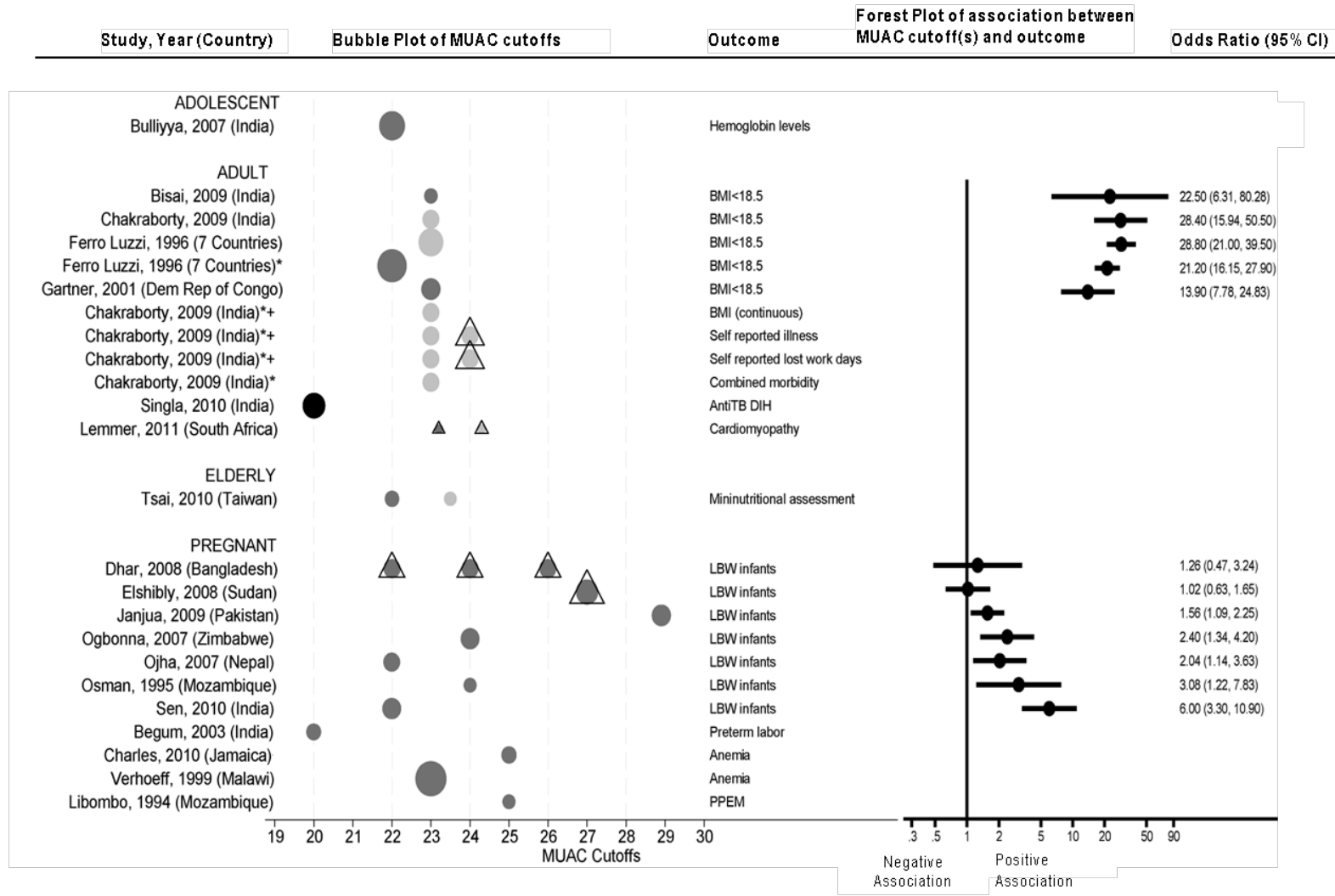
Bubble plot legend: Size of circle represents relative sample size: Black circles indicate study includes both males and female; dark gray circles indicate study includes females only; light gray circles indicate study includes males only. Triangle around circle indicates findings were not statistically significant (p>.05), Significance based on comparisons above and below MUAC cutoff displayed unless footnoted with +.

* = Same reference as above by same author; outcome is different.

+ = Reference group is ≥25 cm for both MUAC cutoffs displayed.

3.1.4 Pregnant Women

Eight (Dhar and Bhadra 2008, Elshibly and Schmalisch 2008, Janjua et al. 2009, Ogbonna et al. 2007, Ojha and Malla 2007, Osman et al. 1995, Sen et al. 2010, Begum et al. 2003) of the 11 studies on pregnant women examined the association between low MUAC and birth outcomes, while the remaining three (Charles et al. 2010, Verhoeff et al. 1999, Libombo et al. 1994) examined low MUAC in association with measures of maternal health. The vast majority of the studies examining birth outcomes reported significantly higher risk of poor birth outcomes (infant LBW or preterm labor) in those with low vs. normal MUAC as defined by the various cutoffs shown in Figure 2, with risk ratios ranging from 1.6 (Janjua et al. 2009) to 6.0 (Sen et al. 2010). The two studies that did not find a significant association between low MUAC and infant LBW (Dhar and Bhadra 2008, Elshibly and Schmalisch 2008) both based their choice of cutoff (<24 cm and <27 cm, respectively) on what was determined to be optimal (highest sensitivity and specificity) in their study samples. In Pakistan, Janjua et al. (2009) based their relatively high cutoff on the median in their population (≤28.9 cm) and found a significantly elevated risk of infant LBW in those below that cutoff.

In addition to birth outcomes, low MUAC was also significantly associated with poor maternal health outcomes, including anemia (Charles et al. 2010, Verhoeff et al. 1999) and postpartum endometritis-myometritis (Libombo et al. 1994).

3.2 Longitudinal Studies

We identified 20 longitudinal studies that met our study eligibility criteria, none of which were conducted on an adolescent population. Five of the studies were conducted among adult populations (Liu et al. 2011, Oliveira et al. 2012, Gustafson et al. 2007, Gourlay et al. 2012, McGrath et al. 2010), three among the elderly (Wijnhoven et al. 2012, Allard et al. 2004, Sagawa et al. 2011), and 11 among pregnant women (Lechtig 1988, Assefa et al. 2012, Karim and Mascie-Taylor 1997, Mohanty et al. 2006, Rollins et al. 2007, Sebayang et al. 2012, Kalanda et al. 2006, Lee et al. 2009, Achadi et al. 1995, Villamor et al. 2003, Venkatesh et al. 2005). Figure 3 displays the MUAC cutoffs for 19 of these studies. One study could not be displayed in Figure 3 because it did not state the actual cutoff used, only that the cutoff was <80 percent of the reference value in Japan (Sagawa et al. 2011).

3.2.1 Adults

All of the adult studies were among HIV (HIV-1 or HIV-2) or TB-infected populations (Supplemental Tables 1A–1D). Four of the five studies looked at the association between low MUAC and risk of mortality but over varying time periods. Three of these studies reported significantly increased risk of mortality among those below the defined MUAC cutoff than those above the cutoff (Liu et al. 2011, Oliveira et al. 2012, Gustafson et al. 2007). These studies followed HIV- or TB-infected participants over periods of 3–8 months before and after initiation of treatment. The fourth study looked at the association of low MUAC with long-term mortality (7 years) in an HIV-2-infected population in Guinea-Bissau and found no association (Gourlay et al. 2012).

The fifth study was in HIV patients who were clinically eligible for ART in Malawi. The study found that low MUAC was associated with dropout (defaulting from clinical care) before ART initiation (McGrath et al. 2010). A large proportion of these patients who failed to initiate ART were found to have died, suggesting that low MUAC could be a useful screening tool to identify sicker ART-eligible patients who would benefit from more active outreach to initiate treatment.

Figure 3. MUAC Cutoffs for Longitudinal Studies, Organized by Population and Outcome
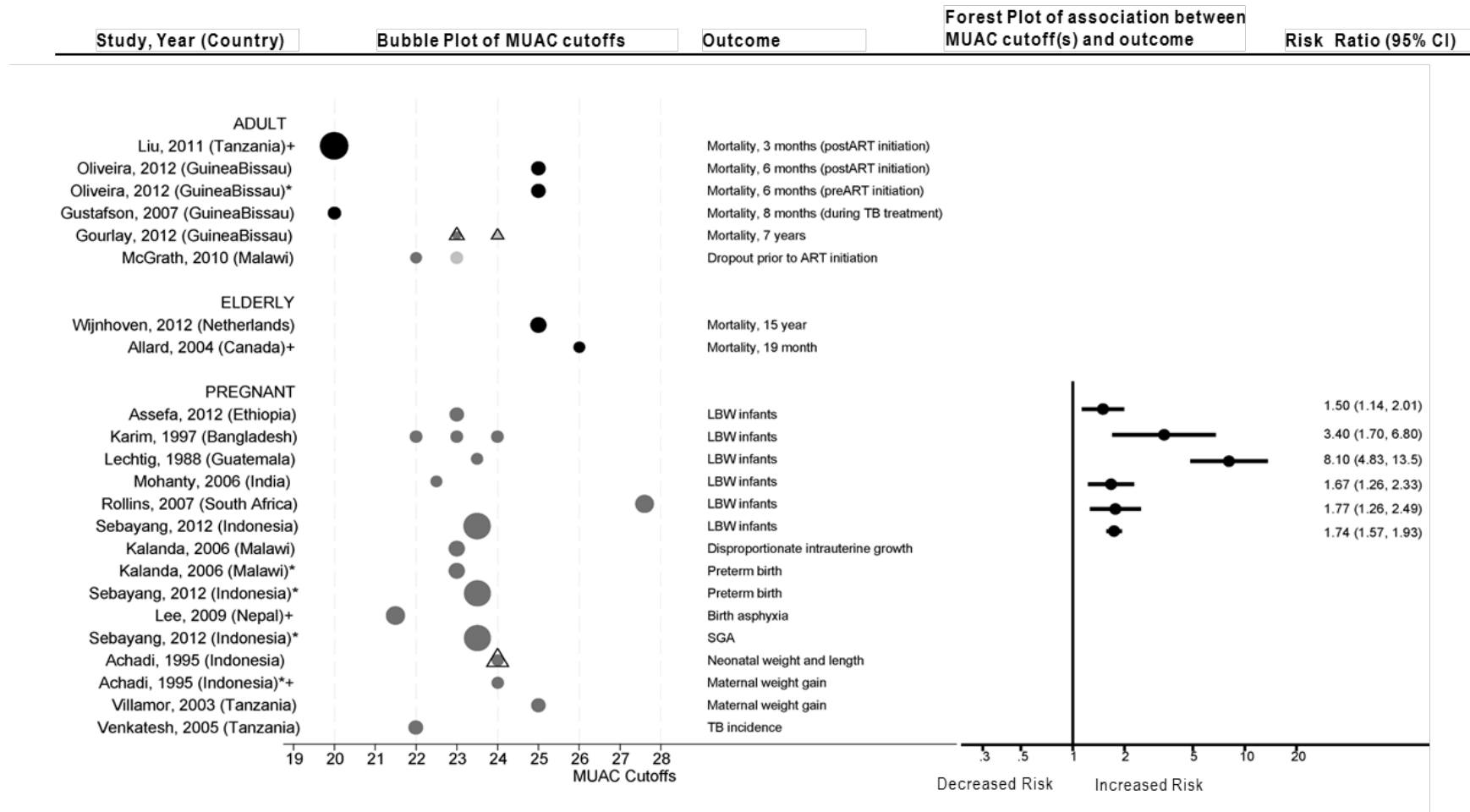
Bubble plot legend: Size of circle represents relative sample size: Black circles indicate study includes both males and female; dark gray circles indicate study includes females only; light gray circles indicate study includes males only. Triangle around circle indicates findings were not statistically significant (p>.05). Significance based on comparisons above and below MUAC cutoff displayed unless footnoted with +. SGA = small for gestational age.

* = Same reference as above by same author; outcome is different.

+ = Reference groups: ≥27 cm (Liu 2011); >29 cm (Allard 2004); ≥29 cm (Achadi 1995)

3.2.2 The Elderly

We found three longitudinal studies specifically among elderly populations. All were conducted in resource-rich countries; two were among elderly people living in a long-term care facility or nursing home (Allard et al. 2004, Sagawa et al. 2011), and the third was in a community-dwelling population (Wijnhoven et al. 2012). Although the cutoff for low MUAC was different in all of the studies, all three found that low MUAC was significantly associated with the outcomes assessed: increased risk of 15-year mortality in community-dwelling elderly people (Wijnhoven et al. 2012), 19-month mortality in the elderly living in a long-term care facility (Allard et al. 2004), and poor immune response to influenza vaccine in a nursing-home population in Japan (Sagawa et al. 2011).

3.2.3 Pregnant Women

We identified 12 longitudinal studies reporting the association between low MUAC and birth outcomes among pregnant women. Half of the studies looked at the association between low MUAC and infant LBW (Lechtig 1988, Assefa et al. 2012, Karim and Mascie-Taylor 1997, Mohanty et al. 2006, Rollins et al. 2007, Sebayang et al. 2012), all of which found significantly increased risk among mothers with low MUAC during pregnancy.

Other birth outcomes that were examined in association with low MUAC were disproportionate intrauterine growth (Kalanda et al. 2006), preterm birth/labor (Sebayang et al. 2012, Kalanda et al. 2006), birth asphyxia (Lee et al. 2009), small for gestational age (Sebayang et al. 2012), and neonatal weight and length (Achadi et al. 1995). Longitudinal outcomes occurring in the mother included maternal weight gain (Achadi et al. 1995, Villamor et al. 2003) and TB incidence among HIV-1-infected women in Tanzania (Venkatesh et al. 2005). All of these outcomes, except for neonatal weight and length, were significantly associated with low MUAC.

As depicted in Figure 3, MUAC cutoffs used in studies among pregnant women were wide-ranging (<21.5 cm to ≤27.6 cm), although the majority used cutoffs ranging from 22 cm to 24 cm. In pregnant women in South Africa, Rollins et al. (2007) used the relatively high cutoff of ≤27.6 cm, which was the median in their population.

3.3   Diagnostic Test Accuracy of MUAC

While the above studies assessed the strength of association between low MUAC and various measures of poor nutritional status and health outcomes, this section includes studies that presented information on the diagnostic test accuracy of specific MUAC cutoffs against various outcomes. We identified 14 studies that presented results on a range of MUAC cutoffs against a range of diagnostic criteria (outcomes). Two of these studies were conducted on adolescent populations (Mazicioglu et al. 2010, Martin et al. 2009), six in general adult populations (Collins 1996, Oliveira et al. 2012, Gustafson et al. 2007, Rodrigues et al. 1994, Khadivzadeh 2002, Olukoya 1990), and six in pregnant women (Dhar and Bhadra 2008, Elshibly and Schmalisch 2008, Sen et al. 2010, Karim and Mascie-Taylor 1997, Mohanty et al. 2006, Olukoya and Giwa-Osagie 1991).

As shown in Supplemental Table 2, the data presented in these studies are highly variable, making it difficult to synthesize findings across studies. Some studies presented AUC statistics but no data on sensitivity or specificity for any MUAC cutoffs (Mazicioglu et al. 2010, Martin et al. 2009, Elshibly and Schmalisch 2008). Others presented sensitivity data only but no specificity data (Olukoya 1990, Olukoya and Giwa-Osagie 1991). Nearly every study assessed MUAC cutoffs against a different outcome, except for five studies on pregnant women that assessed MUAC cutoffs against infant LBW (Dhar and Bhadra 2008, Elshibly and Schmalisch 2008, Sen et al. 2010, Karim and Mascie-Taylor 1997, Mohanty et al.

2006) and two studies that assessed MUAC cutoffs against BMI (Rodrigues et al. 1994, Khadivzadeh 2002). None of the five infant LBW studies identified the same MUAC cutoff as optimal based on maximizing sensitivity and specificity in their study samples (Dhar: 24 cm, Elshibly: 27 cm, Karim: 23 cm, Mohanty: 22 cm, and Sen: 21.5 cm). Similarly, sensitivities and specificities varied greatly between the two studies that evaluated MUAC against different BMI cutoffs. In a large population of healthy, non-pregnant, and non-lactating women in Iran, Khadivzadeh et al. (2002) reported high ranges of sensitivity (81%–97%) and specificity (80%–93%) for several MUAC cutoffs (23.5–24.5 cm) against the outcome of BMI <19.8. However, in a similar but smaller population of women in India, Rodrigues et al. (1994) reported much lower ranges of sensitivity (51%–92%) and specificity (50%–85%) for a similar range of MUAC cutoffs against a slightly different outcome (BMI <18.5).

4   Discussion

The articles presented in this review illustrate a wide range of outcomes that have been associated with low MUAC in a variety of populations. Fewer studies have assessed the sensitivity and specificity of specific MUAC cutoffs against diagnostic criteria, and results of these studies have not been consistent. Taken together, the results suggest that low MUAC can be used to identify individuals at increased risk of adverse outcomes across adolescents, adults, the elderly, and pregnant women, but there is insufficient evidence on which MUAC cutoff optimizes sensitivity and specificity for any particular diagnostic criteria or population.

According to our literature search, the study of low MUAC as a predictor of poor outcome first appeared in the literature in 1988 when Lechtig (1988) published a study comparing the association of several traditionally high-risk anthropometric indicators during pregnancy with risk of having a LBW baby in Guatemala. The results showed that low MUAC (≤23.5 cm) performed just as well as the other measures (weight gain during pregnancy, uterine height, and weight gain as a percentage of weight-for-height) and had several advantages, including simplicity and low cost. Largely based on these results, a simple armband with a cutoff of 23.5 cm was developed and has been used on pregnant women in several countries in South America. Since the publication of that study, the need to identify pregnant women at risk of poor birth outcomes in resource-limited settings has continued to grow, as evidenced by the continuing publication of papers with this focus, including a recently published review article calling for simple and standardized anthropometric indicators (such as low MUAC) to predict acute malnutrition and poor birth outcomes among pregnant women in humanitarian contexts (Ververs et al. 2013). A significant association between low maternal MUAC and risk of a LBW outcome has been consistently shown both cross-sectionally and longitudinally, with only a couple of exceptions (Dhar and Bhadra 2008, Elshibly and Schmalisch 2008).

In 1994, as the evidence base for the utility of low MUAC for identifying pregnant women at risk of poor birth outcomes was increasing, Rodrigues et al. (1994) recognized a similar need for a simpler measure of nutritional status among non-pregnant women in low-resource settings and published a study comparing sensitivities and specificities of different MUAC cutoffs against BMI <18.5 among a population of healthy, non-pregnant women in India. They identified a cutoff of <24 cm to be most appropriate in their population, with sensitivity and specificity of 71.1 percent and 69.6 percent, respectively.

This led to the idea of establishing MUAC cutoffs in the more general adolescent/adult population, which first appeared in the literature in the late 1990s with the need to quickly screen and prioritize large numbers of severely malnourished individuals for special nutritional support in the context of large emergency situations, such as famine, war, or disease outbreaks (Ferro-Luzzi and James 1996, Collins 1996, James et al. 1994). Although low BMI was recognized as a valuable tool for detecting severe malnutrition and predicting increased morbidity and mortality, it was often found to be a difficult measure to use in settings where resources are scarce and demands are high. In their search for a simpler and quicker screening tool, Ferro-Luzzi and James (1996) analyzed data from seven large surveys of adults living in low-resource countries across Africa and Asia and found strong associations between low MUAC (<22 cm for women and <23 cm for men) and low BMI (<18.5).

Since this study was published, there have been only a handful of other studies (Chakraborty et al. 2009, Bisai et al. 2009, Gartner et al. 2001) that have examined the association between low MUAC and low BMI. All found strong and significant associations between MUAC <23 (or ≤23) cm and BMI <18.5. Only one study included both men and women (Ferro-Luzzi and James 1996); the other studies included either only men (Chakraborty et al. 2009) or only women (Bisai et al. 2009, Gartner et al. 2001). More

and larger diagnostic test accuracy studies need to be done to identify a specific recommended MUAC cutoff as a substitute for BMI criteria. In addition, the BMI criterion also must be standardized, as the current sensitivity and specificity data that are published (Collins 1996, Rodrigues et al. 1994, Khadivzadeh 2002) used not only varying MUAC cutoffs, but different BMI cutoffs as well.

Only 4 of the 47 studies identified in our literature review (all among the elderly) were conducted in resource-rich countries (Tsai et al. 2010, Wijnhoven et al. 2012, Allard et al. 2004, Sagawa et al. 2011); the rest were conducted among populations in resource-poor countries. This is not surprising, as low-resource settings are most in need of nutritional screening tools that are simpler to apply than weight and/or BMI measurements.

A large proportion (60 percent) of studies identified in our literature review were published in the past 5 years (since 2008), and most of the studies on adults were conducted in HIV- and/or TB-infected populations. This may reflect increased access to treatment in low-resource settings and the specific need for treatment programs to identify and prioritize those with acute malnutrition at the start of treatment for additional nutritional support. In HIV treatment settings, low BMI (<16 or <18.5) has consistently been shown to increase risk of early mortality after initiating ART (Koethe et al. 2010, Toure et al. 2008, Calmy et al. 2006).

Few of the studies reviewed here were specifically designed to address the establishment of a low MUAC cutoff for identifying individuals at risk of adverse health outcomes. Instead, most studies were designed to determine whether poor nutritional status (of which low MUAC was just one of several measures) was associated with a particular outcome. Therefore, these studies usually selected only one cutoff for low MUAC and did not consider any other cutoffs. Many studies reported results from both adjusted and unadjusted regression models. Although every study adjusted for a different set of variables, most of the time low MUAC remained an independent predictor of outcome when BMI was not also included in the model. Often the association between low MUAC and clinical outcome would become non-significant after adjusting for BMI, which is not surprising if the two measures are strongly associated. We do not report any adjusted odds ratios from multivariable regression models that included both MUAC and BMI in this review, since our objective was not to determine the additional effect of low MUAC on health outcomes after taking into account another anthropometric measure. Instead, our aim was to determine the association between low MUAC and poor health outcomes in the absence of other anthropometric measures, such as BMI.

As mentioned earlier, conclusions drawn from cross-sectional study designs are useful for establishing low MUAC as an indicator of another nutritional or clinical measure occurring at the same point in time, while longitudinal designs are useful for assessing how well low MUAC predicts a future outcome. Our review identified too few studies with identical outcome measurements to be able to synthesize results across studies. Three exceptions were the cross-sectional associations between low MUAC and BMI <18.5 (four studies), between low maternal MUAC and infant LBW (seven studies), and the longitudinal association between low maternal MUAC and LBW infants (six studies). Our review suggests that: 1) in non-pregnant adults, low MUAC may be a good substitute for BMI <18.5, and 2) in pregnant women, low MUAC at any time during pregnancy is associated with higher risk of having an infant with LBW. While most of these studies chose cutoffs of 22–24 cm and found significant associations with the outcomes, none of the studies adequately explored the optimal MUAC cutoffs associated with these outcomes.

Sample sizes of all the studies included in this review were relatively large, ranging from hundreds to tens of thousands. Only two studies had sample sizes less than 100: one had 90 participants (Collins 1996) and the other had 35 participants (Lemmer et al. 2011). For studies on pregnant women, the point during

pregnancy when MUAC was measured and the time after birth when the infant was weighed were not standardized across studies. Other design issues that were not standardized across studies include the arm on which MUAC measurements were taken and the age ranges for defining adolescents, adults, and elderly populations. Although some studies did report which arm that was measured (usually the left arm), many others did not. While studies show that handedness does matter and measurements taken on the right arm tend to be larger than those taken on the left, the difference has been shown to be small and therefore not worthy of attention (Martorell et al. 1988). However, given the scarcity of data addressing this issue, studies should state in their methods section the arm on which the measurements are taken.

Our review has several limitations. First, the articles selected for review were limited to published articles indexed in the Medline, CAB abstracts, and Global Health databases. We did not search the gray literature, which could offer some additional insights into the utility of low MUAC in programmatic settings. Second, we were only able to review English-language studies. Third, our search results may be affected by publication bias, as studies that measured MUAC along with other measures of nutritional status may have only reported the nutritional measures that were statistically significant in their abstract. Our abstract review process would have missed articles where MUAC was not included in the abstract because the results were not statistically significant or because MUAC was not the main risk factor of interest in the study. In addition, studies where a significant association between low MUAC and a health outcome were not detected may not have even been published. Unfortunately, we are not able to assess the impact of these potential biases on our findings.

In summary, our review of the literature reveals significant associations between low MUAC (as defined by various cutoffs) and several adverse health outcomes. The most consistent associations were found among pregnant women for the outcome of infant LBW and among adults for the outcome of BMI <18.5. There was not a preponderance of evidence for any of the other health outcomes to draw firm conclusions. There were also too few diagnostic test accuracy studies to be able to recommend an optimum MUAC cutoff for any particular health outcome at this time.

Given the multitude of studies that have collected data on both MUAC and health outcomes across a diverse range of populations (many of which were not included in this review because MUAC was analyzed as a continuous variable) and the increasing demand for the establishment of a standard MUAC cutoff for PLHIV, pregnant women, and populations in crisis, a meta-analysis using individual-patient data would be the most timely and cost-effective next step to answer some of the remaining questions. Issues that would need to be resolved by various stakeholders before taking this next step would be to decide whether there is interest in establishing a low MUAC cutoff solely as a substitute for BMI indicators or whether there is additional need or interest in establishing optimal MUAC cutoffs for predicting other health outcomes. In terms of BMI indicators, the studies that we identified all examined the association between low MUAC and BMI <18.5 (an indicator reflecting mild, moderate, and severe malnutrition), but in many circumstances it may also be useful to establish specific MUAC cutoffs for both moderate malnutrition (defined as BMI ≥16 and <17) and severe malnutrition (defined as BMI <16).

Other issues to be addressed include which health-related outcomes and populations should be prioritized and what levels of sensitivity and specificity should a particular MUAC cutoff have before it can be recommended. Finally, more research is needed to determine whether different standardized cutoffs should be recommended for various subpopulations (e.g., men vs. women, or adolescents vs. adults) or different contexts (e.g., humanitarian aid/famine relief vs. HIV treatment programs).

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Annex 1. Supplemental Tables

Supplemental Table 1A. Adolescents

Author, Year	Country	Total N, % Female (F)	Ages (years)	Additional Population Characteristics	MUAC Cutoff (cm)	Outcome	Results
Cross-Sectional Studies							
Bulliyya, 2007	India	1,937, 100% F	11–19	Not attending school	<22	Hemoglobin levels (continuous)	*Mean hemoglobin levels significantly lower in those with MUAC <22 vs. ≥22*

Supplemental Table 1B. The Elderly

Author, Year	Country	Total N, % Female (F)	Ages (years)	Additional Population Characteristics	MUAC Cutoff (cm)	Outcome	Results
Cross-Sectional Studies							
Tsai, 2010	Taiwan	301, 54% F	≥65	No acute health conditions	<23.5 men <22 women	MNA	OR=8.65 (95% CI=2.10-35.64) *Men and women with low MUAC are 8.7 times more likely to have low MNA than those above the MUAC cutoff.*
Longitudinal Studies							
Allard, 2004	Canada	408, 67% F	≥60	Long-term care facility	1. <26 vs. >29 2. 26–29 vs. >29	Mortality, 19-month	1. HR=4.2 (95% CI=2.5–7.3) 2. HR=2.9 (95% CI=1.6–5.2) *Those with MUAC <26 have a 4-fold increased risk of mortality vs. those with MUAC >29. Those with MUAC 26–29 have a 3-fold increased risk of mortality vs. those with MUAC >29.*
Sagawa, 2011	Japan	203, 78% F	≥65	Nursing home	<80% of reference value (Japan)	≥4-fold rise in titer after influenza vaccine	OR=0.45 (95% CI=0.21–0.97) *Those in the lower 80th percentile of MUAC are 35% less likely to have adequate immune response to influenza vaccine than those in the top 20th percentile.*
Wijnhoven, 2012	Netherlands	1,687, 50% F	≥55	Community dwelling	<25	Mortality, 15-year	*Those with MUAC <25 have 4.7 times increased risk of mortality vs. those with MUAC ≥25.*

Supplemental Table 1C. Adults

Author, Year	Country	Total N, % Female (F)	Ages (years)	Additional Population Characteristics	MUAC Cutoff (cm)	Outcome	Results
Cross-Sectional Studies							
Singla, 2010	India	606, 50% F	16–65	TB	<20	Anti-TB drug-induced hepatotoxicity (DIH)	Adj OR=2.56, 95% CI=1.58–4.15 *Those with anti-TB DIH are 2.6 times more likely to have low MUAC vs. those w/o anti-TB DIH, after adjusting for age >35 years and serum albumin <3.5g/dL.*
Bisai, 2009	India	123, 100% F	Mean (SD): 34.8 (15.2)	Non-pregnant, Non-lactating	<23	BMI <18.5	OR=22.5 (95%CI=6.3–80.2) *Women with MUAC <23 are 22.5 times more likely to have BMI <18.5 vs. women with MUAC ≥23.*
Ferro-Luzzi, 1996	China, India, Ethiopia, Zimbabwe, Mali, Somalia, Papua New Guinea	5,669, 57% F	Not stated		<23 men <22 women	BMI <18.5	Men: OR=28.8 (95%CI=21.0–39.5) Women: OR=21.2 (95%CI=16.2–27.9) *Men with MUAC <23 are 28.8 times more likely to have BMI <18.5 vs. men with MUAC ≥23. Women with MUAC <22 are 21.2 times more likely to have BMI <18.5 vs. women with MUAC ≥23.*
Chakraborty, 2009	India	474, 0% F	>18	Urban slum dwellers	≤23	BMI <18.5	OR=28.4 (95%CI=15.9–50.5) *Men with MUAC ≤23 are 28.4 times more likely to have BMI <18.5 vs. men with MUAC >23.*
Gartner, 2001	Democratic Republic of Congo	544, 100% F	18–60		<23	BMI <18.5	OR=13.9 (95%CI=7.8–24.9) *Women with MUAC <23 are 13.9 times more likely to have BMI <18.5 vs. women with MUAC ≥23.*
Chakraborty, 2009*	India	474, 0% F	>18	Urban slum dwellers	≤23, 23.1–24.9, ≥25	BMI (continuous)	F test p-value <.001 *Mean BMI is lower with lower levels of MUAC.*

Author, Year	Country	Total N, % Female (F)	Ages (years)	Additional Population Characteristics	MUAC Cutoff (cm)	Outcome	Results
Lemmer, 2011	South Africa	35, 40% F	Median (IQR): 34.5 (29.2–45.8) for CM and 36 (31–42) for no CM	HIV	M: ≤24.3 F: ≤23.2	Cardiomyopathy (CM)	*Low MUAC is not associated with CM in final multivariate logistic regression model.*
Chakraborty, 2009*	India	474, 0% F	>18	Urban slum dwellers	1. ≤23 vs. ≥25 2. 23.1–24.9 vs. ≥25	Self-reported lost work days	1. OR=2.6 (95% CI=1.4–4.6) 2. OR=1.7 (95% CI=0.95–3.1) *Men with MUAC ≤23cm are 2.6 times more likely to report lost work days vs. men with MUAC ≥25. There is no difference in reports of lost work days between men with MUAC 23.1–24.9 and men with MUAC ≥25.*
Longitudinal Studies							
McGrath, 2010	Malawi	632, 58% F	21.7% <30	HIV (ART eligible)	M: <23 F: <22	Dropping out before ART initiation	HR=2.0 (95% CI=1.3–3.2) *Those with MUAC below the cutoffs were 2 times more likely to drop out before ART initiation vs. those with MUAC above the cutoffs.*
Liu, 2011	Tanzania	18,271, 65% F	≥15	HIV, initiating ART	1. <20 2. 20–21.9 3. 22–24.9 4. 25–26.9 5. ≥27	Mortality, 3 months (post-ART initiation)	1 vs. 5: RR=10.2 (95% CI=8.4–12.5) 2 vs. 5: RR=5.1 (95% CI=4.1–6.3) 3 vs. 5: RR=2.6 (95% CI=2.1–3.1) 4 vs. 5: RR=1.4 (95% CI=1.1–1.8) (p for trend=<.001) *Risk of mortality decreases with increasing level of MUAC (reference is MUAC ≥27 for each RR).*

Author, Year	Country	Total N, % Female (F)	Ages (years)	Additional Population Characteristics	MUAC Cutoff (cm)	Outcome	Results
Oliveira, 2012	Guinea-Bissau	1,054, ~70% F	≥15	HIV-1 and/or HIV-2, ART-naïve at baseline	≤25	Mortality, 6 months (post-ART initiation)	HR=3.5 (95% CI=1.7–7.1) *Risk of mortality 6 months post-ART initiation is 3.5 times higher in those with MUAC ≤25 vs. those with MUAC >25.*
Oliveira, 2012*	Guinea-Bissau	1,049, ~70% F	≥15	HIV-1 and/or HIV-2, ART-naïve at baseline	≤25	Mortality, 6 months (pre-ART initiation)	HR=7.2 (95% CI= 3.7–13.9) *Risk of mortality 6 months pre-ART initiation is 7.2 times higher in those with MUAC ≤25 vs. those with MUAC >25.*
Gustafson, 2007	Guinea-Bissau	709, 38% F	≥16	Active TB	<20	Mortality, 8 months (during TB treatment)	MRR=3.3 (95% CI=2.2–4.9) *Among those with active TB, risk of 8-month mortality during TB treatment is 3.3 times higher in those with MUAC <20 vs. those with MUAC ≥20.*
Gustafson, 2007*	Guinea-Bissau	441, 37% F	≥16	Active TB and HIV-negative	<20	Mortality, 8 months (during TB treatment)	HR=2.6 (95% CI=1.7–7.4) *Among those with active TB and without HIV infection, risk of 8-month mortality during TB treatment is 2.6 times higher in those with MUAC <20 vs. those with MUAC ≥20.*
Gustafson, 2007*	Guinea-Bissau	243, 41% F	≥16	Active TB with HIV-1 and/or HIV-2	<20	Mortality, 8 months (during TB treatment)	HR=2.5 (95% CI=1.5–4.2) *Among those with active TB and with HIV-1 and/or HIV-2 infection, risk of 8-month mortality during TB treatment is 2.5 times higher in those with MUAC <20 vs. those with MUAC ≥20.*

Author, Year	Country	Total N, % Female (F)	Ages (years)	Additional Population Characteristics	MUAC Cutoff (cm)	Outcome	Results
Gourlay, 2012	Guinea-Bissau	146, 68% F	≥15	HIV-2	M: <24 F: <23	Mortality, 7 years	HR=2.2 (95%CI=0.9-5.3) *Risk of mortality is 2.2 times higher in those with MUAC below the stated cutoffs vs. those with MUAC above the cutoffs.*

* Same reference as study above by same author.
Abbreviations: OR: odds ratio, RR: relative risk, HR: hazard ratio, IQR: interquartile range

Supplemental Table 1D. Pregnant Women

Author, Year	Country	N	Age (in years) and Additional Population Characteristics	MUAC Cutoff (cm)	Time of MUAC Measurement	Outcome	Time Infant Weighed (LBW only)	Results
Cross-Sectional Studies								
Charles, 2010	Jamaica	204	15% <20	<25	Antenatal care independent of stage of pregnancy	Anemia		OR=3.1 (95% CI=1.26-7.71) *Women with MUAC <25 were 3.1 times more likely to have anemia vs. women with MUAC ≥25.*
Verhoeff, 1999	Malawi	4,104	Mean (SD): 19 (2.8) primagravidae, 27 (5.8) multigravidae, 60% adolescents (≤19 years)	<23	1st antenatal visit	Anemia		1. Primigravidae: χ^2 p<0.01 2. Secundigravidae: χ^2 p<0.05 3. Multigravidae: χ^2 p>0.05 *MUAC <23 is significantly associated with anemia for those that are primigravidae and secundigravidae but not multigravidae.*
Dhar, 2008	Bangladesh	316	Age not stated	<22	Postpartum	LBW infants	Not stated, assume close to delivery	OR=1.26 (95%CI=0.47-3.24) *Low MUAC is not associated with infant LBW.*
Dhar, 2008*	Bangladesh	316	Age not stated	<24	Postpartum	LBW infants	Not stated, assume close to delivery	OR=1.71 (95%CI=0.89-3.32) *Low MUAC is not associated with infant LBW.*
Dhar, 2008*	Bangladesh	316	Age not stated	<26	Postpartum	LBW infants	Not stated, assume close to delivery	OR=1.68 (95%CI=0.89-3.52) *Low MUAC is not associated with infant LBW.*
Elshibly, 2008	Sudan	1,000	16–52	<27	Within 24 hours after delivery	LBW infants	Within 24 hours of delivery	RR=1.02 (95%CI=0.63-1.65) *Low MUAC is not associated with infant LBW.*

Author, Year	Country	N	Age (in years) and Additional Population Characteristics	MUAC Cutoff (cm)	Time of MUAC Measurement	Outcome	Time Infant Weighed (LBW only)	Results
Janjua, 2009	Pakistan	540	Median: 25; 7% <20	≤28.9	After delivery	LBW infants	Within 12 hours of delivery	PR=1.56 (95% CI=1.09-2.25) *Women with MUAC <28.9 were 1.6 times more likely to have an LBW infant vs. women with MUAC ≥28.9.*
Ogbonna, 2007	Zimbabwe	498	4% <18	<24	Postpartum	LBW infants	At birth	OR=2.4 (95% CI=1.3-4.2) *Women with MUAC <24 were 2.4 times more likely to have an LBW infant vs. women with MUAC ≥24.*
Ojha, 2007	Nepal	308	17% <20	<22	Postpartum	LBW infants	Not stated, assume close to delivery	OR=2.04 (95%CI=1.14-3.63) *Women with MUAC <22 were 2 times more likely to have an LBW infant vs. women with MUAC ≥22.*
Osman, 1995	Mozambique	102	45% 15–19	<24	During labor	LBW infants	At birth	OR=3.08 (95% CI: 1.23-7.83) *Women with LBW infants were 3 times more likely to have MUAC <24 vs. women with normal-weight infants.*
Sen, 2010	India	503	16% <20	<22	Within 24 hours after delivery	LBW infants	Within 24 hours of delivery	OR=6.0 (95%CI=3.3-10.9) *Women with MUAC <22 were 6 times more likely to have an LBW infant vs. women with MUAC ≥22.*
Libombo, 1994	Mozambique	102	74% ≤19	<25	After delivery	Postpartum endometritis-myometritis (PPEM)		OR=2.66 (95% CI=1.10-6.49) *Women with PPEM were 2.7 times more likely to have MUAC <25 vs. women without PPEM.*

Author, Year	Country	N	Age (in years) and Additional Population Characteristics	MUAC Cutoff (cm)	Time of MUAC Measurement	Outcome	Time Infant Weighed (LBW only)	Results
Begum, 2003	India	282	Mean (SD): 28.2 (4.5) women with preterm labor 25.8 (4.0) women with at-term labor	<20	After delivery	Preterm labor (yes/no)		OR 7.78 (95% CI=3.91-15.62) *Women with preterm labor were 7.8 times more likely to have MUAC <20 vs. women with at-term labor.*
Longitudinal Studies								
Lee, 2009	Nepal	3,189	34% <20	<21.5 vs. ≥23	During pregnancy	Birth asphyxia		RR=1.3 (95%CI=1.0-1.8) *Birth asphyxia is 1.3 times more likely to occur in women with MUAC <21.5 during pregnancy vs. MUAC ≥23.*
Kalanda, 2006	Malawi	1,571	19% adolescent, 26% with HIV	<23	1st antenatal visit	Disproportionate intrauterine growth		OR=2.1 (95% CI: 1.1-3.4) *Women with MUAC <23 were 2.1 times more likely to have disproportionate growth vs. women with MUAC ≥23.*
Verhoeff, 2001	Malawi	1,423	18% ≤19, 26% with HIV	<23	1st antenatal visit	Intra-uterine growth retardation (IUGR)		OR=1.5 (95% CI=1.1-1.9) *Women with MUAC <23 were 1.5 times more likely to have IUGR vs. women with MUAC ≥23.*
Assefa, 2012	Ethiopia	956	7% <20	<23	During pregnancy	LBW infants	Within 24 hours of delivery	OR=1.5 (95% CI=1.14-2.01) *Women with MUAC <23 were 1.5 times more likely to have an LBW infant vs. women with MUAC ≥23.*

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Author, Year	Country	N	Age (in years) and Additional Population Characteristics	MUAC Cutoff (cm)	Time of MUAC Measurement	Outcome	Time Infant Weighed (LBW only)	Results
Karim, 1997	Bangladesh	248	17–35	<22 <23 <24	Close to term and immediately after birth	LBW infants	Within 5 days after birth	<22: OR=3.4 (95% CI=1.7-6.8) <23: OR=5.0 (95% CI=1.4-17.9) <24: OR=2.9 (95% CI=1.3-6.6) *Women with MUAC below the stated cutoff were significantly more likely to have an LBW infant vs. women with MUAC above the cutoff.*
Lechtig, 1988	Guatemala	445	Age not stated	≤23.5	During pregnancy	LBW infants	Not stated	OR=8.1 (95% CI=4.8-13.5) *Women with MUAC ≤23.5 were 8.1 times more likely to have an LBW infant vs. women with MUAC >23.5.*
Mohanty, 2006	India	395	Age not stated	≤22.5	1st trimester	LBW infants	Within 24 hours of delivery	RR=1.67 (95%CI=1.26-2.33) *Women with MUAC ≤22.5 were 1.7 times more likely to have an LBW infant vs. women with MUAC >22.5.*
Rollins, 2007	South Africa	2,128	Age not stated, ~51% with HIV infection	≤27.6	Antenatal visit	LBW infants	Within 3 days of delivery	Adj OR=1.77 (p<0.001) *Women with MUAC ≤27.6 were 1.8 times more likely to have an LBW infant vs. women with MUAC >27.6, after adjusting for maternal HIV status and gender.*

Author, Year	Country	N	Age (in years) and Additional Population Characteristics	MUAC Cutoff (cm)	Time of MUAC Measurement	Outcome	Time Infant Weighed (LBW only)	Results
Sebayang, 2012	Indonesia	14,040	Mean (SD): 25.4 (5.9)	<23.5	Antenatal visit	LBW infants	Within 1 hour after delivery	OR=1.74 (95% CI=1.57-1.93) *Women with MUAC <23.5 were 1.7 times more likely to have an LBW infant vs. women with MUAC ≥23.5.*
Achadi, 1995	Indonesia	481	12–49	<24, 24 to <26, 26 to <29, ≥29	Once each trimester	Maternal weight gain		ANOVA p-value <0.001 *Mean levels of maternal weight gain are significantly lower with higher levels of MUAC.*
Villamor, 2003	Tanzania	957	Age not stated, HIV positive	≤25	Monthly during antenatal visits	Rate of maternal weight gain up to week 27		T-test p-value=.02 *Women with MUAC ≤25 had a significantly faster rate of weight gain up to week 27 vs. women with MUAC >25. (no association at week 37, p=.28).*
Achadi, 1995*	Indonesia	451	12–49	<24, 24 to <26, ≥26	Once each trimester	Neonatal weight and length		ANOVA p-value >0.05 *No significant difference in neonatal weight or neonatal length between levels of MUAC.*
Verhoeff, 2001*	Malawi	1,423	18% ≤19, 26% with HIV	<23	1st antenatal visit	Preterm birth		OR=1.8 (95%CI=1.3-2.3) *Women with MUAC <23 were 1.8 times more likely to have a preterm birth vs. women with MUAC ≥23.*
Kalanda, 2006*	Malawi	1,571	19% adolescent, 26% with HIV	<23	1st antenatal visit	Preterm birth		OR=2.0 (95% CI: 1.4-2.9) *Women with MUAC <23 were 2 times more likely to have a preterm birth vs. women with MUAC ≥23.*

Author, Year	Country	N	Age (in years) and Additional Population Characteristics	MUAC Cutoff (cm)	Time of MUAC Measurement	Outcome	Time Infant Weighed (LBW only)	Results
Sebayang, 2012*	Indonesia	13,498	Mean (SD): 25.4 (5.9)	<23.5	Antenatal visit	Preterm birth		OR=1.13 (95%CI=1.03-1.24) *Women with MUAC <23.5 were 1.1 times more likely to have a preterm birth vs. women with MUAC ≥23.5.*
Sebayang, 2012*	Indonesia	13,451	Mean (SD): 25.4 (5.9)	<23.5	Antenatal visit	Small for gestational age (SGA)		OR=1.47 (95% CI=1.33-1.63) *Women with MUAC <23.5 were 1.5 times more likely to have an SGA infant vs. women with MUAC ≥23.5*
Venkatesh, 2005	Tanzania	1,008	Median (IQR): 24 (21–28), HIV-positive	<22	During pregnancy	TB incidence		HR=2.4 (95% CI=1.24-4.64) *Women with MUAC <22 were 2.4 times more likely to have an incident TB infection vs. women with MUAC ≥22.*

* Same reference as study above by same author.
Abbreviations: OR: odds ratio; RR: relative risk; HR: hazard ratio

Supplemental Table 2. Diagnostic Test Accuracy Statistics from Published Studies

Author, Year	Location	Population	Ages (in years) and Additional Population Characteristics	Total N, % Female (F)	Outcome	AUC (p-value)	MUAC Cutoff (cm)	Sensitivity	Specificity	PPV	NPV
Martin, 2009	Australia	Adolescent	Age not stated	55 (411 repeated assessments), 94.6% F	Hospitalization	0.78	20			29	93
Mazicioglu, 2010	Turkey	Adolescent	15–17	770, 100% F 769, 0% F	Hypertension	0.53 (.5) 0.62 (.001)	24.9 24.6				
			11–14	705, 100% F 616, 0% F		0.64 (.001) 0.75 (.001)	22.5 21.4				
Oliveira, 2012	Guinea-Bissau	Adult	≥15 years, HIV-1 and/or HIV-2, ART-naïve at baseline	625	Mortality, 6 months (pre-ART)	0.75	25	71.9	57.8		
Rodrigues, 1994	India	Adult	20–40, healthy, non-pregnant	567, 100% F	BMI <18.5		21	9.2	97.1	66.7	
							22	26.2	93.1	70.4	
							23	50.9	84.5	67.3	
							24	71.1	69.9	59.4	
							25	91.7	49.9	53.3	
Khadivzadeh, 2002	Iran	Adult	15–49, healthy, non-pregnant, non-lactating	2,000, 100% F	BMI <19.8		23.5	80.5	92.5	69.5	95.9
							23.8	85.7	89.7	68.9	95.9
							24	93.6	83.9	60.6	98.1
							24.5	96.6	80.2	56.5	98.9

Author, Year	Location	Population	Ages (in years) and Additional Population Characteristics	Total N, % Female (F)	Outcome	AUC (p-value)	MUAC Cutoff (cm)	Sensitivity	Specificity	PPV	NPV
Gustafson, 2007	Guinea-Bissau	Adult	≥16 years active TB	709, 38% F	Mortality, 8 months (during TB treatment)		21	54	76		
Collins, 1996	Sudan	Adult	Age not stated, severely malnourished inpatients at feeding center during famine	98, 58% F	BMI <10		14.5	100	100	100	100
					BMI <11		15.5	50	99	88	92
					BMI <12		17	71	97	92	86
					BMI <13		18.5	83	90	89	85
					BMI <14		20	87	78	91	70
					BMI <15		21	91	67	95	50
					BMI <16		22.5	100	33	96	100
Olukoya, 1990	Nigeria	Adult	15-49, non-pregnant, >6 wks postpartum	433, 100% F	Weight <45 kg		20	21.3		48.1	
							23	62.3		44.2	
							24	75.4		36.8	
							25	85.2		29.5	
Sen, 2010	India	Pregnant	16% <20	503, 100% F	LBW infants	0.78	21.5	81.3	72.1		
Elshibly, 2008	Sudan	Pregnant	16–52	1,000, 100% F	LBW infants	0.54 (0.35)	27				
Dhar, 2008	Bangladesh	Pregnant	Age not stated	316, 100% F	LBW infants		22	14.6	88.1	18	85.2
							24	52.1	61.2	19.4	87.7
							26	72.9	38.4	17.5	88.8
Karim, 1997	Bangladesh	Pregnant	17–35	248, 100% F	LBW infants		22	13.7	96.9	53.8	81.1
							23	68.6	55.9	28.9	87.2
							24	80.4	41.5	26.5	89
Mohanty, 2006	India	Pregnant	Age not stated	395, 100% F	LBW infants		21.5	44.6	74.8	43.9	75.4
							22	57.2	65.7	39.7	75.3

Author, Year	Location	Population	Ages (in years) and Additional Population Characteristics	Total N, % Female (F)	Outcome	AUC (p-value)	MUAC Cutoff (cm)	Sensitivity	Specificity	PPV	NPV
							22.5	60.3	58	38.8	76.8
							23	65.3	49.3	36.2	76.3
							23.5	76.9	40.1	36.2	79.7
Olukoya, 1991	Nigeria	Pregnant	15–44	1,256, 100% F	Maternal weight <45 kg, first trimester		23	85.7		54.5	
							24	85.7		22.2	
							25	85.7		10.9	
							26	100		7.6	

Abbreviations: PPV: positive predictive value, NPV: negative predictive value