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Determining Optimal Mid-Upper Arm Circumference (MUAC) Cutoffs Maximizing Admission of Wasted Children to Treatment in the Philippines

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Abstract

In low resource settings where it is challenging to obtain accurate weight-for-height Z-scores (e.g., equipment to accurately measure height and weight is not readily available, minimally trained community health workers, etc.), the Mid-Upper Arm Circumference (MUAC) is a simple tool used to identify wasted children. However, some researchers and practitioners argue that relying solely on MUAC may miss identification of many wasted children, leading to untimely intervention and potentially death. Our study aimed to identify the best-performing MUAC cutoffs to accurately detect wasting by Weight-for-Height z-scores (WHZ) in Filipino children aged 6-59 months. We analyzed the 2018-2019 Expanded National Nutrition Survey (ENNS) to assess the diagnostic performance of MUAC cutoffs in identifying moderate and severe wasting. The optimal cutoff is identified as the cutoff having the highest AUROC curve. Our findings suggest that the current MUAC cutoffs showed poor performance in identifying severe (sensitivity: 13%; specificity: 99%; AUROC: 0.558) and moderate (Sensitivity: 22%; Specificity: 96%; AUROC: 0.0586) wasting. The optimal MUAC cutoff to optimize the identification of severe and moderate wasting was <13.6cm (sensitivity: 62%; specificity: 76%; AUROC: 0.690) and 14.0cm (sensitivity: 80%; specificity: 67%; AUROC: 0.737), respectively. While there was almost no effect of the gender on optimal MUAC cutoff, but it increased with age. We found that the combination of WAZ < -2 or MUAC ≤ 12.7cm (Sensitivity: 84%; Specificity: 78%; AUROC: 0.810) for moderate wasting and WAZ < -2 or MUAC ≤ 11.7cm (Sensitivity: 80%; Specificity: 80%; AUROC: 0.800) for severe wasting were the optimal criteria. These cutoffs exhibited vastly improved diagnostic sensitivity at the cost of acceptable decreases in specificity. Our results are intended to contribute to local and global evidence to further refine the identification and management of acute malnutrition, improving access and coverage for the Philippine Integrated Management of Acute Malnutrition (PIMAM) services. These include the consideration of alternative case definitions (incorporating WAZ with MUAC) in the diagnostic criteria for wasting in contexts where the WHZ indicator cannot be used. Further implementation studies, however, is recommended to validate findings and better understand its practical use and cost to the health system are vital to implementing changes effectively and sustainably in identifying and treating acute malnutrition in the Philippines.

Keywords: wasting, mid-upper arm circumference, weight-for-age, weight-for-height, Philippines

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1. Introduction

In low resource settings where it is challenging to obtain accurate weight-for-height Z-scores (e.g., equipment to accurately measure height and weight is not readily available, minimally trained health workers, etc.), the Mid-Upper Arm Circumference (MUAC) is a simple tool used to identify wasted children in need of life-saving treatment (Lambebo et al., 2022; UNICEF, 2023). The MUAC is measured using a color-coded tape that can be intuitively used by health workers, mothers, families, and caregivers to assess if a child is acutely malnourished or underweight for their length or height. Wasting in children is usually associated with recent weight loss due to illness, inadequate diet, and suboptimal feeding practices (UNICEF, 2021). Early identification is particularly crucial as wasting during the first 1000 days of a child's life, defined as the period covering pregnancy until the first two years, is particularly damaging to a child's development later in life, affecting not just nutritional outcomes but all other physical and mental health outcomes as well. Furthermore, it is also critical especially on near-term mortality as prevention and treatment of wasting are part of child survival interventions (DOH and UNICEF 2015; Lenters, Wazny, and Bhutta 2016; USAID 2015; WHO 2013).

The WHO recommends using any of these three criteria to identify children between 6-59 months with wasting: (a) MUAC, (b) the presence of bilateral pitting edema, (c) or the weight-for-height (WFH) Z-score. Using the latter two criteria, however, requires trained health workers and anthropometric equipment that may be difficult to bring to the field or are only present in health facilities that may not be easily accessible to all children and their mothers. Consequently, in the Philippines, the MUAC is an innovative, simple, and affordable tool with the potential to expand access to and coverage of the Philippine Integrated Management for Acute Malnutrition Program (PIMAM), the national protocol for preventing, detecting, and managing moderate and severe acute wasting (DOH & UNICEF, 2015). Measurement using MUAC can also be performed by mothers, promoting early detection of wasting in their own children (UNICEF, 2023). Specifically, the MUAC may aid the PIMAM in meeting the SDG target of 3.7% prevalence of wasting for children under five by 2030, for which progress has plateaued for the past 30 years (World Health Organization 2014) (see Figure 1).

Researchers, however, argue that relying on MUAC alone or independently may overlook a significant number of wasted children at high risk of near term death who would miss timely intervention (Grellety & Golden, 2018; Guesdon et al., 2021; Jima et al., 2021; Laillou et al., 2014; Lamsal et al., 2021; Luque-Fernandez et al., 2010; Schwinger et al., 2019; Talapalliwar & Garg, 2015; Tessema et al., 2020). The current MUAC cutoffs recommended by the WHO exhibit varying sensitivities and specificities in different settings, with limited performance in identifying severe (6-20% sensitivity, 91-99% specificity) and moderate wasting (13-23% sensitivity, 98-99% specificity) at cutoffs of 12.5cm and 11.5cm, respectively. With a high false

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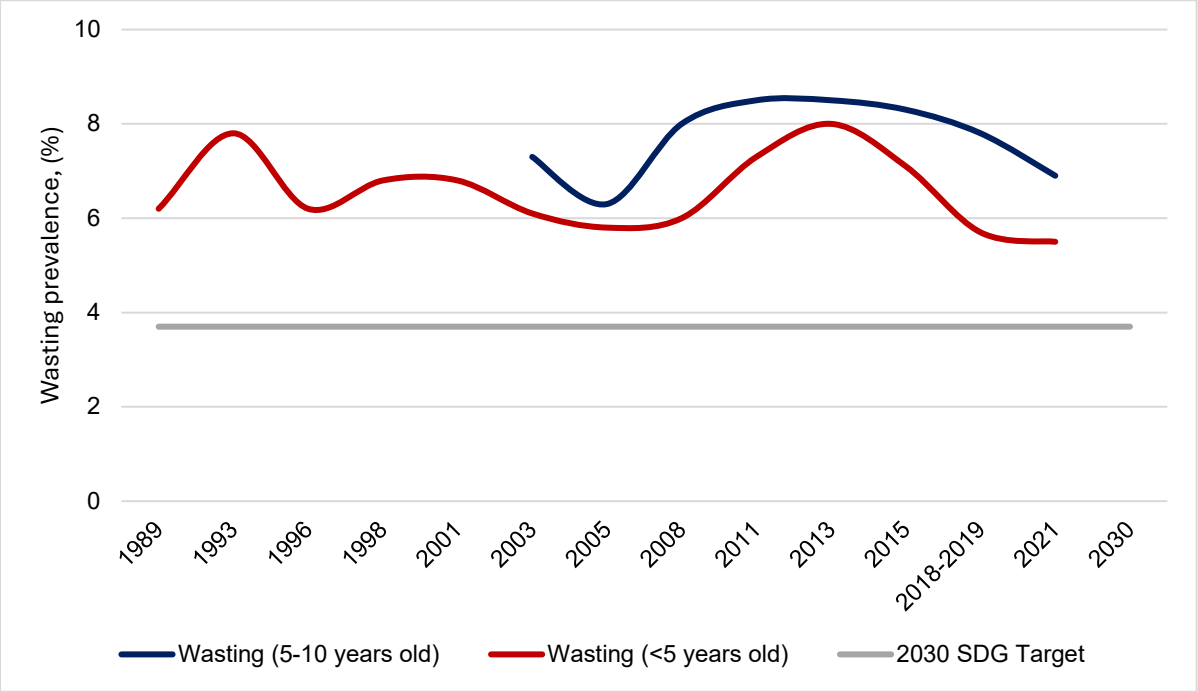
negative rate, these globally recommended MUAC cutoffs perform poorly in identifying children who are truly wasted compared with the weight-for-height Z-score (Jima et al., 2021; Laillou et al., 2014; Lamsal et al., 2021; Luque-Fernandez et al., 2010; Talapalliwar & Garg, 2015; Tessema et al., 2020).

Figure 1. Prevalence of childhood wasting in the Philippines, 1989-2021



Source: Authors' illustration of data from the Philippine National Nutrition Surveys (DOST-FNRI)

To improve the performance of the MUAC, researchers advocate slightly liberalizing the cutoffs and making them more suitable for specific populations: Studies have proposed optimal MUAC cutoffs ranging from 12.5-13.4cm for severe wasting, and 13.2-13.8cm for moderate wasting, with adjustments for age and sex (Jima et al., 2021; Laillou et al., 2014; Lamsal et al., 2021; Luque-Fernandez et al., 2010; Talapalliwar & Garg, 2015; Tessema et al., 2020). Also, a systematic review done by Khara et al. (2023) also revealed that combining case definitions with MUAC, specifically weight-for-age, may be better at predicting mortality in children (Khara et al., 2023). In addition, child body morphologies may vary across geographic regions and a globally determined cutoffs may not be exactly applicable to Filipino children, especially in settings where there is high co-existence of stunting and wasting. To this end, our study aim is to identify the best performing MUAC cutoffs to accurately detect wasting in Filipino children aged 6-59 months, accounting for child characteristics that include age, sex, weight, presence of stunting, wealth quintile, and rural residence.

2. Methods

We used data from the 2018 and 2019 Expanded National Nutrition Survey (ENNS), a cross-sectional survey implemented by the Philippine Department of Science and Technology – Food and Nutrition Research Institute (DOST-FNRI). The survey covers the following components: socio-economic; anthropometric; biochemical; clinical and health; dietary; food security; maternal health; nutrition, infant and young child feeding (IYCF) practices; and government program participation. The 2018 and 2019 rounds of the ENNS aimed to survey 80 of the 112 provinces and highly urbanized cities in the Philippines for a nationally representative sample for each round for a total of 78,476 children (aged 0-120 months old) from 94,999 households.

For anthropometric measurements, the ENNS deployed trained nutritionist-dietitians and other allied health professionals to collect the height, weight, and MUAC of study participants following standard operating protocols (DOST-FNRI, 2022). Standing height, measured with a stadiometer (Seca GmbH & Co. KG), was collected for children aged 2 years and above, while recumbent length was measured using a medical plastic infantometer for those under 2 years. Weight measurements utilized a double-window digital scale, and for children requiring assistance, the guardian carried the child before measuring their weight. MUAC was measured using two-meter non-stretchable tapes (Seca GmbH & Co. KG). All measurements were taken twice to the nearest 0.1 centimeter, with a third reading conducted if the difference between the first two measurements exceeded 0.5cm.

For our analysis, we excluded children with incomplete anthropometric and socioeconomic information for a final sample of 30,522 children aged 6-59 months. To assess the accuracy of various MUAC cutoffs, we used weight-for-height (WFH) Z-scores as the reference standard. According to the WHO Child Growth Standards, children are classified as moderately or severely wasted given the cutoffs for WFH and MUAC in
Table 1**.** We classified children as severely wasted when a child's WFH Z-score is less than –3 standard deviations (SD) below the median and moderately wasted when the WFH Z-score is less than –2SD but greater than or equal to -3SD. Using MUAC, a child is severely wasted if his or her MUAC measures less than or equal to 11.5cm and moderately wasted if his or her MUAC is above 11.5cm but less than or equal to 12.5cm.

Table 1. Summary of nutritional status distributions

	Weight-for-Height (z-scores)	MUAC (cm)
Moderately Wasted	$-2SD < Z \leq -3SD$	$11.5 < x \leq 12.5$
Severely Wasted	$Z < -3SD$	≤ 11.5

We calculated the sensitivity, specificity, positive and negative predictive values, and area under the receiver-operator characteristic (AUROC) curve (see Table 2 for diagnostic indicators) of MUAC cutoffs from 11.0cm to 14.9cm in increments of 0.1cm. Moreover, we assessed MUAC's performance within child subpopulations: age categories (4-5, 6-23, 24-59 months), sex, presence of stunting (calculated using height-for-age $-2SD < Z \leq -3SD$ (for moderate stunting) and $Z < -3SD$ (for severe stunting)), underweight status (weight-for-age), wealth quintile, and rural or urban residence. Lastly, we also evaluated MUAC's performance when used with underweight status; that is, children are classified as moderately wasted if weight-for-age z-scores are $-2SD < Z \leq -3SD$ and severely wasted if $Z < -3SD$.

Proposed optimal cutoffs were selected based on the highest AUROC. As the AUROC measures the overall performance of a diagnostic test, it can be used as a criterion to measure the discriminative ability of a test. AUROC represents the average specific value across all possible values, an AUROC of 1 means perfect accuracy, while an AUROC of 0.5 would mean that the test has little discriminative ability. Therefore, a higher AUROC value closer to 1 reflects superior overall test performance (Park et al. 2004). All analyses were conducted using STATA MP 16.0.

Table 2. Summary of the indicators used in assessing the diagnostic performance of MUAC

Indicator	Description
Sensitivity (Se)	Probability of having positive test results for true positive cases according to the reference standard $$Se = \frac{True\ Positive}{True\ Positive + False\ Negative}$$
Specificity (Sp)	Probability of having negative test results for true negative cases $$Sp = \frac{True\ Negative}{True\ Negative + False\ Positive}$$
Positive predictive value (PPV)	Proportion of positive cases are truly positive. $$PPV = \frac{True\ Positive}{True\ Positive + False\ Positive}$$
Negative predictive value (NPV)	Proportion of negative cases who are truly negative. $$NPV = \frac{True\ Negative}{True\ Negative + False\ Negative}$$
Area under the receiver-operator characteristic (AUROC) curve	Plot of the true positive rate (sensitivity) as the y-coordinate and false positive rate (1-Specificity) as the x-coordinate. (Hosmer Jr., Lemeshow, and Sturdivant 2013; Mandrekar 2010) • <0.5 - No discrimination • 0.5-0.7 - Poor • 0.7-0.8 - Acceptable • 0.8-0.9 - Excellent • 0.9-1.0 - Outstanding

Ethics approval

The authors accessed anonymized public use files through a Data Sharing Agreement with the FNRI. The secondary datasets were accessed by the authors on a secured remote server. For the conduct of the ENNS itself, the Food and Nutrition Research Institute Institutional Ethics Review Committee (FNRIEC) approved the procedures and implementation of the ENNS in accordance with the guidelines in the Declaration of Helsinki (DOST-FNRI, 2022). Informed consent was gathered by FNRI from the respondents.

3. Results

Sample Characteristics and Wasting Prevalence

Table 3 provides the characteristics of the 30,522 children aged 6-59 months included in this analysis. The majority (70.8%) of the children fall in the older age group of 24-59 months with slightly more males (51.8%) than females. Almost one-third (32.2%) of the children were stunted and one-fourth (20.4%) were underweight for their age. Over half (57.9%) of the children were from the poorest 40% income households, and most (65.9%) lived in rural areas.

Overall, the MUAC identified slightly more children as moderately and severely wasted compared with the WFH z-score: 5.3% and 1.2% of the children were moderately and severely wasted using current MUAC cutoffs, 4.6% and 1.0% using WFH Z-score, and 9.0% and 2.1% using either criteria (see **Table 3**). Looking at age groups, the current MUAC cutoffs identified more wasted children in the 6-23 months age group, while the WFH z-score identified more in

the older age group of 24-59 months. Across sex, MUAC identified more wasted children among females whereas WFH z-score identified more among males. In terms of stunting and underweight status, the MUAC identified more severely wasted children among those who are also stunted, while the WFH z-score identified more moderately and severely wasted children among those who are also underweight.

Table 3. Characteristics and prevalence of moderate and severe wasting among children 6-59months in the ENNS, 2018-2019

Variable	n, (%)	Moderate Wasting (n, %)						Severe Wasting (n, %)					
		WHZ (-2SD < Z ≤ -3SD)		MUAC (>11.5 and ≤ 12.5)		WHZ (-2SD < Z ≤ -3SD) or MUAC (>11.5 and ≤ 12.5)		WHZ (Z < -3SD)		MUAC (≤ 11.5)		WHZ (Z < -3SD) or MUAC (≤ 11.5)	
		n (%)	Prevalence within sub-group	n (%)	Prevalence within sub-group	n (%)	Prevalence within sub-group	n (%)	Prevalence within sub-group	n (%)	Prevalence within sub-group	n (%)	Prevalence within sub-group
All children	**30,522**	**1419**	**4.6%**	**1626**	**5.3%**	**2737**	**9.0%**	**309**	**1.0%**	**366**	**1.2%**	**636.00**	**2.1%**
Age													
6-23	8924 (29.2)	518 (36.5)	1.7%	1149 (70.7)	3.8%	1475 (53.9)	4.8%	135 (43.7)	0.4%	268 (73.2)	0.9%	373 (58.6)	1.2%
24-59	21598 (70.8)	901 (63.5)	3.0%	477 (29.3)	1.6%	1262 (46.1)	4.1%	174 (56.3)	0.6%	98 (26.8)	0.3%	263 (41.4)	0.9%
Sex													
Male	15818 (51.8)	815 (57.4)	2.7%	652 (40.1)	2.1%	1311 (47.9)	4.3%	184 (59.5)	0.6%	155 (42.3)	0.5%	313 (49.2)	1.0%
Female	14704 (48.2)	604 (42.6)	2.0%	974 (59.9)	3.2%	1426 (52.1)	4.7%	125 (40.5)	0.4%	211 (57.7)	0.7%	323 (50.8)	1.1%
Height-for-age z-score (stunting status)													
2SD < z ≤ -2SD	20680 (67.8)	781 (55)	2.6%	782 (48.1)	2.6%	1423 (52)	4.7%	218 (70.6)	0.7%	157 (42.9)	0.5%	359 (56.4)	1.2%
-2SD < z ≤ -3SD	2721 (8.9)	222 (15.6)	0.7%	330 (20.3)	1.1%	475 (17.4)	1.6%	47 (15.2)	0.2%	102 (27.9)	0.3%	132 (20.8)	0.4%
≤ -3SD	7121 (23.3)	416 (29.3)	1.4%	514 (31.6)	1.7%	839 (30.7)	2.7%	44 (14.2)	0.1%	107 (29.2)	0.4%	145 (22.8)	0.5%
Weight-for-age z-score (underweight status)													
2SD < z ≤ -2SD	23841 (78.1)	289 (20.4)	0.9%	757 (46.6)	2.5%	1007 (36.8)	3.3%	61 (19.7)	0.2%	143 (39.1)	0.5%	203 (31.9)	0.7%
-2SD < z ≤ -3SD	1070 (3.5)	400 (28.2)	1.3%	260 (16)	0.9%	526 (19.2)	1.7%	148 (47.9)	0.5%	110 (30.1)	0.4%	227 (35.7)	0.7%
≤ -3SD	5169 (16.9)	730 (51.4)	2.4%	606 (37.3)	2.0%	1201 (43.9)	3.9%	100 (32.4)	0.3%	112 (30.6)	0.4%	205 (32.2)	0.7%
Wealth quintile													
Poorest	10227 (33.6)	600 (42.5)	2.0%	760 (46.7)	2.5%	1205 (44.1)	4.0%	145 (46.9)	0.5%	169 (46.2)	0.6%	294 (46.2)	1.0%
Poor	7407 (24.3)	370 (26.2)	1.2%	407 (25)	1.3%	701 (25.7)	2.3%	75 (24.3)	0.2%	105 (28.7)	0.3%	171 (26.9)	0.6%
Middle	5516 (18.1)	219 (15.5)	0.7%	245 (15.1)	0.8%	428 (15.7)	1.4%	39 (12.6)	0.1%	44 (12)	0.1%	77 (12.1)	0.3%
Richer	4236 (13.9)	132 (9.3)	0.4%	141 (8.7)	0.5%	247 (9)	0.8%	33 (10.7)	0.1%	30 (8.2)	0.1%	59 (9.3)	0.2%
Richest	3082 (10.1)	92 (6.5)	0.3%	73 (4.5)	0.2%	150 (5.5)	0.5%	17 (5.5)	0.1%	18 (4.9)	0.1%	35 (5.5)	0.1%
Type of Residence													
Rural	20108 (65.9)	992 (69.9)	3.3%	1146 (70.5)	3.8%	1921 (70.2)	6.3%	202 (65.4)	0.7%	251 (68.6)	0.8%	427 (67.1)	1.4%
Urban	10414 (34.1)	427 (30.1)	1.4%	480 (29.5)	1.6%	816 (29.8)	2.7%	107 (34.6)	0.4%	115 (31.4)	0.4%	209 (32.9)	0.7%

Source: Authors' analysis of pooled 2018-2019 Expanded National Nutrition Survey data (Department of Science and Technology - Food and Nutrition Research Institute).

Note: ENNS = Expanded National Nutrition Survey; WHZ = Weight-for-height z-score; MUAC = Mid-Upper Arm Circumference;

Performance of current global MUAC cutoffs in identifying moderate and severe wasting

Overall, the current MUAC cutoffs exhibited poor performance in identifying Filipino children aged 6-59 months with moderate (AUROC: 0.586) and severe wasting (AUROC: 0.557). Specifically, the current cutoffs have high specificity, but very low sensitivity. The cutoffs were 22% sensitive and 96% specific for moderate wasting (See **Table 4**) and 13% sensitive and 99% specific for severe wasting (See **Table 5**). This indicates that only 22% and 13% of moderately and severely wasted children were correctly identified as wasted by the current MUAC cutoffs. On the other hand, 96% and 99% of children who were truly not moderately and severely wasted were correctly ruled out.

Table 4. Diagnostic performance of current MUAC cutoffs in the identification of Moderate Wasting diagnosed using WFH Z-Scores among children aged 4 to 59 months

MUAC (≥ 11.5 to <12.5cm)	*Weight for Height/Length Z-score (-2SD < Z ≤ -3SD)*		Total
	Positive	Negative	
Positive	308	1,318	1,626
Negative	1,111	27,785	28,896
Total	1,419	29,103	30,522

Note: Sensitivity: 21.71%, Specificity: 95.47%, AUROC: 0.586
Source: Authors' calculations

Table 5. Diagnostic performance of current MUAC cutoffs in the identification of Severe Wasting diagnosed using WFH Z-Scores among children aged 4 to 59 months

MUAC (≤ 11.5)	*Weight for Height/Length Z-score (Z < -3SD)*		Total
	Positive	Negative	
Positive	39	327	366
Negative	270	29,886	30,156
Total	309	30,213	30,522

Note: Sensitivity: 12.62%, Specificity: 98.92%, AUROC: 0.557
Source: Authors' calculations

Performance of proposed optimal MUAC cutoffs and case definitions combining MUAC and WAZ for moderate and severe wasting

Table 6 and **Table 7** show the AUROC, sensitivity, specificity, PPV, and NPV of the current and proposed optimal MUAC cutoffs. The detailed information (full tables) of the determination of the optimal cutoffs can be found in **Appendix A** and **Appendix B**.

In general, identified optimal MUAC cutoffs calculated for all children and various sub-groups were higher and with an acceptable performance (based on AUROC) in this sample of children than the current global cutoffs recommended by the WHO (see **Table 6** and **Table 7**). For moderate wasting, the optimal MUAC cutoff was 14.0cm (AUROC 0.741), with a sensitivity of 80% and specificity of 68%, with a PPV of 11.0% and NPV of 98.6% (see **Table 6 and Appendix A**). This means that the MUAC at < 14.0cm correctly identified 80% of children who were moderately wasted and 68% as not moderately wasted by weight-for-height criteria. For severe wasting, the optimal MUAC cutoffs was <13.6cm (AUROC 0.690), demonstrating a sensitivity of 62% and specificity of 76%, with a PPV of 2.6% and NPV of 99.5%. **(see Table 7 and Appendix B**).

In practical terms, MUAC at <13.6cm correctly identified 62% of children who were severely wasted and 76% as not severely wasted. Both optimal MUAC cutoffs for moderate and severe wasting exhibited higher negative PPV at >98% and low PPV at 11.0% and 2.6%.

The same general trend of higher MUAC cutoffs (13.0-14.5cm), better performance (0.650-0.751, acceptable), but low PPV (0.6-46.8%) and high NPV (69.7-99.8%) compared to current cutoffs were found in calculations for child subpopulations. The optimal cutoffs for moderate and severe wasting for the age groups of 6-23, and 24-59 months are 13.2cm and 13.0cm, and 14.1cm and 14.5cm, showing an increase in the cutoff as age increases. (see **Table 6 and Table 7**). Looking at sex, the optimal cutoffs for moderate and severe wasting in male children were 14.0cm and 13.7cm, and in females 13.9cm and 13.4cm.

Lastly, we found that classifying children as wasted using either MUAC or weight-for-age resulted in optimal cutoffs close to global cutoffs with high sensitivities and specificities when calculated among all children. For moderate wasting, the optimal cutoff was 12.4cm or WAZ <-2 (AUROC: 0.815, Sensitivity: 83.23%, Specificity: 79.79%, PPV: 16.72%, NPV: 98.99%). For severe wasting, optimal cutoff was 11.6cm or WAZ <-2 (AUROC: 0.801, Sensitivity: 80.58%, Specificity: 79.62%, PPV: 3.89%, NPV: 99.75%).

Table 6. Diagnostic performance of current and identified optimal MUAC cutoffs and evaluated alternative case definitions for moderate wasting

Categories	*Moderate Wasting*					
	Cutoff (cm)	AUROC (LB-UB)	Sensitivity	Specificity	PPV	NPV
All children	Current (≥ 11.5 to <12.5cm)	0.586 (0.575-0.597)	21.71%	95.47%	18.94%	96.16%
	<14.0	0.741 (0.730-0.751)	79.63%	68.47%	10.97%	98.57%
	<13.9 or WAZ <-3	0.756 (0.746-0.767)	81.61%	69.63%	11.58%	98.73%
	<12.4 or WAZ <-2	0.815 (0.805-0.825)	83.23%	79.79%	16.72%	98.99%
Age (months)						
6-23 m	(≥ 11.5 to <12.5cm)	0.628 (0.607-0.649)	37.07%	88.62%	16.71%	95.81%
	<13.2	0.741 (0.723-0.759)	80.12%	68.03%	13.38%	98.23%
24-59	(≥ 11.5 to <12.5cm)	0.556 (0.545-0.567)	12.87%	98.26%	24.32%	96.28%
	<14.1	0.751 (0.737-0.766)	75.25%	75.03%	11.60%	98.58%
Sex						
Male	(≥ 11.5 to <12.5cm)	0.579 (0.566-0.593)	19.14%	96.69%	23.93%	95.65%
	<14.0	0.748 (0.734-0.763)	78.40%	71.25%	12.90%	98.38%
Female	(≥ 11.5 to <12.5cm)	0.597 (0.579-0.614)	25.17%	94.17%	15.61%	96.71%
	<13.9	0.737 (0.720-0.753)	80.13%	67.23%	9.48%	98.75%
Weight-for-age z-score (underweight status)						
≤ -3SD (Severe)	(≥ 11.5 to <12.5cm)	0.573 (0.546-0.601)	33.50%	81.19%	51.54%	67.16%
	<12.7	0.589 (0.558-0.619)	52.25%	65.52%	47.50%	69.68%
-2SD < z ≤ -3SD (Moderate)	(≥ 11.5 to <12.5cm)	0.539 (0.525-0.554)	18.49%	89.39%	22.28%	86.96%
	<13.7	0.624 (0.607-0.642)	73.56%	51.27%	19.89%	92.18%
2SD < z ≤ -2SD (Normal	(≥ 11.5 to <12.5cm)	0.552 (0.532-0.572)	13.49%	96.95%	5.15%	98.92%
	<14.0	0.693 (0.665-0.720)	64.01%	74.50%	2.99%	99.41%
Height-for-age z-score (stunting status)						
≤ -3SD (Severe)	(≥ 11.5 to <12.5cm)	0.623 (0.591-0.655)	34.68%	89.88%	23.33%	93.94%
	<13.1	0.715 (0.684-0.747)	69.37%	73.67%	18.97%	96.44%
-2SD < z ≤ -3SD (Moderate)	(≥ 11.5 to <12.5cm)	0.578 (0.558-0.598)	21.88%	93.69%	17.70%	95.08%
	<13.8	0.726 (0.706-0.746)	79.57%	65.68%	12.58%	98.11%
2SD < z ≤ -2SD (Normal)	(≥ 11.5 to <12.5cm)	0.573 (0.560-0.587)	17.93%	96.77%	17.90%	96.78%
	<14.0	0.752 (0.737-0.767)	75.93%	74.49%	10.46%	98.75%

Table 7. Diagnostic performance of current and identified optimal MUAC cutoffs and evaluated alternative case definitions for severe wasting

Categories	*Severe Wasting*					
	Cutoff (cm)	AUROC (LB-UB)	Sensitivity	Specificity	PPV	NPV
All children	Current (<11.5cm)	0.558 (0.539-0.576)	12.62%	98.92%	10.66%	99.10%
	<13.6	0.690 (0.662-0.717)	61.81%	76.09%	2.58%	99.49%
	<13.4 or WAZ <-3	0.752 (0.727-0.777)	72.17%	78.26%	3.28%	99.64%
	<11.6 or WAZ <-2	0.801 (0.779-0.823)	80.58%	79.62%	3.89%	99.75%
Age (months)						
6-23 m	<11.5cm	0.598 (0.562-0.633)	22.22%	97.29%	11.19%	98.79%
	<13.0	0.650 (0.607-0.692)	55.56%	74.40%	3.23%	99.09%
24-59	<11.5cm	0.524 (0.507-0.540)	5.17%	99.58%	9.18%	99.23%
	<14.5	0.698 (0.667-0.729)	78.16%	61.47%	1.62%	99.71%
Sex						
Male	<11.5cm	0.567 (0.541-0.592)	14.13%	99.17%	16.77%	98.99%
	<13.7	0.704 (0.669-0.738)	65.22%	75.49%	3.04%	99.46%
Female	<11.5cm	0.545 (0.518-0.572)	10.40%	98.64%	6.16%	99.23%
	<13.4	0.683 (0.641-0.726)	63.20%	73.48%	2.00%	99.57%
Weight-for-age z-score (underweight status)						
≤ -3SD (Severe)	<11.5cm	0.562 (0.528-0.596)	20.95%	91.43%	28.18%	87.81%
	<12.0	0.588 (0.547-0.628)	35.14%	82.43%	24.30%	88.79%
-2SD < z ≤ -3SD (Moderate)	<11.5cm	0.525 (0.499-0.550)	7.00%	97.93%	6.25%	98.16%
	<13.6	0.564 (0.516-0.613)	60.00%	52.87%	2.45%	98.53%
2SD < z ≤ -2SD (Normal	<11.5cm	0.505 (0.489-0.521)	1.64%	99.40%	0.70%	99.75%
	<14.2	0.611 (0.548-0.673)	55.74%	66.37%	0.42%	99.83%
Height-for-age z-score (stunting status)						
≤ -3SD (Severe)	<11.5cm	0.665 (0.595-0.734)	36.17%	96.82%	16.67%	98.85%
	<12.7	0.797 (0.738-0.857)	78.72%	80.70%	6.69%	99.54%
-2SD < z ≤ -3SD (Moderate)	<11.5cm	0.561 (0.510-0.612)	13.64%	98.57%	5.61%	99.46%
	<13.4	0.707 (0.637-0.777)	68.18%	73.21%	1.56%	99.73%
2SD < z ≤ -2SD (Normal	<11.5cm	0.533 (0.516-0.551)	7.34%	99.31%	10.19%	99.02%
	<14.5	0.683 (0.655-0.711)	77.52%	59.05%	1.98%	99.60%

Characteristics of children incorrectly classified ("false positive") as wasted vis-à-vis Weight for Height z-score

Table 8 present the characteristics of false positive children. For those children falsely labelled as severely wasted and moderate wasted vis-à-vis weight-for-height z-score, the average weight-for-age and height-for-age z-scores range from -2.3 to -2.7, near to the WFH classification cutoff of Z<-3 and majority of these children are also underweight and stunted. Moreover, most of the children have low dietary diversity scores and are not meeting the minimum acceptable diet.

Table 8. Characteristics of children incorrectly classified as wasted vis-à-vis Weight for Height z-score

Categories	For severe wasting		For moderate wasting	
	N	False Positive	n	False positive
All sample	6,157		5,883	
Age				
6-23 months	8924	1532 (17.2)	8924	1766 (19.8)
24-59 months	21598	4625 (21.4)	21598	4117 (19.1)
Sex				
Male	15818	3141 (19.9)	15818	2850 (18)
Female	14704	3016 (20.5)	14704	3033 (20.6)
Underweight Status (weight-for-age)				
Mean WAZ Z-score	6157	-2.5	5883	-2.3
Not Underweight	23841	165 (0.7)	23841	770 (3.2)
Severely Underweight	1070	922 (86.2)	1070	670 (62.6)
Moderately Underweight	5169	5069 (98.1)	5169	4439 (85.9)
Stunting Status (height-for-age)				
Mean HFA Z-score	6157	-2.7	5883	-2.6
Not Stunted	20680	1197 (5.8)	20680	1322 (6.4)
Severely Stunted	2721	2037 (74.9)	2721	1885 (69.3)
Moderately Stunted	7121	2923 (41)	7121	2676 (37.6)
Dietary Intake				
Mean energy intake (calories)	3115	651.2	3011	637.7
Mean intake – Carbohydrates (g)	3115	103	3011	101.0
Mean intake – Protein (g)	3115	21.8	3011	21.4
Mean intake – Fat (g)	3115	17	3011	16.5
Food, practices, and services			1519	
Dietary diversity score - 0	232	46 (19.8)	232	54 (23.3)
Dietary diversity score - 1	1609	318 (19.8)	1609	396 (24.6)
Dietary diversity score - 2	2882	487 (16.9)	2882	547 (19)
Dietary diversity score - 3	2305	393 (17)	2305	437 (19)
Dietary diversity score - 4	1287	206 (16)	1287	242 (18.8)
Dietary diversity score - 5	443	60 (13.5)	443	71 (16)
Dietary diversity score - 6	76	8 (10.5)	76	8 (10.5)
Dietary diversity score - 7	5	1 (20)	5	0 (0)
MMF (% meeting)	8031	1338 (16.7)	8031	1551 (19.3)
MAD (% meeting)	1006	1519 (17.2)	1006	194 (19.3)

Source: Authors' analysis of pooled 2018-2019 Expanded National Nutrition Survey

4. Discussion

In settings like the Philippines where equipment is scarce and measuring accurate weight-for-height Z scores is challenging in the field, the MUAC is a highly practical and simple tool that can be used in the early identification of wasted children. Literature has shown, however, that the current WHO-recommended global MUAC cutoffs poorly overlap with WHZ cutoffs, hence, has poor diagnostic performance in identified children wasted by WHZ criteria in various settings. Given that the MUAC has the potential to expand the coverage of programs for the integrated management of acute malnutrition, we thus investigated alternative MUAC cutoffs that may better identify wasting by weight-for-height in children 6-59 months in the Philippines. Based on the AUROC score, we found that the combination of MUAC ≤ 12.4cm or WAZ < -2 for moderate wasting and MUAC ≤ 11.6cm or WAZ < -2 or for severe wasting were the optimal case definitions. In comparison to current global MUAC cutoffs, these alternative case definitions exhibited vastly improved diagnostic sensitivity at the cost of acceptable decreases in specificity for the identification of children with moderate and severe wasting by the WHZ criteria. However, there was variation according to age and sex.

Our study confirms that MUAC, using current WHO cutoffs, is a highly specific but poorly sensitive diagnostic test for identifying wasting diagnosed by WHZ in Filipino children 6-59 months. Consistent with the results in other countries (Laillou et al., 2014; Lamsal et al., 2021; Talapalliwar & Garg, 2015; Tessema et al., 2020), using this cut-off in the field may lead to a high proportion of false negatives or wasted children that may be left undiagnosed and untreated. Aligning with these past studies, our findings underscore the importance of considering the specific context of the country of implementation. Generalized cutoffs may not be universally applicable due to variations in population health, genetics, or body morphology.

Less conservative MUAC cutoffs for all Filipino children and cutoffs specific to child subpopulations exhibited much better diagnostic performance in terms of AUROC score and sensitivity in exchange for lowered specificity. While there seems to be potential for tailored MUAC cutoffs based on child demographic factors, it raises concerns about the increased complexity of implementation in the context of limited resources and trained personnel. Having several cutoffs may introduce confusion in the field and significant increases in costs for procurement of specific MUAC tapes and training of field personnel. Consequently, this may negate MUAC's potential as an easy and quick tool to identify wasted children in the field that even child caregivers can use.

Interestingly, we found that MUAC when combined with weight-for-age (WFA) <-2, showed significant improvement in the AUROC and sensitivity for both moderate (AUROC: 0.815, Sensitivity: 83.233%, Specificity: 79.79%) and severe wasting (AUROC: 0.801, Sensitivity: 80.58%, Specificity: 79.62%) at alternative cutoffs only 0.2cm greater than current global cutoffs (moderate: 12.4cm, severe: 11.6cm). Studies have shown the association of WFA with wasting (weight-for-height), making WFA a potential anthropometric indicator that could also predict wasting in settings where measurement of height is not possible (Kassie & Workie, 2019; Nguefack-Tsague et al., 2013). Practically, measuring weight is still accessible to caregivers, and slightly adjusting the cutoffs will not imply huge costs in the re-production of specific MUAC tapes or training of field personnel.

One tradeoff of a much-improved sensitivity that decreases false negatives is the decrease in test specificity compared to the current cutoffs. This may result in increased false positives or admitting children that are not wasted to treatment which may potentially strain the local

healthcare system. Nonetheless, some of these children who may be false positive may be those at high risk of acute malnutrition or have other nutrition-related problems that need treatment. Looking at the characteristics of false positive children (See **Table 8**), most of them are also underweight and stunted, near the WFH threshold of being wasted, have low dietary diversity scores, and are not meeting the minimum acceptable diet. Hence, these children may benefit from the interventions being provided that could halt the progression to more severe deterioration of nutrition status and improve the nutrition outcomes of the child. In this context, the increase in false positives for the combined WAZ and MUAC criteria may be justified, given that the cost of a false negative or missed treatment is substantial in terms of lifelong morbidity and increased risk of mortality.

Strengths, Limitations, and Further Studies

Our study has several limitations. First, the consideration of the presence of edema was not incorporated in the analyses due to limitations in the available data. Second, children coming from indigenous populations with characteristics that might not be comparable to the general population were not accounted for in the analysis due to limitations in the data. Despite the limitations of the data, this dataset is the largest and only national survey that collects detailed anthropometric measurements for children (Patalen et al., 2020). Third, the results for subgroup analyses (by age, sex, underweight, and stunting status) should be interpreted carefully due to the low prevalence of severe and moderate wasting. Nevertheless, this is the first study in the Philippines that examines alternative MUAC cutoffs that may be more suitable to and accurate for Filipino children compared to simply adapting globally accepted cutoffs.

Our findings aim to contribute to the local and global evidence to further refine the identification and management of acute malnutrition improving access and coverage for PIMAM services. We recommend further implementation studies to validate findings and better understand its practical use and cost to the health system:

- **Longitudinal Studies:** Conduct long-term prospective studies to observe the health outcomes of children identified as wasted and classified as not eligible for intervention using the extended MUAC cutoffs/new case definitions. This data could validate the effectiveness and safety of interventions and help refine the cutoff points.

- **Health System Impact Assessment:** Evaluate the potential strain on the healthcare system due to increased admissions. Assess the capacity of healthcare facilities, availability of therapeutic foods, and the ability to provide quality care to the rising number of admitted cases.

5. Implications for the Philippines

As a practical and simple tool for the field and the community, the MUAC may improve the access and coverage for PIMAM services. In resource-limited settings, measuring height may be challenging due to the lack of equipment and difficulty in transporting these in far-flung areas.

The Philippines has generally stagnated in its wasting prevalence in the past 30 years (See **Figure** 1), falling short of the 2022 5% national target in the Philippine Plan of Action for Nutrition as of 2018. However, between the years 2013 and 2018, there has been a significant decrease. Among children under 5, the Food and Nutrition Institute (FNRI) reports that prevalence decreased from 8% in 2013 to 7.1% in 2015 to 5.6% in 2018. (Food and Nutrition Research Institute 2014, 2016a, 2018). This is slightly lower than the prevalence reported in the Asia-Pacific region during this year at 6.1%, and the lowest in the Southeast Asian region, except for Singapore and Brunei, which were at less than half of the prevalence in the Philippines (OECD 2022).

This prevalence, however, remains substantial with around 800,000 children estimated to be wasted annually. The Global Burden of Disease Study 2019 estimates that of the global total disability-adjusted life years (DALYs) among children under 5, 26% were attributable to childhood wasting, while of the global total DALYs among children aged 5 to 9, 7.4% were attributable to childhood wasting (Vos et al. 2020). United Nations Children's Fund (UNICEF) in 2017 found that economic losses resulting from lost future workforce attributed to child mortality from childhood wasting, nutritional deficiencies, and maternal hygiene and nutrition amounted to 667M/year, or around 0.2% of GDP (UNICEF, 2017).

Improving the diagnostic performance of a tool that could easily be used in the field, like MUAC, can potentially contribute to better screening mechanisms, improved coverage for wasting that will enable early detection and referral for appropriate care. If sustained, could potentially reduce the wasting prevalence further, reaching the 2030 Sustainable Development Goals target.

While the study's preliminary results provide valuable insights, further research, careful consideration of local contexts, and active community engagement are vital to implementing changes effectively and sustainably in identifying and treating acute malnutrition in the Philippines.

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7. Appendix

Appendix A. Diagnostic performance of MUAC cutoffs in identifying moderate wasting

MUAC Cut-off	*Cases (n)*	*Sensitivity*	*Specificity*	*PPV*	*NPV*	*AUROC*	*95% CI*	
All sample							**LB**	**UB**
<10cm	55	0.21%	99.82%	5.45%	95.35%	0.500	0.499	0.501
<10.1cm	60	0.28%	99.81%	6.67%	95.35%	0.500	0.499	0.502
<10.2cm	77	0.49%	99.76%	9.09%	95.36%	0.501	0.499	0.503
<10.3cm	84	0.49%	99.74%	8.33%	95.36%	0.501	0.499	0.503
<10.4cm	98	0.78%	99.70%	11.22%	95.37%	0.502	0.500	0.505
<10.5cm	102	0.78%	99.69%	10.78%	95.37%	0.502	0.500	0.505
<10.6cm	112	0.85%	99.66%	10.71%	95.37%	0.503	0.500	0.505
<10.7cm	131	1.27%	99.61%	13.74%	95.39%	0.504	0.501	0.507
<10.8cm	135	1.27%	99.60%	13.33%	95.39%	0.504	0.501	0.507
<10.9cm	160	1.97%	99.55%	17.50%	95.42%	0.508	0.504	0.511
<11cm	170	2.04%	99.52%	17.06%	95.42%	0.508	0.504	0.511
<11.1cm	196	2.61%	99.45%	18.88%	95.44%	0.510	0.506	0.514
<11.2cm	247	3.81%	99.34%	21.86%	95.49%	0.516	0.511	0.521
<11.3cm	278	4.44%	99.26%	22.66%	95.52%	0.519	0.513	0.524
<11.4cm	339	5.64%	99.11%	23.60%	95.56%	0.524	0.518	0.530
<11.5cm	366	6.06%	99.04%	23.50%	95.58%	0.525	0.519	0.532
<11.6cm	437	7.05%	98.84%	22.88%	95.62%	0.529	0.523	0.536
<11.7cm	519	8.67%	98.64%	23.70%	95.68%	0.537	0.529	0.544
<11.8cm	567	9.51%	98.52%	23.81%	95.71%	0.540	0.532	0.548
<11.9cm	704	11.84%	98.16%	23.86%	95.80%	0.550	0.542	0.558
<12cm	779	13.32%	97.97%	24.26%	95.86%	0.556	0.548	0.565
<12.1cm	985	16.49%	97.42%	23.76%	95.99%	0.570	0.560	0.579
<12.2cm	1318	20.44%	96.47%	22.00%	96.13%	0.585	0.574	0.595
<12.3cm	1470	22.27%	96.03%	21.50%	96.20%	0.592	0.581	0.602
<12.4cm	1838	26.29%	94.97%	20.29%	96.35%	0.606	0.595	0.618
<12.5cm	1992	27.77%	94.51%	19.78%	96.41%	0.611	0.600	0.623
<12.6cm	2233	30.51%	93.82%	19.39%	96.51%	0.622	0.610	0.634
<12.7cm	2638	35.02%	92.64%	18.84%	96.69%	0.638	0.626	0.651
<12.8cm	2818	36.93%	92.12%	18.59%	96.77%	0.645	0.633	0.658
<12.9cm	3310	41.09%	90.63%	17.61%	96.93%	0.659	0.646	0.671
<13cm	3611	44.47%	89.76%	17.47%	97.07%	0.671	0.658	0.684
<13.1cm	4209	49.47%	87.95%	16.68%	97.28%	0.687	0.674	0.700
<13.2cm	5181	55.53%	84.91%	15.21%	97.51%	0.702	0.689	0.715
<13.3cm	5620	58.35%	83.53%	14.73%	97.63%	0.709	0.696	0.722
<13.4cm	6450	62.93%	80.91%	13.84%	97.81%	0.719	0.706	0.732
<13.5cm	6807	64.76%	79.77%	13.50%	97.89%	0.723	0.710	0.735
<13.6cm	7414	67.79%	77.83%	12.98%	98.02%	0.728	0.716	0.741
<13.7cm	8328	72.02%	74.90%	12.27%	98.21%	0.735	0.723	0.747
<13.8cm	8803	74.14%	73.37%	11.95%	98.31%	0.738	0.726	0.749
<13.9cm	9807	77.94%	70.10%	11.28%	98.49%	0.740	0.729	0.751
<14cm	**10305**	**79.63%**	**68.47%**	**10.97%**	**98.57%**	**0.741**	**0.730**	**0.751**

<14.1cm	11289	82.10%	65.21%	10.32%	98.68%	0.737	0.726	0.747
<14.2cm	12716	85.55%	60.48%	9.55%	98.85%	0.730	0.721	0.740
<14.3cm	13319	86.33%	58.44%	9.20%	98.87%	0.724	0.714	0.733
<14.4cm	14393	88.30%	54.85%	8.71%	98.97%	0.716	0.707	0.725
<14.5cm	14820	88.94%	53.41%	8.52%	99.00%	0.712	0.703	0.720
<14.6cm	15567	90.20%	50.91%	8.22%	99.07%	0.706	0.697	0.714
<14.7cm	16688	91.47%	47.12%	7.78%	99.13%	0.693	0.685	0.701
<14.8cm	17215	92.11%	45.34%	7.59%	99.16%	0.687	0.680	0.695
<14.9cm	18349	93.59%	41.51%	7.24%	99.25%	0.676	0.669	0.682
<10cm or WAZ <-2	6266	79.63%	82.35%	18.03%	98.81%	0.810	0.799	0.821
<10.1cm or WAZ <-2	6269	79.63%	82.34%	18.03%	98.81%	0.810	0.799	0.821
<10.2cm or WAZ <-2	6277	79.63%	82.31%	18.00%	98.81%	0.810	0.799	0.820
<10.3cm or WAZ <-2	6282	79.63%	82.30%	17.99%	98.81%	0.810	0.799	0.820
<10.4cm or WAZ <-2	6289	79.63%	82.27%	17.97%	98.81%	0.810	0.799	0.820
<10.5cm or WAZ <-2	6290	79.63%	82.27%	17.97%	98.81%	0.810	0.799	0.820
<10.6cm or WAZ <-2	6294	79.63%	82.26%	17.95%	98.81%	0.809	0.799	0.820
<10.7cm or WAZ <-2	6301	79.77%	82.24%	17.97%	98.82%	0.810	0.799	0.821
<10.8cm or WAZ <-2	6304	79.77%	82.23%	17.96%	98.81%	0.810	0.799	0.821
<10.9cm or WAZ <-2	6314	79.92%	82.20%	17.96%	98.82%	0.811	0.800	0.821
<11cm or WAZ <-2	6316	79.92%	82.19%	17.95%	98.82%	0.811	0.800	0.821
<11.1cm or WAZ <-2	6322	79.92%	82.17%	17.94%	98.82%	0.810	0.800	0.821
<11.2cm or WAZ <-2	6338	80.13%	82.13%	17.94%	98.83%	0.811	0.801	0.822
<11.3cm or WAZ <-2	6345	80.20%	82.11%	17.94%	98.84%	0.812	0.801	0.822
<11.4cm or WAZ <-2	6369	80.48%	82.04%	17.93%	98.85%	0.813	0.802	0.823
<11.5cm or WAZ <-2	6383	80.62%	82.00%	17.92%	98.86%	0.813	0.803	0.824
<11.6cm or WAZ <-2	6406	80.62%	81.92%	17.86%	98.86%	0.813	0.802	0.823
<11.7cm or WAZ <-2	6434	80.90%	81.84%	17.84%	98.87%	0.814	0.803	0.824
<11.8cm or WAZ <-2	6449	81.04%	81.79%	17.83%	98.88%	0.814	0.804	0.825
<11.9cm or WAZ <-2	6497	81.04%	81.63%	17.70%	98.88%	0.813	0.803	0.824
<12cm or WAZ <-2	6528	81.32%	81.53%	17.68%	98.90%	0.814	0.804	0.825
<12.1cm or WAZ <-2	6624	81.68%	81.22%	17.50%	98.91%	0.814	0.804	0.825
<12.2cm or WAZ <-2	6778	82.10%	80.71%	17.19%	98.93%	0.814	0.804	0.824

<12.3cm or WAZ <-2	6851	82.38%	80.48%	17.06%	98.94%	0.814	0.804	0.824
<12.4cm or WAZ <-2	**7064**	**83.23%**	**79.79%**	**16.72%**	**98.99%**	**0.815**	**0.805**	**0.825**
<12.5cm or WAZ <-2	7143	83.37%	79.52%	16.56%	98.99%	0.814	0.804	0.824
<12.6cm or WAZ <-2	7247	83.72%	79.18%	16.39%	99.01%	0.815	0.805	0.824
<12.7cm or WAZ <-2	7462	84.50%	78.48%	16.07%	99.05%	0.815	0.805	0.825
<12.8cm or WAZ <-2	7561	84.71%	78.15%	15.90%	99.05%	0.814	0.805	0.824
<12.9cm or WAZ <-2	7827	85.13%	77.26%	15.43%	99.07%	0.812	0.802	0.822
<13cm or WAZ <-2	7989	85.91%	76.74%	15.26%	99.11%	0.813	0.804	0.823
<13.1cm or WAZ <-2	8351	86.54%	75.52%	14.70%	99.14%	0.810	0.801	0.820
<13.2cm or WAZ <-2	8987	87.81%	73.40%	13.86%	99.20%	0.806	0.797	0.815
<13.3cm or WAZ <-2	9265	88.16%	72.46%	13.50%	99.21%	0.803	0.794	0.812
<13.4cm or WAZ <-2	9808	89.08%	70.64%	12.89%	99.25%	0.799	0.790	0.807
<13.5cm or WAZ <-2	10026	89.43%	69.91%	12.66%	99.27%	0.797	0.788	0.805
<13.6cm or WAZ <-2	10417	89.92%	68.59%	12.25%	99.29%	0.793	0.784	0.801
<13.7cm or WAZ <-2	11036	90.49%	66.49%	11.63%	99.31%	0.785	0.777	0.793
<13.8cm or WAZ <-2	11359	90.84%	65.40%	11.35%	99.32%	0.781	0.773	0.789
<13.9cm or WAZ <-2	12095	92.25%	62.94%	10.82%	99.40%	0.776	0.768	0.783
<14cm or WAZ <-2	12452	92.67%	61.73%	10.56%	99.42%	0.772	0.765	0.779
<14.1cm or WAZ <-2	13189	93.23%	59.23%	10.03%	99.45%	0.762	0.755	0.769
<14.2cm or WAZ <-2	14299	94.15%	55.46%	9.34%	99.49%	0.748	0.741	0.755
<14.3cm or WAZ <-2	14779	94.43%	53.82%	9.07%	99.50%	0.741	0.735	0.748
<14.4cm or WAZ <-2	15645	95.14%	50.88%	8.63%	99.54%	0.730	0.724	0.736
<14.5cm or WAZ <-2	16003	95.42%	49.66%	8.46%	99.55%	0.725	0.719	0.732
<14.6cm or WAZ <-2	16614	95.63%	47.58%	8.17%	99.55%	0.716	0.710	0.722
<14.7cm or WAZ <-2	17561	95.98%	44.34%	7.76%	99.56%	0.702	0.696	0.707
<14.8cm or WAZ <-2	18009	96.05%	42.80%	7.57%	99.55%	0.694	0.688	0.700
<14.9cm or WAZ <-2	18982	96.62%	39.49%	7.22%	99.58%	0.681	0.675	0.686
<10cm or WAZ <-3	1112	28.26%	97.56%	36.06%	96.54%	0.629	0.617	0.641
<10.1cm or WAZ <-3	1115	28.26%	97.55%	35.96%	96.54%	0.629	0.617	0.641

<10.2cm or WAZ <-3	1125	28.33%	97.52%	35.73%	96.54%	0.629	0.617	0.641
<10.3cm or WAZ <-3	1132	28.33%	97.49%	35.51%	96.54%	0.629	0.617	0.641
<10.4cm or WAZ <-3	1142	28.40%	97.46%	35.29%	96.54%	0.629	0.618	0.641
<10.5cm or WAZ <-3	1145	28.40%	97.45%	35.20%	96.54%	0.629	0.617	0.641
<10.6cm or WAZ <-3	1152	28.47%	97.43%	35.07%	96.54%	0.630	0.618	0.641
<10.7cm or WAZ <-3	1162	28.61%	97.40%	34.94%	96.55%	0.630	0.618	0.642
<10.8cm or WAZ <-3	1165	28.61%	97.39%	34.85%	96.55%	0.630	0.618	0.642
<10.9cm or WAZ <-3	1183	29.03%	97.35%	34.83%	96.57%	0.632	0.620	0.644
<11cm or WAZ <-3	1190	29.11%	97.33%	34.71%	96.57%	0.632	0.620	0.644
<11.1cm or WAZ <-3	1208	29.18%	97.27%	34.27%	96.57%	0.632	0.620	0.644
<11.2cm or WAZ <-3	1238	29.74%	97.20%	34.09%	96.60%	0.635	0.623	0.647
<11.3cm or WAZ <-3	1260	30.16%	97.14%	33.97%	96.61%	0.637	0.625	0.648
<11.4cm or WAZ <-3	1305	30.66%	97.01%	33.33%	96.63%	0.638	0.626	0.650
<11.5cm or WAZ <-3	1326	30.94%	96.95%	33.11%	96.64%	0.639	0.627	0.652
<11.6cm or WAZ <-3	1384	31.43%	96.78%	32.23%	96.66%	0.641	0.629	0.653
<11.7cm or WAZ <-3	1445	32.42%	96.62%	31.83%	96.70%	0.645	0.633	0.657
<11.8cm or WAZ <-3	1477	32.84%	96.53%	31.55%	96.72%	0.647	0.635	0.659
<11.9cm or WAZ <-3	1574	33.83%	96.24%	30.50%	96.76%	0.650	0.638	0.663
<12cm or WAZ <-3	1635	34.81%	96.08%	30.21%	96.80%	0.654	0.642	0.667
<12.1cm or WAZ <-3	1799	36.22%	95.58%	28.57%	96.85%	0.659	0.646	0.672
<12.2cm or WAZ <-3	2091	38.62%	94.70%	26.21%	96.94%	0.667	0.654	0.679
<12.3cm or WAZ <-3	2224	39.75%	94.30%	25.36%	96.98%	0.670	0.657	0.683
<12.4cm or WAZ <-3	2551	42.14%	93.29%	23.44%	97.06%	0.677	0.664	0.690
<12.5cm or WAZ <-3	2692	43.20%	92.86%	22.77%	97.10%	0.680	0.667	0.693
<12.6cm or WAZ <-3	2908	45.17%	92.21%	22.04%	97.18%	0.687	0.674	0.700
<12.7cm or WAZ <-3	3268	48.48%	91.13%	21.05%	97.32%	0.698	0.685	0.711
<12.8cm or WAZ <-3	3434	50.11%	90.64%	20.70%	97.39%	0.704	0.691	0.717
<12.9cm or WAZ <-3	3881	53.28%	89.26%	19.48%	97.51%	0.713	0.700	0.726
<13cm or WAZ <-3	4151	55.81%	88.46%	19.08%	97.62%	0.721	0.708	0.734

<13.1cm or WAZ <-3	4694	59.34%	86.76%	17.94%	97.77%	0.731	0.718	0.743
<13.2cm or WAZ <-3	5603	64.13%	83.87%	16.24%	97.96%	0.740	0.727	0.753
<13.3cm or WAZ <-3	6018	66.31%	82.56%	15.64%	98.05%	0.744	0.732	0.757
<13.4cm or WAZ <-3	6792	69.70%	80.06%	14.56%	98.19%	0.749	0.737	0.761
<13.5cm or WAZ <-3	7125	71.18%	78.99%	14.18%	98.25%	0.751	0.739	0.763
<13.6cm or WAZ <-3	7697	73.50%	77.14%	13.55%	98.35%	0.753	0.741	0.765
<13.7cm or WAZ <-3	8567	76.89%	74.31%	12.73%	98.51%	0.756	0.745	0.767
<13.8cm or WAZ <-3	9015	78.29%	72.84%	12.32%	98.57%	0.756	0.745	0.767
<13.9cm or WAZ <-3	**9998**	**81.61%**	**69.63%**	**11.58%**	**98.73%**	**0.756**	**0.746**	**0.767**
<14cm or WAZ <-3	10483	83.09%	68.03%	11.25%	98.80%	0.756	0.745	0.766
<14.1cm or WAZ <-3	11437	84.85%	64.84%	10.53%	98.87%	0.748	0.739	0.758
<14.2cm or WAZ <-3	12831	87.67%	60.19%	9.70%	99.01%	0.739	0.730	0.748
<14.3cm or WAZ <-3	13424	88.37%	58.18%	9.34%	99.03%	0.733	0.724	0.742
<14.4cm or WAZ <-3	14480	90.13%	54.64%	8.83%	99.13%	0.724	0.716	0.732
<14.5cm or WAZ <-3	14901	90.70%	53.22%	8.64%	99.15%	0.720	0.712	0.728
<14.6cm or WAZ <-3	15639	91.68%	50.73%	8.32%	99.21%	0.712	0.704	0.720
<14.7cm or WAZ <-3	16747	92.74%	46.98%	7.86%	99.25%	0.699	0.691	0.706
<14.8cm or WAZ <-3	17263	93.09%	45.22%	7.65%	99.26%	0.692	0.684	0.699
<14.9cm or WAZ <-3	18389	94.50%	41.42%	7.29%	99.36%	0.680	0.673	0.686

Appendix B. Diagnostic performance of MUAC cutoffs in identifying severe wasting

MUAC Cut-off	*Cases (n)*	*Sensitivity*	*Specificity*	*PPV*	*NPV*	*AUROC*	*95% CI*	
All sample							**LB**	**UB**
<10cm	55	1.94%	99.84%	10.91%	99.01%	0.509	0.501	0.517
<10.1cm	60	2.27%	99.82%	11.67%	99.01%	0.510	0.502	0.519
<10.2cm	77	3.24%	99.78%	12.99%	99.02%	0.515	0.505	0.525
<10.3cm	84	3.56%	99.76%	13.10%	99.02%	0.517	0.506	0.527
<10.4cm	98	3.56%	99.71%	11.22%	99.02%	0.516	0.506	0.527
<10.5cm	102	3.88%	99.70%	11.76%	99.02%	0.518	0.507	0.529
<10.6cm	112	4.85%	99.68%	13.39%	99.03%	0.523	0.511	0.535
<10.7cm	131	5.18%	99.62%	12.21%	99.04%	0.524	0.512	0.536
<10.8cm	135	5.50%	99.61%	12.59%	99.04%	0.526	0.513	0.538
<10.9cm	160	5.83%	99.53%	11.25%	99.04%	0.527	0.514	0.540
<11cm	170	6.47%	99.50%	11.76%	99.05%	0.530	0.516	0.544
<11.1cm	196	7.44%	99.43%	11.73%	99.06%	0.534	0.520	0.549
<11.2cm	247	9.39%	99.28%	11.74%	99.08%	0.543	0.527	0.560
<11.3cm	278	10.68%	99.19%	11.87%	99.09%	0.549	0.532	0.567
<11.4cm	339	11.97%	99.00%	10.91%	99.10%	0.555	0.537	0.573
<11.5cm	366	12.62%	98.92%	10.66%	99.10%	0.558	0.539	0.576
<11.6cm	437	14.24%	98.70%	10.07%	99.12%	0.565	0.545	0.584
<11.7cm	519	16.18%	98.45%	9.63%	99.14%	0.573	0.553	0.594
<11.8cm	567	17.15%	98.30%	9.35%	99.15%	0.577	0.556	0.598
<11.9cm	704	19.74%	97.87%	8.66%	99.17%	0.588	0.566	0.610
<12cm	779	20.71%	97.63%	8.22%	99.18%	0.592	0.569	0.614
<12.1cm	985	22.65%	96.97%	7.11%	99.19%	0.598	0.575	0.622
<12.2cm	1318	24.60%	95.89%	5.77%	99.20%	0.602	0.578	0.626
<12.3cm	1470	26.21%	95.40%	5.51%	99.22%	0.608	0.583	0.633
<12.4cm	1838	29.13%	94.21%	4.90%	99.24%	0.617	0.591	0.642
<12.5cm	1992	29.45%	93.71%	4.57%	99.24%	0.616	0.590	0.641
<12.6cm	2233	33.01%	92.95%	4.57%	99.27%	0.630	0.603	0.656
<12.7cm	2638	37.22%	91.65%	4.36%	99.30%	0.644	0.617	0.671
<12.8cm	2818	37.86%	91.06%	4.15%	99.31%	0.645	0.617	0.672
<12.9cm	3310	41.75%	89.47%	3.90%	99.34%	0.656	0.629	0.684
<13cm	3611	43.37%	88.49%	3.71%	99.35%	0.659	0.632	0.687
<13.1cm	4209	45.63%	86.54%	3.35%	99.36%	0.661	0.633	0.689
<13.2cm	5181	50.49%	83.37%	3.01%	99.40%	0.669	0.641	0.697
<13.3cm	5620	53.07%	81.94%	2.92%	99.42%	0.675	0.647	0.703
<13.4cm	6450	56.96%	79.23%	2.73%	99.45%	0.681	0.653	0.709
<13.5cm	6807	57.93%	78.06%	2.63%	99.45%	0.680	0.652	0.708
<13.6cm	**7414**	**61.81%**	**76.09%**	**2.58%**	**99.49%**	**0.690**	**0.662**	**0.717**
<13.7cm	8328	64.72%	73.10%	2.40%	99.51%	0.689	0.662	0.716
<13.8cm	8803	65.37%	71.53%	2.29%	99.51%	0.685	0.658	0.711
<13.9cm	9807	68.28%	68.24%	2.15%	99.53%	0.683	0.656	0.709
<14cm	10305	68.61%	66.59%	2.06%	99.52%	0.676	0.650	0.702
<14.1cm	11289	70.55%	63.36%	1.93%	99.53%	0.670	0.644	0.695
<14.2cm	12716	76.05%	58.69%	1.85%	99.58%	0.674	0.650	0.698

<14.3cm	13319	77.67%	56.71%	1.80%	99.60%	0.672	0.648	0.695
<14.4cm	14393	80.91%	53.19%	1.74%	99.63%	0.670	0.648	0.693
<14.5cm	14820	82.20%	51.79%	1.71%	99.65%	0.670	0.648	0.691
<14.6cm	15567	83.17%	49.33%	1.65%	99.65%	0.662	0.641	0.684
<14.7cm	16688	85.76%	45.64%	1.59%	99.68%	0.657	0.637	0.677
<14.8cm	17215	86.41%	43.90%	1.55%	99.68%	0.652	0.632	0.671
<14.9cm	18349	87.70%	40.16%	1.48%	99.69%	0.639	0.621	0.658
<10cm or WAZ <-2	6266	80.26%	80.08%	3.96%	99.75%	0.802	0.779	0.824
<10.1cm or WAZ <-2	6269	80.26%	80.07%	3.96%	99.75%	0.802	0.779	0.824
<10.2cm or WAZ <-2	6277	80.26%	80.05%	3.95%	99.75%	0.802	0.779	0.824
<10.3cm or WAZ <-2	6282	80.26%	80.03%	3.95%	99.75%	0.801	0.779	0.824
<10.4cm or WAZ <-2	6289	80.26%	80.01%	3.94%	99.75%	0.801	0.779	0.824
<10.5cm or WAZ <-2	6290	80.26%	80.00%	3.94%	99.75%	0.801	0.779	0.824
<10.6cm or WAZ <-2	6294	80.26%	79.99%	3.94%	99.75%	0.801	0.779	0.824
<10.7cm or WAZ <-2	6301	80.26%	79.97%	3.94%	99.75%	0.801	0.779	0.823
<10.8cm or WAZ <-2	6304	80.26%	79.96%	3.93%	99.75%	0.801	0.779	0.823
<10.9cm or WAZ <-2	6314	80.26%	79.92%	3.93%	99.75%	0.801	0.779	0.823
<11cm or WAZ <-2	6316	80.26%	79.92%	3.93%	99.75%	0.801	0.779	0.823
<11.1cm or WAZ <-2	6322	80.26%	79.90%	3.92%	99.75%	0.801	0.778	0.823
<11.2cm or WAZ <-2	6338	80.26%	79.84%	3.91%	99.75%	0.801	0.778	0.823
<11.3cm or WAZ <-2	6345	80.26%	79.82%	3.91%	99.75%	0.800	0.778	0.823
<11.4cm or WAZ <-2	6369	80.58%	79.74%	3.91%	99.75%	0.802	0.779	0.824
<11.5cm or WAZ <-2	6383	80.58%	79.70%	3.90%	99.75%	0.801	0.779	0.824
<11.6cm or WAZ <-2	**6406**	**80.58%**	**79.62%**	**3.89%**	**99.75%**	**0.801**	**0.779**	**0.823**
<11.7cm or WAZ <-2	6434	80.91%	79.53%	3.89%	99.76%	0.802	0.780	0.824
<11.8cm or WAZ <-2	6449	80.91%	79.48%	3.88%	99.75%	0.802	0.780	0.824
<11.9cm or WAZ <-2	6497	80.91%	79.32%	3.85%	99.75%	0.801	0.779	0.823
<12cm or WAZ <-2	6528	80.91%	79.22%	3.83%	99.75%	0.801	0.779	0.823
<12.1cm or WAZ <-2	6624	80.91%	78.90%	3.77%	99.75%	0.799	0.777	0.821
<12.2cm or WAZ <-2	6778	80.91%	78.39%	3.69%	99.75%	0.796	0.774	0.819
<12.3cm or WAZ <-2	6851	80.91%	78.15%	3.65%	99.75%	0.795	0.773	0.817
<12.4cm or WAZ <-2	7064	81.55%	77.45%	3.57%	99.76%	0.795	0.773	0.817

<12.5cm or WAZ <-2	7143	81.55%	77.19%	3.53%	99.76%	0.794	0.772	0.816
<12.6cm or WAZ <-2	7247	81.88%	76.85%	3.49%	99.76%	0.794	0.772	0.815
<12.7cm or WAZ <-2	7462	82.20%	76.14%	3.40%	99.76%	0.792	0.770	0.813
<12.8cm or WAZ <-2	7561	82.52%	75.82%	3.37%	99.76%	0.792	0.770	0.813
<12.9cm or WAZ <-2	7827	82.85%	74.94%	3.27%	99.77%	0.789	0.768	0.810
<13cm or WAZ <-2	7989	83.50%	74.41%	3.23%	99.77%	0.790	0.769	0.810
<13.1cm or WAZ <-2	8351	84.14%	73.22%	3.11%	99.78%	0.787	0.766	0.807
<13.2cm or WAZ <-2	8987	85.11%	71.13%	2.93%	99.79%	0.781	0.761	0.801
<13.3cm or WAZ <-2	9265	85.76%	70.21%	2.86%	99.79%	0.780	0.760	0.800
<13.4cm or WAZ <-2	9808	87.06%	68.43%	2.74%	99.81%	0.777	0.758	0.796
<13.5cm or WAZ <-2	10026	87.06%	67.71%	2.68%	99.80%	0.774	0.755	0.793
<13.6cm or WAZ <-2	10417	88.03%	66.42%	2.61%	99.82%	0.772	0.754	0.791
<13.7cm or WAZ <-2	11036	88.35%	64.38%	2.47%	99.82%	0.764	0.746	0.782
<13.8cm or WAZ <-2	11359	88.35%	63.31%	2.40%	99.81%	0.758	0.740	0.776
<13.9cm or WAZ <-2	12095	89.32%	60.88%	2.28%	99.82%	0.751	0.734	0.768
<14cm or WAZ <-2	12452	89.32%	59.70%	2.22%	99.82%	0.745	0.728	0.763
<14.1cm or WAZ <-2	13189	89.97%	57.27%	2.11%	99.82%	0.736	0.719	0.753
<14.2cm or WAZ <-2	14299	91.26%	53.61%	1.97%	99.83%	0.724	0.708	0.740
<14.3cm or WAZ <-2	14779	91.26%	52.02%	1.91%	99.83%	0.716	0.700	0.732
<14.4cm or WAZ <-2	15645	91.91%	49.16%	1.82%	99.83%	0.705	0.690	0.721
<14.5cm or WAZ <-2	16003	92.23%	47.98%	1.78%	99.83%	0.701	0.686	0.716
<14.6cm or WAZ <-2	16614	92.23%	45.95%	1.72%	99.83%	0.691	0.676	0.706
<14.7cm or WAZ <-2	17561	93.20%	42.83%	1.64%	99.84%	0.680	0.666	0.694
<14.8cm or WAZ <-2	18009	93.53%	41.35%	1.60%	99.84%	0.674	0.660	0.688
<14.9cm or WAZ <-2	18982	93.53%	38.13%	1.52%	99.83%	0.658	0.644	0.672
<10cm or WAZ <-3	55	47.90%	96.81%	13.31%	99.45%	0.724	0.696	0.751
<10.1cm or WAZ <-3	60	47.90%	96.80%	13.27%	99.45%	0.723	0.696	0.751
<10.2cm or WAZ <-3	77	48.22%	96.77%	13.24%	99.46%	0.725	0.697	0.753
<10.3cm or WAZ <-3	84	48.54%	96.75%	13.25%	99.46%	0.726	0.699	0.754

<10.4cm or WAZ <-3	98	48.54%	96.72%	13.13%	99.46%	0.726	0.698	0.754
<10.5cm or WAZ <-3	102	48.54%	96.71%	13.10%	99.46%	0.726	0.698	0.754
<10.6cm or WAZ <-3	112	48.54%	96.68%	13.02%	99.46%	0.726	0.698	0.754
<10.7cm or WAZ <-3	131	48.54%	96.65%	12.91%	99.46%	0.726	0.698	0.754
<10.8cm or WAZ <-3	135	48.54%	96.64%	12.88%	99.46%	0.726	0.698	0.754
<10.9cm or WAZ <-3	160	48.54%	96.58%	12.68%	99.46%	0.726	0.698	0.754
<11cm or WAZ <-3	170	48.54%	96.56%	12.61%	99.46%	0.726	0.698	0.753
<11.1cm or WAZ <-3	196	49.19%	96.50%	12.58%	99.46%	0.728	0.701	0.756
<11.2cm or WAZ <-3	247	49.51%	96.41%	12.36%	99.47%	0.730	0.702	0.758
<11.3cm or WAZ <-3	278	49.84%	96.34%	12.22%	99.47%	0.731	0.703	0.759
<11.4cm or WAZ <-3	339	50.49%	96.20%	11.95%	99.48%	0.733	0.705	0.761
<11.5cm or WAZ <-3	366	50.49%	96.13%	11.76%	99.48%	0.733	0.705	0.761
<11.6cm or WAZ <-3	437	50.81%	95.94%	11.34%	99.48%	0.734	0.706	0.762
<11.7cm or WAZ <-3	519	51.46%	95.74%	11.00%	99.48%	0.736	0.708	0.764
<11.8cm or WAZ <-3	567	51.78%	95.64%	10.83%	99.49%	0.737	0.709	0.765
<11.9cm or WAZ <-3	704	51.78%	95.32%	10.17%	99.49%	0.735	0.708	0.763
<12cm or WAZ <-3	779	51.78%	95.12%	9.79%	99.48%	0.734	0.707	0.762
<12.1cm or WAZ <-3	985	52.10%	94.58%	8.95%	99.48%	0.733	0.705	0.761
<12.2cm or WAZ <-3	1318	52.75%	93.62%	7.80%	99.49%	0.732	0.704	0.760
<12.3cm or WAZ <-3	1470	53.72%	93.19%	7.46%	99.49%	0.735	0.707	0.762
<12.4cm or WAZ <-3	1838	55.66%	92.13%	6.74%	99.51%	0.739	0.711	0.767
<12.5cm or WAZ <-3	1992	55.66%	91.66%	6.39%	99.51%	0.737	0.709	0.764
<12.6cm or WAZ <-3	2233	58.25%	90.97%	6.19%	99.53%	0.746	0.719	0.774
<12.7cm or WAZ <-3	2638	59.55%	89.79%	5.63%	99.54%	0.747	0.719	0.774
<12.8cm or WAZ <-3	2818	59.87%	89.25%	5.39%	99.54%	0.746	0.718	0.773
<12.9cm or WAZ <-3	3310	61.49%	87.78%	4.90%	99.55%	0.746	0.719	0.774
<13cm or WAZ <-3	3611	62.78%	86.90%	4.67%	99.56%	0.748	0.721	0.775
<13.1cm or WAZ <-3	4209	64.72%	85.13%	4.26%	99.58%	0.749	0.722	0.776
<13.2cm or WAZ <-3	5181	67.64%	82.15%	3.73%	99.60%	0.749	0.723	0.775

<13.3cm or WAZ <-3	5620	69.26%	80.79%	3.56%	99.61%	0.750	0.724	0.776
<13.4cm or WAZ <-3	**6450**	**72.17%**	**78.26%**	**3.28%**	**99.64%**	**0.752**	**0.727**	**0.777**
<13.5cm or WAZ <-3	6807	72.82%	77.16%	3.16%	99.64%	0.750	0.725	0.775
<13.6cm or WAZ <-3	7414	75.08%	75.29%	3.01%	99.66%	0.752	0.728	0.776
<13.7cm or WAZ <-3	8328	76.38%	72.43%	2.75%	99.67%	0.744	0.720	0.768
<13.8cm or WAZ <-3	8803	76.38%	70.94%	2.62%	99.66%	0.737	0.713	0.760
<13.9cm or WAZ <-3	9807	78.32%	67.71%	2.42%	99.67%	0.730	0.707	0.753
<14cm or WAZ <-3	10305	78.32%	66.10%	2.31%	99.67%	0.722	0.699	0.745
<14.1cm or WAZ <-3	11289	79.29%	62.96%	2.14%	99.66%	0.711	0.688	0.734
<14.2cm or WAZ <-3	12716	82.85%	58.38%	2.00%	99.70%	0.706	0.685	0.727
<14.3cm or WAZ <-3	13319	84.14%	56.43%	1.94%	99.71%	0.703	0.682	0.723
<14.4cm or WAZ <-3	14393	86.08%	52.95%	1.84%	99.73%	0.695	0.676	0.715
<14.5cm or WAZ <-3	14820	87.38%	51.57%	1.81%	99.75%	0.695	0.676	0.714
<14.6cm or WAZ <-3	15567	87.70%	49.13%	1.73%	99.74%	0.684	0.666	0.703
<14.7cm or WAZ <-3	16688	89.32%	45.48%	1.65%	99.76%	0.674	0.657	0.691
<14.8cm or WAZ <-3	17215	89.97%	43.78%	1.61%	99.77%	0.669	0.652	0.686
<14.9cm or WAZ <-3	18349	90.61%	40.06%	1.52%	99.76%	0.653	0.637	0.670