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Accuracy of MUAC in the Detection of Severe Wasting With the New WHO Growth Standards

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KEY WORDS

malnutrition, anthropometry, mid-upper-arm circumference, diagnostic errors, epidemiology

ABBREVIATIONS

MUAC—mid-upper-arm circumference
NCHS—National Center for Health Statistics
WHO—World Health Organization
CI—confidence interval

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WHAT'S KNOWN ON THIS SUBJECT: MUAC measurements are used to screen rapidly for malnutrition among children 6 to 59 months of age. With the introduction of a new growth curve for children by the WHO in 2006, an evaluation of MUAC diagnostic accuracy is needed.

WHAT THIS STUDY ADDS: This study confirms the need to change the MUAC cutoff value from <110 mm to <115 mm. This change is needed to maintain the same diagnostic accuracy and to identify children at greatest risk of death resulting from severe wasting.

abstract

OBJECTIVES: The objectives of this study were to estimate the accuracy of using mid-upper-arm circumference (MUAC) measurements to diagnose severe wasting by comparing the new standards from the World Health Organization (WHO) with those from the US National Center for Health Statistics (NCHS) and to analyze the age independence of the MUAC cutoff values for both curves.

METHODS: We used cross-sectional anthropometric data for 34 937 children between the ages of 6 and 59 months, from 39 nutritional surveys conducted by Doctors Without Borders. Receiver operating characteristic curves were used to examine the accuracy of MUAC diagnoses. MUAC age independence was analyzed with logistic regression models.

RESULTS: With the new WHO curve, the performance of MUAC measurements, in terms of sensitivity and specificity, deteriorated. With different cutoff values, however, the WHO standards significantly improved the predictive value of MUAC measurements over the NCHS standards. The sensitivity and specificity of MUAC measurements were the most age independent when the WHO curve, rather than the NCHS curve, was used.

CONCLUSIONS: This study confirms the need to change the MUAC cutoff value from <110 mm to <115 mm. This increase of 5 mm produces a large change in sensitivity (from 16% to 25%) with little loss in specificity, improves the probability of diagnosing severe wasting, and reduces false-negative results by 12%. This change is needed to maintain the same diagnostic accuracy as the old curve and to identify the children at greatest risk of death resulting from severe wasting. *Pediatrics* 2010;126:e195–e201

Human arms contain subcutaneous fat and muscle mass. Under conditions of reduced food intake, lower levels of subcutaneous fat and muscle mass tend to correspond to a decrease in the mid-upper-arm circumference (MUAC). This measurement can be used to diagnose malnutrition.[1–3] MUAC is easy to measure and is relatively independent of gender and age.[4] Because of the simplicity and low cost of measuring MUAC, it is used to screen rapidly for malnutrition among children 6 to 59 months of age.[5,6] MUAC cutoff points of 125 mm (indicating global malnutrition) and 110 mm (indicating severe wasting) have been proposed for all children <5 years of age.[7]

Weight for height, expressed as a *z* score, is used to define severe wasting. A weight-for-height level less than a *z* score cutoff value of −3 is internationally recognized as severe wasting. In 2006, a new curve growth standard for assessing the growth of children throughout the world was introduced by the World Health Organization (WHO). A study comparing curves offered by the WHO and the US National Center for Health Statistics (NCHS) for diagnosis of severe wasting concluded that the WHO curve would identify more children with a high risk of death and would increase the number of children classified as experiencing severe wasting.[8] Therefore, it is also important to compare the accuracy of the current MUAC cutoff point for severe wasting (110 mm) against the standard measures, that is, the 1977 child growth standards of the US NCHS[9] and the 2006 WHO reference curve.[10] The objectives of this study were to estimate the accuracy of using MUAC measurements to diagnose severe wasting, defined as a weight-for-height *z* score less than −3 without bipedal edema, by comparing the new WHO curve with the NCHS curve and to analyze the age independence of the MUAC cutoff values of both curves.

METHODS

Data were obtained from 39 nutritional surveys conducted by Doctors Without Border in 10 countries, that is, Angola, Burundi, Malawi, Sierra Leona, Ethiopia, Niger, Burkina Faso, Chad (Darfur), India, and Afghanistan. Gender, weight, height, and MUAC were recorded for all children. The weight-for-length ratio was calculated for children who were <24 months of age. A total of 34 937 children between 65 and 110 cm in height without bipedal edema were included in our analyses. The device used to measure the MUAC of children was a plastic, colored, insertion tape (incapable of stretching and unresponsive to temperatures) marked in millimeters, with cutoff points from red to yellow at 110 mm and from yellow to green at 125 mm (more information about measurers and the MUAC device is provided in the Appendix).[11]

For the statistical analyses, we first calculated the nutritional indicators of severe wasting (more information is available in the Appendix), weight-for-height *z* scores less than −3 for all children, according to the NCHS and WHO curves. We then compared the diagnostic accuracy of the 2 curves by using 2 × 2 tables to determine the sensitivity, specificity, positive predictive value, and Youden index (more information about Youden index estimation is available in the Appendix)[12] of various MUAC cutoff points (110, 115, 125, 135, 140, and 145 mm). The proportion of children with severe wasting who would be missed with the MUAC measure also was calculated. We used receiver operating characteristic curves to estimate the area under the curve[13] for different MUAC cutoff values, to compare the discriminatory capacity of the WHO and NCHS curves for severe wasting.

To analyze the age and gender independence of the sensitivity and specificity of MUAC measurements in the diagnosis of severe wasting with the new curve, 2 logistic regression models were used to build receiver operating characteristic curves (more information about the models is available in the Appendix). The areas under both curves (unadjusted and adjusted for gender and height, as a proxy of age) were compared by using the test described by Hanley and McNeil.[14]

Finally, the age independence of the sensitivity and specificity of MUAC measurements in the diagnosis of severe wasting with the WHO and NCHS curves was assessed. Height was used as a proxy for age according to the following categories: 60.0 to 73.9 cm, 6 to 11 months; 74.0 to 84.9 cm, 12 to 23 months; 85.0 to 93.9 cm, 24 to 35 months; 94.0 to 101.9 cm, 36 to 47 months; 102.0 to 110.0 cm, 48 to 59 months.[15]

RESULTS

According to the old NCHS reference curve, the prevalence of severe wasting (defined as the proportion of children 6 to 59 months of age with weight-for-height *z* scores below −3, without edema) was 1.5% (548 children). According to the new WHO curve, however, the prevalence was 3.9% (1419 children). The prevalence of severe wasting diagnosed with the new WHO reference curve increased by 2.4% (95% confidence interval [CI]: 2.2%–2.6%).

Table 1 shows the accuracy of various MUAC cutoff points according to both the NCHS and WHO reference curves. The best cutoff point for the diagnosis of severe wasting according to the NCHS curve was 130 mm (Youden index: 0.63), and that according to the WHO curve was 135 mm (Youden index: 0.61). The predictive capacity of MUAC measurements with these cutoff points improved remarkably when the WHO curve was used instead of the NCHS curve (NCHS curve, positive predictive value: 7.0% [95% CI: 6.3%–7.6%]; WHO curve, positive predictive value: 13.0% [95% CI: 12.2%–13.6%]). In addition, the proportion of false-negative results with a 135-mm MUAC cutoff value was 15.5% with the WHO standards and increased to 20.4% when the NCHS standards were used. However, it should be noted that the highest Youden index value was obtained when cases were defined by using the NCHS reference and a MUAC cutoff value of 130 mm, rather than the WHO curve. On the basis of area-under-the-curve values, MUAC measurements performed better against the NCHS reference at cutoff values up to 140 mm; it was only at 140 and 145 mm that such measurements performed better against the WHO curve. This difference was statistically significant (Hanley-McNeil test, MUAC cutoff value of 140 mm, NCHS versus WHO curve, $z = 2.5$; $P = .01$; MUAC cutoff value of 145 mm, NCHS versus WHO curve, $z = 2.2$; $P = .02$). Graphically, the best MUAC cutoff point with the NCHS curve was confirmed to be 130 mm (area under the curve: 0.82 [95% CI: 0.79−0.83]), and the best cutoff point with the WHO curve was 135 mm (area under the curve: 0.80 [95% CI: 0.79−0.82]) (Fig 1).

The predicted values of both logistic regression models (unadjusted and adjusted for height and gender) were used to build 2 receiver operating characteristic curves to analyze the age and gender independence of the sensitivity and specificity of MUAC measurements for the diagnosis of severe wasting by using the WHO standards. The areas under the curve, compared with the Hanley-McNeil test, did not differ statistically ($z = 0.48$; $P > .05$). The area under the curve for the unadjusted curve was 0.89 (95% CI:

TABLE 1 Comparison of Different MUAC Cutoff Points Among 34 937 Children Between 60 and 110 cm of Height Through Weight-for-Height *z* Scores Below −3

MUAC Cutoff Value, mm	Below Cutoff Value, *n* (%)	Sensitivity, Estimate (95% CI), %		Specificity, Estimate (95% CI), %		Youden Index		Area Under Curve, Estimate (95% CI)		Positive Predictive Value, Estimate (95% CI), %		Proportion of Children With Low Weight-for-Height Values Missed With MUAC Measurements, %	
		NCHS	WHO	NCHS	WHO	NCHS	WHO	NCHS	WHO	NCHS	WHO	NCHS	WHO
110	322 (0.9)	23.9 (20.2–27.6)	16.0 (14.0–17.9)	99.4 (99.4–99.5)	99.7 (99.6–99.7)	0.23	0.16	0.62 (0.59–0.64)	0.58 (0.56–0.59)	40.0 (34.5–45.6)	69.2 (64.0–74.4)	76.1	84.0
115	626 (1.8)	34.7 (30.6–38.8)	25.0 (22.6–27.2)	98.7 (98.6–98.8)	99.1 (99.0–99.2)	0.33	0.24	0.67 (0.64–0.69)	0.62 (0.60–0.64)	29.9 (26.2–33.5)	55.6 (51.6–59.5)	65.3	75.0
120	1621 (4.6)	50.8 (46.5–55.1)	42.3 (39.6–44.9)	96.1 (95.8–96.3)	96.9 (96.7–97.1)	0.47	0.39	0.73 (0.71–0.76)	0.70 (0.68–0.71)	16.9 (15.0–18.7)	36.4 (34.0–38.8)	49.2	57.7
125	2914 (8.3)	63.8 (59.6–67.9)	55.2 (52.5–57.8)	92.5 (92.2–92.8)	93.6 (93.3–93.8)	0.56	0.49	0.78 (0.76–0.81)	0.74 (0.73–0.76)	11.8 (10.6–13.0)	26.5 (24.9–28.1)	36.2	44.8
130	6123 (17.5)	79.6 (76.1–83.0)	74.1 (71.7–76.4)	83.5 (83.0–83.8)	84.8 (84.4–85.2)	0.63	0.59	0.82 (0.79–0.83)	0.79 (0.78–0.81)	7.0 (6.3–7.6)	17.0 (15.9–17.8)	20.4	25.9
135	9141 (26.2)	87.4 (84.5–90.3)	84.5 (82.5–86.4)	74.8 (74.3–75.2)	76.2 (75.8–76.7)	0.62	0.61	0.81 (0.79–0.82)	0.80 (0.79–0.82)	5.2 (4.7–5.6)	13.0 (12.2–13.6)	12.6	15.5
140	14 684 (42.0)	92.4 (90.0–94.7)	93.2 (91.8–94.5)	58.7 (58.2–59.2)	60.1 (59.6–60.6)	0.51	0.53	0.76 (0.74–0.77)	0.77 (0.75–0.77)	3.4 (3.1–3.7)	8.9 (8.4–9.3)	7.6	6.8
145	18 744 (53.7)	94.0 (91.7–96.0)	95.3 (94.1–96.4)	47.0 (46.4–47.5)	48.1 (47.5–48.6)	0.41	0.43	0.74 (0.68–0.72)	0.71 (0.70–0.72)	2.7 (2.5–2.9)	7.1 (6.7–7.5)	6.0	4.7

The standard for screening for severe wasting was NCHS or WHO values. Compared with NCHS and WHO weight-for-height *z* scores below −3, the prevalence of severe wasting according to NCHS values was 1.5% and that according to WHO values was 3.9%.

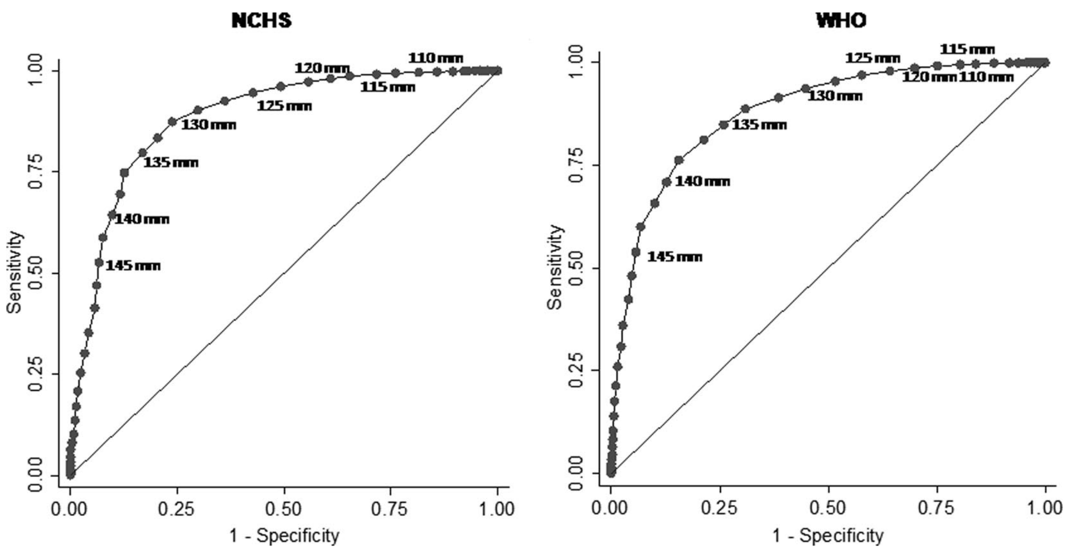

FIGURE 1
Receiver operating characteristic curves for severe wasting, defined as weight-for-height *z* scores below −3, with NCHS (area under the curve: 0.82 [95% CI: 0.79–0.83]) and WHO (area under the curve: 0.80 [95% CI: 0.79–0.82]) standards and different MUAC cutoff values.

0.88–0.90), and the area under the curve for the curve adjusted for gender and height was 0.90 (95% CI: 0.89–0.92).

The results in Table 2 confirm this relative height (as a proxy for age) independence of the sensitivity and specificity of MUAC measurements for children between the ages of 6 and 59 months. For children 24 to 59 months of age, the sensitivity and specificity of MUAC measurements were independent of age; for children <24 months of age, however, the sensitivity and specificity of MUAC measurements were relatively independent of age.

DISCUSSION

Our results showed an increase in the number of children classified as having severe wasting when the new WHO curve was compared with older standards. This finding confirms the results of other studies.[16,17] This increased prevalence of severe wasting should have an impact on the planning of nutritional support programs in sub-Saharan Africa, because of the more-inclusive nature of the WHO standard-based case definition. During a famine, unstable conditions may make it difficult to determine the height and weight of children, and the use of MUAC measurements for children 6 to 59 months of age might overestimate severe wasting. With a higher cutoff point, false-positive results increase and malnutrition is therefore overestimated; however, false-negative results decrease.

MUAC was found to be the best indicator for screening and detection of malnutrition in a community.[7] Screening methods based on comparisons with growth curves or weight gain are not likely to be predictive of mortality risk; arm circumference measurements, even without corrections for age or height, are substantially better than weight-for-age, height-for-age, or weight-for-height measurements.[18] A MUAC cutoff point of <110 mm was most related to mortality risk and therefore is suitable for use in malnutrition screening and detection efforts among children between 6 and 59 months of age.[7,19–23] However, with the new WHO reference curve, an increase of 5 mm (from 110 mm to 115 mm) in the MUAC cutoff value is necessary to maintain a level of diagnostic accuracy equal to that of the old curve.

With the new WHO curve, the overall performance of MUAC measurements, in terms of sensitivity and specificity, has deteriorated; therefore, to maintain the same diagnostic accuracy as the old curve and to identify the children at greatest risk of death resulting from severe wasting, a change in the cutoff value is needed. Our major findings are related to the need to change the MUAC cutoff point used to diagnose severe wasting from <110 mm to <115 mm. This increase of 5 mm produces a large change in sensitivity (from 16% to 25%), with little loss in specificity. In addition, this increase improves the probability of diagnosing severe wasting, compared with the NCHS curve, and reduces false-negative results by 12% because of the more-inclusive nature of the WHO curve-based case definition.

The relative age and gender independence of the sensitivity and specificity of MUAC measurements and the ease of use are some of their most important characteristics.[4–7] The results of our study also revealed that the age independence of the sensitivity and specificity of MUAC measurements improves with the switch from the NCHS standards

TABLE 2 Sensitivity, Specificity, and Youden Index for MUAC Indicators in Identifying Severe Wasting (Weight-for-Height *z* Scores Below −3) Among 34 937 Children 6 to 59 Months of Age, According to Height

Height (Age Proxy)	MUAC Cutoff Value, mm	WHO			NCHS		
		Sensitivity, %	Specificity, %	Youden Index	Sensitivity, %	Specificity, %	Youden Index
60.0–73.9 cm (6–11 mo)	110	32.0	99.0	0.31	48.1	97.6	0.46
	115	47.8	97.4	0.45	68.8	95.3	0.64
	120	71.8	90.4	0.62	89.6	87.4	0.77
	125	84.6	81.6	0.66	92.2	78.2	0.70
	130	93.2	62.9	0.56	97.4	59.9	0.57
	135	95.3	50.4	0.46	98.7	48.0	0.47
	140	98.5	29.7	0.28	100	28.2	0.28
	145	99.4	19.3	0.19	100	18.3	0.18
74.0–84.9 cm (12–23 mo)	110	18.9	99.6	0.19	28.1	99.4	0.28
	115	32.2	98.8	0.31	44.8	98.5	0.43
	120	54.4	95.8	0.50	65.1	95.1	0.60
	125	67.2	91.2	0.58	79.2	90.4	0.70
	130	82.5	78.8	0.61	89.6	77.8	0.67
	135	87.8	67.2	0.55	92.2	66.3	0.59
	140	92.8	47.7	0.41	94.3	47.0	0.41
	145	95.8	34.8	0.31	96.4	34.3	0.31
85.0–93.9 cm (24–35 mo)	110	12.7	99.9	0.13	25.0	99.8	0.25
	115	17.8	99.7	0.18	28.3	99.6	0.28
	120	34.7	98.6	0.33	43.5	98.2	0.42
	125	51.2	96.7	0.48	63.0	96.1	0.59
	130	73.7	90.7	0.64	79.3	89.7	0.69
	135	83.1	83.8	0.67	88.0	82.8	0.71
	140	92.0	68.6	0.61	92.4	67.7	0.60
	145	94.4	56.2	0.51	93.5	55.4	0.49
94.0–101.9 cm (36–47 mo)	110	5.8	99.9	0.06	10.0	99.9	0.10
	115	9.0	99.7	0.09	13.3	99.6	0.13
	120	24.7	98.8	0.24	27.8	98.4	0.26
	125	38.1	97.2	0.35	40.0	96.5	0.37
	130	61.9	92.3	0.54	65.6	91.3	0.57
	135	76.7	86.0	0.63	78.9	84.7	0.64
	140	89.7	72.8	0.63	88.9	71.6	0.61
	145	91.0	61.3	0.52	90.0	60.2	0.50
102.0–110.0 cm (48–59 mo)	110	2.7	100	0.03	7.0	100.0	0.07
	115	4.9	99.9	0.05	11.6	99.9	0.12
	120	9.1	99.7	0.09	17.4	99.5	0.17
	125	19.4	98.9	0.18	31.4	98.5	0.30
	130	49.0	95.7	0.45	57.0	94.5	0.52
	135	74.1	90.2	0.64	75.6	88.3	0.64
	140	91.3	78.2	0.63	86.0	76.1	0.62
	145	93.9	66.3	0.60	88.4	64.5	0.53

to the new WHO curve. When the NCHS reference curve is used, the sensitivity and specificity of MUAC measurements are at their most age dependent and the MUAC cutoff value increases by 1.5 cm between the ages of 6 and 59 months. With the new curve, an increase of only 1 cm is targeted among children between the ages of 6 and 59 months.

Other researchers also found that the MUAC cutoff points increase by 1.5 cm between the ages of 6 and 59 months according to the NCHS curve.[24–26] This reinforces the validity of our finding that the relative age independence of the sensitivity and specificity of MUAC measurements improves with the new curve. The improved predictive capacity and the relative age independence of the sensitivity and specificity of MUAC measurements indicate that the standards of the new WHO curve are better able to screen for severe wasting.[27]

Our study may contain a classification bias, because the surveys were conducted in 10 different countries at different times and by different staff members. Similarly, we think that there might have been a selection bias related to the ethnicity of the children. Anthropometric nutritional surveys from Ethiopia and Somalia found that *z* scores and MUAC case definitions returned different estimates of the prevalence of acute malnutrition in pastoralist livelihood zones but similar estimates of the prevalence of severe wasting in agrarian livelihood zones.[28] Nevertheless, the new WHO curve uses a pooled sample from the 6 participating countries and provides a tool that is timely and appropriate for contemporary ethnic diversity and the development of increasingly multiracial societies. The WHO curve also demonstrates that healthy children from around the world who are raised in healthy environments, according to recommended feeding practices, have strikingly similar patterns of growth.[29]

CONCLUSIONS

With the new WHO curve, the performance of MUAC measurements has deteriorated. This poorer performance, in terms of sensitivity and specificity, confirms the need to change the MUAC cutoff value from <110 mm to <115 mm. This increase of 5 mm produces a large change in sensitivity (16% to 25%) with little loss in specificity, improves the probability of diagnosing severe wasting, and reduces false-negative results by 12%. This change is needed to maintain the same diagnostic accuracy as the old curve and to identify the children at greatest risk of death resulting from severe wasting.

APPENDIX

MUAC Measurers

The measurers were people already working in nutritional programs. The measurers were supervised by a person who was responsible for proper application of the sampling procedures and was responsible for a team with respect to the measurements and other procedures defined in the survey guidelines. All measurers were trained by a nutritional nurse regarding the proper gathering of anthropometric measurements. A pretest was conducted to test the teams and the reliability of primary measurements. At the end of the pretest, the quality of the anthropometric measurements taken by the measurers was reviewed.

Device Used to Measure MUAC

The device used was a plastic, colored, insertion tape (incapable of stretching and unresponsive to temperatures) marked in millimeters, with cutoff points from red to yellow at 110 mm and from yellow to green at 125 mm.

Calculation of Indicator of Severe Wasting (Weight-for-Height *z* Score)

Severe wasting, defined as weight-for-height *z* scores below −3 for all children according to the NCHS curve, were calculated with Epi Info 6 (Centers for Disease Control and Prevention, Atlanta, GA). The *z* scores for the new WHO standards were calculated with the igrowup macro package (available at www.who.int/childgrowth/software/en).

Estimation of Age and Gender Independence of Sensitivity and Specificity of MUAC Cutoff Values From WHO Curve

Two logistic regression models were used to analyze the age and gender independence of the sensitivity and specificity of MUAC measurements in the diagnosis of severe wasting according to the WHO curve. The first model was built by using the WHO dichotomous indicator (yes/no) of severe wasting as a dependent variable and MUAC as an independent variable. The second model was adjusted for gender and height (as a proxy for age). The models were as follows: unadjusted model: log(severe wasting) = $\beta_0 + (\beta_1 \times \text{MUAC})$; adjusted model: log(severe wasting) = $\beta_0 + (\beta_1 \times \text{MUAC}) + (\beta_2 \times \text{height}) + (\beta_3 \times \text{gender})$. The predicted values of both models were used to build 2 receiver operating characteristic curves. The areas under the curves were compared with the Hanley-McNeil test.

Youden Index

The Youden index represents an attempt to summarize test accuracy into a single numeric value, that is, Youden index = sensitivity + specificity − 1 = $S - (1 - E)$. The minimum value is −1 and the maximum value is +1. A perfect test would have a Youden index value of +1.

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