

University of Wollongong

Research Online

Faculty of Science, Medicine and Health -
Papers: Part B

Faculty of Science, Medicine and Health

1-1-2020

Determining a global mid-upper arm circumference cut-off to assess underweight in adults (men and non-pregnant women)

Alice M. Tang
Tufts University

Mei Chung
Tufts University

Kimberly R. Dong
Tufts University

Paluku Bahwere
Valid International

Kaushik Bose
Vidyasagar University

See next page for additional authors

Follow this and additional works at: <https://ro.uow.edu.au/smhpapers1>

Publication Details Citation

Tang, A. M., Chung, M., Dong, K. R., Bahwere, P., Bose, K., Chakraborty, R., Charlton, K. E., Das, P., Ghosh, M., Hossain, M. I., Nguyen, P., Patsche, C. B., Sultana, T., Deitchler, M., & Maalouf-Manasseh, Z. (2020). Determining a global mid-upper arm circumference cut-off to assess underweight in adults (men and non-pregnant women). Faculty of Science, Medicine and Health - Papers: Part B. Retrieved from <https://ro.uow.edu.au/smhpapers1/1671>

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Determining a global mid-upper arm circumference cut-off to assess underweight in adults (men and non-pregnant women)

Keywords

global, women), non-pregnant, (men, mid-upper, adults, arm, underweight, assess, cut-off, determining, circumference

Publication Details

Tang, A. M., Chung, M., Dong, K. R., Bahwere, P., Bose, K., Chakraborty, R., Charlton, K., Das, P., Ghosh, M., Hossain, M. I., Nguyen, P., Patsche, C. B., Sultana, T., Deitchler, M. & Maalouf-Manasseh, Z. (2020). Determining a global mid-upper arm circumference cut-off to assess underweight in adults (men and non-pregnant women). *Public Health Nutrition*, Online First

Authors

Alice M. Tang, Mei Chung, Kimberly R. Dong, Paluku Bahwere, Kaushik Bose, Raja Chakraborty, Karen E. Charlton, Priyanka Das, Mihir Ghosh, Md I. Hossain, Phuong Nguyen, Cecilie B. Patsche, Tania Sultana, Megan Deitchler, and Zeina Maalouf-Manasseh

1 **ABSTRACT**

2 **Objective.** To determine if a global mid-upper arm circumference (MUAC) cutoff can be
3 established to classify underweight in adults (men and non-pregnant women).

4 **Design.** We conducted an individual participant data meta-analysis (IPDMA) to explore the
5 sensitivity (SENS) and specificity (SPEC) of various MUAC cutoffs for identifying underweight
6 among adults (defined as body mass index (BMI) $<18.5 \text{ kg/m}^2$). Measures of diagnostic accuracy
7 were determined every 0.5 cm across MUAC values from 19.0 to 26.5 cm. A bivariate random
8 effects model was used to jointly estimate SENS and SPEC while accounting for heterogeneity
9 between studies. Various subgroup analyses were performed.

10 **Setting.** Twenty datasets from Africa, South Asia, Southeast Asia, North America, and South
11 America were included.

12 **Participants.** All eligible participants from the original datasets were included.

13 **Results.** The total sample size was 13,835. Mean age was 32.6 years and 65% of participants
14 were female. Mean MUAC was 25.7 cm and 28% of all participants had low BMI ($<18.5 \text{ kg/m}^2$).
15 The area under the receiver operating characteristic curve (AUROC) for the pooled dataset was
16 0.91 (range across studies: 0.61-0.98). Results showed that MUAC cutoffs in the range of ≤ 23.5
17 cm to ≤ 25.0 cm could serve as appropriate screening indicators for underweight.

18 **Conclusions.** MUAC was highly discriminatory in its ability to distinguish adults with BMI
19 above and below 18.5 kg/m^2 . This IPDMA is the first step towards determining a global MUAC
20 cutoff for adults. Validation studies are needed to determine whether the proposed MUAC cutoff
21 of 24 cm is associated with poor functional outcomes.

22

23 **Keywords:** mid-upper arm circumference, MUAC, nutritional screening, underweight,
24 individual participant data meta-analysis, IPDMA, low BMI, cutoff

25 **Introduction**

26 Body mass index (BMI) is a widely used measure of nutritional status in adults. The
27 World Health Organization (WHO) has established global BMI cutoffs for adults over 20 years
28 of age with the range $<18.5 \text{ kg/m}^2$ indicating underweight. Although several recent and large
29 pooled and meta-analytic studies show a shift in focus towards examining the adverse health
30 effects of high BMI levels, these studies continue to show elevated morbidity and mortality in
31 the lowest ranges of BMI. ⁽¹⁻⁵⁾ In many resource-limited or emergency settings, accurate
32 measurements of BMI may be difficult to obtain due to lack of access to properly maintained
33 equipment (weight scales and stadiometers). In addition, health workers must be trained to read
34 relatively complicated charts to convert weight and height measurements to BMI.

35 Mid-upper arm circumference (MUAC) is a potential alternative measure to BMI to
36 screen for adult underweight. MUAC is a measure of the circumference of the upper arm at the
37 midpoint between the tip of the elbow (olecranon process) and tip of the shoulder blade
38 (acromion process).⁽⁶⁾ While MUAC measurements are generally a reflection of both muscle and
39 subcutaneous fat, in undernourished individuals who tend to have smaller amounts of
40 subcutaneous fat, MUAC measurements can reflect chronic energy deficiency.⁽⁶⁾ MUAC
41 measurements are linear and can be taken with a simple tape measure. With appropriate MUAC
42 cutoffs, the assessment could be performed by anyone with minimal training using even a simple
43 paper strip that designates the cutoff values using color codes.

44 In 2013, we completed a systematic review examining low MUAC as an indicator or
45 predictor of nutrition and health outcomes in adults and adolescents.⁽⁷⁾ Our review found that
46 MUAC correlates well with BMI in adult populations and that people with low MUAC (variably
47 defined by the original studies) are significantly more likely to have low BMI ($<18.5 \text{ kg/m}^2$).⁽⁸⁻¹¹⁾
48 Low MUAC was also shown to be a significant predictor of short-term mortality.⁽¹²⁻¹⁴⁾ Yet
49 globally recognized MUAC cutoffs have not been established to classify underweight among
50 adults. Within the past decade, countries and programs, particularly those working in the fields
51 of human immunodeficiency virus (HIV) and tuberculosis (TB), have tried to establish their own
52 MUAC cutoffs to determine eligibility for program services, but there is limited evidence that
53 these cutoffs are optimal for identifying individuals who are undernourished and who are at
54 higher risk for morbidity or mortality.⁽¹⁵⁻¹⁷⁾

55 To date, there is no guidance from the WHO about what MUAC cutoff should trigger
56 further action in adults. However, WHO has recommended a MUAC cutoff of <11.5 cm as a
57 screening tool for acute malnutrition in children 6 to 60 months of age.⁽¹⁸⁾ This cutoff has
58 become a globally recognized standard for the identification and management of severe acute
59 malnutrition in children and is often used to determine eligibility for, and to monitor progress in,
60 facility-based and community-level nutritional interventions.⁽¹⁹⁾ Global MUAC cutoffs for adults
61 could also serve to strengthen and harmonize programming across various sectors, including
62 HIV, TB, and broader community health and nutrition activities.

63 To determine the potential for developing standardized MUAC cutoffs to identify adults
64 at risk of undernutrition, we undertook an individual participant data meta-analysis (IPDMA) to
65 examine the diagnostic accuracy of various MUAC cutoffs for identifying underweight
66 (BMI<18.5 kg/m²) among men and non-pregnant women, henceforth referred to simply as “non-
67 pregnant adults.” In our systematic review, BMI <18.5 kg/m² was the outcome most consistently
68 found to be associated with low MUAC. The decision to conduct meta-analyses using individual-
69 level data rather than study-level (published) data was primarily dictated by the fact that most of
70 the published studies did not examine or provide data on the sensitivity or specificity of various
71 MUAC cutoffs.⁽⁷⁾ An original report which included 17 studies was published online in June
72 2017.⁽²⁰⁾ The current paper extends the findings of this report by including three additional
73 datasets obtained after the report was finalized.

74

75 **Methods**

76 Prior to seeking datasets, eligibility criteria and an analysis plan were established and
77 approved through our technical advisory group (TAG), which consisted of members from the
78 National Institutes of Health (NIH), the United States Agency for International Development
79 (USAID), and the World Health Organization (WHO). To be eligible for the IPDMA, datasets
80 had to include non-pregnant adults over the age of 18, with a minimum sample size of 100, and
81 be collected on or after the year 2000. We chose the year 2000 because that was the year that
82 antiretroviral therapy for HIV became widely accessible to people living with HIV in low-
83 resource settings. In addition, investigators had to be willing to share participant-level data. The
84 following minimal set of variables was requested: MUAC, height and weight (or BMI), sex, and
85 age.

86 Of the 13 studies that were included in our systematic review⁽⁷⁾, three were not eligible
87 for this IPDMA: one was conducted prior to 2000⁽⁸⁾ and two had sample sizes fewer than 100.^{(21,}
88 ²²⁾ We attempted to contact researchers from the remaining 10 studies and ultimately received
89 datasets from two of them. One researcher provided two eligible datasets (GUI-HIV and GUI-
90 TBC) and another research group provided six eligible datasets (IND-BKW, IND-FSD, IND-
91 MSD, IND-ORA, IND-SDW, and IND-UNI). We then put out a call for datasets through our
92 technical advisory group (TAG) and updated our literature search. Through these methods, we
93 were able to obtain six additional datasets (BAN, MAL-HNW, MAL-HWW, SAF, VIE-FEM,
94 and ZAM). We also included six eligible datasets from the Tufts team commissioned to conduct
95 the IPDMA (ARG, IND-IDU, NAM, USA-IDU, USA-HIV, and VIE-IDU. Thus, the present
96 analysis includes data from 20 unique datasets. Data from four studies (IND-UNI, MAL-HNW,
97 NAM, and ZAM) were unpublished at the time this manuscript was written. Table 1 provides a
98 brief summary of the studies included in this IPDMA. The twenty studies represent the target
99 populations that would most likely use an established low MUAC cutoff to determine eligibility
100 for limited health and nutrition services, i.e. people living with HIV and/or TB, low-resource and
101 development settings, and individuals at risk of undernutrition (e.g. injection drug users).

102

103 **Statistical Analyses**

104 All datasets were converted and analyzed using the Stata statistical software (StataCorp,
105 College Station, TX, USA). Each dataset was assessed against published manuscripts or original
106 research protocols to create an overview of the included participants and study procedures. For
107 each dataset, we performed data checks of all variables received, ensuring that units, categories,
108 coding, and labels were consistent across studies. Investigators were contacted to confirm
109 missing data, to check extreme or invalid values, and to obtain clarification of study variables
110 and procedures.

111 To better understand the data from each individual study and the degree of potential
112 heterogeneity between studies, basic descriptive statistics were calculated for each study. These
113 variables included age, sex, education level, HIV status, MUAC, height, weight, and BMI. The
114 collection of information on education was not consistent across studies. Some studies asked for
115 the number of years of schooling, while others collected data in predetermined categories which
116 were not equivalent between studies. For the purposes of summarizing and comparing education

117 levels across studies, we created three general categories: no education, education at or up to the
118 primary school level (grades 1 to 8, 1–8 years of schooling, or less than high school), and
119 education at or above the secondary school level (grades 9 to ≥ 12 , ≥ 9 years of schooling,
120 completion of high school or beyond).

121 MUAC was measured to the nearest 0.1 cm in all studies except for GUI-TBC, where
122 MUAC was measured to the nearest 0.2 cm. Histograms of MUAC and BMI were constructed to
123 determine the distribution of these measurements for each study separately and for all datasets
124 combined (Supplementary Figures 1 to 4). Scatterplots of BMI by MUAC were examined to
125 determine the association between the two variables, for each study separately and for all
126 datasets combined (Supplementary Figures 5 and 6). Pearson correlation coefficients between
127 MUAC and BMI were calculated for each study separately and for all studies combined. The
128 outcome of low BMI was defined as BMI < 18.5 kg/m², consistent with the cutoff for
129 underweight recommended by the WHO.⁽²³⁾

130 We then examined the diagnostic accuracy of MUAC in predicting low BMI, using
131 MUAC cutoffs in increments of 0.5 cm over the range of 19.0 to 26.5 cm. For each MUAC
132 cutoff, we constructed a 2x2 table showing the cross-tabulation of BMI category (BMI < 18.5 vs.
133 BMI ≥ 18.5) and MUAC (above or below the specified cutoff). We computed sensitivity (SENS),
134 specificity (SPEC), positive predictive value (PPV), and negative predictive value (NPV) over
135 the range of MUAC cutoffs for each of the 20 datasets. We also obtained the area under the
136 receiver operating characteristic curve (AUROC) for each study. Next, we combined the datasets
137 into one pooled dataset and created a unique participant identification number and study
138 identifier variable to identify participants within studies. We estimated SENS, SPEC, and
139 positive and negative Likelihood Ratios (LR+ and LR-) for each MUAC cutoff value using the
140 user-written *metandi* and *midas* commands in Stata.^(24, 25) These commands perform a bivariate
141 (or joint) meta-analysis of SENS and SPEC using a two-level mixed-effect logistic regression
142 model with MUAC as the only independent variable predicting low BMI. At the first level,
143 within-study variability is accounted for by modeling the counts of the 2x2 tables within each
144 study. At the second level, the between-study variability (heterogeneity) is accounted for,
145 allowing for the non-independence of SENS and SPEC across studies. We also obtained the
146 AUROC for the pooled dataset.

147

148 **RESULTS**

149 The number of participants in each study ranged from 182 (ZAM) to 4,926 (VIE-FEM)
150 (Table 1). The VIE-FEM dataset was by far the largest, with nearly five times the number of
151 participants as the second largest dataset (GUI-HIV, with n=1,055).

152 Table 2 shows the demographic characteristics of the participants, by individual study
153 and for all studies combined. Overall, the mean age was 32.6 ± 12.1 years, with ages ranging from
154 18 to 91 years. The average age for each study was predominantly in the 30s, with a few
155 exceptions. Three studies targeted slightly younger populations (BAN, IND-UNI, and VIE-
156 FEM), and two studies included slightly older participants (USA-IDU and USA-HIV). One study
157 (SAF) specifically targeted an elderly population and thus had a mean age of 71.5 ± 7.9 years.

158 Nearly two-thirds of participants in the pooled dataset were female (64.4%). Two studies
159 (IND-FSD and VIE-FEM) included only female participants and five studies (IND-BKW, IND-
160 MSD, IND-ORA, IND-IDU, and VIE-IDU) included only male participants.

161 Six of the 17 studies did not collect data on education status. Of the remaining 11 studies,
162 education level differed widely between studies. Two studies (IND-BKW and IND-FSD)
163 included a majority of participants that had no schooling. Two studies (ARG and IND-IDU)
164 included a majority of participants with primary school education, and six studies (GUI-TBC,
165 IND-UNI, NAM, USA-HIV, VIE-FEM, and VIE-IDU) included a majority with secondary
166 school education or above.

167 HIV status was not ascertained in half of the studies. Five studies (GUI-HIV, MAL-
168 HNW, MAL-HWW, USA-HIV, and ZAM) included HIV-positive participants only and the
169 remaining five studies (ARG, IND-IDU, NAM, USA-IDU, and VIE-IDU) included both HIV-
170 positive and HIV-negative participants.

171 Table 3 shows the MUAC and BMI measurements by individual study and for all studies
172 combined. MUAC measurements ranged from a low of 11.6 cm in GUI-HIV to a high of 57.0
173 cm in USA-HIV. The average MUAC measurement varied between studies, ranging from 19.7
174 cm in MAL-HWW to 32.7 cm in SAF. Overall, 28.4% of participants had low BMI (<18.5
175 kg/m^2). Prevalence of low BMI ranged from approximately 5% or less in six studies (ARG, GUI-
176 TBC, MAL-HNW, SAF, USA-HIV, and USA-IDU) to 89% in two studies (MAL-HWW and
177 ZAM). Supplementary Figures 5 and 6 show the scatterplots of BMI by MUAC for each study
178 separately and combined. Correlations between BMI and MUAC were strong and statistically

179 significant for all studies, ranging from 0.45 (IND-ORA) to 0.89 (SAF). Fourteen of the 20
180 studies had correlation coefficients at or above 0.80. For the pooled dataset, the correlation
181 coefficient was 0.85 ($p < .00001$). The ROC curve for the pooled dataset (Figure 1) indicates clear
182 discrimination between the distributions of MUAC measurements among those with low BMI
183 compared to those with normal to high BMI. The ROC curve approaches the upper left-hand
184 corner of the graph, indicating high SENS is achieved with high SPEC. AUROC ranged from
185 0.61 (ZAM) to 0.98 (ARG and USA-HIV), with 13 of the 20 values being ≥ 0.90 (Table 3).
186 AUROC for the pooled dataset was 0.91.

187 Supplementary Tables 2 to 17 compare SENS, SPEC, PPV, and NPV for predicting low
188 BMI across studies for each MUAC cutoff from 19.0 cm to 26.5 cm, in increments of 0.5 cm. As
189 shown, the values of SENS, SPEC, PPV, and NPV at each MUAC cutoff varied widely between
190 studies.

191 Table 4 shows the summary estimates of SENS, SPEC, positive and negative likelihood
192 ratios (LR+ and LR-) derived from the bivariate random-effects model. SENS and SPEC ranged
193 from 4.9% and 99.7%, respectively, at a MUAC cutoff of 19.0 cm to 98.0% and 51.0%,
194 respectively, at a MUAC cutoff of 26.5 cm. The MUAC cutoff with the highest SENS at or
195 above a SPEC of 70% was 25.0 cm. However, cutoffs with lower (but still acceptable) SENS
196 values and higher SPEC values could extend down to 23.0 cm. For example, a cutoff of 23.0 cm
197 would misclassify 35% of those with BMI $< 18.5 \text{ kg/m}^2$ as being adequately nourished and 7% of
198 individuals with BMI $\geq 18.5 \text{ kg/m}^2$ as being undernourished. Based on the likelihood ratios, a
199 person with BMI $< 18.5 \text{ kg/m}^2$ is 9.7 times more likely to have a MUAC $\leq 23.0 \text{ cm}$ than an
200 individual with BMI $\geq 18.5 \text{ kg/m}^2$, and a person with BMI $< 18.5 \text{ kg/m}^2$ is 60% less likely to have
201 a MUAC $> 23.0 \text{ cm}$ than a person with BMI $\geq 18.5 \text{ kg/m}^2$. A higher cutoff of 25.0 cm would
202 correctly classify 93% of individuals with low BMI as being undernourished but would
203 misclassify approximately 27% of those with BMI $\geq 18.5 \text{ kg/m}^2$. Based on the likelihood ratios, a
204 person with BMI $< 18.5 \text{ kg/m}^2$ is 3.5 times more likely to have a MUAC $\leq 25.0 \text{ cm}$ and 90% less
205 likely to have a MUAC $> 25.0 \text{ cm}$ than an individual with BMI $\geq 18.5 \text{ kg/m}^2$.

206 Table 5 compares the results obtained from various sensitivity and subgroup analyses that
207 we conducted. Nine studies had either a low prevalence ($< 10\%$) of individuals with BMI < 18.5
208 or a low prevalence ($< 11\%$) of individuals with normal to high BMI, resulting in less stable
209 estimates of SENS and SPEC. We conducted a sensitivity analysis excluding these nine studies

210 and found that, compared to the full dataset, SENS increased and SPEC decreased across all
211 MUAC cutoffs. We obtained very similar results when excluding five upper middle or high-
212 income countries (ARG, NAM, SAF, USA-HIV, AND USA-IDU) from the analyses. Subgroup
213 analyses by sex and HIV status found that SENS was higher and SPEC lower in females and
214 people living with HIV than their male or HIV-negative counterparts.

215

216 **Discussion**

217 The purpose of this IPDMA was to determine whether a global MUAC cutoff could be
218 recommended as a screening tool to assess underweight in nonpregnant adults. Currently, the
219 screening tool most commonly used to determine underweight is low BMI ($<18.5 \text{ kg/m}^2$).
220 However, the measurement of BMI requires equipment (weight scales and stadiometers) that
221 needs to be properly set-up and maintained, and skilled individuals to measure the height and
222 weight and calculate the BMI. For these reasons, in settings where obtaining accurate
223 measurements of BMI is not feasible, a simple identification of low MUAC could serve as a
224 surrogate for low BMI. Using 20 compiled datasets from various parts of the world, we found
225 that MUAC has an excellent ability to discriminate between those with low BMI ($<18.5 \text{ kg/m}^2$)
226 and those with normal to high BMI ($\geq 18.5 \text{ kg/m}^2$). The results remained robust across the
227 various sensitivity and subgroup analyses we performed. We found that, although individual
228 measures of SENS and SPEC at each of the MUAC cutoffs varied between studies, the
229 diagnostic accuracy of MUAC for identifying adults with low BMI was consistently high.
230 AUROCs ranged from 0.61 to 0.98 for individual studies, with most studies having values ≥ 0.90 .
231 The AUROC was 0.91 for all studies combined, which is considered to be in the “excellent”
232 range based on general interpretations for the AUROC.⁽²⁶⁾ Results of the meta-analysis showed
233 that MUAC cutoffs in the range of 23.5 cm to 25.0 cm could potentially serve as appropriate
234 indicators for low BMI, with acceptable levels of SENS and SPEC at each of these cutoffs for
235 the purpose of initial screening for underweight in the community or in a clinical setting. MUAC
236 cutoffs in the range of 24.0 cm to 25.0 cm provided optimal levels of SENS and SPEC for many
237 of the subgroups analyzed.

238 The selection of the optimal MUAC cutoff for identifying moderate and severe
239 undernutrition in non-pregnant adults must take into consideration the tradeoff between failing to
240 capture the entire population in need of services (false negative rate) and referring too many

241 individuals who are not in need of services to the health care system or program (false positive
242 rate). At a MUAC cutoff of 24.0 cm, SENS was 84% and SPEC was 83%. At this cutoff, the
243 false negative and false positive rates would be 16% and 17%, respectively. Lowering the
244 MUAC cutoff to 23.5 cm would increase the false negative rate to 25% and decrease the false
245 positive rate to 11%. At a MUAC cutoff of 25.0 cm, SENS increased to 93% and SPEC
246 decreased to 73%, lowering the false negative rate to 7%, but increasing the false positive rate to
247 27%.

248 The recommendation for a MUAC cutoff (or a range of cutoffs) based on this IPDMA is
249 only a first step towards determining a standardized and global MUAC cutoff to identify
250 undernutrition among nonpregnant adults. While many countries and programs currently use low
251 MUAC as a tool for assessing nutritional status and determining eligibility for limited nutrition
252 interventions, the lack of a standardized cutoff makes it difficult to compare studies
253 internationally and to evaluate the effect of nutritional interventions in larger contexts. The
254 widespread collection and reporting of outcomes based on a single standardized MUAC cutoff
255 would facilitate better understanding of the effectiveness of MUAC as a screening tool for adult
256 underweight in various contexts and settings. It is important to note that the purpose of nutrition
257 assessment is to identify individuals who are at risk of malnutrition and who would benefit from
258 nutrition and/or clinical intervention. WHO defines malnutrition as “deficiencies, excesses or
259 imbalances in a person’s intake of energy and/or nutrients”.⁽²⁷⁾ Others have defined malnutrition
260 as “a subacute or chronic state of nutrition in which a combination of varying degrees of over- or
261 under-nutrition and inflammatory activity have led to a change in body composition and
262 diminished function”.⁽²⁸⁾ A comprehensive nutrition assessment therefore requires several
263 elements, including: 1) evaluation of an individual’s history and clinical diagnoses; 2) physical
264 examination for signs of malnutrition (e.g., edema or specific nutrient deficiencies) and/or
265 clinical indicators of inflammation (fever, hypothermia, tachycardia); 3) anthropometric data,
266 such as weight, BMI, skinfolds, or circumferences; 4) evaluation of usual dietary intake; 5)
267 laboratory indicators if available (e.g., C-reactive protein, white blood cell count, glucose); and
268 6) functional outcomes, such as strength and mobility.⁽²⁹⁾ As it is not feasible to conduct a
269 complete nutrition assessment on every individual in a community, or even on every individual
270 who enters a health care facility, valid screening tools that are simple, quick, acceptable, and
271 inexpensive are needed. Ideally, low MUAC would be used as a screening tool in community

272 and clinic settings to accurately identify individuals who are at highest risk of undernutrition
273 leading to impaired function and poor clinical outcomes, and for whom intervention would
274 improve their nutritional status and clinical outcomes and restore function. It is important to keep
275 in mind that no one screening tool is optimal for all individuals in all situations. Each has its
276 strengths and limitations in different contexts, and each can be affected by an individual's
277 clinical status. Therefore, screening tools such as low MUAC should only be used as an initial
278 step that triggers further and more detailed nutrition assessment, followed by intervention if
279 appropriate. Although programs and policymakers will need to consider available resources
280 when deciding on the optimal MUAC cutoff, we propose that in the context of initial screening
281 under ideal situations, a high SENS (low false negative rate) is more critical than a high SPEC
282 (low false positive rate).

283 This study had some limitations. Our initial systematic review identified 10 potentially
284 eligible datasets of which we were only able to obtain two for the IPDMA. The remaining
285 datasets in this analysis were obtained from our own research studies, through referrals from our
286 TAG, and through further solicitation of studies in the literature that included MUAC as a
287 continuous measure (our systematic review included only studies that analyzed MUAC as a
288 binary/categorical variable). Therefore, in the end, we were not able to use a formal systematic
289 process for identifying all the datasets included in this analysis. In addition, although a large
290 variety of geographical regions and settings were represented in this analysis, the datasets we
291 obtained may not be representative of those regions or settings. Unfortunately, national nutrition
292 surveys that would be representative of our target population, such as the Demographic Health
293 Surveys, do not routinely collect MUAC in adults. Furthermore, readers should use caution when
294 interpreting the results, which may be affected by confounders, both measured and unmeasured.
295 For example, the presence of edema, which was not measured in most datasets, is a likely
296 confounder in the association between MUAC and BMI.

297 We posited that the applicability of our IPDMA results may be limited due to
298 heterogeneity in population characteristics, specifically the wide variability in prevalence of low
299 BMI. Leeflang et al. have proposed several contexts in which SENS and SPEC can vary with
300 disease prevalence (contrary to what is commonly taught in epidemiology courses), including the
301 use of an imperfect reference standard, such as low BMI.^(30, 31) We used meta-regression
302 techniques to explore the extent to which this may have occurred in our IPDMA using MUAC

303 cutoffs of 24.0 and 25.0 cm as examples. For both cutoffs, we found that very little of the
304 variability in SENS was due to the variation in prevalence of low BMI (Adjusted $R^2=5.3\%$ for
305 $MUAC \leq 24.0$ and 1.9% for $MUAC \leq 25.0$ (Supplemental Figure 7)). However, nearly one-third
306 to one-half of the variation in SPEC was due to the variation in low BMI prevalence (Adjusted
307 $R^2=48.3\%$ for $MUAC \leq 24.0$ and 31.9% for $MUAC \leq 25.0$). In sensitivity analyses removing the
308 nine studies with low prevalence of $BMI < 18.5 \text{ kg/m}^2$ or $BMI \geq 18.5 \text{ kg/m}^2$, the proportion of
309 variability in SPEC due to the variation in low BMI prevalence was reduced to 0% for both
310 MUAC cutoffs (Supplemental Figure 8). The remaining variability, which is larger for SPEC
311 than for SENS, is due to unknown factors.

312 One of the unknown factors contributing to this variability could be ethnicity. Much of
313 the literature examining ethnic differences in body composition has focused on the associations
314 between BMI, adiposity, and health risks associated with overweight and obesity.⁽³²⁻³⁵⁾ Ethnic
315 differences in the effect of undernutrition on the relative loss of fat from the limbs and trunk is
316 largely unknown. To our knowledge, very little is published on ethnic differences in MUAC
317 measurements, particularly among undernourished adults. In children 6 to 60 months of age, one
318 study suggests that the association between $MUAC < 11.5 \text{ cm}$ and mortality may be modified by
319 ethnicity.⁽³⁶⁾ It is quite possible that the association between MUAC cutoffs and low BMI differs
320 by ethnicity; however our dataset was not robust enough to examine this. Readers can examine
321 differences by countries and geographic regions in the supplementary tables provided, but we
322 were not able to compare different ethnicities within or across datasets. Large scale studies in
323 each population or country would be required to determine whether a low MUAC cutoff might
324 differ by ethnicity. In addition, further consideration should be given to the implications of
325 establishing different cutoffs for different subgroups (whether it be by ethnicity, age, or disease
326 group) as this would hinder comparisons across countries and would be impractical for
327 community-level screening.

328 Based on our results, we propose that a MUAC cutoff of 24.0 cm meets the criterion for
329 optimizing SENS and SPEC across various subpopulations when assessed against low BMI. A
330 meaningful MUAC cutoff would be one below which function and clinical outcomes deteriorate.
331 Whether a MUAC cutoff of 24.0 cm fits this criterion needs to be tested and validated in future
332 longitudinal studies. Comparisons of MUAC against measures such as lean body mass or grip
333 strength would provide further evidence that a global MUAC cutoff could be valuable as a

334 screening tool for undernutrition. As a valid and reliable screening tool, the use of MUAC in
335 place of BMI would reduce the amount of time and technical skill required for nutrition
336 screening in community settings, resulting in a larger number of individuals who would benefit
337 from further nutrition assessment and intervention. We stress that the proposed MUAC cutoff is
338 currently only intended for use as a screening tool to trigger referral for further assessment; it is
339 not recommended to be used for diagnosis or as an entry criterion into food or nutrition
340 supplementation programs until further validation studies with clinical outcomes have been
341 conducted.

342 Finally, although the focus of this report is on adult underweight, we do acknowledge the
343 growing global burden of overweight and obesity at both the individual and population level, and
344 the need for screening tools to help prioritize the limited services that are available in low-
345 resource settings. Therefore, future studies should also explore MUAC as a potential screening
346 tool for overweight and obesity.

347 **REFERENCES**

- 348 1. Aune D, Sen A, Prasad M, et al. BMI and all cause mortality: systematic review and non-
349 linear dose-response meta-analysis of 230 cohort studies with 3.74 million deaths among
350 30.3 million participants. *BMJ*. 2016;353:i2156.
- 351 2. Berrington de Gonzalez A, Hartge P, Cerhan JR, et al. Body-mass index and mortality
352 among 1.46 million white adults. *The New England journal of medicine*. 2010;363:2211-
353 9.
- 354 3. The Global BMI Mortality Collaboration. Body-mass index and all-cause mortality:
355 individual-participant-data meta-analysis of 239 prospective studies in four continents.
356 *Lancet*. 2016;388:776-86.
- 357 4. Roh L, Braun J, Chiolero A, et al. Mortality risk associated with underweight: a census-
358 linked cohort of 31,578 individuals with up to 32 years of follow-up. *BMC Public Health*.
359 2014;14(1):1-9.
- 360 5. Whitlock G, Lewington S, Sherliker P, et al. Body-mass index and cause-specific
361 mortality in 900,000 adults: collaborative analyses of 57 prospective studies. *Lancet*.
362 2009;373:1083-96.
- 363 6. Gibson RS. *Principles of Nutritional Assessment*. Second ed. Oxford: Oxford University
364 Press; 2005.
- 365 7. Tang AM, Dong K, Deitchler M, et al. Use of cutoffs for mid-upper arm circumference
366 (MUAC) as an indicator or predictor of nutritional and health-related outcomes in
367 adolescents and adults: a systematic review. Washington, DC: FHI 360/FANTA; 2013.
368 Available from: <https://www.fantaproject.org/research/muac-adolescents-adults>
- 369 8. Ferro-Luzzi A, James WP. Adult malnutrition: simple assessment techniques for use in
370 emergencies. *British Journal of Nutrition*. 1996;75(1):3-10.
- 371 9. Bose K, Bisai S, Das P, et al. Relationship of income with anthropometric indicators of
372 chronic energy deficiency among adult female slum dwellers of Midnapore Town. *J Hum*
373 *Ecol*. 2007;22(2):171-6.
- 374 10. Chakraborty R, Bose K, Bisai S. Use of mid-upper arm circumference as a measure of
375 nutritional status and its relationship with self reported morbidity among adult Bengalee
376 male slum dwellers of Kolkata, India. In: Ellsworth SJ, Schuster RC, editors. *Appetite*
377 *and nutritional assessment*. New York: NOVA Science Pub Inc.; 2009. p. 377-85.
- 378 11. Collins S. Using middle upper arm circumference to assess severe adult malnutrition
379 during famine. *JAMA*. 1996;276(5):391-5.
- 380 12. Liu E, Spiegelman D, Semu H, et al. Nutritional status and mortality among HIV-infected
381 patients receiving antiretroviral therapy in Tanzania. *Journal of Infectious Diseases*.
382 2011;204(2):282-90.
- 383 13. Oliveira I, Andersen A, Furtado A, et al. Assessment of simple risk markers for early
384 mortality among HIV-infected patients in Guinea-Bissau: a cohort study. *BMJ Open*.
385 2012;2(6).

- 386 14. Gustafson P, Gomes VF, Vieira CS, et al. Clinical predictors for death in HIV-positive
387 and HIV-negative tuberculosis patients in Guinea-Bissau. *Infection*. 2007;35(2):69-80.
- 388 15. The Federal Democratic Republic of Ethiopia Ministry of Health. National Guidelines for
389 HIV/AIDS and Nutrition. Ethiopia; 2008. Available from:
390 [http://www.fantaproject.org/sites/default/files/resources/Ethiopia-HIV-Nutrition-](http://www.fantaproject.org/sites/default/files/resources/Ethiopia-HIV-Nutrition-Guidelines-2008.pdf)
391 [Guidelines-2008.pdf](http://www.fantaproject.org/sites/default/files/resources/Ethiopia-HIV-Nutrition-Guidelines-2008.pdf)
- 392 16. Republic of Namibia Ministry of Health and Social Services. Nutrition Assessment,
393 Counselling and Support for PLHIV: Operational Guidelines. Namibia; 2010. Available
394 from:
395 [http://www.fantaproject.org/sites/default/files/resources/Namibia_Operational_Guideline](http://www.fantaproject.org/sites/default/files/resources/Namibia_Operational_Guidelines_2010.pdf)
396 [s_2010.pdf](http://www.fantaproject.org/sites/default/files/resources/Namibia_Operational_Guidelines_2010.pdf)
- 397 17. Republic of Zambia Ministry of Health. Nutrition Guidelines for Care and Support of
398 People Living with HIV and AIDS. Zambia; 2011. Available from:
399 [http://www.fantaproject.org/sites/default/files/resources/Zambia_Nutrition_HIV_Guideli](http://www.fantaproject.org/sites/default/files/resources/Zambia_Nutrition_HIV_Guidelines_June2011.pdf)
400 [nes_June2011.pdf](http://www.fantaproject.org/sites/default/files/resources/Zambia_Nutrition_HIV_Guidelines_June2011.pdf)
- 401 18. WHO/UNICEF. WHO child growth standards and the identification of severe acute
402 malnutrition in infants and children. A Joint Statement by the World Health Organization
403 and the United Nations Children's Fund. Report. Geneva; 2009. Available from:
404 <http://www.who.int/nutrition/publications/severemalnutrition/9789241598163/en/>
- 405 19. WHO child growth standards and the identification of severe acute malnutrition in infants
406 and children. A joint statement by the World Health Organization and the United Nations
407 Children's Fund. Geneva, New York; 2009. Available from:
408 https://www.who.int/nutrition/publications/severemalnutrition/9789241598163_eng.pdf
- 409 20. Tang AM, Chung M, Dong K, et al. Determining a global mid-upper arm circumference
410 cutoff to assess underweight in adults (men and nonpregnant women). Washington, DC:
411 FHI 360/FANTA; 2017. Available from:
412 [https://www.fantaproject.org/sites/default/files/resources/Global-MUAC-Cutoffs-](https://www.fantaproject.org/sites/default/files/resources/Global-MUAC-Cutoffs-nonPregnant-Adults-Jun2017.pdf)
413 [nonPregnant-Adults-Jun2017.pdf](https://www.fantaproject.org/sites/default/files/resources/Global-MUAC-Cutoffs-nonPregnant-Adults-Jun2017.pdf)
- 414 21. Lemmer CE, Badri M, Visser M, et al. A lower body mass index is associated with
415 cardiomyopathy in people with HIV infection: evidence from a case comparison study.
416 *South African Medical Journal*. 2011;101(2):119-21.
- 417 22. Gourlay AJ, van Tienen C, Dave SS, et al. Clinical predictors cannot replace biological
418 predictors in HIV-2 infection in a community setting in West Africa. *Int J Infect Dis*.
419 2012;16(5):e337-43.
- 420 23. WHO (World Health Organization). Physical status: the use and interpretation of
421 anthropometry. Report of a WHO Expert Committee. World Health Organization,
422 Geneva; 1995. Available from:
423 https://www.who.int/childgrowth/publications/physical_status/en/
- 424 24. Harbord RM, Whiting P. metandi: Meta-analysis of diagnostic accuracy using
425 hierarchical logistic regression. *Stata Journal*. 2009;9(2):211-29.

- 426 25. Dwamena BA. MIDAS: Stata module for meta-analytical integration of diagnostic
427 accuracy studies 2007 [Available from:
428 <https://econpapers.repec.org/software/bocbocode/s456880.htm>.
- 429 26. Carter JV, Pan J, Rai SN, et al. ROC-ing along: Evaluation and interpretation of receiver
430 operating characteristic curves. *Surgery*. 2016;159(6):1638-45.
- 431 27. World Health Organization. What is malnutrition? 2016 [Available from:
432 <http://www.who.int/features/qa/malnutrition/en/>.
- 433 28. Soeters PB, Reijven PL, van Bokhorst-de van der Schueren MA, et al. A rational
434 approach to nutritional assessment. *Clinical nutrition (Edinburgh, Scotland)*.
435 2008;27(5):706-16.
- 436 29. Jensen GL, Hsiao PY, Wheeler D. Adult nutrition assessment tutorial. *J Parenter Enteral*
437 *Nutr*. 2012;36(3):267-74.
- 438 30. Leeflang MM, Bossuyt PM, Irwig L. Diagnostic test accuracy may vary with prevalence:
439 implications for evidence-based diagnosis. *J Clin Epidemiol*. 2009;62(1):5-12.
- 440 31. Leeflang MM, Rutjes AW, Reitsma JB, et al. Variation of a test's sensitivity and
441 specificity with disease prevalence. *CMAJ*. 2013;185(11):E537-44.
- 442 32. WHO Expert Consultation. Appropriate body-mass index for Asian populations and its
443 implications for policy and intervention strategies. *Lancet*. 2004;363(9403):157-63.
- 444 33. Heymsfield SB, Peterson CM, Thomas DM, et al. Why are there race/ethnic differences
445 in adult body mass index-adiposity relationships? A quantitative critical review. *Obes*
446 *Rev*. 2016;17(3):262-75.
- 447 34. Maligie M, Crume T, Scherzinger A, et al. Adiposity, fat patterning, and the metabolic
448 syndrome among diverse youth: the EPOCH study. *J Pediatr*. 2012;161(5):875-80.
- 449 35. Misra A. Impact of ethnicity on body fat patterning in Asian Indians and blacks: relation
450 with insulin resistance. *Nutrition*. 2003;19(9):815-6.
- 451 36. Gupta A, Tielsch JM, Khattry SK, et al. Ethnic and age differences in prediction of
452 mortality by mid-upper arm circumference in children below 3 years of age in Nepal.
453 *Public Health Nutr*. 2018;21(12):2230-7.
- 454 37. Sheehan HB, Benetucci J, Muzzio E, et al. High rates of serum selenium deficiency
455 among HIV- and HCV-infected and uninfected drug users in Buenos Aires, Argentina.
456 *Public Health Nutr*. 2012;15(3):538-45.
- 457 38. Sultana T, Karim MN, Ahmed T, et al. Assessment of under nutrition of Bangladeshi
458 adults using anthropometry: can body mass index be replaced by mid-upper-arm-
459 circumference? *PLoS One*. 2015;10(4):e0121456.
- 460 39. Patsche CB, Rudolf F, Mogensen SW, et al. Low prevalence of malnourishment among
461 household contacts of patients with tuberculosis in Guinea-Bissau. *Int J Tuberc Lung Dis*.
462 2017;21(6):664-9.
- 463 40. Ghosh M, Bose K, editors. Statistical association of adiposity measures with body
464 composition among adult brick-kiln workers of Murshidabad District, West Bengal,

- 465 India. International Conference on Bioinformatics and Biostatistics for Agriculture,
466 Health and Environment; 2017; Rajshahi, Bangladesh.
- 467 41. Tang AM, Bhatnagar T, Ramachandran R, et al. Malnutrition in a population of HIV-
468 positive and HIV-negative drug users living in Chennai, South India. Drug and alcohol
469 dependence. 2011;118(1):73-7.
- 470 42. Chakraborty R, Bose K, Koziel S. Use of mid-upper arm circumference in determining
471 undernutrition and illness in rural adult Oraon men of Gumla District, Jharkhand, India.
472 Rural & Remote Health. 2011;11(3):1754.
- 473 43. Das P, Khatun A, Bose K, et al. The validity of mid-upper arm circumference as an
474 indicator of low BMI in population screening for undernutrition: a study among adult
475 slum dwellers in eastern India. Public Health Nutr. 2018;21(14):2575-83.
- 476 44. Bahwere P. Mangochi Research on the Nutrition Care of Chronically Sick Adults using
477 Chickpea Sesame based Ready-to-Use Therapeutic Food. Save the Children USA,
478 Lilongwe. 2007.
- 479 45. Charlton KE, Kolbe-Alexander TL, Nel JH. Development of a novel nutrition screening
480 tool for use in elderly South Africans. Public Health Nutrition. 2005;8(5):468-79.
- 481 46. Jacobson DL, Tang AM, Spiegelman D, et al. Incidence of metabolic syndrome in a
482 cohort of HIV-infected adults and prevalence relative to the US population (National
483 Health and Nutrition Examination Survey). J Acquir Immune Defic Syndr.
484 2006;43(4):458-66.
- 485 47. Tang AM, Forrester JE, Spiegelman D, et al. Heavy injection drug use is associated with
486 lower percent body fat in a multi-ethnic cohort of HIV-positive and HIV-negative drug
487 users from three U.S. cities. The American journal of drug and alcohol abuse.
488 2010;36(1):78-86.
- 489 48. Nguyen P, Ramakrishnan U, Katz B, et al. Mid-upper-arm and calf circumferences are
490 useful predictors of underweight in women of reproductive age in northern Vietnam.
491 Food Nutr Bull. 2014;35(3):301-11.
- 492 49. Tang AM, Sheehan HB, Jordan MR, et al. Predictors of Weight Change in Male HIV-
493 Positive Injection Drug Users Initiating Antiretroviral Therapy in Hanoi, Vietnam. AIDS
494 research and treatment. 2011;2011:890308.
- 495

Table 1. Brief description of studies Included in the individual participant data meta-analysis (IPDMA)

Study Abbreviation	Country	Year(s) of Study	Brief Study Description	Sample Size^b
ARG ⁽³⁷⁾	Argentina	2005–2006	HIV-positive and HIV-negative drug users in Buenos Aires, Argentina	204
BAN ⁽³⁸⁾	Bangladesh	2012	Patients of the Dhaka Hospital of the International Centre for Diarrheal Disease Research, Bangladesh	650
GUI-HIV ⁽¹³⁾	Guinea-Bissau	2007–2009	Antiretroviral therapy (ART)-naïve, HIV-infected patients in Guinea-Bissau	1,055
GUI-TBC ⁽³⁹⁾	Guinea-Bissau	2014	Healthy controls and household contacts of tuberculosis (TB) patients in Guinea-Bissau	769
IND-BKW ⁽⁴⁰⁾	India	2014-2016	Adult male brick-kiln workers in Murishdabad district, West Bengal, India	501
IND-FSD ⁽⁹⁾	India	2006	Female slum dwellers in Midnapore Town, West Bengal, India	333
IND-IDU ⁽⁴¹⁾	India	2007	Current and former male injection drug users (IDUs) in Chennai, Tamil Nadu, India	374
IND-MSD ⁽¹⁰⁾	India	2003–2004	Male slum dwellers in Kolkata, India	474
IND-ORA ⁽⁴²⁾	India	2007	Oraon men of Gumla District, Jharkhand, India	205
IND-SDW ⁽⁴³⁾	India	2015-2017	Male and female slum dwellers in Midnapore Town, Paschim Midnapore, West Bengal, India	992
IND-UNI ^a	India	2013–2014	University students in Midnapore Town, West Bengal, India	599
MAL-HNW ^a	Malawi	2008–2010	ART-naïve, HIV-infected adults without wasting in three districts in Malawi (Lilongwe, Mzuzu, and Kasungu)	329
MAL-HWW ⁽⁴⁴⁾	Malawi	2006–2007	ART-naïve, HIV-infected adults with wasting and MUAC <22.0 cm in Mangochi, Malawi	186
NAM ^a	Namibia	2014	Adults recruited from bar district in Windhoek, Namibia	407
SAF ⁽⁴⁵⁾	South Africa	2002	Free-living and institutionalized elderly black South Africans in Cape Town, South Africa	283
USA-HIV ⁽⁴⁶⁾	USA	2001–2013	HIV-infected adults in the Greater Boston area, United States	553
USA-IDU ⁽⁴⁷⁾	USA	2005–2007	Current and former IDUs in the United States in Boston, MA; Baltimore, MD; and Providence, RI	520
VIE-FEM ⁽⁴⁸⁾	Vietnam	2011–2012	Nonpregnant females of reproductive age in Thai Nguyen Province, Vietnam	4,926
VIE-IDU ⁽⁴⁹⁾	Vietnam	2006–2008	Current and former male IDUs in Hanoi, Vietnam	297
ZAM ^a	Zambia	2009–2010	HIV-infected adults with wasting in Lusaka, Zambia	182

^a Study has not been published yet. See Supplementary Table 1 for more complete descriptions of unpublished studies.

^b This refers to the total number of observations with MUAC measurements. Missing values on individual variables (e.g., BMI) may slightly reduce the numbers for analysis. Total N=13,835.

Table 2. Participant characteristics, by individual study and for all studies combined

STUDY ID	N	Age (years) ^a		Sex ^b		Education ^{c,d}			HIV(+) ^e
		Min - Max	Mean ± SD	Male N (%)	Female N (%)	None N (%)	Primary N (%)	Secondary N (%)	
ARG	204	18.4-50.6	31 (7.1)	179 (88)	25 (12)	8 (4)	159 (78)	37 (18)	69 (34)
BAN	650	19-60	27.7 (7.4)	260 (40)	390 (60)	171 (26)	194 (30)	285 (44)	Not tested
GUI-HIV	1055	18-76	37.5 (10.9)	313 (30)	742 (70)	No Data			1,055 (100)
GUI-TBC	769	18-90	33.1 (13.8)	335 (44)	434 (56)	101 (13)	240 (31)	428 (56)	Not tested
IND-BKW	501	18-74	36.6 (11.6)	501 (100)	0 (0)	338 (68)	40 (8)	123 (25%)	Not tested
IND-FSD	333	18-80	34.2 (14)	0 (0)	333 (100)	196 (59)	123 (37)	14 (4)	Not tested
IND-IDU	374	22-61	38.7 (7.2)	374 (100)	0 (0)	85 (23)	222 (59)	67 (18)	178 (48)
IND-MSD	474	18-84	37.5 (14.2)	474 (100)	0 (0)	136 (29)	148 (31)	190 (40)	Not tested
IND-ORA	205	18-70	38 (13.4)	205 (100)	0 (0)	No Data			Not tested
IND-SDW	992	18-85	35.9 (14.5)	490 (49)	502 (51)	368 (37)	239 (24)	384 (38)	Not tested
IND-UNI	599	18-28	22.1 (1.6)	228 (38)	371 (62)	0 (0)	0 (0)	599 (100)	Not tested
MAL-HNW	329	18-57	33.9 (8.1)	122 (37)	206 (63)	No Data			329 (100)
MAL-HWW	186	18-58	34.1 (9)	56 (30)	130 (70)	No Data			186 (100)
NAM	407	18-74	29.9 (9.7)	236 (58)	171 (42)	36 (9)	39 (10)	331 (82)	73 (18)
SAF	283	60-91	71.5 (7.9)	53 (19)	230 (81)	No Data			Not tested
USA-HIV	553	24.1-75.4	46.1 (7.9)	372 (67)	181 (33)	0 (0)	6 (1)	547 (99)	553 (100)
USA-IDU	520	22-67.8	43.8 (7.5)	335 (64)	185 (36)	187 (36)	206 (40)	123 (24)	284 (55)
VIE-FEM	4922	18-44.7	26.4 (4.5)	0 (0)	4922 (100)	0 (0)	404 (8)	4516 (92)	Not tested
VIE-IDU	297	19-46.9	31.2 (5.2)	297 (100)	0 (0)	1 (0)	3 (1)	293 (99)	202 (68)
ZAM	182	20-49	33.2 (7.7)	91 (50)	91 (50)	No Data			182 (100)
COMBINED^f	13,835	18-91	32.6 (12.1)	4921 (36)	8913 (64)	1627 (14)	2023 (18)	7937 (69)	3111 (23)

^a Number of participants missing data on age: MAL-HNW (n=4), MAL-HWW (n=1), SAF (n=5), USA-IDU (n=9), VIE-FEM (n=23), VIE-IDU (n=1).

^b Number of participants missing data on sex: MAL-HNW (n=1).

^c Number of participants missing data on education: IND-SDW (n=1), NAM (n=1), USA-IDU (n=4), VIE-FEM (n=2).

^d For USA-IDU, categories are < High School, Some High School, >High School.

^e For NAM, HIV status based on self-report; for VIE-IDU, n=1 missing data on HIV status.

^f Statistics for the combined datasets for the education and HIV-status characteristics exclude studies that did not collect data on these variables.

Table 3. Mid-upper arm circumference (MUAC), body mass index (BMI), Pearson correlation coefficients, and Area under the ROC curve (AUROC), by individual study and for all studies combined

Study ID	MUAC (cm)		BMI (kg/m ²)		BMI <18.5	Correlation coefficient	AUROC
	Min - Max	Mean (SD)	Min - Max	Mean (SD)	N (%)		
ARG	21.3-48.0	28.7 (3.6)	17.6-45.8	24.0 (3.8)	3 (1.5)	0.85	0.98
BAN	18.2-39.0	25.5 (3.1)	14.4-44.7	21.0 (3.7)	190 (29.2)	0.84	0.90
GUI-HIV	11.6-42.2	26.0 (4.4)	11.3-45.7	20.3 (4.3)	391 (37.4)	0.87	0.95
GUI-TBC	20.2-47.2	29.9 (4.3)	16.2-50.9	24.7 (4.8)	31 (4)	0.85	0.91
IND-BKW	19.6-32.6	24.6 (2.1)	14.6-30.3	20.1 (2.4)	123 (24.6)	0.84	0.92
IND-FSD	14.5-37.1	22.7 (3.2)	12.7-32.9	19.6 (3.7)	153 (45.9)	0.80	0.91
IND-IDU	13.1-39.8	24.4 (3.3)	12.8-31.3	18.7 (3.0)	198 (53.2)	0.81	0.92
IND-MSD	13.6-39.4	25.0 (2.9)	11.6-33.5	20.3 (3.3)	156 (32.9)	0.84	0.92
IND-ORA	14.4-27.6	23.5 (2.0)	15.3-25.0	18.0 (1.6)	133 (64.9)	0.45	0.78
IND-SDW	14.5-43.6	23.4 (3.1)	9.0-50.8	21.7 (4.1)	231 (23.3)	0.72	0.89
IND-UNI	14.3-43.7	25.2 (3.3)	8.5-38.6	22.0 (3.7)	90 (15)	0.74	0.86
MAL-HNW	22.4-36.6	26.9 (2.6)	18.1-41.4	22.7 (3.3)	1 (0.3)	0.82	0.95
MAL-HWW	14.0-23.0	19.7 (1.8)	11.1-23.1	16.4 (1.9)	161 (89)	0.68	0.79
NAM	17.0-42.0	27.8 (3.6)	13.8-62.2	23.0 (5.1)	35 (8.7)	0.53	0.79
SAF	18.4-55.6	32.7 (6.4)	14.1-59.4	31.4 (8.2)	15 (5.4)	0.89	0.96
USA-HIV	20.3-57.0	31.8 (5.1)	15.3-57.1	26.5 (5.7)	17 (3.1)	0.86	0.98
USA-IDU	17.6-50.0	31.5 (4.9)	15.2-61.5	27.7 (6.5)	18 (3.5)	0.84	0.95
VIE-FEM	16.0-40.0	24.5 (2.3)	14.5-32.6	19.6 (2.0)	1545 (31.4)	0.84	0.91
VIE-IDU	17.5-34.5	25.5 (2.7)	13.5-31.7	20.2 (2.4)	78 (26.3)	0.80	0.88
ZAM	13.3-25.0	20.6 (1.5)	10.7-22.2	16.9 (1.6)	162 (89)	0.46	0.61
COMBINED	11.6-57.0	25.7 (4.2)	8.5-62.2	21.2 (4.6)	3731 (28.4)	0.85	0.91

^aNumber of participants missing data on BMI: GUI-HIV (n=10), GUI-TBC (n=3), IND-IDU (n=2), MAL-HWW (n=5), NAM (n=3), SAF (n=4), USA-IDU (n=1), VIE-FEM (n=2).

Table 4. Summary Estimates of SENS, SPEC, positive likelihood ratio (LR+)^a and negative likelihood ratio (LR-)^b at selected MUAC cutoffs for all studies combined

MUAC (cm)	SENS	SPEC	LR+	LR-	# Studies
≤19.0	4.9 (2.2, 10.5)	99.7 (99.2, 99.9)	16.7 (5.7, 48.6)	1.0 (0.9, 1.0)	15
≤19.5	7.9 (4.1, 14.7)	99.6 (99.0, 99.9)	20.8 (9.2, 46.9)	0.9 (0.9, 1.0)	15
≤20.0	11.3 (6.0, 20.2)	99.6 (98.9, 99.9)	31.8 (13.2, 76.4)	0.9 (0.8, 1.0)	16
≤20.5	16.0 (9.4, 26.0)	99.3 (98.3, 99.7)	22.9 (11.6, 45.0)	0.8 (0.8, 0.9)	17
≤21.0	22.8 (13.9, 35.1)	99.0 (97.5, 99.6)	22.1 (12.2, 40.2)	0.8 (0.7, 0.9)	18
≤21.5	31.0 (20.0, 44.7)	98.4 (95.7, 99.4)	19.6 (9.2, 41.8)	0.7 (0.6, 0.8)	19
≤22.0	45.5 (29.9, 62.0)	96.4 (89.7, 98.8)	12.7 (5.8, 27.8)	0.6 (0.4, 0.7)	19
≤22.5	58.1 (37.7, 76.1)	94.7 (85.2, 98.3)	11.1 (5.1, 24.1)	0.4 (0.3, 0.7)	20
≤23.0	64.8 (47.0, 79.3)	93.3 (86.4, 96.9)	9.7 (5.8, 16.4)	0.4 (0.2, 0.6)	19
≤23.5	75.1 (61.2, 85.2)	89.0 (79.4, 94.4)	6.8 (4.0, 11.6)	0.3 (0.2, 0.4)	19
≤24.0	84.1 (74.1, 90.8)	83.2 (71.7, 90.7)	5.0 (3.1, 8.1)	0.2 (0.1, 0.3)	19
≤24.5	89.9 (82.1, 94.6)	77.4 (64.1, 86.8)	4.0 (2.5, 6.3)	0.1 (0.1, 0.2)	19
≤25.0	92.9 (87.7, 96.0)	73.3 (61.8, 82.3)	3.5 (2.4, 5.0)	0.1 (0.1, 0.2)	18
≤25.5	95.7 (92.0, 97.7)	66.7 (53.8, 77.6)	2.9 (2.0, 4.1)	0.1 (0.0, 0.1)	18
≤26.0	97.6 (94.6, 98.9)	58.7 (44.8, 71.3)	2.4 (1.7, 3.2)	0.0 (0.0, 0.1)	18
≤26.5	98.0 (95.7, 99.1)	51.0 (37.3, 64.6)	2.0 (1.5, 2.6)	0.0 (0.0, 0.1)	18

^a Positive Likelihood Ratio (LR+) = ratio between the probability of MUAC ≤cutoff given BMI <18.5 and the probability of MUAC ≤cutoff given BMI ≥18.5 = SENS / (1-SPEC)

^b Negative Likelihood Ratio (LR-) = ratio between the probability of MUAC >cutoff given BMI <18.5 and the probability of MUAC >cutoff given BMI ≥18.5 = (1-SENS) / SPEC

Table 5. Comparing False Negative (FN) and False Positive (FP) Rates between Various Subgroups of Participants and Studies

MUAC cutoff (cm)	All data combined		Low Prevalence Studies Removed ^a		LMIC ^b only		Males		Females		HIV-Negative		HIV-Positive	
	FN ^c %	FP ^d %	FN %	FP %	FN %	FP %	FN %	FP %	FN %	FP %	FN %	FP %	FN %	FP %
23.0	35	7	28	10	28	10	46	5	25	6	58	2	29	6
23.5	25	11	19	16	19	17	36	8	17	10	43	3	22	10
24.0	16	17	12	24	12	24	24	13	12	15	32	7	15	17
24.5	10	23	7	32	8	32	16	19	8	19	24	9	11	22
25.0	7	27	4	43	5	37	11	22	5	26	20	13	9	19
25.5	4	33	2	51	3	45	6	28	3	32	16	16	4	24

^a Excludes studies with low (<10%) prevalence of individuals with BMI <18.5 (ARG, GUI-TBC, MAL-HNW, NAM, SAF, USA-HIV, and USA-IDU) or a low prevalence (<11%) of individuals with normal to high BMI (MAL-HWW, ZAM)

^b LMIC = low and middle-income countries only (Excludes the following upper middle and high-income countries: ARG, NAM, SAF, USA-HIV, AND USA-IDU)

^c FN = percentage of individuals with BMI<18.5 kg/m² who are missed using the MUAC cutoff.

^d FP = percentage of individuals with BMI ≥18.5 kg/m² who are referred for further screening.

Figure legend

Figure 1. Receiver operating characteristic curve for all studies included in the individual participant data meta-analysis (IPDMA) combined. Area under ROC curve = 0.91