Anthropological Review • Vol. 84(3), 301–315 (2021)

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Anthropological Review
Available online at: https://doi.org/10.2478/anre-2021-0018

Validating mid-upper arm circumference (MUAC) cut off points as an indicator of nutritional status among nine tribal populations of India

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Abstract: Mid-upper arm circumference (MUAC) is an alternative anthropometric measurement to assess undernutrition but a universally accepted cut-off is yet to be established. The objectives of the present study are to determine whether the proposed sex-specific global cut-offs are suitable across several tribes in India. This cross-sectional study was conducted among nine tribal populations in India (1046 males, 1087 females). Weight, height and MUAC values were obtained, and body mass index (BMI) was calculated. The BMI cut-off (<18.5 kg/m^2) was used to determine chronic energy deficiency (CED). The ROC Curve analyses of binomial logistic regression for MUAC *versus* CED revealed optimal cut-off point of MUAC as 23.8 cm (in males) and 21.8 cm (in females). MUAC cut-offs were similar in females, relative to males, in all tribes. Males with MUAC<24cm and females with MUAC<22 encompassed significantly higher numbers of CED than those with MUAC≥24 and ≥22 cm, respectively (χ^2-value males: 254.9, $p<0.001$; females: 493.60, $p<0.01$). A single cut off point of MUAC may not be universally applicable for diverse populations and both sexes as well. It seemed that there is no alternative than to undertake further validation studies in various populations before using the MUAC cut off to identify undernourished or CED condition.

Key words: MUAC, BMI, Indian tribes, ROC curve.

Introduction

Undernutrition is a major cause of mortality and morbidity in developing countries among the poorest and the vulnerable sections of the population (Menon and Peñalvo 2019). India is a country that has been continuously defamed for its alarming prevalence of undernutrition (Razak et al. 2015). Although, undernu-

Original Research Article Received: May 4, 2021; Revised: August 12, 2021; Accepted: August 13, 2021
DOI: 10.2478/anre-2021-0018

trition in children is one of the major health concerns in India, a large proportion of the adults are also suffering from chronic state of nutritional deprivation. Especially, the tribal populations, constituting 8.6% of the total population, living in widely varying geographical regions, are perhaps the most vulnerable sections in respect of both poverty and chronic undernutrition (Das and Mehta 2012). High prevalence of undernutrition is a cause for the poor health status in Indian tribal groups (Dey and Bisai 2019). Poor socio-economic status, inadequate diet, lack of health awareness and inadequate access to basic healthcare facilities are the various reasons behind undernutrition in the tribal societies (Das and Bose 2012; Sen et al. 2011). Chronic energy deficiency (CED), determined by body mass index (BMI) <18.5 kg/m^2, is a widely used measure of undernutrition in adults (WHO 2004; WHO Expert Consultation 2004). It was defined as a state of 'steady underweight' in which an individual is in energy balance irrespective of a loss of body weight or energy stores (Ferro-Luzzi et al. 1992; James et al. 1994). In populations, higher prevalence of CED in adults was consistently shown to be significantly associated with higher morbidity, mortality and health impairments (Chakraborty et al. 2009a; Sun et al. 2016), as well as low productivity and low socio-economic status (SES) (Chakraborty et al. 2009b; Khongsdier 2012).

Assessment of the nutritional status among the vulnerable segments of a population plays significant role in understanding the overall health status of the population (WHO 2004; WHO Expert Consultation 2004). BMI has long been considered to be a widely acceptable surrogate anthropometric measure of nutritional status for both undernutrition, particularly, CED, and overnutrition (i.e., overweight and/or obesity). Globally, a BMI cut-off values of <18.5 kg/m^2 is recommended for the assessment of CED among adults (WHO 2004; WHO Expert Consultation 2004). However, BMI involves simple measurements of height and body weight, it requires two instruments for measurements, and a minimum level of education and numeric skill for calculation. Even these minimum requirements sometimes become difficult to mobilise in resource poor field settings, particularly for rapid assessment of a large number of people in a short time (Das et al. 2018; WHO 2004). Considering such operational problem with BMI, the mid-upper arm circumference (MUAC) is strongly recommended as an alternative measurement to assess undernutrition in infants, children and adults WHO, UNICEF 2019) and even in pregnant women (Fakier et al. 2017). It is mostly because MUAC is a simple, non-invasive measurement requiring simple equipment, i.e., a tape measure, and thus, suitable for epidemiological and clinical settings, particularly, in resource-limited set up (Das et al. 2018; Thorup et al. 2020; WHO 2004). Besides, MUAC shows consistently a high correlation with BMI across age (Das et al. 2018; Tang et al. 2020). Low MUAC is strongly associated with wasting (low weight-for-height) in children (Sachdeva et al. 2016; Sen et al. 2011), CED in adults (Chakraborty et al. 2009a; Chakraborty et al. 2011; Das et al. 2018) and an increased risk of adverse clinical outcomes (Oliveira et al. 2012) and morbidities (Chakraborty et al. 2009a). MUAC was also shown to predict all-cause mortality better than BMI in epidemiological studies (Chen et al. 2014; Schaap et al. 2018).

There are globally recommended age- and sex-specific MUAC cutoffs to determine undernutrition among children (WHO, UNICEF 2019) and sex-specific cutoff for adults (James et al. 1994; WHO Expert Consultation 2004). Although MUAC highly correlates with BMI in adult populations, distinct ethnic differences do exist in the pattern of body fat deposition as well as in the relationship between total adiposity (measured as BMI) and regional adiposity (measured by body circumferences and skinfolds) (Bose et al. 2007). Therefore, it was extensively argued that a universally recommended MUAC cut off to identify a specific level of BMI (e.g., 18.5 kg/m^2) may not be the most appropriate for all ethnic groups and populations, even within one country, such as in India (Chakraborty et al. 2009c; Chakraborty et al. 2011; Das et al. 2018). Therefore, a number of studies provided evidence-based arguments for population specific MUAC cut offs to identify the state of CED (Olukoya 1990; Chakraborty et al. 2009c; Chakraborty et al. 2011) in lieu of the WHO recommended universal adult cut offs of 23 cm and 22 cm, for males and females, respectively (James et al. 1994; WHO 2004). However, the choice between the appropriateness of the global versus population specific cut-offs remained controversial (Chakraborty and Bose 2014). For instance, in India, some studies proposed population specific cut offs (Rodrigues et al. 1994; Chakraborty et al. 2009c; Chakraborty et al. 2011)and others still found evidence in favour of the appropriateness of the universal cut offs (Das et al. 2018). Considering the need to develop a general MUAC cut off based on the data from a wide range of populations for a wider public health interest, a recent multicentre study by Tang et al. (2020) proposed a globally applicable 24 cm MUAC cut off for adult males and non-pregnant women. However, this proposal is still far from universal public health application until further studies are conducted among diverse populations worldwide to assess its universal validity (Maalouf-Manasseh et al. 2020). The above-mentioned global study, and also another published commentary, based on the study, finally concluded that further validation studies are urgently needed to assess the applicability of the proposed cut off value of 24 cm. The authors also recommended extending the analyses to several settings and including more data from humanitarian/emergency situations (Maalouf-Manasseh et al. 2020).

India is a country of enormous diversity both in terms of human biology and culture. Even after considerable admixture throughout evolutionary history, the recent genomic studies revealed that the traceable ancestral lineages constituting Indian populations were no less than five (Basu et al. 2016). More particularly, the tribal populations in India are highly diverse and have traces of many evolutionary lineages with distinct and wide cultural diversity (Majumder and Basu 2014). There are more than 700 tribal groups comprising of 8.6% of population in India having highly diverse and distinct biological, ecological and cultural characteristics (Kumaret al. 2004). However, they are the most socio-economically backward communities and bear the greatest burden of child, as well as adult undernutrition and also mostly manifest low mean BMI (Chakraborty and Bose 2014; Kshatriya and Acharya 2016a).

It seems, therefore, that there is perhaps a wide scope left for assessment of the universal applicability of the hitherto proposed global cut-off points of MUAC, including the most recent ones by Tang et al. (2020) in particular, by conducting more population-based studies among the various types of populations. In this context, the Indian tribal groups seem to be of particular importance, considering their intra-group homogeneity (e.g., endogamy) and intergroup heterogeneity in terms of biology, culture, ecology, socio-economic conditions and being in a process of continuous transformations(Kshatriya and Acharya 2016a; Majumder and Basu 2014). Keeping with this specific scope, the objectives of the present study were to test whether the proposed global cut-offs are suitable across several Indian tribes of diverse physical characteristics and whether we can really use a single cut off for all tribal populations in spite of their diversities, and if the MUAC cut offs are similar in males and females.

Materials and Methods

Study design and Populations

This community-based cross-sectional study was conducted between January 2011 and December 2013 among nine tribal populations from three Indian states, namely, Gujarat (GJ), Odisha (OD) and West Bengal (WB). The tribal groups included Dhodias, Kuknas, and Chaudharis (GJ), Santals, Bhumijs, and Bathudis (OD) and Santals, Oraons, and Koras (West Bengal). A multi-stage sampling procedure was adopted to select the participants. A total of 66 tribal villages from the four districts in the three states were chosen on the basis of their habitation in the areas that underwent considerable acculturation and developmental activities by the state and other organizations. The villages under study were predominantly inhabited by tribal groups and relatively closer to the nearest 'urban centers' with moderate access to those developmental facilities. A detailed description of these areas of study and the sampling procedures may be obtained in the previous publications based on this study(Kshatriya and Acharya 2016a, 2016b). A team of two trained biological anthropologists conducted the fieldwork and collected the socio-economic, demographic and anthropometric data. All information and anthropometric measurements were obtained from the individuals in their respective households. Individuals without apparent or reported ailments and any physical deformity and developmental disorders, health issues or chronic disorders in the past year and surgical episodes were included as participants after obtaining informed consent. The necessary ethical approval of the present study was obtained from the Departmental Review Committee of Department of Anthropology, University of Delhi. An informed written consent was obtained from each research participant, and objectives and nature of participation were explained before the data collection. The present study was carried out according to the ethical guidelines for human experimental research as laid down in the Helsinki Declaration (Portaluppi et al. 2010).

Anthropometric measurements

The anthropometric measurements of height (to the nearest 1mm), weight (to the nearest 100g) and MUAC (to the nearest 1mm) were recorded using standard procedures with standardized anthropometer, weight scale and measuring tape, respectively (Das et al. 2018; WHO 2004). The MUAC was obtained at the point, midway between the acromion and the radiale of the upper-arm, using a plastic coated non-stretchable measuring tape on the left side (Das et al. 2018). Participants were requested to come with light clothes prior to measurements. BMI was calculated as weight in kilogram (kg) divided by height in meter squared (kg/m^2). Nutritional status was determined by the WHO-classification for the Asia-Pacific populations (WHO Expert Consultation 2004) based on BMI (kg/m^2) as: CED (BMI $<$18.5), normal (BMI = 18.5–22.9), overweight (BMI = 23.0–24.9) and obese (BMI $\geq$ 25.0). The same anthropometric instruments were used for the measurements of all participants to avoid instrumental differences. The accuracy of instruments was verified and standardized in regular intervals.

Statistical analysis

Descriptive statistics of mean and standard deviation (SD) were calculated to describe age, height, weight and MUAC. Range of each of these variables was also reported. Four categories of BMI-based nutritional status were created and the percentage of each of these categories was calculated to determine prevalence by sex. One-way analysis of variance (ANOVA) was performed to assess significance of difference in mean values of MUAC across the four BMI/nutritional categories and F-value was used to represent the size of association. The χ^2-analysis was also employed to assess the interrelationship between prevalence of particular nutritional states (e.g., CED, obesity) and sex (male and female). Receiver-operating characteristic (ROC) curve analysis was performed to calculate the optimal MUAC cut-off point to identify CED in contrast to non-CED. ROC curve analysis was done for each tribe and each sex. In these analyses Sensitivity (SN), specificity (SP), area under curve (AUC), and Youden Index (YI) were utilised to identify these cut-off points. The statistical analyses were conducted in the SPSS-10 and MedCalc statistical packages. Level of significance were considered at $p<0.05$.

Results

The overall and population-specific sample size, mean, standard deviation (SD) and range for age, height, weight, BMI and MUAC for each tribal ethnic group is presented in Table 1. Mean values of weight and height were significantly higher ($p<0.05$) in males than in females, whereas, the mean BMI and MUAC values were significantly higher ($p<0.01$) in females than in males (results not shown).The mean (SD) MUAC for the whole sample was 25.0 (2.8) and 22.1 (2.4), in males and females, respectively. These values were higher than 25 cm among the males in the six tribal groups from Gujarat and Odisha, but lower in tribes of West Bengal. However, such pattern was not noticed among the females. In case of BMI, there was no population-specific trend, The West Bengal tribes, nevertheless, showed a tendency towards lower mean BMI values compared to those of the other states.

The Pearson correlation coefficient (r) analyses of height, weight, BMI and MUAC showed significant associations in MUAC and height (r = 0.48, $p<0.001$), MUAC and weight (r = 0.84, $p<0.001$) and MUAC and BMI (r = 0.74, $p<0.001$). Similarly, sex-specific positive correlations values were also observed between MUAC and height (male, r = 0.21, females, r = 0.23; $p<0.001$),

Table 1. Population wise-descriptive statistics (mean, SD and range) of BMI and MUAC among the adult tribal people

State	Tribe	Sex	Age (year) Mean (SD)	Age SD	Age Range	Height (cm) Mean	Height SD	Height Range	Weight (kg) Mean	Weight SD	Weight Range	BMI (kg/m^2) Mean	BMI SD	BMI Range	MUAC (cm) Mean	MUAC SD	MUAC Range
Gujarat	Chaudhari	M (118)	41.2	13.1	19–76	162.8	6.6	138.0–177.0	52.8	9.0	37.7–77.8	19.9	3.1	13.8–29.0	25.5	2.3	20.0–32.5
		F (121)	40.5	11.6	20–60	151.4	5.2	139.5–170.5	43.4	6.8	29.7–66.2	18.9	2.9	14.3–27.6	21.9	2.2	17.0–26.5
	Dhodia	M (119)	41.5	11.7	20–65	161.5	6.6	143.5–175.0	53.7	9.8	34.3–77.0	20.5	3.2	13.9–29.2	25.9	2.7	19.0–34.0
		F (120)	40.4	11.6	20–60	149.8	5.0	137.2–161.8	46.4	8.4	31.3–72.2	20.7	3.4	15.2–34.2	23.1	2.5	19.1–30.0
	Kukna	M (116)	40.0	12.3	19–65	162.2	7.9	150.0–177.5	52.9	8.9	27.7–81.6	20.1	2.9	11.7–28.0	26.2	2.6	20.5–36.0
		F (120)	40.0	11.6	20–68	150.1	4.7	138.8–161.4	44.8	6.8	33.0–61.0	19.9	2.8	14.3–26.8	22.9	2.3	18.6–29.0
Odisha	Bathudi	M (117)	40.3	12.4	20–65	156.4	6.2	139.0–177.0	47.7	7.5	32.4–71.5	19.5	2.7	13.6–26.5	25.6	2.3	21.1–36.0
		F (120)	40.2	12.2	21–60	147.0	6.0	133.4–163.0	38.6	6.2	24.6–54.8	17.9	2.7	11.9–25.9	21.4	2.2	17.0–29.0
	Bhumij	M (108)	42.9	12.3	21–65	160.8	6.2	146.0–177.5	54.5	9.4	36.2–77.8	21.0	3.1	15.2–29.8	26.5	3.2	17.0–35.5
		F (122)	40.8	11.4	21–60	149.9	5.6	132.6–166.5	44.2	7.5	31.9–77.2	19.6	2.9	14.4–34.0	22.3	2.3	18.0–30.5
	Santal	M (117)	41.4	13.4	20–65	161.5	6.8	142.0–177.6	52.4	8.4	36.6–78.7	20.0	2.5	14.5–26.6	25.4	2.8	17.6–33.0
		F (119)	39.2	12.6	20–60	149.8	5.9	135.5–168.6	46.1	7.8	31.8–68.7	20.3	3.0	14.2–31.0	23.2	2.5	18.0–31.0
West Bengal	Kora	M (114)	40.1	12.9	20–64	158.9	6.9	143.0–174.5	47.9	6.9	24.5–67.0	18.9	1.9	11.7–23.7	22.8	1.8	18.7–27.0
		F (119)	40.0	12.3	20–60	147.1	5.0	133.4–160.5	38.2	6.3	22.0–53.3	17.7	2.7	11.4–23.9	20.8	2.2	15.5–26.0
	Oraon	M (115)	39.1	12.6	20–65	162.1	6.6	138.0–178.0	51.6	7.6	33.0–73.5	19.6	2.5	13.7–27.9	24.0	2.2	18.0–29.1
		F (124)	39.7	11.8	20–60	148.3	5.8	134.6–159.0	39.8	6.8	29.0–66.6	18.0	2.7	13.9–29.5	21.2	2.0	17.2–29.1
	Santal	M (123)	39.8	13.2	20–65	161.5	6.5	143.3–178.5	52.3	8.6	34.0–76.5	20.0	2.6	14.4–26.8	23.6	2.2	17.1–30.0
		F (122)	39.8	12.8	20.62	141.8	5.8	134.5–168.6	43.4	7.5	30.2–65.8	19.6	3.2	13.2–30.1	22.2	2.2	21.8–22.6
All states	All tribes	M (1046)	40.7	12.7	19–76	160.9	6.7	138.0–178.5	51.8	8.8	24.5–81.6	19.9	2.8	11.7–29.8	25.0	2.8	17.0–36.0
		F (1087)	40.1	11.9	20–0	149.1	5.5	132.6–170.5	42.8	7.7	22.0–77.2	19.2	3.1	11.4–34.2	22.1	2.4	15.5–31.0

MUAC and weight (male, r = 0.73, females, r = 0.86; $p<0.001$) and MUAC and BMI (male, r = 0.75, females, r = 0.84; $p<0.001$) (results not shown). Linear regression analysis showed that the MUAC was found to significantly ($p<0.01$) predict BMI. However, the variation explained was much higher in females (R^2 = 0.709) than in males (R^2 = 0.256). The variation around the regression line was significantly greater in males (SEE = 4.89) than in females (SEE = 1.69) (Fig. 1).

Sex-specific prevalence of different nutritional categories (according to BMI cut offs) and mean MUAC for each of those categories are presented in Table 2. The overall prevalence of CED was significantly higher among females (45.1%) compared to males (32.1%), whereas, overweight and obese, together, was slightly higher in females (14.7%) than males (11.2%) ($\chi2$ = 55.31 $p<0.01$). The mean MUAC showed a consistently increasing trend from lowest to the highest BMI categories, both in males and fe-

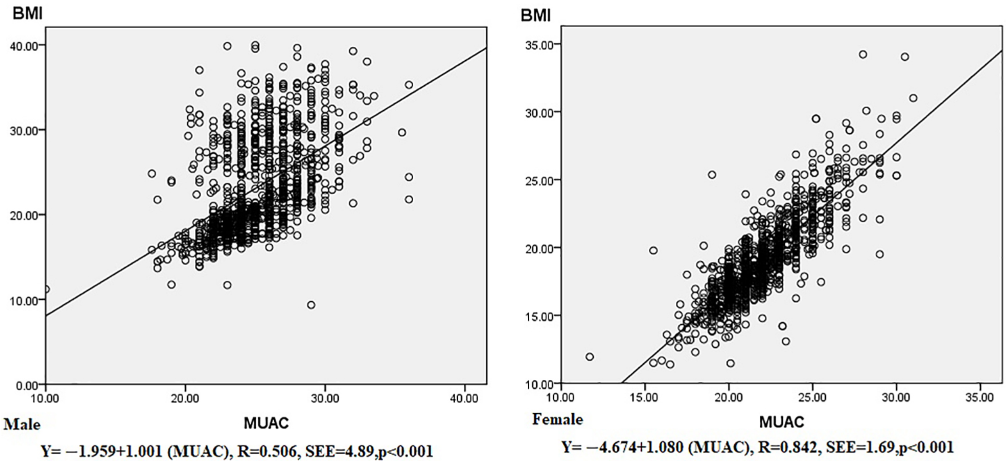

Fig. 1. Relationship between BMI and MUAC in male and female adult tribal people

Table 2. Sex-specific descriptive statistics of MUAC according to different BMI categories among adult individuals

	BMI categories†	N (%)	Mean	SD	Range		F
Male (N = 1046)	CED (<18.5 kg/m²)	336 (32.1)	22.8	1.92	17.6	28.0	97.67*
	Normal (18.5-22.9 kg/m²)	557 (53.2)	25.1	2.07	20.3	34.0	
	Overweight (23.0-24.9 kg/m²)	95 (9.1)	28.0	2.41	17.0	36.0	
	Obese(≥25.0 kg/m²)	59(5.6)	29.5	3.45	21.0	33.5	
	All male#	–	25.0	2.77	17.0	36.0	
Female (N = 1087)	CED (<18.5 kg/m²)	490 (45.1)	21.3	1.40	15.5	24.5	405.92**
	Normal (18.5-22.9 kg/m²)	475 (43.7)	23.0	1.61	15.5	29.0	
	Overweight (23.0-24.9 kg/m²)	62 (5.7)	25.1	1.31	21.0	28.0	
	Obese(>25.0 kg/m²)	60 (5.5)	27.2	2.35	19.0	31.0	
	All female#	–	22.1	2.40	15.5	31.0	

**$p<0.001$; † (WHO, 2000; WHO Expert Consultation, 2004).

males, with the lowest value in CED and the highest in obese (Male: F = 97.67, Female: F = 405.92; both $p<0.001$).

Table 3 presents the results of ROC Curve analyses of MUAC (continuous) *versus* CED status (CED versus non-CED), separately for each sex, according to tribe. It shows the sensitivity (SN), specificity (SP), and area under ROC curve (AUC), along with their 95% CI, and standard errors (SE), respectively, for the optimal cut off value of MUAC to identify CED against non-CED. For the whole sample of males of all tribes together (N = 1046), the optimal cut off point of MUAC was 23.8 cm with SN of 80.3 and SP of 73.8, the ROC curve covering 85% area (AUC = 0.85). On the other hand, the females (N = 1087), as a whole, showed a MUAC value of 21.8 cm with SN and SP of 82.6 and 84.6, respectively. However, the ROC curve performed better with AUC covering 92% in females than in males (83%) (p<0.05). The associated Youden Index was also higher in females (0.67) than in males (0.54). While looking at the MUAC optimal cut offs for different tribal populations under study, it seemed that in females, the values were uniform, relative to males, being closely around 22.0. On the other hand, in males, the cut offs vary within a range of 23-24.4 cm. In some tribe, the values were closer to 23 cm (Bhumij, Santal and Kora of OD and WB). For the other males of the other tribes, the values were close to 24 cm (all GJ tribes, Bathudi of OD and Or-

Table 3. Results of receiver-operating characteristic (ROC) curve analyses of MUAC vs. chronic energy deficiency status (BMI<18.5 kg/m^2) among the different tribes

Tribe	MUAC Cut off	Sensitivity	Specificity	AUC	SE	95% CI	Yuden index
Male							
Bathudi_O	24.0	63.27	85.71	0.83	0.04	0.75–0.89	0.490
Bhumij_O	23.0	68.18	89.36	0.85	0.04	0.77–0.98	0.617
Santal_O	23.0	60.76	91.95	0.85	0.04	0.78–0.91	0.622
Chaudhari_G	24.4	74.47	86.11	0.87	0.03	0.80–0.93	0.606
Dhodia_G	24.0	70.59	87.06	0.89	0.03	0.82–0.94	0.712
Kukna_G	24.0	70.59	91.67	0.94	0.02	0.88–0.97	0.715
Kora_WB	21.8	48.94	94.03	0.81	0.04	0.72–0.88	0.433
Oraon_WB	23.7	87.18	74.67	0.86	0.04	0.78–0.92	0.618
Santal_WB	23.4	97.30	69.77	0.89	0.03	0.82–0.94	0.671
Overall	23.8	80.29	73.80	0.85	0.01	0.82–0.87	0.540
Female							
Bathudi_O	22.0	90.79	75.56	0.90	0.03	0.83–0.95	0.669
Bhumij_O	21.8	82.22	85.71	0.89	0.02	0.83–0.94	0.679
Santal_O	22.0	78.38	80.49	0.85	0.04	0.78–0.91	0.589
Chaudhari_G	22.2	98.31	70.97	0.92	0.02	0.86–0.96	0.693
Dhodia_G	21.7	82.86	90.59	0.93	0.03	0.87–0.97	0.743
Kukna_G	22.3	89.58	80.56	0.92	0.02	0.86–0.96	0.701
Kora_WB	21.7	93.33	82.61	0.93	0.02	0.87–0.98	0.759
Oraon_WB	22.4	96.15	67.39	0.89	0.03	0.82–0.94	0.644
Santal_WB	21.6	72.73	85.07	0.86	0.03	0.81–0.93	0.578
Overall	21.8	82.60	84.58	0.91	0.01	0.90–0.93	0.672

aon of WB). Overall, it seems from the results that the ROC curves were better fit ($p<0.05$) in females than in males (Fig. 2).

In Table 4 the mean (SD) values of MUAC and BMI, the prevalence of CED and their respective Odds ratios are presented according to the (two MUAC categories (undernourished vs normal) based on the optimal cut off values rounded off to the nearest whole number (males: <24 cm, females: <22 cm). The mean MUAC (t-value males: 42.40, d.f., 1044, $p<0.001$, females: 41.39, d.f., 1085, $p<0.001$) and BMI (t-value males: 15.45, d.f., 1044, p<0.01, females: 27.93, d.f., 1085, $p<0.01$) were significantly lower in the undernourished groups than the normal. The undernourished males (MUAC<24 cm) and females (MUAC<22 cm) encompassed significantly higher numbers of CED than the normal groups (χ2-value males: 254.9, d.f., 1, $p<0.001$; females: 493.6, d.f., 1, $p<0.001$). The males having MUAC <24 cm had 9.8 times higher risks of being CED than MUAC≥24 cm. The females, on the other hand, having MUAC <22 cm was as high as 41 times likely to be CED compared to those with MUAC ≥22 cm.

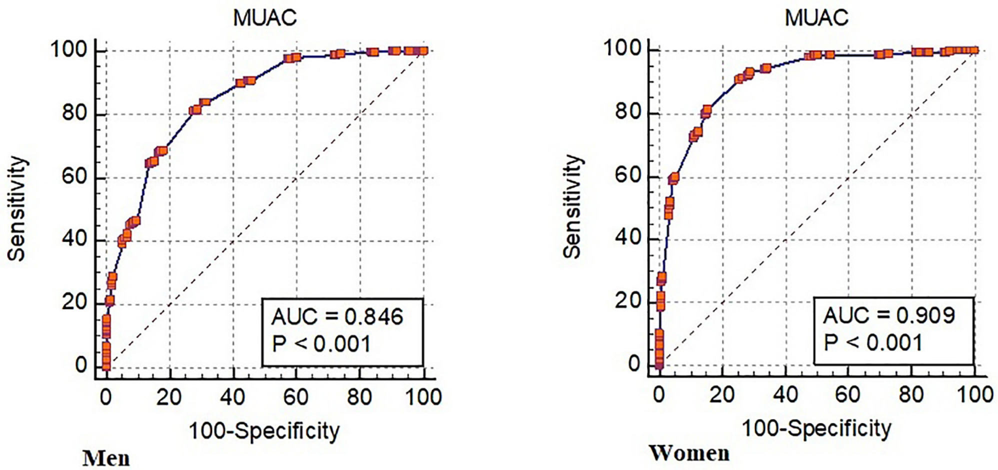

Fig. 2.ROC curve of MUAC vs CED status in Indian adult tribal men and women

Table 4. Mean (SD) of MUAC and BMI and prevalence of chronic energy deficiency (CED) according to mid-upper arm circumference (MUAC) categories of the adult tribal populations

MUAC (cm)	N (%)	Mean (SD) MUAC (cm)	Mean (SD) BMI (kg/m^2)	CED (%)	Odds ratio (95% CI)
Male (N = 1046)					
<24.0	342 (32.7)	22.08 (1.26)	17.82 (1.85)	66.96	9.77 (7.24–13.18)
≥24.0	704 (67.3)	26.49 (2.08)	20.98 (2.61)	33.04	1 (Reference)
		t = 42.40; $p<0.001$	t = 22.53; $p<0.001$	χ^2 = 254.9, $p<0.001$	
Female (N = 1087)					
<22.0	679 (62.5)	20.62 (1.32)	17.57 (1.95)	69.07	41.16 (25.77–65.74)
≥22.0	247 (37.5)	24.62 (1.64)	21.93 (2.78)	8.50	1 (Reference)
		t = 41.39; $p<0.001$	t = 27.93; $p<0.001$	χ^2 = 493.6, $p<0.01$	

Discussion

The objective of the present study was to assess whether one global cut off point of MUAC could be relied upon to identify CED in diverse populations as proposed by WHO (2004)and Tang et al.(2020) and also for both males and females as proposed by Tang et al.(2020). The present study indicated inter-population variation in the relationship between BMI and MUAC among the nine tribes studied. It was also revealed that the MUAC cut offs tended to differ between males and females, as well as between populations. Thus, it cast reasonable doubts on an undisputed utility of a single MUAC cut off to screen for CED in males and females and across populations, especially, in a diverse country like India. Our study showed that in males, the optimal MUAC cut off to identify CED was 23.8 cm, i.e., very close to the recently proposed global value (Tang et al. 2020), as well as to the earlier studies on Indian slum dwelling men (Chakraborty et al. 2009c) and Oran tribal men (Chakraborty et al. 2011), i.e., 24 cm. On the other hand, the females of this study demonstrated 21.8 cm as the optimal cut off, which is very close to the conventional international cut of as proposed by WHO (2004).

MUAC is an undisputedly used anthropometric measure for screening of undernutrition in adults, especially, when there are limited time and resource, as it is easy to measure by using minimum equipment and manpower (Das et al. 2018; Tang et al. 2020). Although, it was used to assess nutritional status in different populations worldwide, including people with serious medical conditions (e.g., HIV or tuberculosis) (Bahwere et al. 2011), a universally applicable single MUAC cut off is yet to be accepted. In a pioneering study, James et al. (1994) proposed the MUAC cut offs of 23 cm and 22 cm, and consequently, WHO recommended these values as the international reference to identify undernourished adult males and non-pregnant women, respectively (WHO 2004). Since then, numerous researches have been consistently showing that these values were not always appropriate for all populations of the world, and therefore, several efforts were made to find out potentially appropriate cut offs for specific populations.

Many countries and public health programmes have also established their own MUAC cut offs. However, evidence is not very strong in support of these cut offs to be used as optimal ones (Tang et al. 2020), and it has been further difficult in countries like India to come into a consensus on a single MUAC cut off for adults, not even separately for each sex. Studies which used a MUAC cut off of 23 cm and 22 cm in adult males and females, found strong associations between MUAC values lower than these cut offs and CED (<18.5 kg/m^2) with high odds ratios (Powell-Tuck and Hennessy 2003; Bisai and Bose 2009; Chakraborty et al. Chakraborty et al. 2011). There were studies in India which found evidence closely in favour of these WHO recommended values of 23cm and 22cm for males and females (Das et al. 2018; Das et al., 2020). On the other hand, a MUAC of 24 cm was proposed as appropriate in a study from the Southern India (Rodrigues et al. 1994), among the Oraon tribal men from another eastern Indian state (Chakraborty et al. 2011), and also among the slum dwellers of eastern India (Chakraborty et al. 2009a, 2009c). Thorup et al. (2020) reported that MUAC of 24.5 cm was found to be the most appropriate to predict CED status together for both men and women in Nepal. On the basis of such findings, indicating higher MUAC cut off values than the universally proposed values by WHO, it was also argued that such tendency was perhaps due to the diverse ethnic origin and variation in body fat patterning and differences in the relationship between BMI and body fat across populations (Chakraborty et al. 2009c). More precisely, as the people of South Asian origins demonstrate relatively higher body fat content than the Whites at similar level of BMI, they may possess a thicker layer of subcutaneous fat at a relatively lower BMI level (WHO Expert Consultation 2004; Chakraborty et al. 2009a; Chakraborty et al. 2011). This might be a cause for having a relatively higher MUAC even at a lower level of BMI (e.g., in CED), resulting in the higher cut off values of MUAC to detect CED (Chakraborty et al. 2009c; Chakraborty et al. 2011; Das et al. 2018). Finally ,the recent global meta-data analysis also revealed that a MUAC cut of 24 cm for both adult men and non-pregnant women was suitable for the purpose of screening for CED (Tang et al. 2020). This study also included a few datasets representing Indian populations. Nevertheless, another recent study in an eastern Indian slum, revealed MUAC values of 22.7 cm and 21.9 cm (very close to WHO values) to be the most sensitive cut-off points to differentiate between CED and non-CED individuals among the males and females, respectively (Das et al. 2018).

Thus, the issue of whether we can use a single MUAC cut off universally, or not, doesn't seem to have resolved with the recent proposition (Maalouf-Manasseh et al. 2020; Tang et al. 2020). The said global study, nevertheless, suggested that further validation studies are required before the proposed cut off could be used universally. In this backdrop, the present study examined whether a uniform MUAC cut off, or at least, a close range of values, could be obtained among diverse populations in India. The results revealed that MUAC of 23.8 cm in males and 21.8 cm in females, were the most sensitive cut-off points to differentiate between CED and non-CED individuals (Table 3). It is worth noting that the obtained cut off point for males (23.8 cm) was rather close to the global recommendation of 24 cm by Tang et al. (2020) as well similar to the values found in a sample of slum dwelling Indian men and in Oraon tribal men (Chakraborty et al. 2009a; 2009c; 2011). On the other hand, the value obtained for females (21.8 cm) was close to the WHO proposal of 22 cm for adult females (WHO 2004)and also similar to the value proposed by the study conducted on another group of Indian slum dwelling women (Das et al. 2018). However, these two values were for the whole samples of males and females including all the tribal populations under study. Nevertheless, looking at the MUAC cut off values across tribes and sexes, it seemed that there was considerable population variation among the males. In some tribes, the values were close to 23 cm (viz. Bhumij, Santal and Kora of OD and WB), and in others, the values were close to 24 cm (all GJ tribes, Bathudi of OD and Oraon of WB). The cut off values in females were more or less consistent, being close around 22 cm. It was also observed that the ROC curves were better fit in females than in males in almost all tribes. To provide with an exact reason for this sex difference and population variation was, however, out of the ambit of the present study. One possible reason may be that the relationship between BMI and MUAC was more consistent from lower to higher values of BMI in females than in males, and that MUAC predicted BMI better in females than in males ($p<0.001$), as the results of the linear regression analysis indicated (Figure 1). The ROC curves in females were also better fit than in males, as revealed in an earlier study among rural slum dwellers (Tang et al. 2020).

It is now well documented that the major underlying factors for the prevalence of malnutrition (i.e., undernutrition and overnutrition) are inequalities in resource distribution, socio-economic conditions, disease burden and ethnic variations in developing countries (Chakraborty and Bose 2014; Chakraborty et al. 2009b). Several researchers have reported that inadequate access to food, protective nutrients, healthcare facilities, poverty, socio-economic and poor living conditions are the major causes of high undernutrition (e.g., CED) in Indian populations (Rodrigues et al. 1994). The National Family Health Survey (NFHS-4, 2015-16) reported that prevalence of CED was found to be 20.2% among males and 22.9% among the females (IIPS and ICF 2017). The prevalence of CED (32.1% males; 45.1% females) among the tribal populations under the present study was much higher than the national average. MUAC is an established substitute for BMI in rapid screening in nutritional emergencies (James et al. 1994), when individuals usually have thinner subcutaneous fat and the change in MUAC more precisely reflects changes in muscle mass (Das et al. 2018; Debnath et al. 2017; Sen et al. 2011). In such conditions, there is no better alternative than the MUAC measurement as an indicator of protein-energy malnutrition or a state of starvation. Thus, it may also imply that in populations which are well known to suffer from a chronic energy stress, such as the Indian tribes, MUAC can also closely reflect both body fat and muscle mass. Therefore, in such high CED prevalent situation it is of utmost importance to adopt easy techniques of screening, such as with an optimal MUAC cut-off for identifying moderate and severe undernutrition. However, such an approach should balance between incapability of encompassing all the individuals in need of support and including too many people who are not in acute need at that point of time. Thus, although it may not be possible to identify an accurate cut off, a closer one might be the most effective. Therefore, it seems that there is no alternative at this point of time to undertake more studies with diverse population samples with the objective to validate and revalidate the cut off values of MUAC.

On the other hand, there could be also some cautions of determining MUAC cut off against another cut off of based on BMI values as the gold standard of undernutrition assessment. It is because BMI is, perhaps, not always the most accurate indicator of body energy storage, and for that matter, adult undernutrition (Chakraborty et al. 2009a; Chakraborty et al. 2011). A second caution is the confounding effect of oedema on the relationship between BMI and MUAC (Rodrigues et al. 1994). Besides all these, BMI cut off of <18.5 kg/m^2 may not be appropriate for identifying undernutrition in adults who are adapted in limited resource set ups (Chakraborty et al. 2011). Therefore, the obtained cut off values of MUAC should be validated against functional outcomes, such as, strength and mobility, and also lean mass, to test its functional accuracy in population screening. Further, it seems that there is no better alternative than undertaking prospective follow up studies with the functional outcome components in the research design (Chen et al. 2014).

Conclusion

The results of the present study showed that a single cut off point of MUAC may not be universally applicable in diverse populations as well as in both sexes. It seemed that there is no alternative than to undertake more and more validation study in diverse types of populations before using a MUAC cut off to identify undernourished condition.

Acknowledgements

Authors gratefully acknowledge the help and co-operation of all the people of the study area, especially the participants, local community leaders and village headmen for their support during the fieldwork. The extended help and co-operation of the Department of Anthropology, Delhi University is also acknowledged.

The project was funded by Indian Council of Medical Research (ICMR), Government of India, in the form of major research project [5/4/8-2/2010 NCD II].

The Author's contribution

GKK was the awardee of the original research project, responsible for acquisition and organisation of data and contributed substantially to the final manuscript; RC conceived the idea, analysed data and wrote the first draft. NM analysed data and added important intellectual content to the manuscript; KB also carefully revised the manuscript and gave several important inputs to finalise the manuscript. All the listed authors have made substantial contributions to this manuscript.

Conflict of interest

The authors declare that there is no conflict of interest.

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