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Determining a Global Mid-Upper Arm Circumference Cutoff to Assess Malnutrition in Pregnant Women

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Abbreviations and Acronyms

AUROCC	area under the receiver operating characteristic curve
C&T	care and treatment
CBA	cost-benefit analysis
CI	confidence interval
cm	centimeter(s)
dL	deciliter(s)
DRC	Democratic Republic of Congo
EBF	exclusive breastfeeding
FN	false negative
FP	false positive
g	gram(s)
HIV	human immunodeficiency virus
IPDMA	individual participant data meta-analysis
LBW	low birth weight
µg	microgram(s)
µL	microliter(s)
mg	milligram(s)
MUAC	mid-upper arm circumference
NBW	normal birth weight
NIH	National Institutes of Health
NPV	negative predictive value
PPV	positive predictive value
RE	retinol equivalent(s)
ROC	receiver operating characteristic
SD	standard deviation
SENS	sensitivity
SES	socioeconomic status
SGA	small for gestational age
SPEC	specificity
TN	true negative
TP	true positive
USAID	U.S. Agency for International Development
VTS	Vertical Transmission Study
WFP	World Food Programme
WHO	World Health Organization

Executive Summary

Background. Undernutrition in women, before and during pregnancy, is recognized as a key determinant of poor pregnancy outcomes including poor fetal development, preterm births, and small for gestational age and low birth weight (LBW) babies, often leading to increased infant morbidity and mortality. Maternal undernutrition is highly prevalent in resource-poor settings, generally ranging from 10% to 19% in these settings, but reaching up to more than 20% in some areas, such as in sub-Saharan Africa, south-central and southeastern Asia, and Yemen. In addition, more than 95% of the estimated 20 million babies born annually with LBW are born in resource-poor countries.

Mid-upper arm circumference (MUAC) is often used as an indicator of protein-energy malnutrition or starvation, particularly in children in resource-poor settings where individuals tend to have smaller amounts of subcutaneous fat. MUAC is increasingly being used to assess nutritional status and determine eligibility for services among adults, especially in pregnant women and people living with HIV and/or tuberculosis. Assessment of MUAC in adults living in resource-poor countries offers the advantages of being a simple measure that can be carried out in both community- and facility-based settings, and requiring minimal equipment and training compared with weight and height measurements. While a globally accepted cutoff for low MUAC (<11.5 cm) has been established by the World Health Organization for children 6–60 months of age, no such cutoff exists for low MUAC in adults.

Previous studies among pregnant women have shown a consistent association between low maternal MUAC and an increased risk of having an LBW baby. Despite the evidence of a strong association, global MUAC cutoffs have not been established to identify pregnant women who are undernourished and therefore at risk of adverse birth outcomes. Establishment of standardized MUAC cutoffs for pregnant women could help strengthen and harmonize programming in maternal health and nutrition programs.

Methods. Tufts University, a partner on the Food and Nutrition Technical Assistance III Project funded by the U.S. Agency for International Development, undertook an individual participant data meta-analysis to explore the potential for deriving a meaningful cutoff for low MUAC to identify pregnant women at risk of delivering an LBW infant. We compiled data from seven studies of pregnant women, four from Africa (Democratic Republic of Congo [DRC], Ethiopia, Malawi, and South Africa) and three from South Asia (Bangladesh, Nepal, and Pakistan). For each study individually, and then summarized across all studies, we determined measures of diagnostic accuracy (sensitivity [SENS], specificity [SPEC], area under the receiver operating characteristic curve [AUROCC], and the receiver operating characteristic [ROC] curve) for every 0.5 cm across a range of MUAC values from 19.0 cm to 26.5 cm. The summary statistics used a bivariate random effects model to account for the heterogeneity between studies, and the models included MUAC as the only independent variable predicting an LBW outcome.

Results. The number of participants in each study ranged from 539 in Pakistan to 16,108 in Bangladesh. Mean maternal age ranged from 21.9 years in Bangladesh to 28.5 years in Ethiopia. Parity levels varied by study, with approximately 80% of mothers in Bangladesh, Malawi, and Pakistan having given birth 0–2 times previously compared to only 40% of mothers in Ethiopia having given birth 0–2 times previously. Two studies (DRC and Malawi) included only HIV-positive women and in one study (South Africa) approximately 50% of mothers were HIV-positive. MUAC measurements ranged from a low of 11 cm in Ethiopia to a high of 47 cm in DRC and Malawi. The mean MUAC measurement varied between studies, ranging from 21.8 cm in Nepal to 29.0 cm in Pakistan. Infant birth weight was approximately normally distributed in all studies, with means ranging from 2,433 g in Bangladesh to 3,104 g in South Africa. The

percent of infants born with LBW was highly variable between studies, ranging from 55.3% in Bangladesh to approximately 8.7% in Malawi and 9.2% in South Africa.

Measures of SENS, SPEC, positive predictive value, and negative predictive value for all MUAC cutoffs varied greatly between individual studies, but MUAC was similarly nondiscriminatory in its ability to distinguish pregnant women at risk and not at risk of delivering an LBW baby. AUROCC fell within the "poor" discriminatory range based on general interpretations for the AUROCC, ranging from 0.57 to 0.64 for individual studies, and 0.64 for all studies combined. Results of the meta-analysis showed that, across the lower range of MUAC cutoffs (19.0 cm to 23.0 cm), SPEC tended to be relatively high compared to SENS. In the higher range of MUAC cutoffs, SENS increased, but at the expense of SPEC. Based on the results of this meta-analysis, a global MUAC cutoff for pregnant women would be selected to have either a high SENS with low SPEC, or a low SENS with high SPEC.

Conclusions. Identifying the optimal MUAC cutoff to identify undernutrition in pregnant women is a complex problem involving tradeoffs between the availability of resources to intervene or follow-up with a pregnant woman who is screened as being at risk, the effectiveness of different interventions, and the degree of expected improvement in birth outcomes. We recommend that countries and programs conduct a cost-benefit analysis before adopting a specific MUAC cutoff. If a cutoff with a high SENS is selected at the expense of SPEC, health care systems must have the ability to handle large numbers of false positives (women who are falsely identified as "at risk"). Similarly, if a cutoff with high SPEC is selected at the expense of SENS, programs may end up spending a large amount of resources screening women and identifying only a small proportion who are truly at risk. Finally, based on the wide variability of SENS and SPEC between studies, it may be difficult to recommend a MUAC cutoff for a given purpose that would be suitably discriminatory in all settings.

1. Background

Maternal undernutrition is highly prevalent in resource-poor settings, ranging from 10% to 19% in these settings, but is particularly high (>20%) in sub-Saharan Africa, south-central and southeastern Asia, and Yemen.[1] Each year around the world, an estimated 15 million babies are born preterm (gestational age <37 weeks),[2] and about 20 million are born with low birth weight (LBW) (birth weight <2,500 g),[3] with more than 95% of these births occurring in resource-poor countries. A healthy pregnancy outcome depends largely on the availability and supply of nutrients from maternal stores to the developing fetus. Undernutrition in women, before and during pregnancy, is therefore recognized as a key determinant of poor pregnancy outcomes (poor fetal development, preterm births, and small for gestational age [SGA] and LBW babies), leading to increased infant morbidity and mortality.[1,4,5]

Anthropometry is the measurement of the physical dimensions and gross composition of the human body.[6] Anthropometric measurements vary with age and nutritional status and are particularly useful as indicators of body composition when chronic imbalances of protein and energy have occurred.[7] Most anthropometric measures are based on a two-compartment model of body composition: fat and fat-free mass. Fat-free mass consists of skeletal muscle, non-skeletal muscle, soft lean tissues, and the skeleton. It is composed of a mixture of water, minerals, and protein. Since most of the protein is stored in the muscle, techniques to assess muscle mass can be used as indicators of the protein reserves of the body.[7]

Mid-upper arm circumference (MUAC) is often used as a measure of fat-free mass. MUAC is a measurement of the circumference of the upper arm at the midpoint between the olecranon and acromion processes.[7] Since the arm contains both subcutaneous fat and muscle, changes in MUAC can reflect a change in muscle mass, a change in subcutaneous fat, or both. In resource-poor settings, where individuals tend to have smaller amounts of subcutaneous fat, changes in MUAC are more likely to reflect changes in muscle mass.[7] In these settings, MUAC measurements can be useful as an indicator of protein-energy malnutrition or starvation, particularly in situations where measurement of weight or height may not be feasible.[7,8]

Among children aged 6–60 months, the World Health Organization (WHO) has recommended a MUAC cutoff of <11.5 cm as a screening tool for acute malnutrition.[9] This cutoff has become a globally accepted standard and is often used to determine eligibility for both facility- and community-based therapeutic feeding programs. Increasingly, MUAC is also being used to assess nutritional status and determine eligibility for services among adults, especially in pregnant women and people living with HIV and/or tuberculosis.[8,10,11] However, a standardized cutoff for low MUAC for adults does not yet exist. As with children, assessment of MUAC in adults offers the advantages of being a simple measure that can be carried out in both community- and facility-based settings and requires minimal equipment and training compared with weight and height measurements.

Tufts University, a partner on the Food and Nutrition Technical Assistance III Project, funded by the U.S. Agency for International Development (USAID), previously conducted a systematic review of the association between low MUAC and adverse health outcomes among pregnant women[12] and found that low maternal MUAC was consistently shown to be significantly associated with an increased risk of having an LBW baby (risk ratios ranging from 1.5 to 8.1),[13-23] with only a couple of exceptions.[24,25] The MUAC cutoffs used in these studies were wide-ranging (21.5–29.0 cm), although the majority of studies used a cutoff between 22.0 cm and 24.0 cm. Low maternal MUAC was also associated with increased risk of other adverse birth outcomes (preterm labor/birth,[22,26,27] disproportionate intrauterine growth,[27] birth asphyxia,[28] and SGA[22]), although these outcomes were reported on to a much lesser extent than LBW. Despite the evidence of a strong association, global MUAC cutoffs have not been established by WHO to

identify pregnant women who are undernourished and therefore at risk of adverse birth outcomes. Establishment of standardized MUAC cutoffs for pregnant women could help strengthen and harmonize programming in maternal health and nutrition programs.

Therefore, we undertook an individual participant data meta-analysis (IPDMA) to explore the potential for deriving a meaningful cutoff for low MUAC to identify pregnant women at risk of delivering an LBW infant. The decision to conduct a meta-analysis of individual-level data rather than a meta-analysis of study-level (published) data was primarily dictated by the fact that most of the published studies did not address the question of whether an optimal MUAC cutoff could be established and globally implemented. The majority of studies we reviewed presented results on the association between low MUAC and infant birth outcomes by selecting one predetermined cutoff for low MUAC without considering other cutoffs. Studies that did present results on multiple cutoffs presented the data in highly variable ways, making it difficult to synthesize findings across studies. For example, some studies presented area under the receiver operating characteristic curve (AUROCC) statistics but no data on sensitivity (SENS) or specificity (SPEC) for any MUAC cutoffs, while others presented SENS data only and no SPEC data. There are a variety of metrics and considerations for determining the optimal MUAC cutoff, and it is recommended that researchers and policy makers compare different cutoffs using several metrics to select the one that is most relevant.[29,30]

2. Methods

2.1 Technical Advisory Group

At the beginning of the IPDMA process, a technical advisory group (TAG) was assembled to provide us with expertise, guidance, and feedback at key milestones during the IPDMA process. The TAG members consisted of the researchers who contributed their datasets, as well as world-renowned experts in the fields of nutrition and maternal and child health from USAID, WHO, the National Institutes of Health (NIH), and the World Food Programme (WFP). Members of the TAG provided us with feedback at the following milestones: during formation of the collaborative, during development of the data analysis plan, and during review of the draft report.

2.2 Data Ascertainment

Investigators from all eligible studies involving pregnant women in our systematic review were invited to share their individual participant data and join the TAG. To be eligible for the IPDMA, investigators had to be willing to share participant-level data, and the datasets had to have a minimum sample size of 100. Datasets also had to contain, at a minimum, the following list of variables:

1. Maternal MUAC measurement(s) *[continuous]*
2. Infant birth weight *[continuous]* or LBW (<2,500 g) *[yes/no]*
3. Maternal age *[continuous]*
4. If dataset included HIV-positive women: HIV status *[positive/negative]*
5. If HIV-positive: On antiretroviral therapy *[yes/no]*
6. If data were from a clinical trial: Study arm that participant was randomized to *[intervention/control]*

Of the 11 studies conducted among unique datasets of pregnant women that were included in our systematic review, we were able to obtain primary data from only three. We were unable to make contact with two of the researchers, and three declined to participate for various reasons. Three other research groups were interested but after several discussions subsequently decided that they did not have the resources to compile the data needed for this project and did not want to send us their original datasets.

We then put out a call for datasets through our TAG and searched the literature for articles published after the date of our systematic review. Through both of these processes, we were able to obtain an additional four datasets that met our inclusion criteria. Therefore, the present report includes data from seven independent studies with information on maternal MUAC measurements and infant birth weight. **Table 1** provides a summary of the studies included in this IPDMA.

Table 1. List of Studies Included in the IPDMA (Alphabetical by Country)

Country	Principal Investigator	Study name	Rural/ Urban	Years of Study	Sample Size
Bangladesh[31]	Keith West	JiVitA-1 trial	Rural	2002–2007	16,108
Democratic Republic of Congo[32] (DRC)	Andrew Edmonds	PACT-DRC	Urban	2003–2013	1,007
Ethiopia[13]	Nega Assefa	None	Rural	2009–2010	956
Malawi[33]	Roshan Ramlal	Breastfeeding, Antiretrovirals, and Nutrition Study	Rural	2004–2006	1,005
Nepal[34]	Parul Christian	NNIPS-3 trial	Rural	1999–2001	3,170
Pakistan[14]	Naveed Zafar Janjua	None	Urban	2005	539
South Africa[35]	Terusha Chetty	Africa Centre Vertical Transmission Study (VTS)	Rural and peri-urban	2001–2004	2,247

Table 2(a–c) provides a checklist of the variables that were available for analysis in each dataset.

Table 2a. Maternal Variables Included in Datasets

	Bangladesh	DRC	Ethiopia	Malawi	Nepal	Pakistan	South Africa
Height		✓	✓	✓	✓	✓	✓
Weight		✓	✓	✓	✓	✓	✓
Time of weight measurement		c	i	c	✓	i	i
MUAC	✓	✓	✓	✓	✓	✓	✓
Time of MUAC measurement[a]	✓	c	i	c	✓	i	i
Arm of MUAC measurement					✓		
Triceps skinfold				✓		✓	
Biceps skinfold						✓	
Age	✓	✓	✓	✓	✓	✓	✓
Parity	✓		✓	✓	✓	✓	
Education	✓		✓	✓		✓	✓
Literacy			✓	✓			
Marital status			✓	✓			
Ethnicity			✓			✓	
Religion			✓				
HIV status		✓		✓			✓
CD4+ cell count		✓		✓			✓
Time of CD4 measurement		✓					✓

[a] c = calculated from data (i.e., estimated based on gestational age at the time of MUAC measurement: 1st trimester if gestational age ≤13 weeks; 2nd trimester if gestational age >13 and ≤26 weeks; 3rd trimester if gestational age >26 weeks. i = information not given in the dataset but could be inferred from study description.

Table 2b. Infant Variables Included in Datasets

	Bangladesh	DRC	Ethiopia	Malawi	Nepal	Pakistan	South Africa
Sex	✓	✓	✓	✓	✓	✓	✓
Length			✓			✓	✓
Birth weight	✓	✓	✓	✓	✓	✓	✓
Time birth weight measured[a]	i	i	i	i	i	i	i
Head circumference			✓			✓	✓
Chest circumference			✓				
Neonatal death[b]	✓	✓	✓		✓		✓ (can be derived)
Gestational age	✓	✓		✓	✓	✓	

[a] i = inferred from study description. Timing of birth weight measurement was not given for each individual woman in the datasets. However, based on descriptions of study protocols, timing of birth weight measurement can be inferred for each study to within 12, 24, 48, or 72 hours of delivery.
[b] Neonatal death is defined as death within 28 days of birth. Dates and reasons for exiting from the study were given. If a child died, his/her date of the death can be used to determine if death is classified as a neonatal death. If a mother withdrew consent or was lost to follow up BEFORE 28 days after birth, then neonatal death is unknown. If a mother withdrew consent or was lost to follow-up AFTER 28 days after birth, then the infant was alive (not a neonatal death).

Table 2c. Household Variables Included in Datasets

	Bangladesh	DRC	Ethiopia	Malawi	Nepal	Pakistan	South Africa
Monthly income			✓			✓	
Wealth index			✓				
Rural vs. urban	✓	✓	✓		✓	✓	✓

2.3 Statistical Analyses

2.3.1 Descriptive Statistics

All datasets were converted and analyzed using the Stata statistical software (Stata Statistical Software Release 13, StataCorp, College Station, TX, USA). Each dataset was assessed against published manuscripts and/or original research protocols to create an overview of the included patients and study procedures. For each dataset, we performed thorough data checks of the variables received. All variables were checked to ensure that units, categories, coding, and labels were consistent across studies, and equivalent variables were assigned the same variable names and labels across datasets. Individual investigators were contacted to confirm missing data, to check extreme or invalid values, or to obtain clarification of the study variables and procedures. For all studies, the primary outcome, LBW, was defined as birth weight <2,500 g.

To better understand the data from each individual study and the degree of potential heterogeneity between studies, basic descriptive statistics were calculated for each study and compared across studies. The variables included both infant characteristics (sex, birth weight, percent with LBW, and time of birth weight measurement) and maternal characteristics (age, parity, measures of socioeconomic status [SES], proportion HIV-positive, proportion of HIV-positive women on antiretroviral therapy, MUAC measurements, and trimester of MUAC measurement).

Histograms of maternal MUAC and infant birth weight were constructed to determine the distribution of each of these measurements for each study separately and for all datasets combined. Scatterplots of infant birth weight by maternal MUAC were then examined to determine the association between the two variables, for each study separately and for all datasets combined.

We accepted datasets with measurements of MUAC taken at different times during pregnancy and postpartum. **Table A1** (Annex A) describes several studies that report changes in MUAC measurements during pregnancy and postpartum. The studies were conducted in several countries, in both rural and urban settings, among adolescent and adult women, and included women from various levels of SES, parity, and baseline nutritional status. Sample sizes ranged from very small (n=18) to large (n=2,487). In general, the literature suggests that there is either no change[36-38] or a slight increase[39-42] in MUAC during pregnancy (predominantly between the second and third trimesters). The studies that reported no significant change tended to have smaller sample sizes (n=18, 46, and 52). Only one study reported a significant decrease in MUAC during pregnancy (between the second and third trimester),[43] but the decrease was small (−0.2 cm). The reported increases ranged from +0.8 cm to +1.7 cm between the first and third trimesters, and from +0.6 to +1.3 cm between the second and third trimesters. Three studies examined changes in MUAC from pregnancy to postpartum. Two of these studies were conducted among adolescent girls: One reported a 0.9 cm decrease between the third trimester and 12.6 weeks postpartum,[40] while the other reported a 0.6 cm decrease from the first trimester to 6 months postpartum.[44] A third study reported a 2.8 cm decrease from the seventh day postpartum to 6 months postpartum among those who practiced exclusive breastfeeding.[45] Given the findings summarized here and depicted in Annex 1 showing definite changes in MUAC from pregnancy to postpartum, we analyzed subgroups based on when MUAC measurements were taken to determine if there were any differences in the results. In particular, we examined separately the MUAC measurements taken during pregnancy and those taken postpartum.

2.3.2 Measures of Diagnostic Accuracy

We examined MUAC cutoffs at every 0.5 cm, ranging from 19.0 cm to 26.5 cm. For each cutoff, we calculated a 2x2 table showing the cross-tabulation of birth weight status (LBW vs. normal birth weight [NBW]) and MUAC measurement (above or below a specified cutoff) as shown in **Table 3**.

Table 3. 2x2 Cross-Tabulation of MUAC Measurement and Outcome Status

	Poor pregnancy outcome (LBW)		
Test status (MUAC)	LBW	NBW	Total
MUAC ≤ cutoff	True positive (TP)	False positive (FP)	Total ≤ cutoff (TP + FP)
MUAC > cutoff	False negative (FN)	True negative (TN)	Total > cutoff (FN + TN)
	Total LBW (TP + FN)	Total NBW (FP + TN)	

From these data, the following measures were obtained[46]:

SENS: Also referred to as the TP rate, SENS is defined as the probability of having a MUAC ≤ cutoff given an LBW outcome. SENS is estimated using the numbers from Table 3 as TP ÷ (TP + FN).

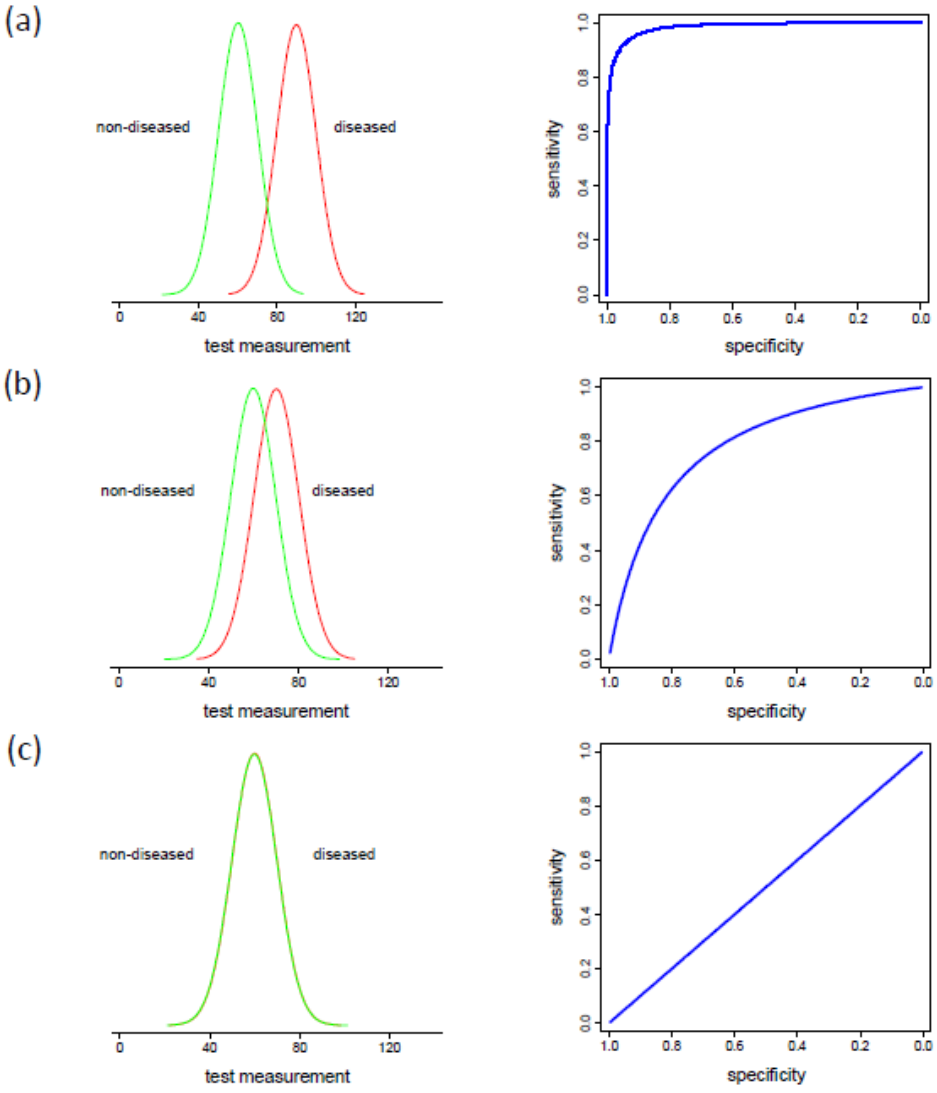
SPEC: Also referred to as the true negative rate, SPEC is defined as the probability of having a MUAC > cutoff given a NBW outcome. SPEC is estimated using the numbers from Table 3 as TN ÷ (FP + TN).

Positive predictive value (PPV): PPV is defined as the probability that a woman with a MUAC ≤ cutoff will deliver an LBW infant. PPV is estimated using the numbers from Table 3 as TP ÷ (TP + FP). PPV depends on the prevalence of LBW in the population. As the prevalence increases, PPV increases.

Negative predictive value (NPV): NPV is defined as the probability that a woman with a MUAC > cutoff will deliver a NBW infant. NPV is estimated using the numbers from Table 3 as TN ÷ (FN + TN). NPV depends on the prevalence of LBW in the population. As the prevalence increases, NPV decreases.

Receiver operating characteristic (ROC) curve: The ROC curve is a graph of the values of SENS and SPEC that are obtained by varying the positivity threshold across all possible values of MUAC. The graph plots SENS against (1 – SPEC). When a cutoff clearly discriminates between the distributions of test measurements (MUAC) among diseased (LBW) and not diseased (NBW) such that there is little or no overlap between the two (**Figure 1(a)**), the ROC curve will indicate that high SENS is achieved with a high SPEC and the curve approaches the upper left-hand corner of the graph where SENS is 1 and SPEC is 1. As the amount of overlap between the distributions increases, the curve approaches the straight upward diagonal of the square (**Figure 1(b)**). If the distribution of MUAC measurements among pregnant women who deliver LBW vs. NBW babies completely coincides, then MUAC would be completely uninformative and the ROC curve would be the upward diagonal of the square (**Figure 1(c)**).

Figure 1. Examples of ROC Curves[46]



AUROCC: AUROCC is a single summary statistic that is used to compare cutoffs on the basis of their ROC curves. The AUROCC equals 1 for a perfect cutoff and 0.5 for a completely uninformative cutoff. The AUROCC can also be interpreted as an average SENS for the cutoff, taken over all SPEC values (or equally as the average SPEC over all SENS values).

We computed SENS, SPEC, PPV, NPV, ROC curves, and AUROCC over the range of MUAC cutoffs for all individual studies.

Next, we pooled together the data from all studies and created a study identifier variable to identify participants within studies. We calculated an unadjusted ROC curve and the AUROCC from the pooled dataset. We then determined the measures of diagnostic accuracy for all studies combined using a two-staged approach, where measures are estimated within each study in the first stage, and then these aggregate data are combined across studies in the second stage. In this manner, summary diagnostic accuracy measures are obtained accounting for the clustering within studies. We used the *metandi* command in Stata to obtain point estimates of SENS and SPEC for each MUAC cutoff value from a standard bivariate random effects model. The *metandi* command fits a two-level mixed-effect logistic

regression model, with independent binomial distributions for the TPs and TNs conditional on the SENS and SPEC in each study, and a bivariate normal model for the logit transforms of SENS and SPEC between studies.

To further investigate the sources of heterogeneity, subgroup analyses were performed. Since the *metandi* command requires a minimum of four studies for meta-analysis, for subgroups with fewer than four studies, a random effects logistic regression model was directly fit using Stata's *xtmelogit* command. In cases where the *xtmelogit* model would not converge (for various reasons), results from the ordinary logistic regression model are presented in the tables, but grayed out.

2.3.3 Deciding on a MUAC Cutoff

Finally, we based our selection of an appropriate MUAC cutoff on the key properties proposed by Myatt et al.[30] (shown in **Table 4**) that the selection of an appropriate indicator for case detection depends on the context in which the case detection is taking place (i.e., epidemiologic survey/surveillance, screening and case detection in the community, case-finding in clinical contexts, or diagnosis in clinical contexts). The measurement of MUAC meets the criteria for several of these properties, including simplicity, acceptability, low cost, objectivity, and quantitativeness, all of which are important or critical for epidemiologic surveillance and community screening. For the three contexts that are most likely to be useful for establishing a global MUAC cutoff for pregnant women (screening and case detection in the community, case-finding in clinical contexts, and diagnosis in clinical contexts), a high SPEC is proposed to be more critical than a high SENS. Therefore, the MUAC cutoff with the highest SENS at or above a set minimum SPEC (e.g., 70%) would be most preferable.

Table 4. Relative Importance of Key Properties of Case Detection in Different Contexts[a]

	Context			
Property	Epidemiologic survey/surveillance	Screening and case detection in the community	Case-finding in clinical contexts	Diagnosis in clinical contexts
Simplicity	++++	++++	–	–
Acceptability	++++	+++	+	–
Cost	++++	++	–	–
Objectivity	++++	++++	++++	++++
Quantitativeness	++++	++++	–	–
Independence of age	++++	++++	–	–
Precision (reliability)	+ (individual) ++++ (group)	++	++++	++++
Accuracy	+ (individual) ++++ (group)	++	++++	++++
Sensitivity	+	++	+++	+++
Specificity	+	++++	++++	++++
Predictive value	+	++	++++	++++

[a] Scoring of importance: – irrelevant, + minor, ++ moderate, +++ major, ++++ crucial.

Source: Myatt et al. 2006.[30] The table reproduces the original analysis of Sackett and Holland,[47] modified to include the properties identified by Beaton and Bengoa[48] and Jelliffe and Jelliffe.[49]

3. Results

3.1 Maternal Characteristics

Table 5 presents maternal characteristics by study. The number of participants in each study ranged from 539 in Pakistan to 16,108 in Bangladesh. The Bangladesh study was by far the largest study, with five times the number of study participants as the second largest (the Nepal study, with 3,170). Based on histograms of participants' ages, the age distributions were approximately normally distributed, with slight left truncation in some studies (**Figure 2**). Mean maternal age ranged from 21.9 years in Bangladesh to 28.5 years in Ethiopia. Parity levels varied by study, with approximately 80% of mothers in Bangladesh, Malawi, and Pakistan having given birth 0–2 times previously vs. only 40% of mothers in Ethiopia having given birth 0–2 times previously. Two studies (Democratic Republic of Congo [DRC] and Malawi) included only women living with HIV and in one study (South Africa) approximately 50% of mothers were living with HIV. HIV status of the mothers was not ascertained in the studies in Bangladesh, Ethiopia, Nepal, and Pakistan; however, the overall HIV burden in these countries is quite low (<0.1% in Bangladesh and Pakistan, 0.2% in Nepal, and 1.2% in Ethiopia according to UNAIDS.[50] Education levels are not shown in Table 5 as the measures of education reported were not consistent across studies. However, examination of the tables in Annex B reveals highly variable levels of education across studies.

Table 5. Maternal Characteristics by Study

	Bangladesh (n=16,108)	DRC (n=1,007)	Ethiopia (n=956)	Malawi (n=1,005)	Nepal (n=3,170)	Pakistan (n=539)	South Africa (n=2,247)
Age							
Range	9–48	14–45	15–49	16–44	10–43	16–42	16–54
Mean (SD)	21.9 (5.9)	30.6 (5.4)	28.5 (7)	26.1 (5)	23.4 (5.7)	25.3 (4.6)	25.1 (6.4)
Median (25th, 75th)	21 (17, 26)	31 (26, 34)	28 (25, 32)	25 (22, 29)	23 (19, 27)	25 (22, 28)	24 (20, 29)
Parity							
0	6,982 (43.3%)		111 (11.6%)	183 (18.2%)	766 (24.2%)	213 (39.5%)	
1–2	6,603 (41%)		297 (31.1%)	590 (58.7%)	1,224 (38.6%)	235 (43.6%)	
3–4	1,979 (12.3%)	–	262 (27.4%)	191 (19%)	726 (22.9%)	79 (14.6%)	–
5–6	402 (2.5%)		164 (17.2%)	38 (3.8%)	318 (10%)	10 (1.9%)	
7+	142 (0.9%)		122 (12.8%)	3 (0.3%)	136 (4.3%)	2 (0.4%)	
HIV Status							
HIV-positive	–	100%	–	100%	–	–	1,090 (48.5%)
HIV-negative	–	0%	–	0%	–	–	1,152 (51.3%)
Indeterminate	100%	0%	100%	0%	100%	100%	5 (0.2%)

Figure 2. Distributions of Maternal Age by Individual Study and Combined across All Studies

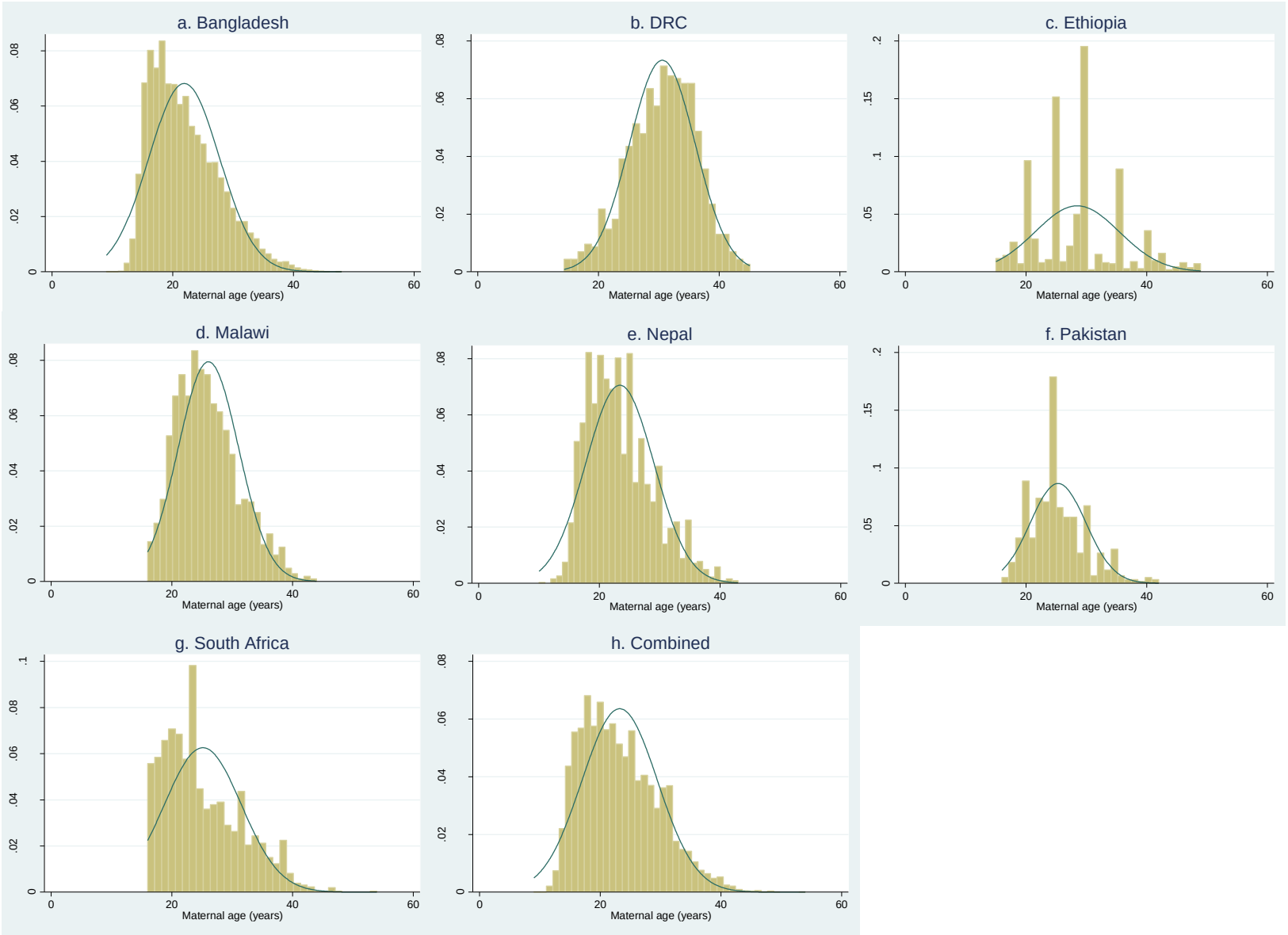


Table 6 shows maternal MUAC measures by study. MUAC measurements ranged from a low of 11 cm in Ethiopia to a high of 47 cm in DRC and Malawi. The mean MUAC measurement varied between studies, ranging from 21.8 cm in Nepal to 29.0 cm in Pakistan. In all studies, MUAC measurements were approximately normally distributed, but with slight deviations, as displayed in **Figure 3a–g**. When data from all studies were combined (**Figure 3h**), there was a predominance of MUAC values in the 21–24 cm range. Note that MUAC was measured to the nearest centimeter in Ethiopia and to the nearest tenth of a centimeter in Bangladesh, DRC, Malawi, Nepal, Pakistan, and South Africa.

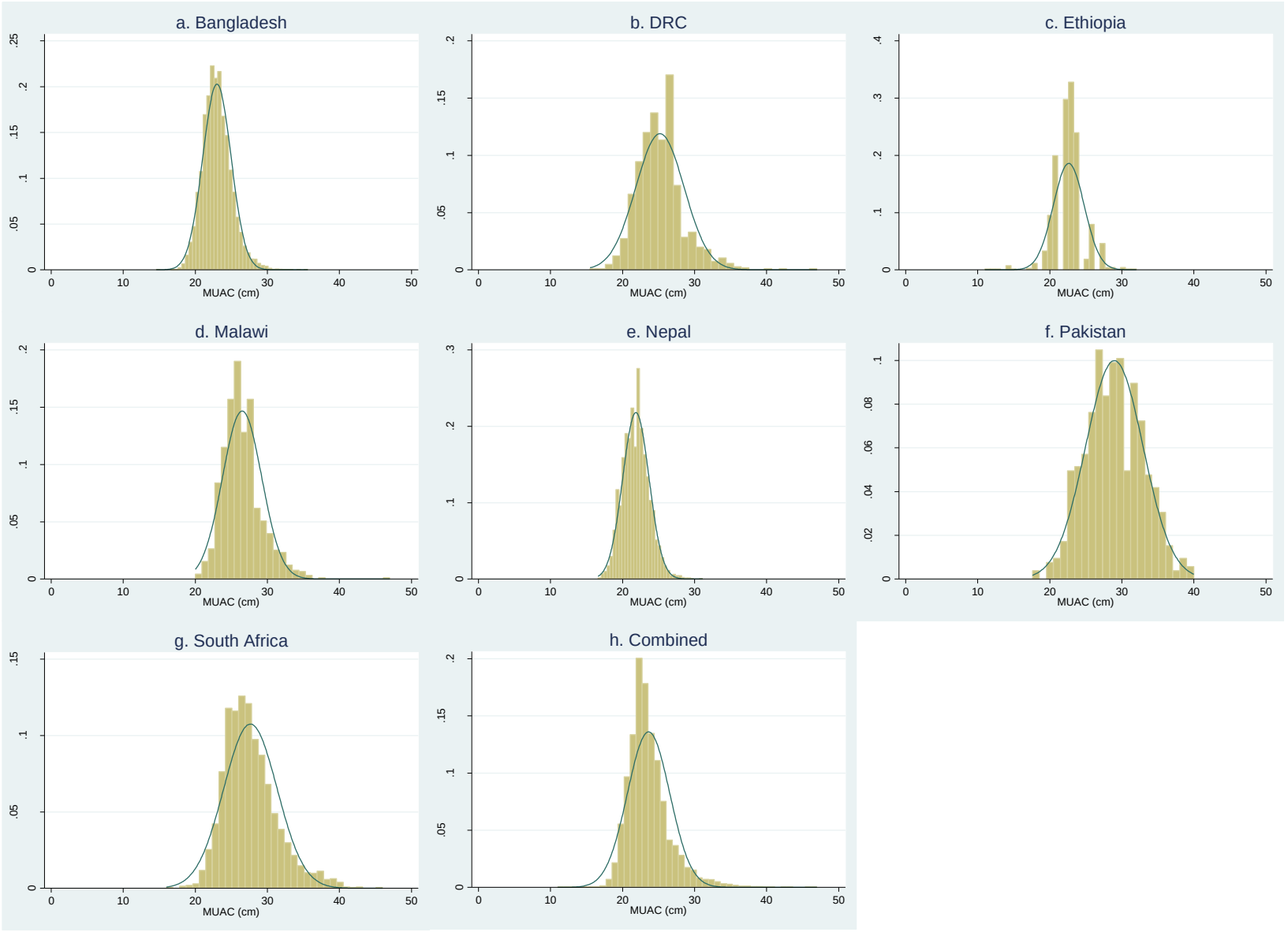
Table 6. Maternal MUAC (cm) by Study

	Bangladesh (n=16,108)	DRC (n=1,007)	Ethiopia (n=956)	Malawi (n=1,005)	Nepal (n=3,170)	Pakistan (n=539)	South Africa (n=2,247)
Range	14.6–35.6	15.5–47.0	11.0–32.0	20.0–47.0	16.6–31.1	17.6–40.0	16.0–46.0
Mean (SD)	23.0 (2.0)	25.2 (3.4)	22.6 (2.1)	26.5 (2.7)	21.8 (1.8)	29.0 (4.0)	27.6 (3.7)
Median (25th, 75th)	22.9 (21.6, 24.2)	25.0 (23.0, 27.0)	23.0 (21.0, 24.0)	26.0 (24.7, 28.0)	21.7 (20.5, 23.0)	28.9 (26.0, 32.0)	27.1 (25.1, 29.6)
Timing of measurement:							
1st trimester	100%	12%	100%	1%	100%	0%	0%
2nd trimester	0%	42%	0%	55%	0%	0%	0%
3rd trimester	0%	46%	0%	44%	0%	0%	0%
Postpartum	0%	0%	0%	0%	0%	100%[a]	100%[b]

[a] MUAC measured at delivery.
[b] MUAC measured at mean of 52±61 days after delivery.

As shown, the data in this analysis include maternal MUAC measurements taken at different times during pregnancy between studies and, in some cases, within individual studies. In Bangladesh, Ethiopia, and Nepal, measurements were taken during the first trimester of pregnancy. MUAC measurements taken during the third trimester of pregnancy were also available for the Bangladesh and Nepal studies, but are not included in the current analysis. MUAC measurements were taken at different times during pregnancy for women in both the DRC and Malawi studies; for both of these studies, time of MUAC measurement depended on when pregnant women were first enrolled in the studies, as women at any stage of pregnancy were eligible to enroll. Two other studies enrolled women at delivery (Pakistan) or post-delivery (South Africa; mean of 52±61 days after delivery); therefore, for these two studies, MUAC measurements were from postpartum visits.

Figure 3. Distributions of Maternal MUAC Measurements by Individual Study and Combined across All Studies



3.2 Infant Characteristics

Table 7 presents infant characteristics by study. Infant birth weight was approximately normally distributed in all studies, with means ranging from 2,433 g in Bangladesh to 3,104 g in South Africa. The percent of infants born with LBW was highly variable between studies, ranging from 55.3% in Bangladesh to approximately 8.7% in Malawi and 9.2% in South Africa. In all studies except the DRC study, slightly more than 50% of all infant births were male.

Table 7. Infant Characteristics by Study

	Bangladesh (n=16,108)	DRC (n=1,007)	Ethiopia (n=956)	Malawi (n=1,005)	Nepal (n=3,170)	Pakistan (n=539)	South Africa (n=2,247)
Infant birth weight							
Range	750–4,370	1,200–5,250	700–4,700	1,400–5,000	1,056–4,454	1,600–4,600	800–5,500
Mean±SD	2,433±425	3,063±555	2,829±851	2,998±440	2,632±428	2,971±472	3,104±494
Median (25th, 75th)	2,440 (2,170, 2,710)	3,040 (2,700, 3,400)	2,900 (2,400, 3,500)	3,000 (2,700, 3,300)	2,634 (2,358, 2,910)	3,000 (2,700, 3,200)	3,100 (2,800, 3,450)
Timing of measurement	≤ 72 hours	≤ 12 hours	≤ 24 hours	≤ 48 hours	≤ 72 hours	≤ 12 hours	≤ 72 hours
# LBW (%)	8,906 (55.3%)	119 (11.8%)	271 (28.3%)	87 (8.7%)	1,193 (37.6%)	69 (12.8%)	207 (9.2%)
Sex							
# Male (%)	8,205 (50.9%)	475 (47.2%)	492 (51.5%)	513 (51%)	1,596 (50.4%)	289 (53.6%)	1,125 (50.1%)

Figure 4 shows the distributions of infant birth weight for each study separately and combined across all studies. Distributions of birth weight appear to be similar between studies. As shown in the graphs, there were slight deviations from the normal distribution for some individual studies, but combining birth weights across all studies resulted in a normal distribution (Figure 4h).

Figure 5 shows the scatterplots of infant birth weight by maternal MUAC for each study separately (a–g) and combined (h). Based on these graphs, we note that there may exist some evidence of a "pooling" effect. This occurs when heterogeneous groups, each of which shows a slight correlation between birth weight and MUAC, are pooled together, resulting in the creation of a stronger, but perhaps spurious, correlation. This situation, in which relationships between groups differ from relationships within groups, is termed *ecological fallacy*.[51] Correlation coefficients between birth weight and MUAC ranged from 0.10 in Ethiopia to 0.27 in the DRC; all were statistically significant at $p<.00001$. For the pooled dataset, the correlation coefficient was 0.34 ($p<.00001$).

Figure 4. Distributions of Infant Birth Weight by Individual Study (a–g) and Combined across All Studies (h)

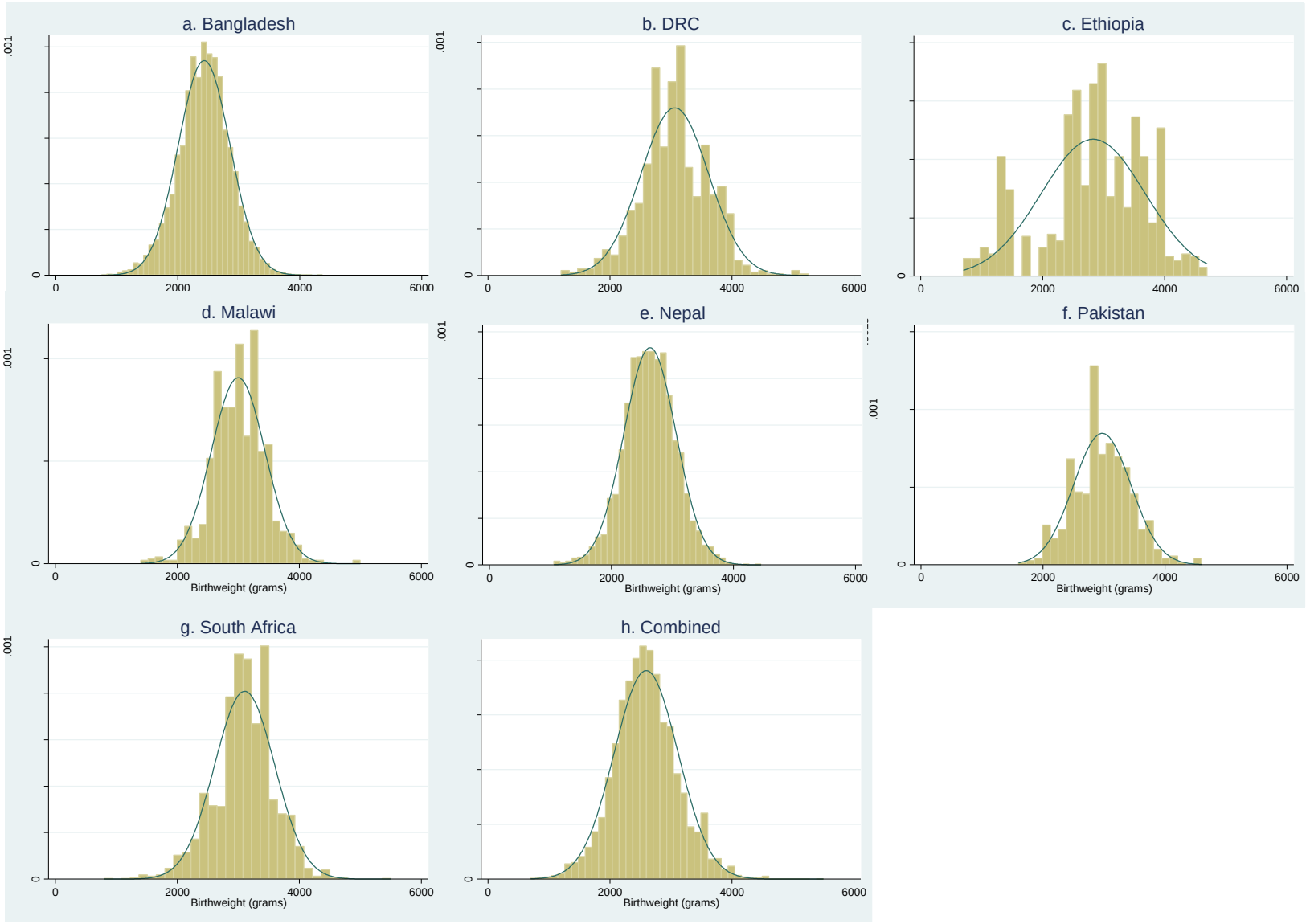
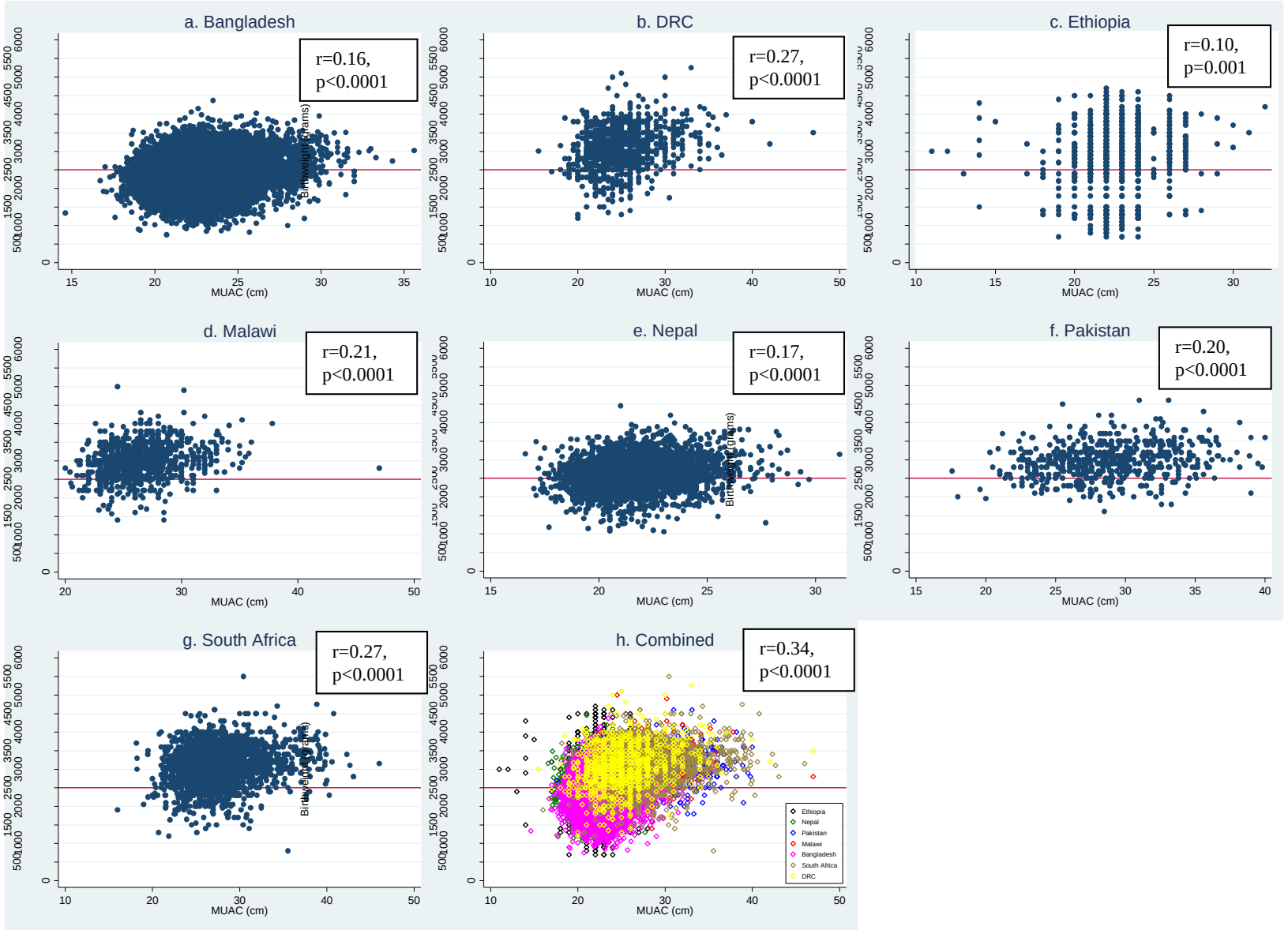


Figure 5. Scatterplots of Infant Birth Weight by Maternal MUAC for Each Study Separately (a–g) and Combined (h)

(Red horizontal line on each graph depicts the cutoff for LBW (2,500 g))



3.3 Measures of Diagnostic Accuracy

Figure 6 shows the ROC curves and AUROCCs separately by study. **Tables 8–14** show the SENS, SPEC, PPV, and NPV over a range of cutoffs for each individual study. **Table 15** presents SENS, SPEC, PPV, and NPV by study for each MUAC cutoff. In the tables, MUAC cutoffs with fewer than 10 individuals in any cell of the 2x2 table (cross-tabulation of MUAC cutoff by LBW outcome) are grayed out due to reduced reliability of the estimate (see Annex C for sample size at each cutoff).

Figure 6. ROC Curves by Study

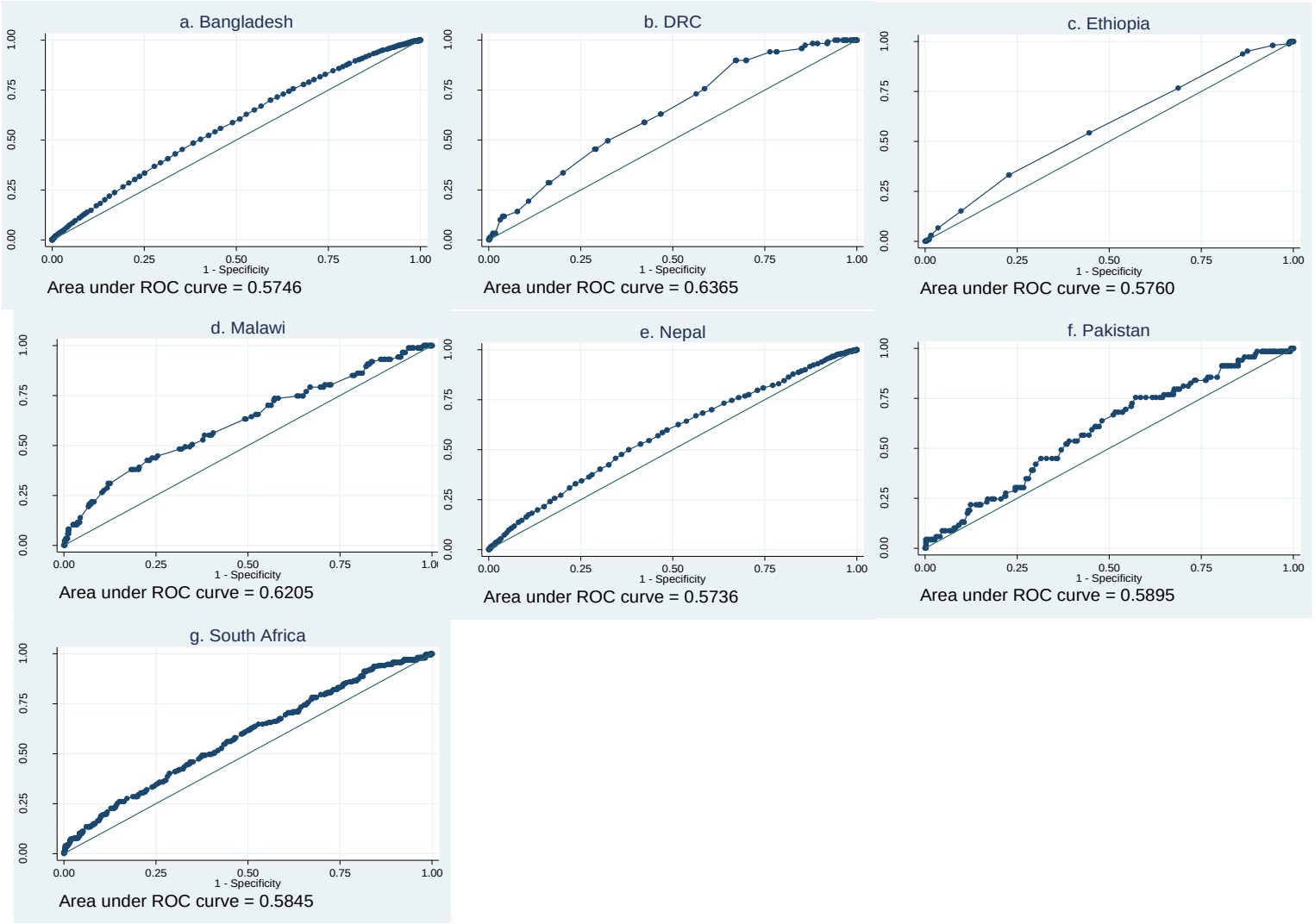


Table 8. SENS, SPEC, PPV, and NPV for Each MUAC Cutoff, Bangladesh (Values Expressed as % (95% CI))

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	1.70 (1.50, 2.00)	99.3 (99.0, 99.4)	74.2 (67.7, 80.0)	45.0 (44.2, 45.7)
≤19.5	3.50 (3.10, 3.90)	98.0 (97.7, 98.3)	68.4 (63.9, 72.7)	45.1 (44.3, 45.9)
≤20.0	6.20 (5.70, 6.70)	96.1 (95.6, 96.5)	66.1 (62.8, 69.3)	45.3 (44.5, 46.1)
≤20.5	11.1 (10.4, 11.7)	92.6 (92.0, 93.2)	65.0 (62.5, 67.4)	45.7 (44.9, 46.5)
≤21.0	17.0 (16.3, 17.8)	88.0 (87.2, 88.7)	63.7 (61.8, 65.7)	46.2 (45.3, 47.0)
≤21.5	26.5 (25.6, 27.4)	80.8 (79.8, 81.7)	63.0 (61.4, 64.6)	47.1 (46.2, 47.9)
≤22.0	36.8 (35.8, 37.8)	72.3 (71.2, 73.3)	62.2 (60.8, 63.5)	48.1 (47.1, 49.0)
≤22.5	48.4 (47.4, 49.5)	61.7 (60.6, 62.8)	61.0 (59.8, 62.1)	49.2 (48.1, 50.2)
≤23.0	58.7 (57.7, 59.7)	51.0 (49.9, 52.2)	59.7 (58.7, 60.7)	50.0 (48.8, 51.1)
≤23.5	70.0 (69.0, 70.9)	40.7 (39.6, 41.9)	59.4 (58.4, 60.3)	52.3 (51.0, 53.6)
≤24.0	77.9 (77.0, 78.7)	31.7 (30.6, 32.8)	58.5 (57.6, 59.4)	53.7 (52.2, 55.2)
≤24.5	84.7 (83.9, 85.4)	23.7 (22.7, 24.7)	57.8 (57.0, 58.7)	55.6 (53.8, 57.3)
≤25.0	89.6 (89.0, 90.2)	17.6 (16.8, 18.5)	57.4 (56.5, 58.2)	57.9 (55.8, 60.0)
≤25.5	93.3 (92.7, 93.8)	12.7 (11.9, 13.5)	56.9 (56.1, 57.7)	60.4 (57.9, 62.9)
≤26.0	95.5 (95.0, 95.9)	9.00 (8.30, 9.70)	56.5 (55.7, 57.3)	61.6 (58.6, 64.5)
≤26.5	97.1 (96.7, 97.4)	6.40 (5.80, 7.00)	56.2 (55.4, 57.0)	64.0 (60.3, 67.5)

Table 9. SENS, SPEC, PPV, and NPV for Each MUAC Cutoff, DRC (Values Expressed as % (95% CI))

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	3.4 (0.9, 8.4)	98.9 (97.9, 99.5)	28.6 (8.4, 58.1)	88.4 (86.3, 90.3)
≤19.5	3.4 (0.9, 8.4)	98.2 (97.1, 99)	20.0 (5.7, 43.7)	88.3 (86.2, 90.3)
≤20.0	10.1 (5.3, 17.0)	96.8 (95.5, 97.9)	30.0 (16.6, 46.5)	88.9 (86.8, 90.8)
≤20.5	11.8 (6.6, 19.0)	96.2 (94.7, 97.3)	29.2 (17.0, 44.1)	89.1 (86.9, 91.0)
≤21.0	14.3 (8.5, 21.9)	92.2 (90.3, 93.9)	19.8 (12.0, 29.8)	88.9 (86.7, 90.9)
≤21.5	19.3 (12.7, 27.6)	89.2 (87.0, 91.2)	19.3 (12.7, 27.6)	89.2 (87.0, 91.2)
≤22.0	28.6 (20.7, 37.6)	83.8 (81.2, 86.1)	19.1 (13.6, 25.7)	89.7 (87.5, 91.7)
≤22.5	33.6 (25.2, 42.8)	79.8 (77.1, 82.4)	18.3 (13.4, 24.0)	90.0 (87.7, 92.0)
≤23.0	45.4 (36.2, 54.8)	71.2 (68.1, 74.1)	17.4 (13.4, 22.1)	90.7 (88.3, 92.7)
≤23.5	49.6 (40.3, 58.9)	67.7 (64.5, 70.7)	17.1 (13.2, 21.4)	90.9 (88.5, 93.0)
≤24.0	58.8 (49.4, 67.8)	57.8 (54.4, 61.0)	15.7 (12.5, 19.5)	91.3 (88.6, 93.5)
≤24.5	63.0 (53.7, 71.7)	53.3 (49.9, 56.6)	15.3 (12.2, 18.8)	91.5 (88.7, 93.7)
≤25.0	73.1 (64.2, 80.8)	43.6 (40.3, 46.9)	14.8 (12.0, 17.9)	92.4 (89.4, 94.7)
≤25.5	75.6 (66.9, 83.0)	41.3 (38.1, 44.6)	14.7 (12.0, 17.8)	92.7 (89.7, 95.0)
≤26.0	89.9 (83.0, 94.7)	32.9 (29.8, 36.1)	15.2 (12.6, 18.1)	96.1 (93.2, 97.9)
≤26.5	89.9 (83.0, 94.7)	30.1 (27.1, 33.2)	14.7 (12.2, 17.5)	95.7 (92.6, 97.8)

Note: MUAC cutoffs with results based on cell sizes of <10 are grayed out due to reduced reliability of the estimate.

Table 10. SENS, SPEC, PPV, and NPV for Each MUAC Cutoff, Ethiopia (Values Expressed as % (95% CI))

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	6.6 (4.0, 10.3)	96.5 (94.8, 97.7)	42.9 (27.7, 59.0)	72.3 (69.3, 75.2)
≤19.5	6.6 (4.0, 10.3)	96.5 (94.8, 97.7)	42.9 (27.7, 59.0)	72.3 (69.3, 75.2)
≤20.0	15.1 (11.1, 20.0)	90.2 (87.7, 92.3)	38.0 (28.8, 47.8)	72.9 (69.7, 75.8)
≤20.5	15.1 (11.1, 20.0)	90.2 (87.7, 92.3)	38.0 (28.8, 47.8)	72.9 (69.7, 75.8)
≤21.0	33.2 (27.6, 39.2)	77.2 (73.9, 80.3)	36.6 (30.6, 42.9)	74.5 (71.1, 77.7)
≤21.5	33.2 (27.6, 39.2)	77.2 (73.9, 80.3)	36.6 (30.6, 42.9)	74.5 (71.1, 77.7)
≤22.0	54.2 (48.1, 60.3)	55.5 (51.7, 59.2)	32.5 (28.2, 37.1)	75.4 (71.4, 79.1)
≤22.5	54.2 (48.1, 60.3)	55.5 (51.7, 59.2)	32.5 (28.2, 37.1)	75.4 (71.4, 79.1)
≤23.0	76.8 (71.3, 81.6)	31.2 (27.8, 34.9)	30.6 (27.2, 34.3)	77.3 (71.9, 82.1)
≤23.5	76.8 (71.3, 81.6)	31.2 (27.8, 34.9)	30.6 (27.2, 34.3)	77.3 (71.9, 82.1)
≤24.0	93.7 (90.1, 96.3)	13.7 (11.2, 16.5)	30.1 (27.0, 33.3)	84.7 (76.6, 90.8)
≤24.5	93.7 (90.1, 96.3)	13.7 (11.2, 16.5)	30.1 (27.0, 33.3)	84.7 (76.6, 90.8)
≤25.0	95.2 (91.9, 97.4)	12.4 (10.0, 15.1)	30.1 (27.0, 33.3)	86.7 (78.4, 92.7)
≤25.5	95.2 (91.9, 97.4)	12.4 (10.0, 15.1)	30.1 (27.0, 33.3)	86.7 (78.4, 92.7)
≤26.0	98.2 (95.7, 99.4)	5.5 (4.0, 7.5)	29.1 (26.2, 32.2)	88.4 (74.9, 96.1)
≤26.5	98.2 (95.7, 99.4)	5.5 (4.0, 7.5)	29.1 (26.2, 32.2)	88.4 (74.9, 96.1)

Note: MUAC cutoffs with results based on cell sizes of <10 are grayed out due to reduced reliability of the estimate.

Table 11. SENS, SPEC, PPV, and NPV for Each MUAC Cutoff, Malawi (Values Expressed as % (95% CI))

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	--- (---, ---)	--- (---, ---)	--- (---, ---)	--- (---, ---)
≤19.5	--- (---, ---)	--- (---, ---)	--- (---, ---)	--- (---, ---)
≤20.0	0.0 (0.0, 4.2)	99.9 (99.4, 100)	0.0 (0.0, 97.5)	91.3 (89.4, 93.0)
≤20.5	1.1 (0.0, 6.2)	99.8 (99.2, 100)	33.3 (0.8, 90.6)	91.4 (89.5, 93.1)
≤21.0	2.3 (0.3, 8.1)	99.6 (98.9, 99.9)	33.3 (4.3, 77.7)	91.5 (89.6, 93.1)
≤21.5	5.7 (1.9, 12.9)	98.9 (98, 99.5)	33.3 (11.8, 61.6)	91.7 (89.8, 93.4)
≤22.0	10.3 (4.8, 18.7)	97.5 (96.3, 98.4)	28.1 (13.7, 46.7)	92.0 (90.1, 93.6)
≤22.5	10.3 (4.8, 18.7)	96.7 (95.4, 97.8)	23.1 (11.1, 39.3)	91.9 (90.0, 93.6)
≤23.0	19.5 (11.8, 29.4)	93.4 (91.5, 94.9)	21.8 (13.2, 32.6)	92.4 (90.6, 94.1)
≤23.5	26.4 (17.6, 37.0)	89.7 (87.5, 91.5)	19.5 (12.8, 27.8)	92.8 (90.9, 94.4)
≤24.0	37.9 (27.7, 49.0)	81.7 (79.0, 84.2)	16.4 (11.6, 22.3)	93.3 (91.3, 94.9)
≤24.5	42.5 (32.0, 53.6)	77.3 (74.5, 80.0)	15.1 (10.9, 20.2)	93.4 (91.4, 95.1)
≤25.0	48.3 (37.4, 59.2)	68.6 (65.5, 71.6)	12.7 (9.3, 16.8)	93.3 (91.2, 95.1)
≤25.5	52.9 (41.9, 63.7)	62.2 (59.0, 65.3)	11.7 (8.7, 15.3)	93.3 (91.0, 95.1)
≤26.0	63.2 (52.2, 73.3)	50.9 (47.6, 54.2)	10.9 (8.3, 13.9)	93.6 (91.1, 95.6)
≤26.5	70.1 (59.4, 79.5)	44.6 (41.3, 47.8)	10.7 (8.3, 13.5)	94.0 (91.4, 96.1)

Note: MUAC cutoffs with results based on cell sizes of <10 are grayed out due to reduced reliability of the estimate.

Table 12. SENS, SPEC, PPV, and NPV for Each MUAC Cutoff, Nepal (Values Expressed as % (95% CI)

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	7.3 (5.9, 8.9)	95.8 (94.8, 96.6)	51.2 (43.4, 58.9)	63.1 (61.4, 64.9)
≤19.5	13.7 (11.8, 15.8)	91.9 (90.6, 93.1)	50.6 (45.0, 56.2)	63.8 (62.0, 65.6)
≤20.0	19.9 (17.6, 22.2)	86.7 (85.1, 88.2)	47.4 (42.9, 51.9)	64.2 (62.3, 66.0)
≤20.5	30.8 (28.2, 33.6)	78.0 (76.1, 79.8)	45.8 (42.3, 49.3)	65.1 (63.2, 67.1)
≤21.0	40.3 (37.5, 43.2)	69.8 (67.7, 71.8)	44.6 (41.6, 47.6)	65.9 (63.9, 68.0)
≤21.5	52.8 (49.9, 55.7)	58.8 (56.6, 61.0)	43.6 (41.0, 46.2)	67.4 (65.1, 69.6)
≤22.0	62.5 (59.7, 65.3)	48.5 (46.2, 50.7)	42.3 (39.9, 44.6)	68.2 (65.7, 70.6)
≤22.5	73.3 (70.7, 75.8)	36.1 (33.9, 38.2)	40.9 (38.8, 43.0)	69.1 (66.2, 71.9)
≤23.0	79.8 (77.4, 82.0)	27.0 (25.0, 29.0)	39.7 (37.8, 41.7)	68.9 (65.5, 72.1)
≤23.5	86.3 (84.3, 88.2)	18.5 (16.8, 20.3)	39.0 (37.1, 40.9)	69.2 (65.1, 73.1)
≤24.0	91.5 (89.8, 93.1)	12.7 (11.3, 14.2)	38.8 (36.9, 40.6)	71.3 (66.3, 76.0)
≤24.5	95.5 (94.1, 96.6)	8.0 (6.8, 9.3)	38.5 (36.7, 40.3)	74.5 (68.1, 80.2)
≤25.0	97.5 (96.4, 98.3)	5.5 (4.5, 6.6)	38.4 (36.6, 40.1)	78.4 (70.6, 84.9)
≤25.5	98.2 (97.3, 98.9)	3.5 (2.7, 4.4)	38.1 (36.3, 39.8)	76.7 (66.6, 84.9)
≤26.0	99.1 (98.4, 99.5)	2.3 (1.7, 3.1)	38.0 (36.3, 39.7)	80.7 (68.1, 90.0)
≤26.5	99.3 (98.7, 99.7)	1.4 (0.9, 2.0)	37.8 (36.1, 39.5)	77.1 (59.9, 89.6)

Note: MUAC cutoffs with results based on cell sizes of <10 are grayed out due to reduced reliability of the estimate.

Table 13. SENS, SPEC, PPV, and NPV for Each MUAC Cutoff, Pakistan (Values Expressed as % (95% CI)

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	1.4 (0.0, 7.8)	99.8 (98.8, 100)	50.0 (1.3, 98.7)	87.3 (84.2, 90.0)
≤19.5	1.4 (0.0, 7.8)	99.8 (98.8, 100)	50.0 (1.3, 98.7)	87.3 (84.2, 90.0)
≤20.0	4.3 (0.9, 12.2)	99.8 (98.8, 100)	75.0 (19.4, 99.4)	87.7 (84.6, 90.3)
≤20.5	4.3 (0.9, 12.2)	99.4 (98.1, 99.9)	50.0 (11.8, 88.2)	87.6 (84.5, 90.3)
≤21.0	4.3 (0.9, 12.2)	98.7 (97.2, 99.5)	33.3 (7.5, 70.1)	87.6 (84.4, 90.2)
≤21.5	4.3 (0.9, 12.2)	98.1 (96.4, 99.1)	25.0 (5.5, 57.2)	87.5 (84.3, 90.2)
≤22.0	5.8 (1.6, 14.2)	97.0 (95.1, 98.4)	22.2 (6.4, 47.6)	87.5 (84.4, 90.2)
≤22.5	5.8 (1.6, 14.2)	96.0 (93.8, 97.6)	17.4 (5.0, 38.8)	87.4 (84.2, 90.1)
≤23.0	8.7 (3.3, 18)	93.4 (90.8, 95.5)	16.2 (6.2, 32.0)	87.5 (84.2, 90.2)
≤23.5	11.6 (5.1, 21.6)	90.9 (87.9, 93.3)	15.7 (7.0, 28.6)	87.5 (84.2, 90.3)
≤24.0	17.4 (9.3, 28.4)	88.5 (85.3, 91.3)	18.2 (9.8, 29.6)	87.9 (84.7, 90.7)
≤24.5	21.7 (12.7, 33.3)	86.2 (82.8, 89.2)	18.8 (10.9, 29.0)	88.2 (84.9, 91.0)
≤25.0	23.2 (13.9, 34.9)	83.2 (79.5, 86.5)	16.8 (9.9, 25.9)	88.1 (84.7, 90.9)
≤25.5	24.6 (15.1, 36.5)	79.4 (75.5, 83.0)	14.9 (8.9, 22.8)	87.8 (84.3, 90.7)
≤26.0	29.0 (18.7, 41.2)	75.6 (71.4, 79.4)	14.8 (9.3, 21.9)	87.9 (84.3, 90.9)
≤26.5	34.8 (23.7, 47.2)	72.6 (68.3, 76.6)	15.7 (10.3, 22.4)	88.3 (84.7, 91.4)

Note: MUAC cutoffs with results based on cell sizes of <10 are grayed out due to reduced reliability of the estimate.

Table 14. SENS, SPEC, PPV, and NPV for Each MUAC Cutoff, South Africa (Values Expressed as % (95% CI)

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	1.0 (0.1, 3.4)	99.9 (99.6, 100)	40.0 (5.3, 85.3)	90.9 (89.6, 92.0)
≤19.5	1.4 (0.3, 4.2)	99.8 (99.4, 99.9)	37.5 (8.5, 75.5)	90.9 (89.6, 92.0)
≤20.0	1.9 (0.5, 4.9)	99.7 (99.4, 99.9)	40.0 (12.2, 73.8)	90.9 (89.7, 92.1)
≤20.5	2.9 (1.1, 6.2)	99.6 (99.2, 99.8)	42.9 (17.7, 71.1)	91.0 (89.7, 92.2)
≤21.0	3.9 (1.7, 7.5)	99.3 (98.9, 99.6)	36.4 (17.2, 59.3)	91.1 (89.8, 92.2)
≤21.5	5.8 (3.0, 9.9)	98.4 (97.7, 98.9)	26.7 (14.6, 41.9)	91.1 (89.9, 92.3)
≤22.0	7.7 (4.5, 12.2)	97.3 (96.5, 98.0)	22.5 (13.5, 34.0)	91.2 (90.0, 92.4)
≤22.5	8.7 (5.2, 13.4)	95.9 (94.9, 96.7)	17.6 (10.8, 26.4)	91.2 (89.9, 92.4)
≤23.0	13.5 (9.2, 19.0)	93.9 (92.7, 94.9)	18.3 (12.5, 25.4)	91.5 (90.2, 92.6)
≤23.5	16.4 (11.7, 22.2)	90.8 (89.4, 92.0)	15.3 (10.8, 20.7)	91.5 (90.2, 92.6)
≤24.0	22.7 (17.2, 29.0)	87.2 (85.7, 88.6)	15.3 (11.4, 19.8)	91.7 (90.4, 92.9)
≤24.5	28.5 (22.5, 35.2)	81.3 (79.5, 82.9)	13.4 (10.3, 16.9)	91.8 (90.4, 93.0)
≤25.0	33.3 (27.0, 40.2)	76.0 (74.1, 77.8)	12.3 (9.7, 15.4)	91.8 (90.4, 93.1)
≤25.5	41.1 (34.3, 48.1)	69.9 (67.8, 71.8)	12.1 (9.8, 14.8)	92.1 (90.7, 93.4)
≤26.0	47.3 (40.4, 54.4)	63.4 (61.2, 65.5)	11.6 (9.5, 14.0)	92.2 (90.7, 93.6)
≤26.5	52.7 (45.6, 59.6)	57.2 (55.0, 59.4)	11.1 (9.2, 13.2)	92.3 (90.6, 93.7)

Note: MUAC cutoffs with results based on cell sizes of <10 are grayed out due to reduced reliability of the estimate.

For all studies, the ROC curve fell close to the 45 degree line extending from the point where SENS and (1 − SPEC) are both equal to 0 to the point where SENS and (1 − SPEC) are both equal to 1 (Figure 6). AUROCC values ranged from 0.57 in Nepal to 0.64 in the DRC, indicating a high degree of overlap between the distributions of MUAC in mothers delivering LBW infants and mothers delivering NBW infants. In other words, MUAC did not clearly discriminate between women who delivered LBW infants and women who did not.

As shown in Table 15, values of SENS and SPEC at each MUAC cutoff varied greatly between studies. For example, at a MUAC cutoff of ≤22.0 cm, SENS varied from 5.8% in Pakistan to 62.5% in Nepal, while SPEC varied from 48.5% in Nepal to 97.5% in Malawi.

Table 15. SENS, SPEC, PPV, and NPV by Study, for Each MUAC Cutoff

MUAC (cm)		Bangladesh	DRC	Ethiopia	Malawi	Nepal	Pakistan	South Africa
≤19.0	SENS	1.7 (1.5, 2.0)	3.4 (0.9, 8.4)	6.6 (4.0, 10.3)	--- (---, ---)	7.3 (5.9, 8.9)	1.4 (0.0, 7.8)	1.0 (0.1, 3.4)
	SPEC	99.3 (99.0, 99.4)	98.9 (97.9, 99.5)	96.5 (94.8, 97.7)	--- (---, ---)	95.8 (94.8, 96.6)	99.8 (98.8, 100)	99.9 (99.6, 100)
	PPV	74.2 (67.7, 80.0)	28.6 (8.4, 58.1)	42.9 (27.7, 59.0)	--- (---, ---)	51.2 (43.4, 58.9)	50.0 (1.3, 98.7)	40.0 (5.3, 85.3)
	NPV	45.0 (44.2, 45.7)	88.4 (86.3, 90.3)	72.3 (69.3, 75.2)	--- (---, ---)	63.1 (61.4, 64.9)	87.3 (84.2, 90.0)	90.9 (89.6, 92)
≤19.5	SENS	3.5 (3.1, 3.9)	3.4 (0.9, 8.4)	6.6 (4.0, 10.3)	--- (---, ---)	13.7 (11.8, 15.8)	1.4 (0.0, 7.8)	1.4 (0.3, 4.2)
	SPEC	98.0 (97.7, 98.3)	98.2 (97.1, 99.0)	96.5 (94.8, 97.7)	--- (---, ---)	91.9 (90.6, 93.1)	99.8 (98.8, 100)	99.8 (99.4, 99.9)
	PPV	68.4 (63.9, 72.7)	20.0 (5.7, 43.7)	42.9 (27.7, 59.0)	--- (---, ---)	50.6 (45.0, 56.2)	50.0 (1.3, 98.7)	37.5 (8.5, 75.5)
	NPV	45.1 (44.3, 45.9)	88.3 (86.2, 90.3)	72.3 (69.3, 75.2)	--- (---, ---)	63.8 (62.0, 65.6)	87.3 (84.2, 90.0)	90.9 (89.6, 92)
≤20.0	SENS	6.2 (5.7, 6.7)	10.1 (5.3, 17.0)	15.1 (11.1, 20.0)	0.0 (0.0, 4.2)	19.9 (17.6, 22.2)	4.3 (0.9, 12.2)	1.9 (0.5, 4.9)
	SPEC	96.1 (95.6, 96.5)	96.8 (95.5, 97.9)	90.2 (87.7, 92.3)	99.9 (99.4, 100)	86.7 (85.1, 88.2)	99.8 (98.8, 100)	99.7 (99.4, 99.9)
	PPV	66.1 (62.8, 69.3)	30.0 (16.6, 46.5)	38.0 (28.8, 47.8)	0.0 (0.0, 97.5)	47.4 (42.9, 51.9)	75.0 (19.4, 99.4)	40.0 (12.2, 73.8)
	NPV	45.3 (44.5, 46.1)	88.9 (86.8, 90.8)	72.9 (69.7, 75.8)	91.3 (89.4, 93.0)	64.2 (62.3, 66.0)	87.7 (84.6, 90.3)	90.9 (89.7, 92.1)
≤20.5	SENS	11.1 (10.4, 11.7)	11.8 (6.6, 19.0)	15.1 (11.1, 20.0)	1.1 (0.0, 6.2)	30.8 (28.2, 33.6)	4.3 (0.9, 12.2)	2.9 (1.1, 6.2)
	SPEC	92.6 (92.0, 93.2)	96.2 (94.7, 97.3)	90.2 (87.7, 92.3)	99.8 (99.2, 100)	78.0 (76.1, 79.8)	99.4 (98.1, 99.9)	99.6 (99.2, 99.8)
	PPV	65.0 (62.5, 67.4)	29.2 (17.0, 44.1)	38.0 (28.8, 47.8)	33.3 (0.8, 90.6)	45.8 (42.3, 49.3)	50.0 (11.8, 88.2)	42.9 (17.7, 71.1)
	NPV	45.7 (44.9, 46.5)	89.1 (86.9, 91.0)	72.9 (69.7, 75.8)	91.4 (89.5, 93.1)	65.1 (63.2, 67.1)	87.6 (84.5, 90.3)	91.0 (89.7, 92.2)
≤21.0	SENS	17.0 (16.3, 17.8)	14.3 (8.5, 21.9)	33.2 (27.6, 39.2)	2.3 (0.3, 8.1)	40.3 (37.5, 43.2)	4.3 (0.9, 12.2)	3.9 (1.7, 7.5)
	SPEC	88.0 (87.2, 88.7)	92.2 (90.3, 93.9)	77.2 (73.9, 80.3)	99.6 (98.9, 99.9)	69.8 (67.7, 71.8)	98.7 (97.2, 99.5)	99.3 (98.9, 99.6)
	PPV	63.7 (61.8, 65.7)	19.8 (12.0, 29.8)	36.6 (30.6, 42.9)	33.3 (4.3, 77.7)	44.6 (41.6, 47.6)	33.3 (7.5, 70.1)	36.4 (17.2, 59.3)
	NPV	46.2 (45.3, 47.0)	88.9 (86.7, 90.9)	74.5 (71.1, 77.7)	91.5 (89.6, 93.1)	65.9 (63.9, 68.0)	87.5 (84.4, 90.2)	91.1 (89.8, 92.2)
≤21.5	SENS	26.5 (25.6, 27.4)	19.3 (12.7, 27.6)	33.2 (27.6, 39.2)	5.7 (1.9, 12.9)	52.8 (49.9, 55.7)	4.3 (0.9, 12.2)	5.8 (3.0, 9.9)
	SPEC	80.8 (79.8, 81.7)	89.2 (87.0, 91.2)	77.2 (73.9, 80.3)	98.9 (98.0, 99.5)	58.8 (56.6, 61.0)	98.1 (96.4, 99.1)	98.4 (97.7, 98.9)
	PPV	63.0 (61.4, 64.6)	19.3 (12.7, 27.6)	36.6 (30.6, 42.9)	33.3 (11.8, 61.6)	43.6 (41.0, 46.2)	25.0 (5.5, 57.2)	26.7 (14.6, 41.9)
	NPV	47.1 (46.2, 47.9)	89.2 (87, 91.2)	74.5 (71.1, 77.7)	91.7 (89.8, 93.4)	67.4 (65.1, 69.6)	87.5 (84.3, 90.2)	91.1 (89.9, 92.3)
≤22.0	SENS	36.8 (35.8, 37.8)	28.6 (20.7, 37.6)	54.2 (48.1, 60.3)	10.3 (4.8, 18.7)	62.5 (59.7, 65.3)	5.8 (1.6, 14.2)	7.7 (4.5, 12.2)
	SPEC	72.3 (71.2, 73.3)	83.8 (81.2, 86.1)	55.5 (51.7, 59.2)	97.5 (96.3, 98.4)	48.5 (46.2, 50.7)	97.0 (95.1, 98.4)	97.3 (96.5, 98.0)
	PPV	62.2 (60.8, 63.5)	19.1 (13.6, 25.7)	32.5 (28.2, 37.1)	28.1 (13.7, 46.7)	42.3 (39.9, 44.6)	22.2 (6.4, 47.6)	22.5 (13.5, 34.0)
	NPV	48.1 (47.1, 49.0)	89.7 (87.5, 91.7)	75.4 (71.4, 79.1)	92 (90.1, 93.6)	68.2 (65.7, 70.6)	87.5 (84.4, 90.2)	91.2 (90.0, 92.4)

MUAC (cm)		Bangladesh	DRC	Ethiopia	Malawi	Nepal	Pakistan	South Africa
≤22.5	SENS	48.4 (47.4, 49.5)	33.6 (25.2, 42.8)	54.2 (48.1, 60.3)	10.3 (4.8, 18.7)	73.3 (70.7, 75.8)	5.8 (1.6, 14.2)	8.7 (5.2, 13.4)
	SPEC	61.7 (60.6, 62.8)	79.8 (77.1, 82.4)	55.5 (51.7, 59.2)	96.7 (95.4, 97.8)	36.1 (33.9, 38.2)	96.0 (93.8, 97.5)	95.9 (94.9, 96.7)
	PPV	61.0 (59.8, 62.1)	18.3 (13.4, 24.0)	32.5 (28.2, 37.1)	23.1 (11.1, 39.3)	40.9 (38.8, 43.0)	17.4 (5.0, 38.8)	17.6 (10.8, 26.4)
	NPV	49.2 (48.1, 50.2)	90.0 (87.7, 92.0)	75.4 (71.4, 79.1)	91.9 (90.0, 93.6)	69.1 (66.2, 71.9)	87.4 (84.2, 90.1)	91.2 (89.9, 92.4)
≤23.0	SENS	58.7 (57.7, 59.7)	45.4 (36.2, 54.8)	76.8 (71.3, 81.6)	19.5 (11.8, 29.4)	79.8 (77.4, 82.0)	8.7 (3.3, 18.0)	13.5 (9.2, 19.0)
	SPEC	51.0 (49.9, 52.2)	71.2 (68.1, 74.1)	31.2 (27.8, 34.9)	93.4 (91.5, 94.9)	27.0 (25.0, 29.0)	93.4 (90.8, 95.5)	93.9 (92.7, 94.9)
	PPV	59.7 (58.7, 60.7)	17.4 (13.4, 22.1)	30.6 (27.2, 34.3)	21.8 (13.2, 32.6)	39.7 (37.8, 41.7)	16.2 (6.2, 32.0)	18.3 (12.5, 25.4)
	NPV	50.0 (48.8, 51.1)	90.7 (88.3, 92.7)	77.3 (71.9, 82.1)	92.4 (90.6, 94.1)	68.9 (65.5, 72.1)	87.5 (84.2, 90.2)	91.5 (90.2, 92.6)
≤23.5	SENS	70.0 (69, 70.9)	49.6 (40.3, 58.9)	76.8 (71.3, 81.6)	26.4 (17.6, 37.0)	86.3 (84.3, 88.2)	11.6 (5.1, 21.6)	16.4 (11.7, 22.2)
	SPEC	40.7 (39.6, 41.9)	67.7 (64.5, 70.7)	31.2 (27.8, 34.9)	89.7 (87.5, 91.5)	18.5 (16.8, 20.3)	90.9 (87.9, 93.3)	90.8 (89.4, 92.0)
	PPV	59.4 (58.4, 60.3)	17.1 (13.2, 21.4)	30.6 (27.2, 34.3)	19.5 (12.8, 27.8)	39.0 (37.1, 40.9)	15.7 (7.0, 28.6)	15.3 (10.8, 20.7)
	NPV	52.3 (51.0, 53.6)	90.9 (88.5, 93.0)	77.3 (71.9, 82.1)	92.8 (90.9, 94.4)	69.2 (65.1, 73.1)	87.5 (84.2, 90.3)	91.5 (90.2, 92.6)
≤24.0	SENS	77.9 (77.0, 78.7)	58.8 (49.4, 67.8)	93.7 (90.1, 96.3)	37.9 (27.7, 49.0)	91.5 (89.8, 93.1)	17.4 (9.3, 28.4)	22.7 (17.2, 29.0)
	SPEC	31.7 (30.6, 32.8)	57.8 (54.4, 61.0)	13.7 (11.2, 16.5)	81.7 (79.0, 84.2)	12.7 (11.3, 14.2)	88.5 (85.3, 91.2)	87.2 (85.7, 88.6)
	PPV	58.5 (57.6, 59.4)	15.7 (12.5, 19.5)	30.1 (27.0, 33.3)	16.4 (11.6, 22.3)	38.8 (36.9, 40.6)	18.2 (9.8, 29.6)	15.3 (11.4, 19.8)
	NPV	53.7 (52.2, 55.2)	91.3 (88.6, 93.5)	84.7 (76.6, 90.8)	93.3 (91.3, 94.9)	71.3 (66.3, 76.0)	87.9 (84.7, 90.7)	91.7 (90.4, 92.9)
≤24.5	SENS	84.7 (83.9, 85.4)	63.0 (53.7, 71.7)	93.7 (90.1, 96.3)	42.5 (32.0, 53.6)	95.5 (94.1, 96.6)	21.7 (12.7, 33.3)	28.5 (22.5, 35.2)
	SPEC	23.7 (22.7, 24.7)	53.3 (49.9, 56.6)	13.7 (11.2, 16.5)	77.3 (74.5, 80.0)	8.0 (6.8, 9.3)	86.2 (82.7, 89.2)	81.3 (79.5, 82.9)
	PPV	57.8 (57.0, 58.7)	15.3 (12.2, 18.8)	30.1 (27.0, 33.3)	15.1 (10.9, 20.2)	38.5 (36.7, 40.3)	18.8 (10.9, 29.0)	13.4 (10.3, 16.9)
	NPV	55.6 (53.8, 57.3)	91.5 (88.7, 93.7)	84.7 (76.6, 90.8)	93.4 (91.4, 95.1)	74.5 (68.1, 80.2)	88.2 (84.9, 91.0)	91.8 (90.4, 93.0)
≤25.0	SENS	89.6 (89.0, 90.2)	73.1 (64.2, 80.8)	95.2 (91.9, 97.4)	48.3 (37.4, 59.2)	97.5 (96.4, 98.3)	23.2 (13.9, 34.9)	33.3 (27.0, 40.2)
	SPEC	17.6 (16.8, 18.5)	43.6 (40.3, 46.9)	12.4 (10.0, 15.1)	68.6 (65.5, 71.6)	5.5 (4.5, 6.6)	83.2 (79.5, 86.5)	76.0 (74.1, 77.8)
	PPV	57.4 (56.5, 58.2)	14.8 (12.0, 17.9)	30.1 (27.0, 33.3)	12.7 (9.3, 16.8)	38.4 (36.6, 40.1)	16.8 (9.9, 25.9)	12.3 (9.7, 15.4)
	NPV	57.9 (55.8, 60.0)	92.4 (89.4, 94.7)	86.7 (78.4, 92.7)	93.3 (91.2, 95.1)	78.4 (70.6, 84.9)	88.1 (84.7, 90.9)	91.8 (90.4, 93.1)
≤25.5	SENS	93.3 (92.7, 93.8)	75.6 (66.9, 83.0)	95.2 (91.9, 97.4)	52.9 (41.9, 63.7)	98.2 (97.3, 98.9)	24.6 (15.1, 36.5)	41.1 (34.3, 48.1)
	SPEC	12.7 (11.9, 13.5)	41.3 (38.1, 44.6)	12.4 (10.0, 15.1)	62.2 (59.0, 65.3)	3.5 (2.7, 4.4)	79.4 (75.4, 82.9)	69.9 (67.8, 71.8)
	PPV	56.9 (56.1, 57.7)	14.7 (12.0, 17.8)	30.1 (27.0, 33.3)	11.7 (8.7, 15.3)	38.1 (36.3, 39.8)	14.9 (8.9, 22.8)	12.1 (9.8, 14.8)
	NPV	60.4 (57.9, 62.9)	92.7 (89.7, 95.0)	86.7 (78.4, 92.7)	93.3 (91.0, 95.1)	76.7 (66.6, 84.9)	87.8 (84.3, 90.7)	92.1 (90.7, 93.4)

MUAC (cm)		Bangladesh	DRC	Ethiopia	Malawi	Nepal	Pakistan	South Africa
≤26.0	SENS	95.5 (95.0, 95.9)	89.9 (83.0, 94.7)	98.2 (95.7, 99.4)	63.2 (52.2, 73.3)	99.1 (98.4, 99.5)	29.0 (18.7, 41.2)	47.3 (40.4, 54.4)
	SPEC	9.0 (8.3, 9.7)	32.9 (29.8, 36.1)	5.5 (4.0, 7.5)	50.9 (47.6, 54.2)	2.3 (1.7, 3.1)	75.5 (71.4, 79.4)	63.4 (61.2, 65.5)
	PPV	56.5 (55.7, 57.3)	15.2 (12.6, 18.1)	29.1 (26.2, 32.2)	10.9 (8.3, 13.9)	38.0 (36.3, 39.7)	14.8 (9.3, 21.9)	11.6 (9.5, 14.0)
	NPV	61.6 (58.6, 64.5)	96.1 (93.2, 97.9)	88.4 (74.9, 96.1)	93.6 (91.1, 95.6)	80.7 (68.1, 90.0)	87.9 (84.3, 90.9)	92.2 (90.7, 93.6)
≤26.5	SENS	97.1 (96.7, 97.4)	89.9 (83.0, 94.7)	98.2 (95.7, 99.4)	70.1 (59.4, 79.5)	99.3 (98.7, 99.7)	34.8 (23.7, 47.2)	52.7 (45.6, 59.6)
	SPEC	6.4 (5.8, 7.0)	30.1 (27.1, 33.2)	5.5 (4.0, 7.5)	44.6 (41.3, 47.8)	1.4 (0.9, 2.0)	72.6 (68.3, 76.5)	57.2 (55.0, 59.4)
	PPV	56.2 (55.4, 57.0)	14.7 (12.2, 17.5)	29.1 (26.2, 32.2)	10.7 (8.3, 13.5)	37.8 (36.1, 39.5)	15.7 (10.3, 22.4)	11.1 (9.2, 13.2)
	NPV	64.0 (60.3, 67.5)	95.7 (92.6, 97.8)	88.4 (74.9, 96.1)	94.0 (91.4, 96.1)	77.1 (59.9, 89.6)	88.3 (84.7, 91.4)	92.3 (90.6, 93.7)

Note: MUAC cutoffs with results based on cell sizes of <10 are grayed out due to reduced reliability of the estimate.

3.4 Measures of Diagnostic Accuracy Using Meta-Analytic Methods

The ROC curve from the pooled dataset (**Figure 7**) shows a level of discrimination slightly better than chance. The AUROCC indicates that if a pair of women were selected at random—one who would deliver an LBW infant and one who would deliver a NBW infant—there is a 64.1% probability that the woman delivering an LBW infant would have a lower MUAC than the woman delivering a NBW infant. This pooled AUROCC is higher than the range of AUROCCs from the individual studies shown in Figure 6 (0.5736–0.6365).

Figure 7. ROC Curve from Pooled Dataset

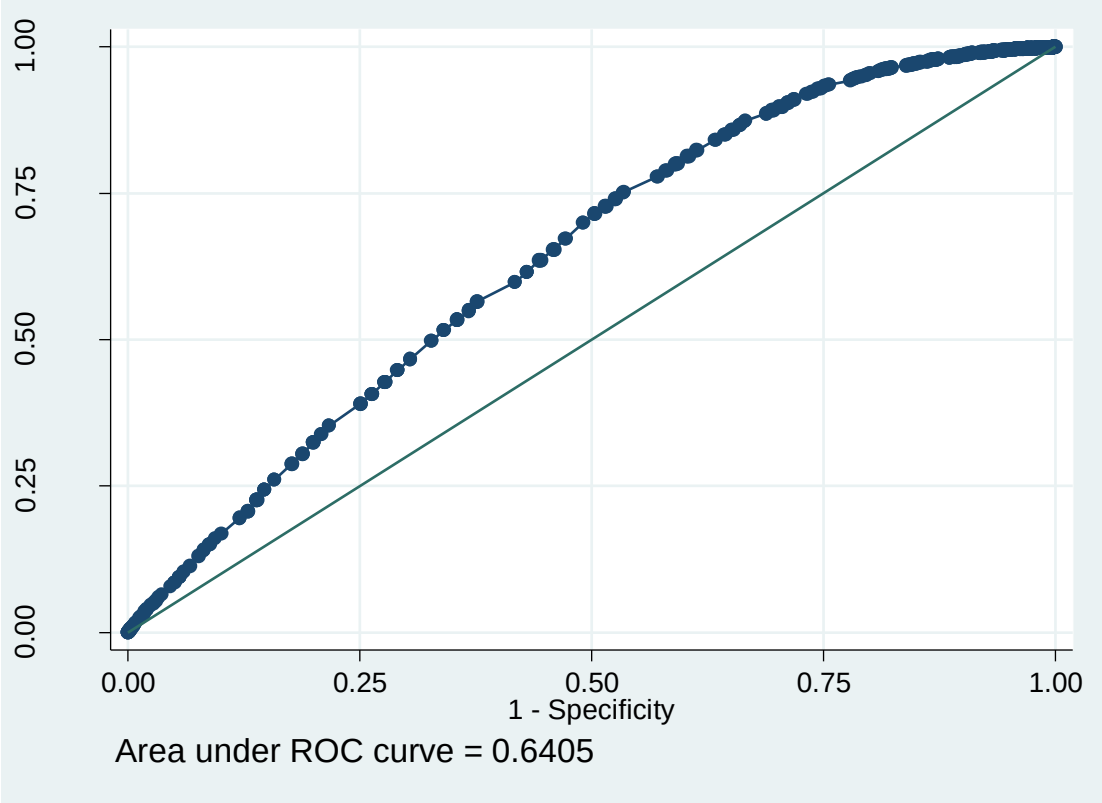


Table 16 shows the summary estimates of SENS and SPEC derived from this analysis. SENS and SPEC ranged from 2.3% and 99.0% at a MUAC cutoff of 19.0 cm to 88.8% and 20.2% at a MUAC cutoff of 26.5 cm.

Table 16. Estimates of SENS and SPEC at Selected MUAC Cutoffs, All Studies Combined

MUAC (cm)	SENS	SPEC
≤19.0[a]	2.3 (1.0, 5.0)	99.0 (97.4, 99.6)
≤19.5[a]	2.9 (1.2, 7.2)	98.4 (96.0, 99.4)
≤20.0	4.4 (1.6, 12.0)	98.4 (93.7, 99.6)
≤20.5	6.9 (2.8, 15.8)	97.5 (91.4, 99.3)
≤21.0	10.2 (3.9, 24.0)	95.3 (85.0, 98.6)
≤21.5	14.9 (6.4, 30.8)	92.4 (79.9, 97.4)
≤22.0	22.7 (10.2, 43.1)	87.2 (68.8, 95.4)
≤22.5	25.7 (11.0, 49.4)	83.0 (61.4, 93.7)
≤23.0	38.4 (18.6, 63.0)	73.4 (46.7, 89.7)
≤23.5	47.4 (25.1, 70.8)	66.7 (39.9, 85.8)
≤24.0	60.1 (33.2, 82.1)	54.1 (26.4, 79.5)
≤24.5	67.0 (38.9, 86.7)	46.8 (21.2, 74.3)
≤25.0	73.8 (44.8, 90.7)	38.9 (16.3, 67.5)
≤25.5	78.9 (50.8, 93.1)	33.2 (13.1, 62.1)
≤26.0	85.8 (59.8, 96.1)	24.3 (8.2, 53.6)
≤26.5	88.8 (64.7, 97.2)	20.2 (6.3, 48.6)

[a] No data available from Malawi study for this cutoff.

The above results show that, up to a cutoff of 23.0 cm, the number of false positives identified would be low, but the number of false negatives identified would be high. In other words, using a cutoff in this range would miss 60% or more of women at risk of having an LBW baby, but would correctly identify more than 73% of women who were not at risk of having an LBW baby. SENS greatly improves in the range of 24 cm and higher, but at the expense of SPEC. Using a cutoff in this higher range will identify a high proportion of women at risk of having an LBW infant (up to 89%), but will also increase the number of false positives that are identified to approximately 80% (at a MUAC cutoff ≤ 26.5).

4. Discussion

The purpose of this IPDMA was to determine whether a global MUAC cutoff could be recommended to assess malnutrition in pregnant women and consequently identify those at risk of delivering an LBW infant. We compiled data from seven studies of pregnant women, four from Africa and three from South Asia. For each study individually, and then summarized across all studies, we determined measures of diagnostic accuracy (SENS, SPEC, AUROCC, and the ROC curve) for every 0.5 cm across a range of MUAC values from 19.0 cm to 26.5 cm. The summary statistics used a bivariate random effects model to account for the heterogeneity between studies, and the models included MUAC as the only independent variable predicting an LBW outcome. Although there was quite a bit of heterogeneity between studies in terms of maternal characteristics (e.g., previous obstetric history, HIV status, timing of MUAC measurement during pregnancy, age), we did not attempt to control for any of these differences in our models, as our main objective was to examine the predictive ability of MUAC alone across settings where information on other factors may not be available or measurable.

We found that measures of SENS, SPEC, PPV, and NPV for all MUAC cutoffs varied greatly between individual studies, but that MUAC was similarly nondiscriminatory in its ability to distinguish pregnant women at risk and not at risk of delivering an LBW baby. AUROCCs ranged from 0.57 to 0.64 for individual studies and was 0.64 for all studies combined, which is generally in the "poor" range based on general interpretations for the AUROCC. Results of the meta-analysis (Table 16) showed that, across the lower range of MUAC cutoffs (19.0 cm to 23.0 cm), SPEC tended to be relatively high compared to SENS. In the higher range of MUAC cutoffs, SENS increased, but at the expense of SPEC.

Identifying the optimal MUAC cutoffs for moderate and severe malnutrition in pregnant women is a complex problem involving tradeoffs between the availability of resources to intervene or follow-up with a pregnant woman who is screened as being at risk, the effectiveness of different interventions, and the degree of expected improvement in health outcomes. If a cutoff with a high SENS is selected at the expense of SPEC, health care systems must have the ability to handle large numbers of false positives (women who are falsely identified as "at risk"). A MUAC cutoff that prioritizes a high SPEC will ultimately lead to significant proportions of women who are at risk but not identified as such. For example, based on the meta-analysis results, a MUAC cutoff of ≤23.0 would result in correctly identifying 38% of pregnant women at risk of delivering an LBW infant, while limiting the number of false positives to 27%. This might be an acceptable cutoff, but we need to keep in mind the lack of consistency between the studies included in this IPDMA. This cutoff would correctly identify only 8.7% of pregnant women at risk of delivering an LBW infant in Pakistan and would result in a false positive rate of 73% in Nepal. Based on the wide range of SENS and SPEC between studies, it may be difficult to recommend a MUAC cutoff that would be suitably discriminatory in all settings.

We explored the potential for developing cutoffs for different subgroups of the population. However, this analysis was limited by the relatively small number of datasets that we had available. Annex D shows the detailed results for each of the subgroups we analyzed. The subgroup analyses revealed some differences in diagnostic accuracy by pre- vs. post-pregnancy MUAC measurements, prevalence of LBW, and continent of study (Asia vs. Africa), but fewer differences by parity level and HIV status, which were the two subgrouping variables that were not included in all of the datasets in the analysis. MUAC cutoff levels for similar levels of SENS and SPEC were higher in studies that measured MUAC post-pregnancy compared to studies that measured MUAC pre-pregnancy. For example, at SENS=75% and SPEC=36%, the MUAC cutoff was 24 cm in pre-pregnancy studies and higher than 26.5 cm in post-pregnancy studies. In reality, the measurement of MUAC at or post-delivery does not help identify pregnant women who are

at risk of delivering an LBW infant (our outcome of interest). We included these datasets in our analyses at the outset under the assumption that MUAC does not change much at or post-delivery. However, our results presented here and in Annex A suggest that measurement of MUAC levels at or post-delivery may have a different diagnostic purpose and may not be relevant for our particular purpose. Removing these studies from the current analysis improves the SENS, but worsens the SPEC, across the entire range of cutoffs (comparison of Tables 16 and D1).

MUAC cutoff levels were also different by LBW prevalence (high vs. low) for the same levels of SENS and SPEC. For example, at SENS and SPEC around 70% and 35%, respectively, the MUAC cutoff was higher than 26.5 cm in studies with low prevalence of LBW and around 23.5 cm in studies with a high prevalence of LBW. Based on our subgroup analyses of Asian vs. African studies, it appears that MUAC cutoffs for similar levels of SENS and SPEC would be higher in African populations compared to Asian populations. This suggests that a different cutoff might be appropriate for each of these continents.

Many factors relating to the infant, the mother, and the physical environment can influence the duration of gestation and fetal growth during pregnancy.[52] Babies born with LBW can be either preterm (<37 weeks of gestation) or pathologically growth restricted, and the outcome of LBW does not distinguish between these two circumstances. SGA babies are those who are born with a birthweight below the 10th percentile for gestational age and sex. While not all SGA babies are pathologically growth restricted (some may just be constitutionally small and not at increased risk for perinatal mortality or morbidity), SGA can provide a more refined outcome measure that is more specific to the mother's nutritional status than LBW. However, obtaining an accurate measure of SGA is difficult in the field as it requires accurate measurements of both birth weight and gestational age. Four of the seven studies included in this IPDMA (Bangladesh, DRC, Nepal, and Pakistan) included measures of gestational age at birth. For all of these studies, estimates of gestational age at birth were difficult to obtain and not always accurate, usually based on self-reports of date of last menstrual period, rather than on more diagnostic criteria, such as fundal height or ultrasound. As a sub-analysis, we examined the diagnostic test accuracy of MUAC cutoffs for predicting SGA in these four studies to determine whether MUAC would be a more sensitive and specific predictor of SGA than LBW. The results of this analysis are shown in Annex E. We used the international standards for newborn weight, developed and published by the Newborn Cross-Sectional Study of the Intergrowth-21st Project,[53] to determine SGA based on the gestational age at birth, sex, and birth weight provided in the four datasets. The Intergrowth-21st Project has published birth weight standards by sex for gestational ages ranging from 33 weeks to 42 weeks+6 days. Data for mothers with gestational ages below or above this range were excluded from this analysis. We found that MUAC was not any better at discriminating between SGA and non-SGA infants based on our datasets. For individual studies, the AUROCCs were slightly lower for the outcome of SGA than they were for the outcome of LBW, and the values of SENS and SPEC varied widely between studies, similar to what we found for the outcome of LBW. The summary measures of SENS and SPEC across the range of MUAC cutoffs were poorer for the outcome of SGA than for the outcome of LBW.

This study had some limitations. Our initial systematic review identified 11 potential datasets, of which we were only able to obtain three for the IPDMA. The remaining four datasets in this analysis were obtained through word-of-mouth from discussions with our TAG. Although several geographical regions and settings from the African and Asian continents were represented in this analysis, the datasets may not be representative of those regions. In addition, readers should use caution when interpreting the subgroup analyses, which are affected by confounding, both measured and unmeasured. For example, Pakistan and South Africa, the two countries that had postpartum measures of MUAC, were also two of the countries with relatively low rates of LBW. Therefore, the subgroup results for pregnancy vs. postpartum

measurements could be attributable to other factors that make Pakistan and South Africa different from the other countries.

In summary, our results indicate that the recommendation of a global MUAC cutoff for pregnant women is not clear-cut. We recommend that countries and programs conduct a cost-benefit analysis (CBA) before adopting a specific MUAC cutoff. The CBA uses a simple-to-interpret summary measure (cost per impact achieved) as the common unit of measurement to weigh the costs of screening and treating all pregnant women identified as being at risk of delivering an LBW infant at each different MUAC cutoff against the cost savings of preventing an LBW birth outcome. Given the relative lack of discriminatory power of MUAC cutoffs that we found in this analysis, decision makers can use the data in Table 16 to balance the cost of screening too many pregnant women using MUAC cutoffs that have high SENS but low SPEC (thereby draining limited nutrition services) vs. the alternative of excluding too many pregnant women who need services but who were not identified due to the use of a MUAC cutoff with low SENS but high SPEC. In 2004, Alderman and Behrman conducted an economic analysis of the benefits of reducing LBW in resource-poor countries and estimated the cost savings to be approximately $580 per LBW outcome prevented.[54] While this figure was calculated over a decade ago and may be imperfect, it gives decision makers a ballpark figure on which to base their CBA.

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Annex A. Changes in MUAC during Pregnancy and Postpartum

Table A1. Summary of Studies Examining Changes in MUAC during Pregnancy and Postpartum

First Author, Year	Study population	Sample size	Age (mean±SD years)	Parity (mean±SD)	Timing of MUAC measurements (mean±SD weeks)	Baseline MUAC (mean±SD cm)	Endpoint MUAC (mean±SD cm) or Change in MUAC (±) (mean±SE cm)	Increase, decrease, or no significant change over time period (change in cm)
Changes during pregnancy								
Jansen, 1984 [43]	Kenya (rural)	813	26.3±6.6	3.4±2.9	TM2: 22.6±2.6 TM3: 33.0±3.5	TM2: 24.7±2.4	TM3: 24.5±2.1	Decrease (-0.2)
Maso, 1988 [39]	U.S. (urban), Black teens (age ≤17 years)	100 (90 NBW, 10 LBW)	NBW:15.5±0.8 LBW:15.8±0.9	All primigravidae[1]	TM2: 22.0±3.0 TM3: 32.0±3.0	TM2: 24.5±0.2 (NBW) 25.3±0.8 (LBW)	TM2 to TM3: +0.96±0.87 (NBW) +1.3±0.7 (LBW)	NBW: No change LBW: Increase
Piperata, 2002[36]	Colombia (urban), Low SES	46 (40 NBW, 4 LBW, 2 unknown)	25.6±5.0	1.6±1.4	TM2: 19.4±3.1 TM3: 32.0±3.8	TM2: 25.1±2.7	TM3: 25.2±2.4	No change (+0.1)
Piers, 1995 [37]	India (urban), mid- to upper SES	18	29.6±5.2	0.6±0.6	TM1: 12 TM2: 24 TM3: 34	TM1: 26.6±2.6	TM2: 27.2±2.5 TM3: 27.4±2.4	TM1 to TM2: No change (+0.6) TM1 to TM3: No change (+0.8 cm)
Lakhani, 1982 [38]	Kenya (urban), middle income Indian women	52 (28 veg, 24 non-veg)	---	≤4	TM2: 26 TM3: 36	TM2: 25.7±2.2 (veg) 26.4±3.8 (non-veg)	TM3: 26.0±2.2 (veg) 26.7±3.6 (non-veg)	Veg: No change (+0.3) Non-veg: No change (+0.3)
Mahaba, 2001 [42]	Egypt (urban)	830	---	43.5% primigravidae, 8.4% ≥4	TM1: 9-12 TM3: 37-40	TM1: 26.8 (90% between 22-23 cm)	TM3: 27.6 cm (90% between 23-34.5 cm)	Increase (+0.8; no significance testing done)

First Author, Year	Study population	Sample size	Age (mean±SD years)	Parity (mean±SD)	Timing of MUAC measurements (mean±SD weeks)	Baseline MUAC (mean±SD cm)	Endpoint MUAC (mean±SD cm) or Change in MUAC (±) (mean±SE cm)	Increase, decrease, or no significant change over time period (change in cm)
Lopez, 2011 [41]	Argentina (urban)	1,066	27.0±5.8	1.04±1.2	TM1: <16 weeks TM2: 28±2 weeks TM3: 36±2 weeks	TM1: 25.7±3.3	TM1 to TM2: +1.1±0.5 TM2 to TM3: +0.6±0.5	TM1 to TM2: Increase TM2 to TM3: Increase
Changes from pregnancy to postpartum								
Rah, 2008 [44]	Bangladesh (rural)	162	12-19 years; 16.4±1.6	All primigravidae	TM1: 10.1±2.8 PP: 6 months	TM1: 23.4±1.7	TM1 to PP: -0.58±0.09	Decrease
Katz, 2010 [40]	Nepal (rural)	2,487	≤25 years	All nulliparous[2]	TM1/TM2: 16 (median) TM3: 31 (median) PP: 12.6 weeks (median)	TM1/TM2: 21.9±1.7	TM1/TM2 to TM3: +0.21±0.16 TM3 to PP: -0.94±0.23	TM1/TM2 to TM3: No change TM3 to PP: Decrease
Okechukwu, 2009 [45]	Nigeria (urban)	527 (322 EBF, 205 non-EBF)	EBF: 27.0±5.0 Non-EBF: 26.5±3.7	EBF: 3.0±1.0 Non-EBF: 3.0±2.1	PP: 7th day PP: 6 months	7th day PP: 23.8±4.6 (EBF) 22.6±3.8 (non-EBF)	6 months PP: 21.0±3.3 (EBF) 24.9±7.0 (Non-EBF)	EBF: Decrease (-2.8 cm) Non-EBF: No change (-2.3 cm)

Abbreviations: SD=standard deviation; cm=centimeters; TM1= 1st trimester; TM2 = 2nd trimester; TM3= 3rd trimester; NBW=normal birth weight; LBW=low birth weight; EBF=exclusive breast feeding; PP=postpartum; veg=vegetarian

[1] Primigravidae: first time pregnancies

[2] Nulliparous: Not given birth previously

Annex B. Descriptions of Studies by Country

Bangladesh

Reference source. Kabir, A.; Merrill, R.D.; Shamim, A.A.; et al. 2014. "Canonical correlation analysis of infant's size at birth and maternal factors: a study in rural Northwest Bangladesh." *PLoS ONE*. 9: e94243.

Study population. The data in this study were collected during a field-based double-masked, cluster randomized, placebo-controlled trial assessing the efficacy of maternal vitamin A or β-carotene supplementation on maternal and infant mortality through 6 months of age. The study was conducted in two rural northwestern districts of Bangladesh, where married women of reproductive age were enumerated and five weekly surveillances were conducted to determine menstrual history. Women who reported having missed their menstrual period in the past 30 days were given a spot pregnancy test and enrolled into the study if pregnancy was confirmed and consent received. A total of 59,721 pregnant women consented and enrolled in the trial.

Upon enrollment (usually during the first trimester), women were measured for MUAC and interviewed about household socioeconomic conditions, education, demographic characteristics, previous pregnancy history, frequencies of dietary intake, and morbidity in the past 7 days.

Anthropometric measurements were taken on 16,290 infants of mothers who consented to take part in a placebo-controlled newborn vitamin A supplementation trial that was nested into the latter half of the maternal trial. Data from 16,108 of these infants were included in the current analysis. Measurements (usually taken within 72 hours of birth) included weight, length, MUAC, and head and chest circumferences. Birth weight was measured to the nearest 10 g using a Tanita BD-585 digital pediatric scale (Tanita Corporation, Tokyo, Japan).

Table B1a. Summary of maternal measures (Bangladesh), N=16,108
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

MUAC (cm)	23.0 ± 2.0 (14.6–35.6), 22.9 (21.6, 24.2)
Height (cm)	---
Weight (kg)	---
Age (years)	21.9 ± 5.9 (9–48), 21 (17, 26)
Parity	
0	6982 (43.3%)
1–2	6603 (41.0%)
3–4	1979 (12.3%)
5–6	402 (2.5%)
7+	142 (0.9%)
Education	
No schooling	6671 (41.4%)
Primary	3647 (22.7%)
Secondary	4897 (30.4%)
Vocational/higher secondary	882 (5.5%)

Table B1b. Summary of infant measures (Bangladesh), N=16,108
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

Male	8205 (50.9%)
Birth weight (g)	2433 ± 425 (750–4370), 2440 (2170, 2710)
Low birth weight	8906 (55.3%)

Democratic Republic of Congo (DRC)

Reference source. Edmonds, A.; Feinstein, L.; Okitolonda, V.; et al. 2015. "Implementation and Operational Research: Decentralization Does Not Assure Optimal Delivery of PMTCT and HIV-Exposed Infant Services in a Low Prevalence Setting." *J Acquir Immune Defic Syndr.* 1:e130-9.

Study population. The data for this study were taken from the U.S. Centers for Disease Control and Prevention-funded HIV prevention, care, and treatment activities conducted by the University of North Carolina at Chapel Hill in partnership with the Kinshasa School of Public Health. The activities (entitled "PACT: Providing AIDS Care and Treatment in the Democratic Republic of Congo under the President's Emergency Plan for AIDS Relief") were designed to support HIV prevention, treatment, and care programs for children and adults, including patients co-infected with tuberculosis and HIV and prevention of mother-to-child transmission of HIV. The program was funded from 2003 to 2013.

Pregnant women identified as HIV-positive during antenatal care or at labor and delivery at any of the maternities in Kinshasa were referred to one of two centralized HIV care and treatment (C&T) sites for comprehensive HIV C&T, including prevention of mother-to-child transmission of HIV. The women in this dataset were pregnant women at the C&T sites who arrived at one of the two sites for C&T during their current pregnancy, during a previous pregnancy, or through a previous HIV-positive child. Mother-infant linkages were constructed using routinely assigned unique patient codes. Each woman's record contained her own patient code, as well as a list of patient codes for family members also receiving care in the University of North Carolina at Chapel Hill DRC program. Therefore, the dataset included data from multiple clinic visits per woman who could be linked to one or more infants. For the purposes of this analysis we chose the earliest clinic visit with a maternal MUAC measurement recorded. There were 852 mothers linked to one infant, 145 mothers linked to 2 infants, and 10 mothers linked to 3 infants. To align with the other datasets in the IPDMA, we randomly selected a single mother-infant pair for each of the 155 mothers who were linked to more than one infant in the dataset. This resulted in data from 1,007 unique mother-infant pairs. Infant birth weight was measured at most sites using a manual weight scale.

Table B2a. Summary of maternal measures (DRC), N=1,007
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

MUAC (cm)	25.2±3.4 (15.5–47.0), 25 (23, 27)
Height (cm)	161.7±6.6 (140.0–188.5), 162 (157, 166)
Age (years)	30.6±5.4 (14.3–45.1), 30.8 (26.4, 34.1)

Table B2b. Summary of infant measures (DRC), N=1,007
Mean ± SD, (Min–Max), Median (25th, 75th) or N (%)

Birthweight (g)	3063±555 (1200–5250), 3040 (2700, 3400)
Low birthweight	119 (11.8%)

Ethiopia

Reference source. Assefa, N.; Berhane, Y.; and Worku, A. 2012. "Wealth status, mid upper arm circumference (MUAC) and antenatal care (ANC) are determinants for low birth weight in Kersa, Ethiopia." *PloS ONE*. 7: e39957.

Study population. The study was conducted in two urban towns and 10 rural *kebeles* (smallest administrative units in Ethiopia, with average population of 5,000). Participants of the study were part of the pregnancy surveillance initiated in the Kersa Demographic Surveillance and Health Research Center field site. Pregnant women were followed monthly and, as necessary, on a weekly basis. Village informants notified the data collectors on the day of deliveries and infant measurements were taken within 24 hours of birth. Questionnaires were administered by the data collectors.

Newborns were weighed naked or in minimal clothing to the nearest 100 g using a a hanging weight scale(Salter Model 235-6S, Brecknell, West Midlands, UK) and following standard techniques.

Table B3a. Summary of maternal measures (Ethiopia), N=956
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

MUAC (cm)	22.6±2.1 (11–32), 23 (21, 24)
Height (cm)	160.2±8.1 (130–200), 160 (155, 165)
Weight (kg)	54.7±6 (35–83), 55 (50, 59)
Age (years)	28.5±7 (15–49), 28 (25, 32)
Parity	
0	111 (11.6%)
1–2	297 (31.1%)
3–4	262 (27.4%)
5–6	164 (17.2%)
7+	122 (12.8%)
Education	
Illiterate	812 (84.9%)
No formal education	27 (2.8%)
Formal education	117 (12.2%)

Table B3b. Summary of infant measures (Ethiopia), N=956
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

Male	492 (51.5%)
Birth weight (g)	2829±851 (700–4700), 2900 (2400, 3500)
Low birth weight	271 (28.3%)

Malawi

Reference source. Ramlal, R.T.; Tembo, M.; Soko, A.; et al. 2012. "Maternal mid-upper arm circumference is associated with birth weight among HIV-infected Malawians." *Nutr Clin Pract.* 27: 416–421.

Study population. The study included 1,005 HIV-infected women enrolled in the Breastfeeding, Antiretrovirals, and Nutrition Study who delivered live singleton births between June 2004 and December 2006. The study was a postnatal clinical trial that evaluated the effectiveness of two interventions for the prevention of mother-to-child HIV transmission during breastfeeding in a factorial design: a maternal nutritional intervention and a maternal and infant antiretroviral intervention. Participants were recruited from four sites with outreach to all pregnant women in Lilongwe, Malawi. Prenatal screening criteria included the following: age ≥14 years, no prior antiretroviral medication use, ≤30 weeks gestation, no serious complications of pregnancy, CD4 count ≥200 cells/μL, hemoglobin ≥7 g/dL, and normal serum liver function tests (≤2.5 times the upper limit of normal). Of the 1,130 eligible women who completed a baseline interview, underwent a physical examination, and provided blood specimens, 125 were excluded due to fetal loss, stillbirth, twins, or late presentation to the clinic (>48 hours after delivery).

Table B4a. Summary of maternal measures (Malawi), N=1,005
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

MUAC (cm)	26.5±2.7 (20–47), 26 (24.7, 28)
Height (cm)	155.9±5.3 (139.9–175.5), 155.6 (152.1, 159.2)
Weight (kg)	58.8±8.2 (38.2–123), 58.1 (53.2, 63.1)
Age (years)	26.1±5.0 (16–44), 25 (22, 29)
Parity	
0	183 (18.2%)
1–2	590 (58.7%)
3–4	191 (19%)
5–6	38 (3.8%)
7+	3 (0.3%)
Education	
None	125 (12.4%)
Primary	529 (52.6%)
Secondary	351 (34.9%)

Table B4b. Summary of infant measures (Malawi), N=1,005
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

Male	513 (51%)
Birth weight (g)	2998±440 (1400–5000), 3000 (2700, 3300)
Low birth weight	87 (8.7%)

Basic sociodemographic information was collected at the baseline interview (age, parity, education level, etc.). CD4 count was measured cross-sectionally during the first screening visit. All women received iron and folate supplements, malaria prophylaxis and treatment, and mosquito nets. None of the women took antenatal antiretrovirals during this or prior pregnancies. As of December 2005, all pregnant women with CD4 counts <500 cells/μL were administered cotrimoxazole after the first trimester. At onset of labor, all women received the HIVNET 012 regimen and a 7-day postnatal "tail" of zidovudine and lamivudine to prevent perinatal HIV transmission.

Maternal MUAC was measured at each visit by trained study nutrition staff. For the current IPDMA, we included the first available MUAC measurement for each woman. MUAC was measured at the midpoint between the olecranon and acromion process, to the nearest 0.1 cm, using a non-stretchable insertion tape

while the arm hung freely at the side. The mean of three separate MUAC determinations at each visit was used for analyses.

Infant birth weight was measured using a Tanita Digital Baby Scale (Tanita, Arlington Heights, IL, USA) to the nearest 0.1 kg immediately after delivery in the hospital or within 48 hours of delivery for home deliveries.

Nepal

Reference source. Christian, P.; Khatry, S.K.; Pradhan, E.K.; et al. 2003. "Effects of alternative maternal micronutrient supplementation on low birth weight in rural Nepal: double-blind randomized community trial." *Brit Med J.* 326:571

Study population. The data for this study were collected during a cluster-randomized, double-blind trial conducted in the southern rural plains district of Sarlahi, Nepal, from December 1999 through April 2001. The trial evaluated the effect of prenatal and postnatal maternal micronutrient supplementation on birth weight, fetal loss, and early infant mortality. The trial contained five arms: 1) vitamin A (1,000 µg of RE); 2) vitamin A and folic acid (400 µg); 3) vitamin A, folic acid, and iron (60 mg); 4) vitamin A, folic acid, iron, and zinc (30 mg); and 5) vitamin A, folic acid, iron, zinc, and multiple micronutrients.

Baseline interviews were conducted and maternal weight, height, and MUAC were measured in the home by trained anthropometrists on study enrollment. A birth assessment was conducted after delivery in the home. The assessment included determination of vital status, maternal and infant morbidity during labor and delivery, and infant anthropometry. Recumbent length was measured to the nearest 0.1 cm on a length board (Shorr Infant Measuring Board, Shorr Productions, RI, USA). Infant weight was measured to the nearest 2 g on a digital scale (Seca 727, Seca GmbH, Hamburg, Germany).

Maternal and infant measurements (excluding weight) were recorded three times and the median value was used. LBW was defined as weight <2,500 g measured within 72 hours of birth. Gestational age was calculated using data from both the maternal report of last menstrual period and the date of the positive pregnancy test result.

A total of 4,926 pregnant women were enrolled in the trial. The current IPDMA includes 3,170 participants with a live singleton birth recorded; infant anthropometry measured within 72 hours of birth; and non-missing values for birth weight, gestational age, and maternal MUAC at first trimester.

Table B5a. Summary of maternal measures (Nepal), N=3,170
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

MUAC (cm)	21.8±1.8 (16.6–31.1), 21.7 (20.5, 23)
Height (cm)	150.4±5.5 (128.1–182.1), 150.3 (146.7, 154.1)
Weight (kg)	43.5±5.5 (26.6–67.7), 43.2 (39.7, 46.7)
Age (years)	23.4±5.7 (10–43), 23 (19, 27)
Parity	
0	766 (24.2%)
1–2	1224 (38.6%)
3–4	726 (22.9%)
5–6	318 (10%)
7+	136 (4.3%)
Education	
No schooling	2586 (81.7%)
Primary education	190 (6%)
Secondary education	214 (6.8%)
Vocational/higher secondary	177 (5.6%)

Table B5b. Summary of infant measures (Nepal), N=3,170
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

Male	1596 (50.4%)
Birth weight (g)	2632±428 (1056–4454), 2634 (2358, 2910)
Low birth weight	1193 (37.6%)

Pakistan

Reference source. Janjua, N.Z.; Delzell, E.; Larson, R.R.; et al. 2009. "Determinants of low birth weight in urban Pakistan." *Public Health Nutrition.*12(6): 789–798.

Study population. This study was conducted in Karachi, the main port and the industrial and trade center of Pakistan, between January and August 2005. The subjects were recruited at two tertiary care hospitals located in the inner city and comprised low- and middle-income patients from various parts of the city. Karachi has the potential for high lead exposure from various environmental sources, such as automobiles, industrial emissions, and occupational exposures. Eligible subjects were women who were admitted for delivery in one of the two study hospitals, planned to deliver a singleton at term (37–42 weeks of gestation), were residents of Karachi for at least 1 year, and were willing to participate in the study. Ten mothers who registered for delivery at the study hospitals were randomly selected each day and invited for eligibility screening. Mothers were excluded if they had physician diagnoses of psychiatric morbidity, kidney or cardiac disease, history of repeated urinary tract infections, sickle cell anemia, thyrotoxicosis, autoimmune diseases, drug dependence, steroid intake during pregnancy, antepartum hemorrhage, placental abnormalities, pre-eclampsia, or a fetus with congenital abnormalities.

Trained registered nurses conducted interviews on sociodemographic factors, obstetric history, diet during pregnancy, and sources of lead exposure. Maternal interviews were conducted both before and after delivery depending on the mother's condition. Maternal weight, height, and MUAC were measured after delivery. Three measurements of MUAC were taken on the non-dominant arm and the mean was calculated. Infant anthropometrics were measured within 12 hours of birth. Birth weight was measured using an infant pan scale, length using a flat board, and head and chest circumferences using a non-stretchable tape.

Table B6a. Summary of maternal measures (Pakistan), N=540
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

MUAC (cm)	29±4 (17.6–40.0), 29 (26.1, 32)
Height (cm)	156.3±6.5 (127.0–198.5), 157 (152, 160)
Weight (kg)	59.9±10.6 (23–91), 59 (52, 67)
Age (years)	25.3±4.6 (16–42), 25 (22, 28)
Parity	
0	213 (39.4%)
1–2	236 (43.7%)
3-4	79 (14.6%)
5–6	10 (1.9%)
7+	2 (0.4%)
Education	
≤5 years	177 (32.8%)
6–12 years	328 (60.7%)
>12 years	35 (6.5%)

Table B6b. Summary of infant measures (Pakistan), N=540
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

Male	289 (53.5%)
Birth weight (g)	2979±505 (1600–7200), 3000 (2700, 3200)
Low birth weight	69 (12.8%)

Of 807 mothers screened, 565 were eligible. Of these, 25 were missing data on the outcome or a major portion of the interview, resulting in 540 observations available for this analysis. There was one extreme value of birth weight (7200 g) that could not be verified; this observation was therefore dropped from the dataset resulting in a sample size of 539 for all subsequent analyses.

South Africa

Reference source. Chetty, T.; Carter, R.J.; Bland, R.M.; et al. 2014. "HIV status, breastfeeding modality at 5 months and postpartum maternal weight changes over 24 months in rural South Africa." *Trop Med Int Health.* 19(7): 852–862.

Study population. The data for this study were collected from the Vertical Transmission Study (VTS), a non-randomized intervention cohort study in KwaZulu-Natal, South Africa. The VTS was designed to investigate the effects of infant feeding practices of HIV-infected women on HIV transmission and infant survival. Between 2001 and 2004, 3,445 women were enrolled during pregnancy from rural and peri-urban clinics. Eligibility for the VTS included age ≥16 years, minimum of 3 months of residence within the study area postpartum, and written informed consent. Antenatally, lay counsellors visited enrolled women at home to discuss study logistics and collect sociodemographic and pregnancy data. Blood was collected antenatally and 6 months postpartum for assessment of CD4+ cell count and HIV ribonucleic acid viral load. No VTS mothers received antiretroviral drugs during pregnancy or during the year after pregnancy, as treatment was unavailable in the government health services before late 2004.

Table B7a. Summary of maternal measures (South Africa), N=2,247
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

MUAC (cm)	27.6±3.7 (16–46), 27.1 (25, 29.6)
Height (cm)	158.6±6.2 (138–179), 158 (155, 163)
Weight (kg)	63.4±13.9 (0.9–114.3), 62.2 (55.9, 70)
Age (years)	25.1±6.4 (16–54), 24 (20, 29)
Education	
None	135 (6%)
Primary	780 (34.7%)
Secondary	1332 (59.3%)
HIV status	
Negative	1152 (51.3%)
Positive	1090 (48.5%)
Indeterminate	5 (0.2%)

Table B7b. Summary of infant measures (South Africa), N=2,247
Mean ± SD (Min–Max), Median (25th, 75th) or N (%)

Male	1125 (50.1%)
Birth weight (g)	3104±494 (800–5500), 3100 (2800, 3450)
Low birth weight	207 (9.2%)

Women who delivered outside of the VTS facility were encouraged to attend the clinic as soon as it was feasible; women were also encouraged to attend the clinic around 6 weeks postpartum, but could attend earlier if more convenient. From 6 weeks postpartum, study nurses assessed women monthly for 9 months, then every 3 months, up to 24 months. At each clinic visit, medical history was documented, and women were measured using standard equipment. Women's height was measured without shoes to the nearest centimeter using a stadiometer. Weight was measured to the nearest 100 g using a calibrated electronic digital scale (Scales 2000, Durban, South Africa). Two separate weight, height, and MUAC measurements were taken at every clinic visit. The mean of the two measures were used in the analyses. For the current IPDMA, we used the first measurement of the mother's MUAC that was available in the dataset. The mean number of days postpartum that MUAC was measured was 52 days (SD=61 days, median=44 days; interquartile range=41 to 49 days; range=1 to 1,541 days).

Study staff at the health facilities weighed and measured the infants as soon as possible after birth using standard equipment. If measurements could not obtained from the infant within 72 hours of delivery (e.g., if the mother had moved out of the area to be with relatives for the delivery), then measurements were abstracted from the local clinic or hospital service measurements that were recorded in the child's health card.

The current dataset includes 2,247 women enrolled in the VTS with non-missing maternal MUAC and infant birth weight measurements. Of these, 1,090 (48.5%) were HIV-positive, 1,152 (51.3%) were HIV-negative, and 5 (0.2%) had indeterminate HIV status.

Annex C. Cumulative Sample Sizes by MUAC Cutoff and Study

Table C1. Cumulative Sample Sizes by MUAC Cutoff and Study

MUAC	Bangladesh	DRC	Ethiopia	Malawi	Nepal	Pakistan	South Africa
≤19.0	209	14	42	0	170	2	5
≤19.5	453	20	42	0	324	2	8
≤20.0	835	40	108	1	500	4	10
≤20.5	1516	48	108	3	803	6	14
≤21.0	2382	86	246	6	1079	9	22
≤21.5	3747	119	246	15	1445	12	45
≤22.0	5277	178	452	32	1765	18	71
≤22.5	7072	219	452	39	2138	23	102
≤23.0	8758	310	679	78	2396	37	153
≤23.5	10502	346	679	118	2641	51	222
≤24.0	11854	445	845	201	2818	66	308
≤24.5	13036	490	845	245	2958	80	441
≤25.0	13912	588	858	330	3031	95	559
≤25.5	14596	611	858	393	3080	114	700
≤26.0	15059	703	913	506	3113	135	845
≤26.5	15389	728	913	570	3135	153	982

Annex D. Detailed Results of Subgroup Analyses

Subgroup Analysis: Pre- and Post-Pregnancy MUAC Measurement

There were five studies (Bangladesh, DRC, Ethiopia, Malawi, and Nepal) that measured maternal MUAC at various trimesters during the prenatal period and two studies (Pakistan and South Africa) that measured maternal MUAC in the postnatal period (up to 6 weeks postpartum). The following figure and tables present the measures of diagnostic accuracy stratified by pre- vs. post-pregnancy MUAC measurement. This subgroup variable is at the study level and thus estimates are presented for the pooled data only and are based on meta-analysis models.

Figure D1. Scatterplot of Birthweight by MUAC, Stratified by Studies Measuring MUAC during the Pre- vs. Post-Pregnancy Period

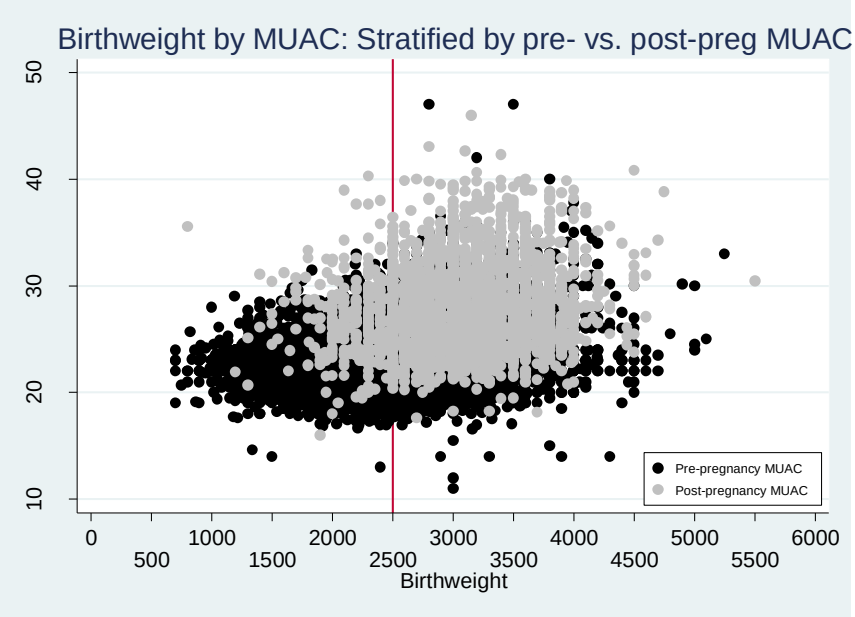
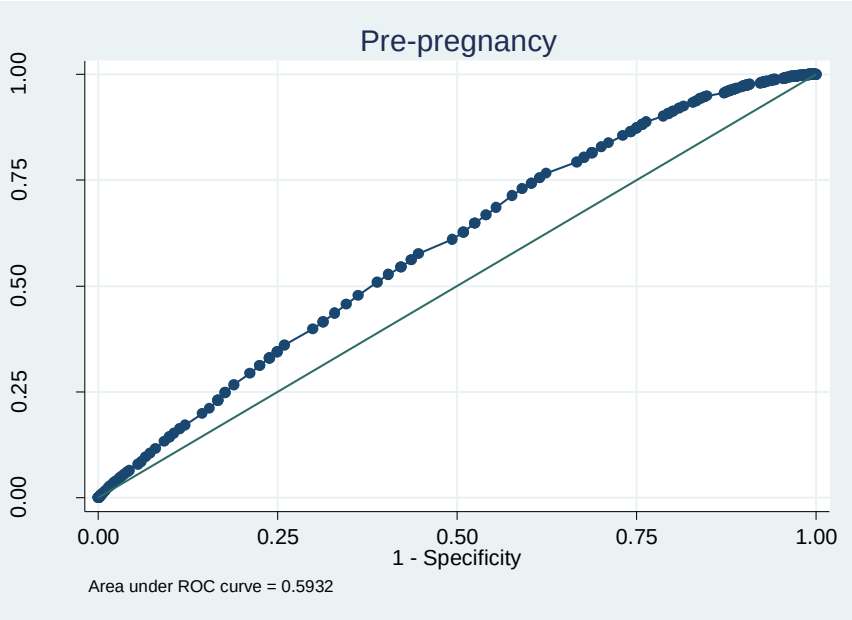


Figure D2. ROC Curves by Pre- vs. Post-Pregnancy Studies



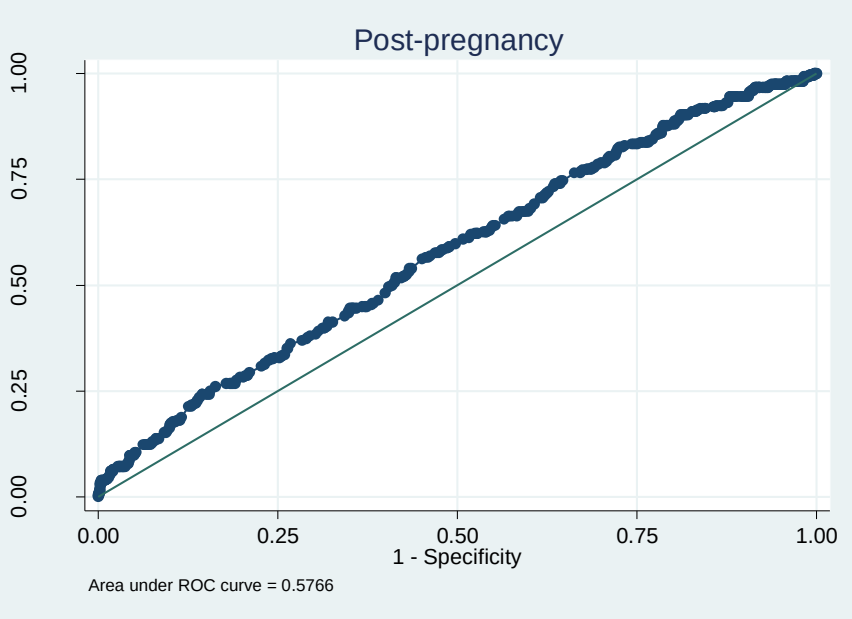


Table D1. Estimated Sensitivities, Specificities, and Diagnostic Odds Ratios for Studies That Measured Maternal MUAC in: a) Pre-Pregnancy and b) Post-Pregnancy Periods (Values Expressed as % (95% CI))

a. Pre-pregnancy: (n=22,246)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	3.9 (2.1, 7.1)	98.1 (96.1, 99.1)
≤19.5	5.7 (3.1, 10.2)	96.8 (94.1, 98.2)
≤20.0	5.2 (1.2, 19.2)	96.8 (87.2, 99.3)
≤20.5	7.8 (2.3, 23.7)	95.1 (83.5, 98.7)
≤21.0	13.3 (3.9, 36.7)	90.9 (72.7, 97.4)
≤21.5	19.8 (7.4, 43.2)	86.4 (66.9, 95.3)
≤22.0	32.2 (24.5, 41.0)	77.3 (68.6, 84.2)
≤22.5	38.2 (17.4, 64.5)	72.0 (44.7, 89.1)
≤23.0	54.1 (29.9, 76.5)	58.4 (30.8, 81.6)
≤23.5	62.6 (40.0, 80.8)	51.0 (25.4, 76.0)
≤24.0	75 (51.4, 89.5)	36.1 (15.1, 64.2)
≤24.5	80.6 (57.9, 92.6)	30.1 (11.7, 58.3)
≤25.0	86.1 (66.3, 95.1)	23.4 (9.0, 48.7)
≤25.5	89.3 (71.7, 96.5)	19.5 (6.9, 44)
≤26.0	93.8 (81.7, 98.1)	12.6 (4.0, 33.1)
≤26.5	95.4 (85.4, 98.7)	10.2 (3.0, 29.1)

b. Post-pregnancy: (n=2,786)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	1.1 (0.4, 3.3)	99.8 (99.6, 100)*
≤19.5	1.4 (0.5, 3.7)	99.8 (99.5, 99.9)*
≤20.0	2.5 (1.2, 5.2)	99.7 (99.4, 99.9) *
≤20.5	3.3 (1.7, 6.1)	99.6 (99.2, 99.8)
≤21.0	4.0 (2.0, 7.0)	99.2 (98.8, 99.5)
≤21.5	5.4 (3.3, 8.8)	98.3 (97.7, 98.8)
≤22.0	7.2 (4.7, 11.0)	97.3 (96.5, 97.8)
≤22.5	8.0 (5.3, 11.8)	95.9 (95.0, 96.6)
≤23.0	12.3 (8.9, 16.7)	93.8 (92.8, 94.7)
≤23.5	15.2 (11.4, 20.0)	90.8 (89.6, 91.9)
≤24.0	21.4 (16.9, 26.6)	87.5 (86.1, 88.7)
≤24.5	25.4 (19.3, 32.7)	83.4 (79.7, 86.6)
≤25.0	30.8 (25.4, 36.6)	77.3 (75.6, 79.0)
≤25.5	37.0 (31.2, 42.9)	71.6 (69.8, 73.4)
≤26.0	38.0 (25.1, 52.8)	69.6 (60.4, 77.4)
≤26.5	43.7 (30.0, 58.4)	65.0 (53.6, 75.0)

Note: Grayed out values were unable to be estimated using meta-analysis commands in Stata and are based on ordinary logistic regression analysis only.

* Estimate based on sample size <20.

Subgroup Analysis: Low vs. High Prevalence of Low Birth Weight

The prevalence of LBW was highly variable between the studies. There were three studies that had relatively high prevalence of LBW (Bangladesh: 55.3%, Ethiopia: 28.3%, and Nepal: 37.6%) compared to the remaining studies with lower prevalence (DRC: 11.8%, Malawi: 8.7%, Pakistan: 12.8%, and South Africa: 9.2%). In this section, we examine differences in the ROC characteristics by subgroup of high vs. low prevalence of LBW. This subgroup variable is at the study level and thus estimates are provided for the pooled data only and are based on meta-analysis models.

Figure D3. Scatterplot of Birthweight by MUAC, Stratified by High vs. Low Prevalence of LBW

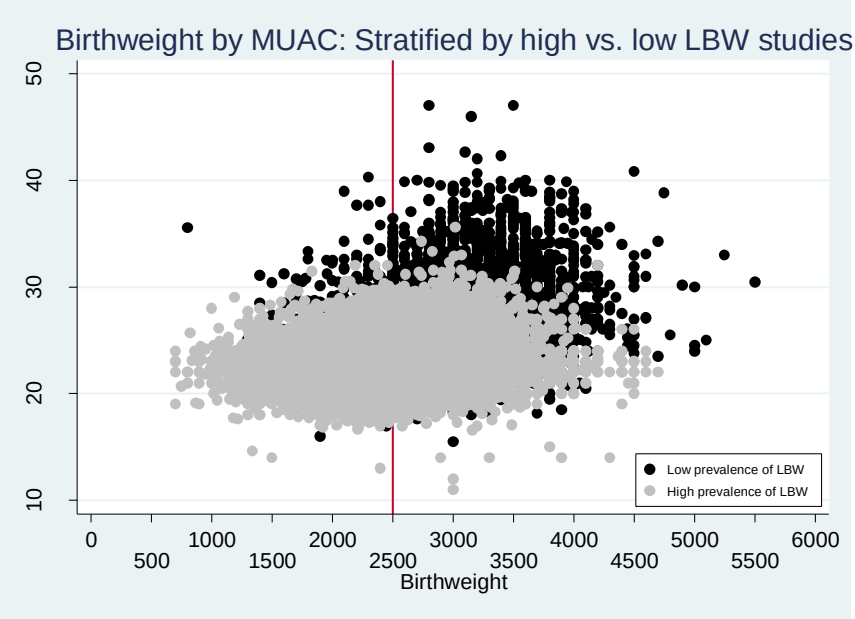
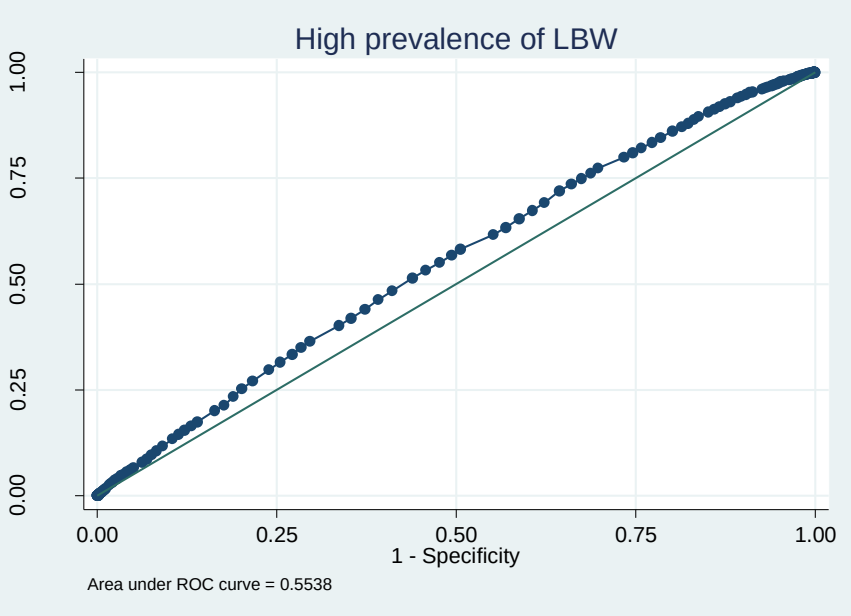


Figure D4. ROC Curves by Studies with High vs. Low Prevalence of LBW



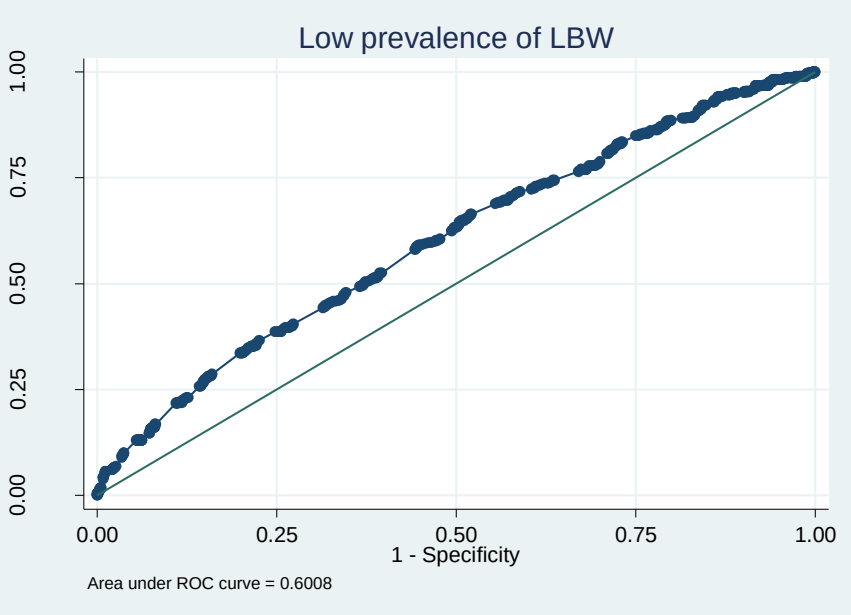


Table D2. Estimated Sensitivities, Specificities, and Diagnostic Odds Ratios for Infant LBW by Selected Maternal MUAC Cutoffs (Values Expressed as % (95% CI))

a. Low LBW prevalence: (n=4,798)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	1.7 (0.6, 4.4)	99.7 (98.9, 99.9)
≤19.5	1.7 (0.7, 3.2)	99.5 (99.2, 99.7)
≤20.0	2.6 (0.9, 7.9)	99.6 (98.2, 99.9)
≤20.5	3.9 (1.6, 9.2)	99.3 (97.8, 99.8)
≤21.0	6.2 (4.2, 8.8)	97.8 (97.4, 98.3)
≤21.5	7.6 (3.9, 14.4)	97.5 (93.9, 99.0)
≤22.0	13.1 (10.2, 16.4)	94.5 (93.8, 95.2)
≤22.5	12.3 (6.0, 23.6)	94.1 (87.7, 97.3)
≤23.0	21.8 (18.2, 25.7)	89.0 (88.1, 90.0)
≤23.5	25.7 (21.9, 29.9)	85.8 (84.7, 86.8)
≤24.0	33.6 (29.4, 38.0)	80.1 (78.9, 81.3)
≤24.5	38.6 (34.2, 43.1)	75.2 (73.9, 76.5)
≤25.0	44.4 (39.9, 49.0)	68.5 (67.1, 69.9)
≤25.5	49.4 (44.8, 53.9)	63.4 (61.9, 64.8)
≤26.0	60.0 (33.2, 81.9)	56.0 (39.8, 71.1)
≤26.5	62.4 (58.0, 66.8)	50.6 (49.1, 52.1)

b. High LBW prevalence: (n=20,234)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	2.5 (2.2, 2.8)	98.4 (98.1, 98.6)
≤19.5	4.7 (4.3, 5.2)	96.7 (96.3, 97.0)
≤20.0	8.0 (7.5, 8.5)	93.8 (93.3, 94.3)
≤20.5	13.4 (12.8, 14.1)	89.5 (88.9, 90.1)
≤21.0	20.1 (19.4, 20.9)	83.6 (82.9, 84.3)
≤21.5	29.7 (28.8, 30.6)	76.1 (75.3, 76.9)
≤22.0	40.2 (39.3, 41.2)	66.3 (65.4, 67.3)
≤22.5	51.4 (50.5, 52.4)	56.1 (55.1, 57.1)
≤23.0	61.6 (60.7, 62.6)	44.8 (43.8, 45.8)
≤23.5	72 (71.2, 72.9)	35.6 (34.7, 36.6)
≤24.0	88.5 (80.1, 93.6)	17.9 (10.6, 28.7)
≤24.5	91.9 (85.5, 95.6)	13.9 (8.2, 22.5)
≤25.0	90.7 (90.1, 91.2)	14.9 (14.2, 15.6)
≤25.5	95.8 (91.6, 97.9)	8.2 (4.2, 15.5)
≤26.0	97.9 (95.3, 99.1)	4.9 (2.6, 9.1)
≤26.5	98.3 (96.4, 99.2)	3.6 (1.7, 7.8)

Note: Grayed out values were unable to be estimated using meta-analysis commands in Stata and are based on ordinary logistic regression models.

Subgroup Analysis: Asia vs. Africa

This subgroup analysis compares measures of diagnostic accuracy between the three studies in Asia (Bangladesh, Nepal, and Pakistan) and the four studies in Africa (DRC, Ethiopia, Malawi, and South Africa). This subgroup variable is at the study level and thus estimates are provided for pooled data only and are based on meta-analysis models.

Figure D5. Scatterplot of Birth Weight by MUAC, Stratified by Asian vs. African Studies

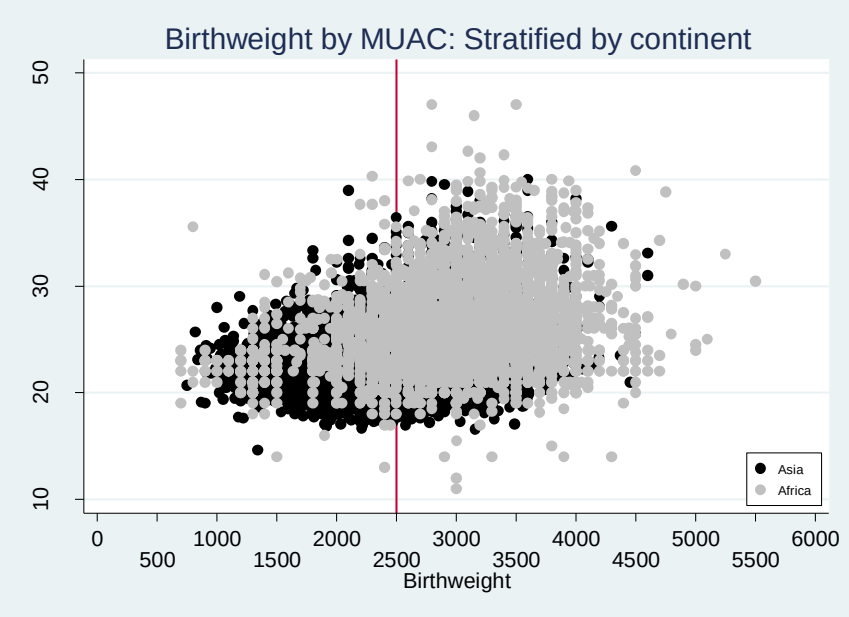
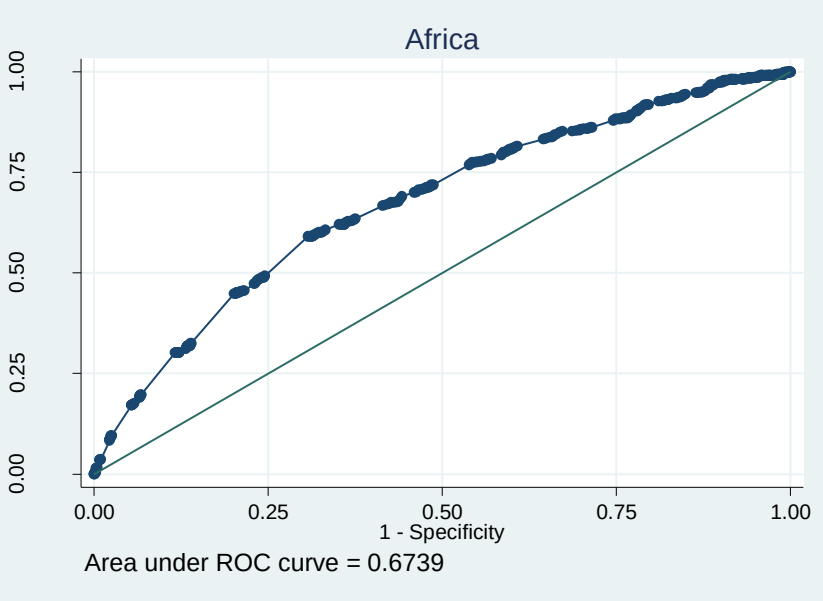


Figure D6. ROC Curves by Asian vs. African Studies



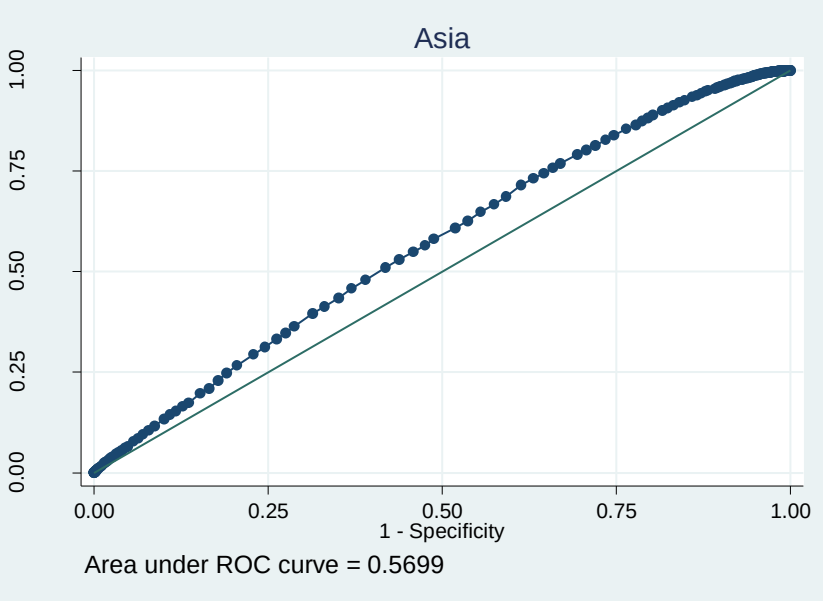


Table D3. Estimated Sensitivities, Specificities, and Diagnostic Odds Ratios for Infant LBW by Selected Maternal MUAC Cutoffs (Values Expressed as % (95% CI))

a. Asian Studies: (n=19,817)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	2.4 (2.1, 2.7)	98.6 (98.3, 98.8)
≤19.5	4.7 (4.3, 5.1)	96.8 (96.5, 97.2)
≤20.0	7.8 (7.3, 8.3)	94.3 (93.9, 94.8)
≤20.5	13.3 (12.7, 14)	90.0 (89.3, 90.6)
≤21.0	19.7 (18.9, 20.5)	84.8 (84.1, 85.5)
≤21.5	29.4 (28.6, 30.3)	77.1 (76.2, 77.9)
≤22.0	39.6 (38.7, 40.6)	68.6 (67.7, 69.5)
≤22.5	51.1 (50.1, 52.0)	58.1 (57.1, 59.1)
≤23.0	60.9 (59.9, 61.8)	48.2 (47.1, 49.2)
≤23.5	71.5 (70.6, 72.4)	38.6 (37.6, 39.6)
≤24.0	79.1 (78.3, 79.8)	30.6 (29.7, 31.5)
≤24.5	85.5 (84.8, 86.2)	23.5 (22.7, 24.4)
≤25.0	90.1 (89.5, 90.7)	18.4 (17.6, 19.1)
≤25.5	93.4 (92.9, 93.9)	14.0 (13.4, 14.8)
≤26.0	95.4 (95.0, 95.8)	10.9 (10.2, 11.5)
≤26.5	96.9 (96.6, 97.3)	8.6 (8.0, 9.2)

b. African studies: (n=5,215)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	3.5 (2.3, 5.2)	99.2 (98.9, 99.4)
≤19.5	3.7 (2.4, 5.3)	99.0 (98.7, 99.3)
≤20.0	8.3 (6.4, 10.7)	97.7 (97.3, 98.2)
≤20.5	5.6 (2.1, 13.9)	98.7 (93.2, 99.7)
≤21.0	17.1 (14.4, 20.1)	94.6 (93.9, 95.3)
≤21.5	19.0 (16.1, 22.2)	93.5 (92.7, 94.2)
≤22.0	20.2 (7.9, 4.3)	90.6 (70.3, 97.5)
≤22.5	31.3 (27.8, 34.9)	86.8 (85.8, 87.8)
≤23.0	44.9 (41.1, 48.7)	79.8 (78.7, 81.0)
≤23.5	47.4 (43.6, 51.2)	77.0 (75.8, 78.2)
≤24.0	59.1 (55.3, 62.8)	69.2 (67.8, 70.6)
≤24.5	62.1 (58.4, 65.8)	64.8 (63.4, 66.2)
≤25.0	68.9 (35.3, 90.0)	48.3 (22.3, 75.2)
≤25.5	70.0 (66.4, 73.4)	54.0 (52.6, 55.5)
≤26.0	76.9 (73.6, 80.0)	46.1 (44.7, 47.6)
≤26.5	79.4 (76.2, 82.4)	41.5 (40.1, 43)

Note: Grayed out values were unable to be estimated using meta-analysis commands in Stata and are based on ordinary logistic regression models.

Subgroup Analysis: Parity

The meta-analysis commands require that subgroup variables be at the study level. Since parity is at an individual participant level, we were not able to obtain parameter estimates using the meta-analysis approach. Therefore, the estimates in this section are based on an ordinary logistic regression model only. Estimates are provided for the pooled data only.

This subgroup analysis excludes two studies that did not have a parity variable in their dataset (DRC and South Africa). For the remaining five studies, we regrouped parity into three categories: 0, 1–4, and 5+.

Figure D7. Scatterplot of Birthweight by MUAC, Stratified by Parity Level

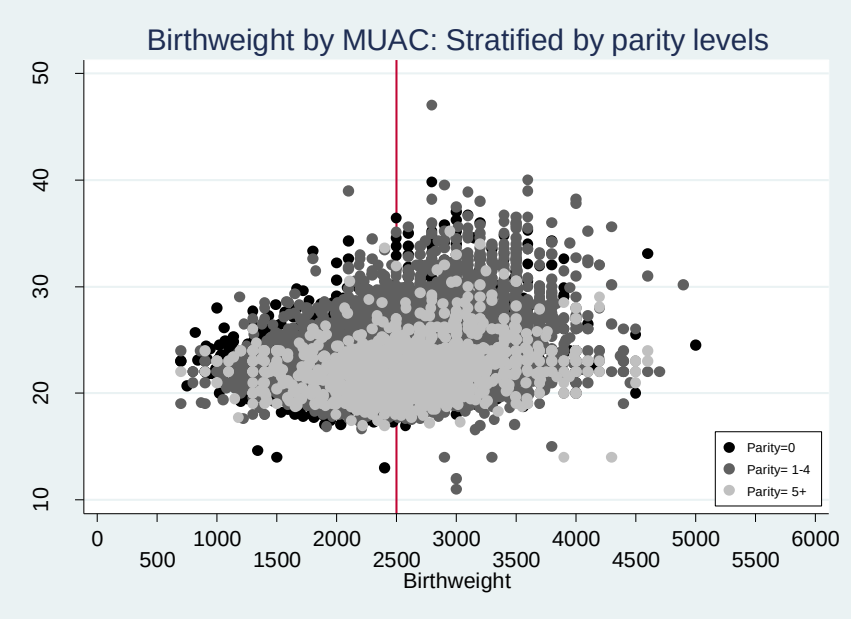
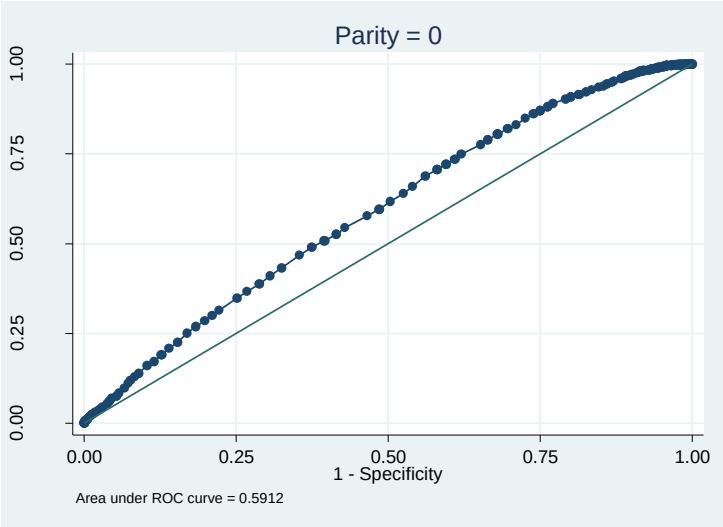
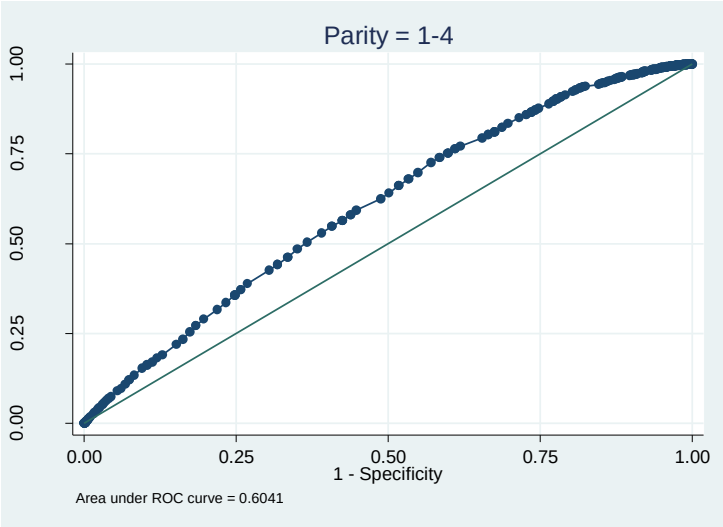


Figure D8. ROC Curves by Parity Level





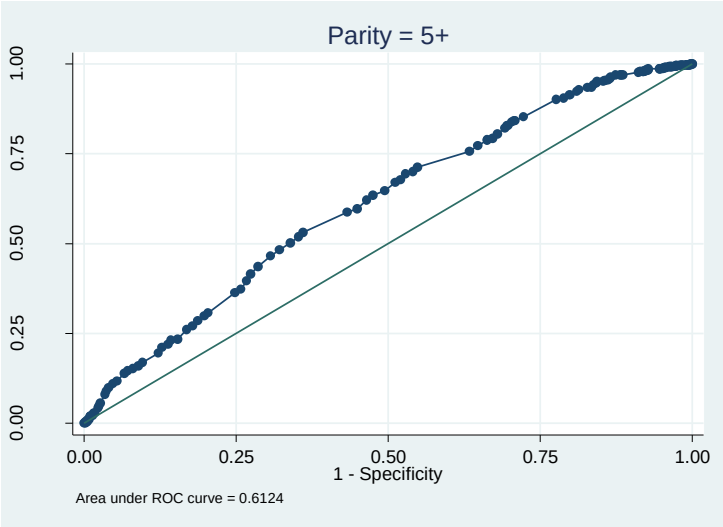


Table D4. Estimated Sensitivities and Specificities for a) Parity=0, b) Parity=1–4, and c) Parity=5+ (Values Expressed as % (95% CI))

a. Parity = 0: (n=8,255)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	1.8 (1.4, 2.2)	99.1 (98.7, 99.4)
≤19.5	3.1 (2.7, 3.6)	98.2 (97.7, 98.6)
≤20.0	5.5 (4.9, 6.2)	96.2 (95.5, 96.9)
≤20.5	9.8 (9.0, 10.7)	93.4 (92.5, 94.2)
≤21.0	16.1 (15.1, 17.2)	89.6 (88.5, 90.6)
≤21.5	25.1 (23.9, 26.4)	83.0 (81.7, 84.3)
≤22.0	34.9 (33.6, 36.2)	74.8 (73.3, 76.3)
≤22.5	46.8 (45.4, 48.2)	64.6 (62.9, 66.2)
≤23.0	57.8 (56.4, 59.1)	53.5 (51.7, 55.2)
≤23.5	68.8 (67.5, 70.1)	43.9 (42.1, 45.6)
≤24.0	77.6 (76.4, 78.8)	34.8 (33.1, 36.4)
≤24.5	84.9 (83.9, 85.9)	27.4 (25.9, 28.9)
≤25.0	90.2 (89.4, 91.1)	20.8 (19.4, 22.2)
≤25.5	93.5 (92.8, 94.2)	15.3 (14.1, 16.6)
≤26.0	96.0 (95.4, 96.5)	11.7 (10.6, 12.8)
≤26.5	97.6 (97.1, 98.0)	9.1 (8.2, 10.2)

b. Parity = 1-4: (n=12,186)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	2.6 (2.2, 3.1)	98.5 (98.2, 98.8)
≤19.5	5.3 (4.7, 5.9)	97.0 (96.6, 97.4)
≤20.0	9.1 (8.3, 9.9)	94.5 (94.0, 95.0)
≤20.5	15.4 (14.4, 16.4)	90.4 (89.7, 91.1)
≤21.0	21.9 (20.8, 23.1)	84.8 (84.0, 85.7)
≤21.5	31.7 (30.4, 33.0)	78.1 (77.1, 79.0)
≤22.0	42.6 (41.3, 44.0)	69.5 (68.5, 70.6)
≤22.5	53.0 (51.7, 54.4)	60.9 (59.8, 62.0)
≤23.0	62.5 (61.2, 63.9)	51.2 (50.0, 52.4)
≤23.5	72.6 (71.3, 73.8)	43.0 (41.8, 44.1)
≤24.0	79.4 (78.3, 80.5)	34.5 (33.4, 35.7)
≤24.5	85.0 (84.0, 86.0)	28.4 (27.4, 29.5)
≤25.0	89.0 (88.1, 89.8)	23.5 (22.6, 24.5)
≤25.5	92.3 (91.5, 93.0)	19.6 (18.7, 20.6)
≤26.0	94.3 (93.6, 94.9)	15.3 (14.5, 16.2)
≤26.5	95.7 (95.1, 96.3)	12.8 (12.0, 13.6)

c. Parity = 5+: (n=1,337)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	8.1 (5.9, 10.8)	96.6 (95.1, 97.7)
≤19.5	13.9 (11.0, 17.2)	93.4 (91.5, 95.0)
≤20.0	19.5 (16.2, 23.2)	87.8 (85.3, 90.0)
≤20.5	26.1 (22.3, 30.1)	83.2 (80.4, 85.7)
≤21.0	36.3 (32.1, 40.6)	75.2 (72.1, 78.1)
≤21.5	46.5 (42.2, 50.9)	69.4 (66.1, 72.5)
≤22.0	58.7 (54.3, 63.0)	56.8 (53.3, 60.2)
≤22.5	67.0 (62.8, 71.0)	48.8 (45.4, 52.3)
≤23.0	75.7 (71.7, 79.3)	36.6 (33.3, 40.0)
≤23.5	82.0 (78.5, 85.3)	30.8 (27.6, 34.1)
≤24.0	90.2 (87.3, 92.6)	22.3 (19.5, 25.4)
≤24.5	93.4 (90.9, 95.4)	17.2 (14.7, 20.0)
≤25.0	95.2 (93.0, 96.9)	14.7 (12.3, 17.3)
≤25.5	96.9 (95.0, 98.2)	12.6 (10.4, 15.0)
≤26.0	97.7 (96.0, 98.8)	8.8 (6.9, 10.9)
≤26.5	98.3 (96.7, 99.2)	7.6 (5.9, 9.6)

Subgroup Analysis: HIV Status

This subgroup analysis includes only the three studies that had information on HIV status (N=4,254). The studies from DRC and Malawi included all HIV-positive women (n=2,012), while the study from South Africa included 51.3% HIV-negative women (n=1,152) and 48.5% HIV-positive women (n=1,090). There were five women with indeterminate HIV status and these were set to missing for this analysis. Again, this subgroup variable is defined at an individual participant level so the estimates are based on an ordinary logistic regression model. Estimates are provided for the pooled data only.

Figure D9. Scatterplot of Birthweight by MUAC, Stratified by HIV Status

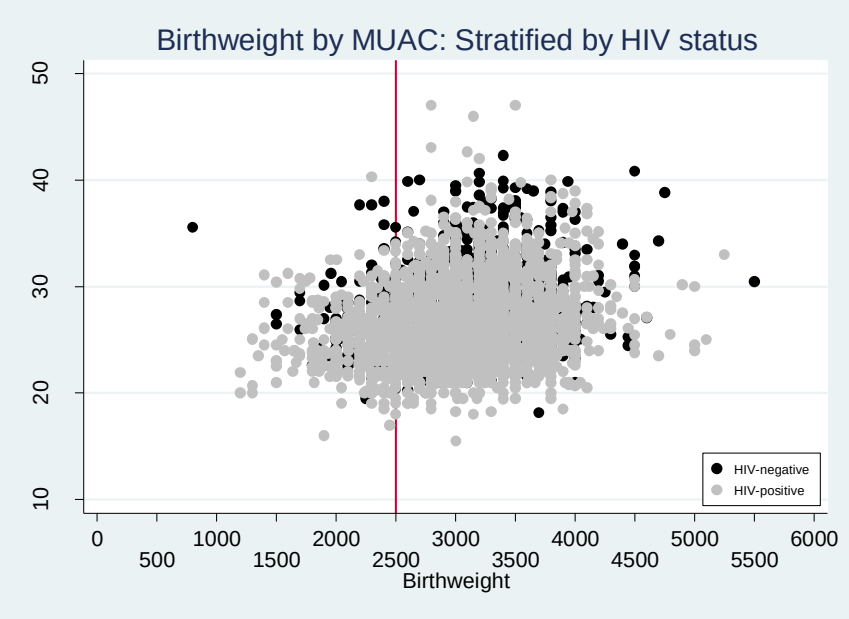
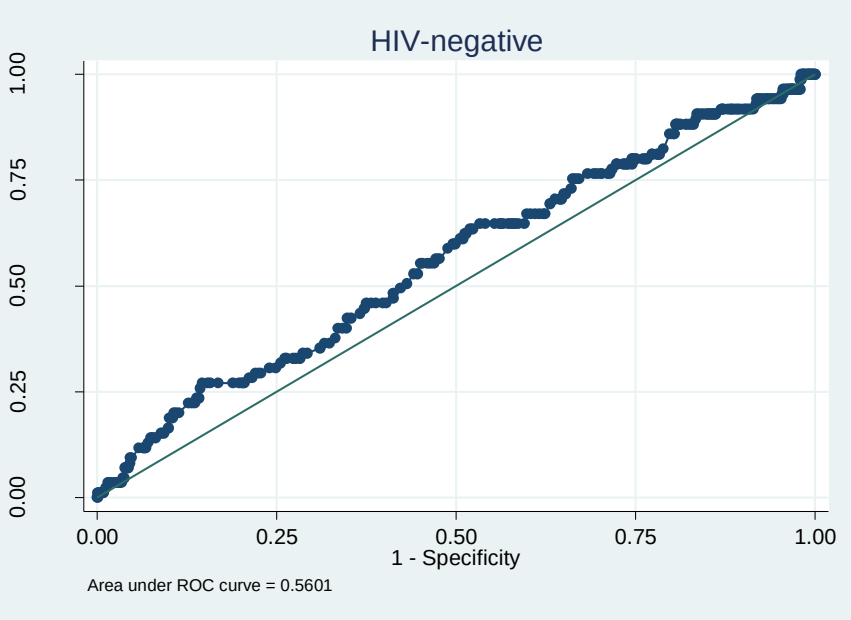


Figure D10. ROC Curves by HIV Status



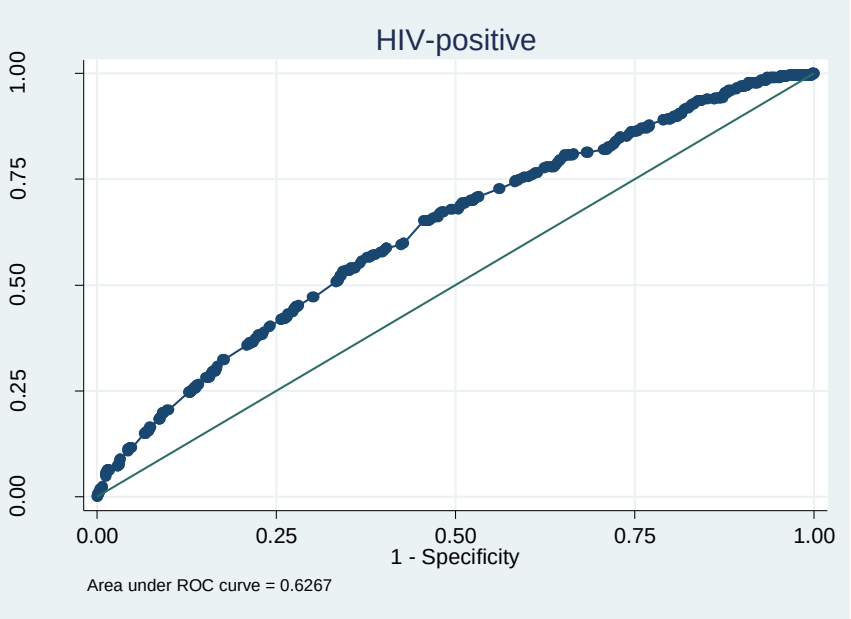


Table D5. Estimated Sensitivities and Specificities for Infant LBW by Selected Maternal MUAC Cutoffs (Values Expressed as % (95% CI))

a. HIV-negative: (n=1,152)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	0.0 (0.0, 4.2)	99.9 (99.5, 100)
≤19.5	1.2 (0.0, 6.4)	99.9 (99.5, 100)
≤20.0	1.2 (0.0, 6.4)	99.9 (99.5, 100)
≤20.5	1.2 (0.0, 6.4)	99.7 (99.2, 99.9)
≤21.0	1.2 (0.0, 6.4)	99.4 (98.8, 99.8)
≤21.5	3.5 (0.7, 10.0)	98.5 (97.6, 99.1)
≤22.0	3.5 (0.7, 10.0)	97.6 (96.4, 98.4)
≤22.5	4.7 (1.3, 11.6)	96.4 (95.1, 97.5)
≤23.0	11.8 (5.8, 20.6)	94.2 (92.6, 95.5)
≤23.5	15.3 (8.4, 24.7)	91.1 (89.2, 92.7)
≤24.0	22.4 (14.0, 32.7)	87.3 (85.1, 89.2)
≤24.5	27.1 (18.0, 37.8)	81.1 (78.6, 83.4)
≤25.0	30.6 (21.0, 41.5)	76.0 (73.3, 78.5)
≤25.5	35.3 (25.2, 46.4)	69.0 (66.1, 71.7)
≤26.0	43.5 (32.8, 54.7)	63.4 (60.4, 66.3)
≤26.5	50.6 (39.5, 61.6)	56.8 (53.8, 59.8)

b. HIV-positive: (n=3,102)		
MUAC (cm)	**SENS**	**SPEC**
≤19.0	1.8 (0.7, 4.0)	99.6 (99.2, 99.8)
≤19.5	1.8 (0.7, 4.0)	99.3 (98.9, 99.6)
≤20.0	4.6 (2.6, 7.5)	98.8 (98.3, 99.2)
≤20.5	6.1 (3.8, 9.3)	98.5 (98.0, 98.9)
≤21.0	8.0 (5.3, 11.4)	97.1 (96.4, 97.7)
≤21.5	11.3 (8.1, 15.3)	95.6 (94.7, 96.3)
≤22.0	17.1 (13.2, 21.7)	92.9 (91.9, 93.9)
≤22.5	19.3 (15.1, 24.0)	90.8 (89.7, 91.9)
≤23.0	27.2 (22.5, 32.4)	86.3 (85.0, 87.6)
≤23.5	31.5 (26.5, 36.8)	82.9 (81.4, 84.3)
≤24.0	40.1 (34.7, 45.6)	75.9 (74.3, 77.5)
≤24.5	45.3 (39.8, 50.8)	71.1 (69.3, 72.7)
≤25.0	52.6 (47.0, 58.1)	63.1 (61.3, 64.9)
≤25.5	58.4 (52.9, 63.8)	58.5 (56.6, 60.3)
≤26.0	68.2 (62.8, 73.2)	49.5 (47.6, 51.4)
≤26.5	71.6 (66.3, 76.4)	44.5 (42.6, 46.3)

Annex E. Use of MUAC to Predict Pregnant Women at Risk of Delivering a Small for Gestational Age (SGA) Infant

The following tables and figures show the detailed results of the diagnostic test accuracy of MUAC for predicting the SGA outcome.

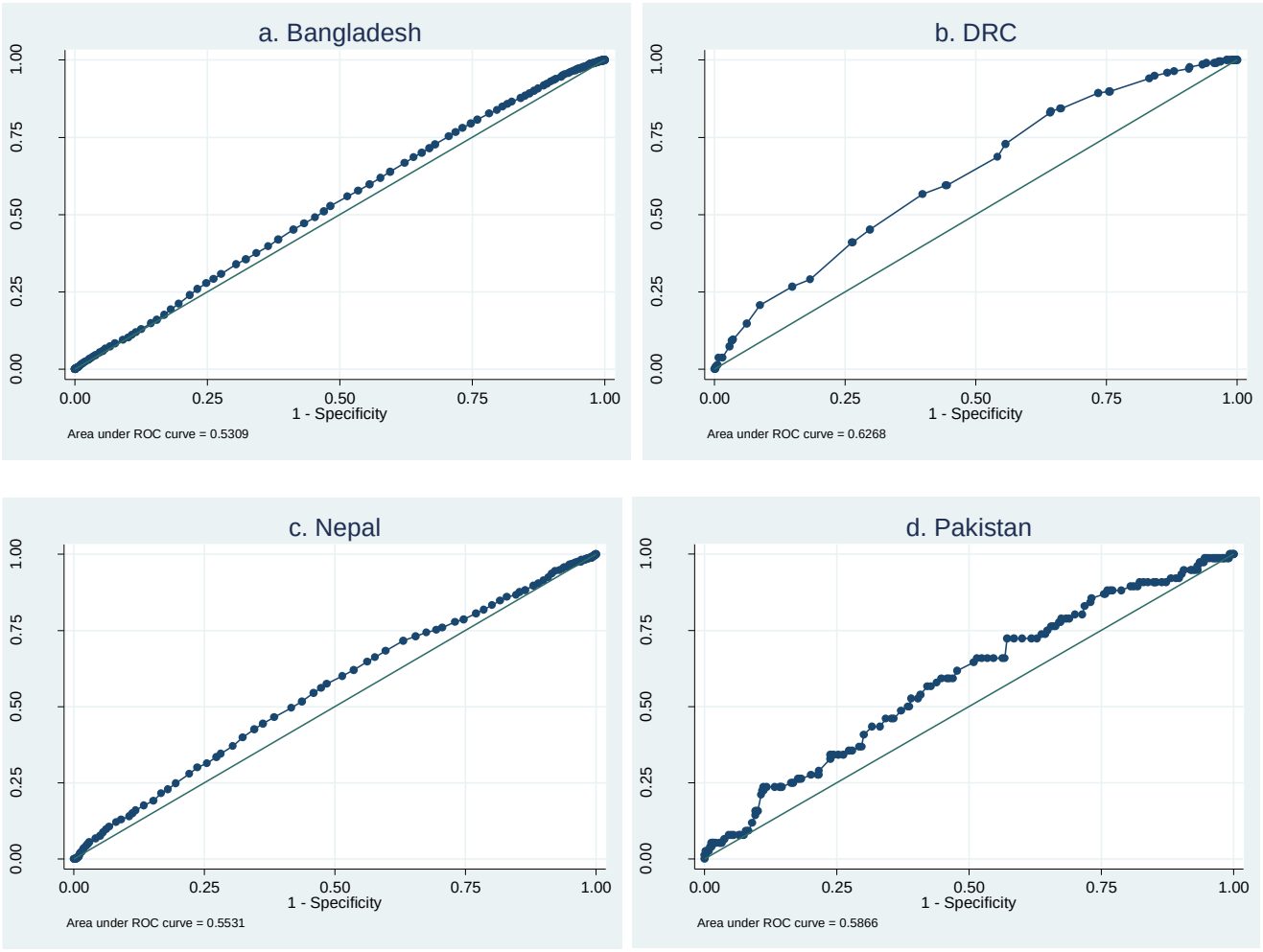
The prevalence of SGA was higher than the prevalence of LBW in all countries, with the prevalence of SGA being considerably higher in the DRC and Nepal (Table E1).

Table E1. Comparison of LBW and SGA by Study

	Bangladesh	DRC	Nepal	Pakistan
# LBW (%)	8906 (55.3%) (n=16,108)	119 (11.8%) (n=1,007)	1193 (37.6%) (n=3,170)	69 (12.8%) (n=539)
# SGA (%)	8,798 (58.3%) (n=15,101)	217 (24.6%) (n=883)	1,389 (48.0%) (n=2,889)	76 (14.2%) (n=534)

Figure E1 shows the ROC curves and AUROCCs separately by study. Tables E2–E5 show the SENS, SPEC, PPV, and NPV over a range of cutoffs for each individual study. Table E6 shows, for each MUAC cutoff, the comparison of SENS, SPEC, PPV, and NPV by study.

Figure E1. ROC Curves for MUAC by SGA by Study



The AUROCC for the four studies ranged from 0.53 (Bangladesh) to 0.63 (DRC). For every study, the AUROCC for SGA was lower than the AUROCC for LBW, but not substantively.

As shown in Tables E2–E6, the values of SENS, SPEC, PPV, and NPV were highly variable between studies, similar to what was shown for the outcome of LBW.

Table E2. Bangladesh (Values Expressed as % (95% CI))

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	1.4 (1.2, 1.7)	98.9 (98.6, 99.2)	65.1 (58.0, 71.8)	41.8 (41.0, 42.6)
≤19.5	3.0 (2.6, 3.4)	97.5 (97.1, 97.9)	62.5 (57.7, 67.1)	41.9 (41.1, 42.7)
≤20.0	5.4 (4.9, 5.9)	95.3 (94.8, 95.8)	61.6 (58.0, 65.0)	41.9 (41.1, 42.7)
≤20.5	9.6 (9.0, 10.2)	91.0 (90.2, 91.7)	59.6 (57.0, 62.2)	41.9 (41.0, 42.7)
≤21.0	14.9 (14.1, 15.6)	85.6 (84.7, 86.5)	59.1 (57.0, 61.1)	41.9 (41.0, 42.7)
≤21.5	24.0 (23.1, 24.9)	78.3 (77.3, 79.3)	60.7 (59.0, 62.3)	42.5 (41.6, 43.4)
≤22.0	34.0 (33.0, 35.0)	69.6 (68.4, 70.7)	60.9 (59.5, 62.3)	43.0 (42.1, 44.0)
≤22.5	45.2 (44.2, 46.3)	58.8 (57.6, 60.0)	60.5 (59.3, 61.7)	43.5 (42.4, 44.5)
≤23.0	55.8 (54.8, 56.9)	48.5 (47.3, 49.8)	60.2 (59.2, 61.3)	44.0 (42.9, 45.2)
≤23.5	66.8 (65.8, 67.7)	37.7 (36.5, 39.0)	59.9 (59.0, 60.9)	44.9 (43.5, 46.2)
≤24.0	75.3 (74.4, 76.2)	29.4 (28.3, 30.6)	59.8 (58.9, 60.7)	46.0 (44.5, 47.6)
≤24.5	82.7 (81.9, 83.5)	21.8 (20.8, 22.9)	59.6 (58.8, 60.5)	47.5 (45.7, 49.4)
≤25.0	87.7 (87.0, 88.4)	15.8 (15.0, 16.8)	59.3 (58.4, 60.1)	48.0 (45.8, 50.2)
≤25.5	91.8 (91.2, 92.4)	11.5 (10.7, 12.3)	59.1 (58.3, 60.0)	50.1 (47.5, 52.7)
≤26.0	94.5 (94.0, 95.0)	8.3 (7.6, 9.0)	59.0 (58.2, 59.8)	52.0 (48.9, 55.1)
≤26.5	96.5 (96, 96.8)	5.9 (5.3, 6.5)	58.9 (58.1, 59.7)	54.5 (50.6, 58.2)

Table E3. DRC (Values Expressed as % (95% CI))

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	3.7 (1.6, 7.1)	99.2 (98.3, 99.8)	61.5 (31.6, 86.1)	76.0 (73.0, 78.8)
≤19.5	3.7 (1.6, 7.1)	98.5 (97.3, 99.3)	44.4 (21.5, 69.2)	75.8 (72.8, 78.7)
≤20.0	7.4 (4.3, 11.7)	97.1 (95.6, 98.3)	45.7 (28.8, 63.4)	76.3 (73.3, 79.1)
≤20.5	9.2 (5.7, 13.9)	96.7 (95.0, 97.9)	47.6 (32.0, 63.6)	76.6 (73.6, 79.4)
≤21.0	14.7 (10.3, 20.2)	93.8 (91.7, 95.5)	43.8 (32.2, 55.9)	77.2 (74.1, 80.0)
≤21.5	20.7 (15.5, 26.7)	91.3 (88.9, 93.3)	43.7 (33.9, 53.8)	77.9 (74.9, 80.8)
≤22.0	26.7 (21.0, 33.1)	85.1 (82.2, 87.8)	36.9 (29.4, 45.0)	78.1 (74.9, 81.1)
≤22.5	29.0 (23.1, 35.6)	81.7 (78.5, 84.5)	34.1 (27.3, 41.4)	77.9 (74.7, 81.0)
≤23.0	41.0 (34.4, 47.9)	73.7 (70.2, 77.0)	33.7 (28.0, 39.8)	79.3 (75.9, 82.4)
≤23.5	45.2 (38.4, 52.0)	70.3 (66.6, 73.7)	33.1 (27.8, 38.8)	79.7 (76.2, 82.9)
≤24.0	56.7 (49.8, 63.4)	60.2 (56.4, 64.0)	31.7 (27.1, 36.6)	81.0 (77.3, 84.4)
≤24.5	59.4 (52.6, 66.0)	55.7 (51.8, 59.5)	30.4 (26.1, 35.0)	80.8 (76.9, 84.3)
≤25.0	68.7 (62.0, 74.8)	45.8 (42.0, 49.7)	29.2 (25.3, 33.4)	81.8 (77.5, 85.6)
≤25.5	72.8 (66.4, 78.6)	44.3 (40.5, 48.2)	29.9 (26.0, 34.0)	83.3 (79.0, 87.1)
≤26.0	82.9 (77.3, 87.7)	35.7 (32.1, 39.5)	29.6 (26.0, 33.4)	86.5 (81.9, 90.3)
≤26.5	84.3 (78.8, 88.9)	33.8 (30.2, 37.5)	29.3 (25.8, 33.1)	86.9 (82.1, 90.7)

Table E4. Nepal (Values Expressed as % (95% CI))

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	6.8 (5.6, 8.3)	95.9 (94.7, 96.8)	60.5 (52.4, 68.2)	52.6 (50.7, 54.5)
≤19.5	12.1 (10.4, 13.9)	91.9 (90.4, 93.2)	57.9 (52.0, 63.7)	53.0 (51.1, 55.0)
≤20.0	17.6 (15.7, 19.7)	86.6 (84.8, 88.3)	54.9 (50.2, 59.6)	53.2 (51.2, 55.2)
≤20.5	27.9 (25.6, 30.4)	77.9 (75.7, 79.9)	53.9 (50.2, 57.6)	53.8 (51.7, 56.0)
≤21.0	37.0 (34.5, 39.6)	69.5 (67.1, 71.9)	52.9 (49.7, 56.1)	54.4 (52.1, 56.6)
≤21.5	49.6 (46.9, 52.3)	58.3 (55.8, 60.8)	52.4 (49.7, 55.2)	55.6 (53.1, 58.0)
≤22.0	60.1 (57.5, 62.7)	48.5 (46.0, 51.1)	52.0 (49.5, 54.4)	56.8 (54.0, 59.5)
≤22.5	71.6 (69.2, 74.0)	36.9 (34.5, 39.4)	51.3 (49.0, 53.5)	58.4 (55.2, 61.6)
≤23.0	77.8 (75.5, 79.9)	27.0 (24.8, 29.3)	49.7 (47.5, 51.8)	56.7 (53.0, 60.4)
≤23.5	84.8 (82.8, 86.7)	18.4 (16.5, 20.5)	49.0 (47.0, 51.1)	56.7 (52.1, 61.1)
≤24.0	89.7 (88.0, 91.3)	12.0 (10.4, 13.8)	48.6 (46.6, 50.5)	55.7 (50.1, 61.2)
≤24.5	94.5 (93.2, 95.7)	7.8 (6.5, 9.3)	48.7 (46.8, 50.6)	60.6 (53.3, 67.6)
≤25.0	96.5 (95.4, 97.4)	5.1 (4.0, 6.3)	48.5 (46.6, 50.4)	61.3 (52.1, 69.9)
≤25.5	97.6 (96.7, 98.4)	3.4 (2.5, 4.4)	48.3 (46.5, 50.2)	60.7 (49.5, 71.2)
≤26.0	98.4 (97.6, 99.0)	2.0 (1.4, 2.8)	48.2 (46.3, 50.0)	57.7 (43.2, 71.3)
≤26.5	98.9 (98.2, 99.4)	1.1 (0.6, 1.7)	48.1 (46.2, 49.9)	51.6 (33.1, 69.8)

Table E5. Pakistan (Values Expressed as % (95% CI))

MUAC (cm)	SENS	SPEC	PPV	NPV
≤19.0	1.3 (0.0, 7.1)	99.8 (98.8, 100)	50.0 (1.3, 98.7)	85.9 (82.7, 88.7)
≤19.5	1.3 (0.0, 7.1)	99.8 (98.8, 100)	50.0 (1.3, 98.7)	85.9 (82.7, 88.7)
≤20.0	2.6 (0.3, 9.2)	99.8 (98.8, 100)	66.7 (9.4, 99.2)	86.1 (82.8, 88.9)
≤20.5	2.6 (0.3, 9.2)	99.3 (98.1, 99.9)	40.0 (5.3, 85.3)	86.0 (82.8, 88.9)
≤21.0	3.9 (0.8, 11.1)	98.9 (97.5, 99.6)	37.5 (8.5, 75.5)	86.1 (82.9, 89.0)
≤21.5	5.3 (1.5, 12.9)	98.5 (96.9, 99.4)	36.4 (10.9, 69.2)	86.2 (83.0, 89.1)
≤22.0	5.3 (1.5, 12.9)	97.2 (95.2, 98.5)	23.5 (6.8, 49.9)	86.1 (82.8, 88.9)
≤22.5	6.6 (2.2, 14.7)	96.3 (94.1, 97.8)	22.7 (7.8, 45.4)	86.1 (82.8, 89.0)
≤23.0	7.9 (3.0, 16.4)	93.4 (90.8, 95.5)	16.7 (6.4, 32.8)	85.9 (82.6, 88.9)
≤23.5	11.8 (5.6, 21.3)	91.0 (88.1, 93.5)	18.0 (8.6, 31.4)	86.2 (82.8, 89.1)
≤24.0	21.1 (12.5, 31.9)	89.3 (86.1, 92.0)	24.6 (14.8, 36.9)	87.2 (83.8, 90.1)
≤24.5	23.7 (14.7, 34.8)	86.7 (83.2, 89.7)	22.8 (14.1, 33.6)	87.3 (83.8, 90.2)
≤25.0	25.0 (15.8, 36.3)	83.6 (79.9, 86.9)	20.2 (12.6, 29.8)	87.0 (83.5, 90.0)
≤25.5	27.6 (18.0, 39.1)	79.9 (75.9, 83.5)	18.6 (11.9, 27.0)	86.9 (83.3, 90.0)
≤26.0	32.9 (22.5, 44.6)	76.2 (72.0, 80.0)	18.7 (12.5, 26.3)	87.3 (83.6, 90.4)
≤26.5	35.5 (24.9, 47.3)	72.7 (68.4, 76.7)	17.8 (12.0, 24.8)	87.2 (83.4, 90.4)

Table E6. Comparison of SENS, SPEC, PPV, and NPV by Study, for Each MUAC Cutoff

MUAC (cm)		Bangladesh	DRC	Nepal	Pakistan
≤19.0	SENS	1.4 (1.2, 1.7)	3.7 (1.6, 7.1)	6.8 (5.6, 8.3)	1.3 (0.0, 7.1)
	SPEC	98.9 (98.6, 99.2)	99.2 (98.3, 99.8)	95.9 (94.7, 96.8)	99.8 (98.8, 100)
	PPV	65.1 (58.0, 71.8)	61.5 (31.6, 86.1)	60.5 (52.4, 68.2)	50.0 (1.3, 98.7)
	NPV	41.8 (41.0, 42.6)	76 (73.0, 78.8)	52.6 (50.7, 54.5)	85.9 (82.7, 88.7)
≤19.5	SENS	3.0 (2.6, 3.4)	3.7 (1.6, 7.1)	12.1 (10.4, 13.9)	1.3 (0.0, 7.1)
	SPEC	97.5 (97.1, 97.9)	98.5 (97.3, 99.3)	91.9 (90.4, 93.2)	99.8 (98.8, 100)
	PPV	62.5 (57.7, 67.1)	44.4 (21.5, 69.2)	57.9 (52.0, 63.7)	50.0 (1.3, 98.7)
	NPV	41.9 (41.1, 42.7)	75.8 (72.8, 78.7)	53.0 (51.1, 55.0)	85.9 (82.7, 88.7)
≤20.0	SENS	5.4 (4.9, 5.9)	7.4 (4.3, 11.7)	17.6 (15.7, 19.7)	2.6 (0.3, 9.2)
	SPEC	95.3 (94.8, 95.8)	97.1 (95.6, 98.3)	86.6 (84.8, 88.3)	99.8 (98.8, 100)
	PPV	61.6 (58.0, 65.0)	45.7 (28.8, 63.4)	54.9 (50.2, 59.6)	66.7 (9.4, 99.2)
	NPV	41.9 (41.1, 42.7)	76.3 (73.3, 79.1)	53.2 (51.2, 55.2)	86.1 (82.8, 88.9)
≤20.5	SENS	9.6 (9.0, 10.2)	9.2 (5.7, 13.9)	27.9 (25.6, 30.4)	2.6 (0.3, 9.2)
	SPEC	91 (90.2, 91.7)	96.7 (95.0, 97.9)	77.9 (75.7, 79.9)	99.3 (98.1, 99.9)
	PPV	59.6 (57, 62.2)	47.6 (32.0, 63.6)	53.9 (50.2, 57.6)	40.0 (5.3, 85.3)
	NPV	41.9 (41, 42.7)	76.6 (73.6, 79.4)	53.8 (51.7, 56.0)	86.0 (82.8, 88.9)
≤21.0	SENS	14.9 (14.1, 15.6)	14.7 (10.3, 20.2)	37.0 (34.5, 39.6)	3.9 (0.8, 11.1)
	SPEC	85.6 (84.7, 86.5)	93.8 (91.7, 95.5)	69.5 (67.1, 71.9)	98.9 (97.5, 99.6)
	PPV	59.1 (57.0, 61.1)	43.8 (32.2, 55.9)	52.9 (49.7, 56.1)	37.5 (8.5, 75.5)
	NPV	41.9 (41.0, 42.7)	77.2 (74.1, 80.0)	54.4 (52.1, 56.6)	86.1 (82.9, 89.0)
≤21.5	SENS	24.0 (23.1, 24.9)	20.7 (15.5, 26.7)	49.6 (46.9, 52.3)	5.3 (1.5, 12.9)
	SPEC	78.3 (77.3, 79.3)	91.3 (88.9, 93.3)	58.3 (55.8, 60.8)	98.5 (96.9, 99.4)
	PPV	60.7 (59.0, 62.3)	43.7 (33.9, 53.8)	52.4 (49.7, 55.2)	36.4 (10.9, 69.2)
	NPV	42.5 (41.6, 43.4)	77.9 (74.9, 80.8)	55.6 (53.1, 58.0)	86.2 (83.0, 89.1)
≤22.0	SENS	34.0 (33.0, 35.0)	26.7 (21.0, 33.1)	60.1 (57.5, 62.7)	5.3 (1.5, 12.9)
	SPEC	69.6 (68.4, 70.7)	85.1 (82.2, 87.8)	48.5 (46.0, 51.1)	97.2 (95.2, 98.5)
	PPV	60.9 (59.5, 62.3)	36.9 (29.4, 45.0)	52.0 (49.5, 54.4)	23.5 (6.8, 49.9)
	NPV	43.0 (42.1, 44.0)	78.1 (74.9, 81.1)	56.8 (54.0, 59.5)	86.1 (82.8, 88.9)
≤22.5	SENS	45.2 (44.2, 46.3)	29.0 (23.1, 35.6)	71.6 (69.2, 74.0)	6.6 (2.2, 14.7)
	SPEC	58.8 (57.6, 60.0)	81.7 (78.5, 84.5)	36.9 (34.5, 39.4)	96.3 (94.1, 97.8)
	PPV	60.5 (59.3, 61.7)	34.1 (27.3, 41.4)	51.3 (49.0, 53.5)	22.7 (7.8, 45.4)
	NPV	43.5 (42.4, 44.5)	77.9 (74.7, 81.0)	58.4 (55.2, 61.6)	86.1 (82.8, 89)

MUAC (cm)		Bangladesh	DRC	Nepal	Pakistan
≤23.0	SENS	55.8 (54.8, 56.9)	41.0 (34.4, 47.9)	77.8 (75.5, 79.9)	7.9 (3.0, 16.4)
	SPEC	48.5 (47.3, 49.8)	73.7 (70.2, 77.0)	27.0 (24.8, 29.3)	93.4 (90.8, 95.5)
	PPV	60.2 (59.2, 61.3)	33.7 (28.0, 39.8)	49.7 (47.5, 51.8)	16.7 (6.4, 32.8)
	NPV	44.0 (42.9, 45.2)	79.3 (75.9, 82.4)	56.7 (53.0, 60.4)	85.9 (82.6, 88.9)
≤23.5	SENS	66.8 (65.8, 67.7)	45.2 (38.4, 52.0)	84.8 (82.8, 86.7)	11.8 (5.6, 21.3)
	SPEC	37.7 (36.5, 39.0)	70.3 (66.6, 73.7)	18.4 (16.5, 20.5)	91.0 (88.1, 93.5)
	PPV	59.9 (59.0, 60.9)	33.1 (27.8, 38.8)	49.0 (47.0, 51.1)	18.0 (8.6, 31.4)
	NPV	44.9 (43.5, 46.2)	79.7 (76.2, 82.9)	56.7 (52.1, 61.1)	86.2 (82.8, 89.1)
≤24.0	SENS	75.3 (74.4, 76.2)	56.7 (49.8, 63.4)	89.7 (88.0, 91.3)	21.1 (12.5, 31.9)
	SPEC	29.4 (28.3, 30.6)	60.2 (56.4, 64.0)	12.0 (10.4, 13.8)	89.3 (86.1, 92.0)
	PPV	59.8 (58.9, 60.7)	31.7 (27.1, 36.6)	48.6 (46.6, 50.5)	24.6 (14.8, 36.9)
	NPV	46.0 (44.5, 47.6)	81.0 (77.3, 84.4)	55.7 (50.1, 61.2)	87.2 (83.8, 90.1)
≤24.5	SENS	82.7 (81.9, 83.5)	59.4 (52.6, 66.0)	94.5 (93.2, 95.7)	23.7 (14.7, 34.8)
	SPEC	21.8 (20.8, 22.9)	55.7 (51.8, 59.5)	7.8 (6.5, 9.3)	86.7 (83.2, 89.7)
	PPV	59.6 (58.8, 60.5)	30.4 (26.1, 35.0)	48.7 (46.8, 50.6)	22.8 (14.1, 33.6)
	NPV	47.5 (45.7, 49.4)	80.8 (76.9, 84.3)	60.6 (53.3, 67.6)	87.3 (83.8, 90.2)
≤25.0	SENS	87.7 (87.0, 88.4)	68.7 (62.0, 74.8)	96.5 (95.4, 97.4)	25.0 (15.8, 36.3)
	SPEC	15.8 (15.0, 16.8)	45.8 (42.0, 49.7)	5.1 (4.0, 6.3)	83.6 (79.9, 86.9)
	PPV	59.3 (58.4, 60.1)	29.2 (25.3, 33.4)	48.5 (46.6, 50.4)	20.2 (12.6, 29.8)
	NPV	48.0 (45.8, 50.2)	81.8 (77.5, 85.6)	61.3 (52.1, 69.9)	87.0 (83.5, 90)
≤25.5	SENS	91.8 (91.2, 92.4)	72.8 (66.4, 78.6)	97.6 (96.7, 98.4)	27.6 (18.0, 39.1)
	SPEC	11.5 (10.7, 12.3)	44.3 (40.5, 48.2)	3.4 (2.5, 4.4)	79.9 (75.9, 83.5)
	PPV	59.1 (58.3, 60.0)	29.9 (26.0, 34.0)	48.3 (46.5, 50.2)	18.6 (11.9, 27.0)
	NPV	50.1 (47.5, 52.7)	83.3 (79.0, 87.1)	60.7 (49.5, 71.2)	86.9 (83.3, 90.0)
≤26.0	SENS	94.5 (94.0, 95.0)	82.9 (77.3, 87.7)	98.4 (97.6, 99.0)	32.9 (22.5, 44.6)
	SPEC	8.3 (7.6, 9.0)	35.7 (32.1, 39.5)	2.0 (1.4, 2.8)	76.2 (72.0, 80.0)
	PPV	59.0 (58.2, 59.8)	29.6 (26.0, 33.4)	48.2 (46.3, 50.0)	18.7 (12.5, 26.3)
	NPV	52.0 (48.9, 55.1)	86.5 (81.9, 90.3)	57.7 (43.2, 71.3)	87.3 (83.6, 90.4)
≤26.5	SENS	96.5 (96.0, 96.8)	84.3 (78.8, 88.9)	98.9 (98.2, 99.4)	35.5 (24.9, 47.3)
	SPEC	5.9 (5.3, 6.5)	33.8 (30.2, 37.5)	1.1 (0.6, 1.7)	72.7 (68.4, 76.7)
	PPV	58.9 (58.1, 59.7)	29.3 (25.8, 33.1)	48.1 (46.2, 49.9)	17.8 (12.0, 24.8)
	NPV	54.5 (50.6, 58.2)	86.9 (82.1, 90.7)	51.6 (33.1, 69.8)	87.2 (83.4, 90.4)

The pooled ROC curve (Figure E2) shows a level of discrimination for SGA (0.5572) that is lower than for the outcome of LBW (0.6405).

Figure E2. ROC Curve from Pooled Dataset

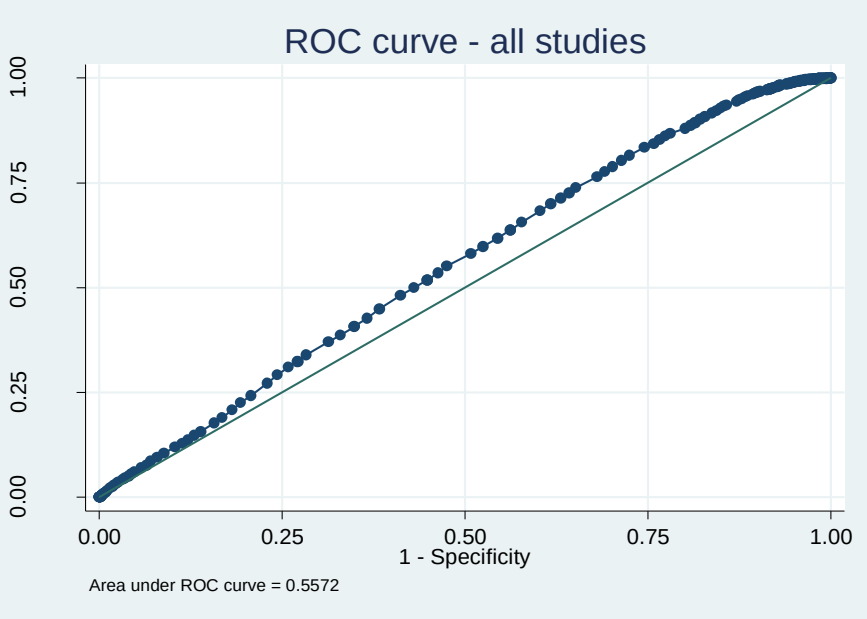


Table E7 shows the summary estimates of SENS and SPEC derived from the meta-analysis of MUAC and SGA across all studies. All measures across the range of MUAC cutoffs were poorer for the outcome of the SGA than for the outcome of LBW.

Table E7. Estimates of SENS and SPEC at Selected MUAC Cutoffs for SGA Outcome, All Studies Combined

MUAC (cm)	SENS	SPEC
≤19.0	1.7 (0.6, 4.7)	98.5 (96.0, 99.5)
≤19.5	2.1 (0.5, 8.4)	96.9 (92.6, 98.8)
≤20.0	3.6 (0.9, 13.1)	94.8 (87.1, 98.0)
≤20.5	5.0 (1.0, 21.2)	91.0 (81.2, 96.0)
≤21.0	7.6 (1.6, 29.7)	85.2 (72.2, 92.7)
≤21.5	11.0 (2.1, 41.4)	78.3 (61.2, 89.3)
≤22.0	14.2 (2.4, 52.5)	67.8 (49.3, 82.0)
≤22.5	18.4 (2.9, 62.6)	58.8 (38.2, 76.8)
≤23.0	24.5 (3.9, 72.1)	46.7 (28.7, 65.6)
≤23.5	31.9 (5.4, 79.2)	37.5 (21.1, 57.3)
≤24.0	42.5 (8.9, 84.9)	28.1 (14.2, 47.9)
≤24.5	49.6 (11.2, 88.5)	20.9 (9.2, 40.9)
≤25.0	57.6 (11.9, 93.1)	15.1 (5.6, 34.7)
≤25.5	63.6 (14.1, 94.9)	11.6 (4.1, 28.6)
≤26.0	71.7 (16.7, 97.0)	7.9 (2.5, 22.0)
≤26.5	77.4 (17.9, 98.2)	6.1 (1.8, 18.8)