Epidemiology Biostatistics and Public Health - 2017, Volume 14, Number 2

Cut-off point estimation of neck circumference to determine overweight and obesity among Asian Indian adults

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DOI: 10.2427/12310
Accepted on February 23, 2017

ABSTRACT

Background: Neck circumference (NC) is a relatively new anthropometric measure of differentiating excess body fat distribution and considered as a marker of upper subcutaneous adiposity.
The present study was undertaken to assess the reliability of use and cut-offs estimation of NC to determine overweight and obesity among Asian Indian adults.
Methods: The present cross-sectional study was carried out among 1830 adults (914 males; 916 females) aged 20-49 years of Karbi Anglong, Northeast-India, using multistage-stratified sampling method. Height, weight, waist circumference (WC) and neck circumference (NC) were recorded using standard procedures. The body mass index (BMI kgm^{-2}) was calculated and overweight and obesity were assessed using standard cut-offs.
Results: Linear and binary logistic regression analyses showed that NC had a better predictive value of BMI ($p<0.001$). The ROC-AUC results showed that NC seems to have relatively better predictive value in greater adiposity (BMI≥30.00 kgm^{-2}) among both males (AUC 0.83, 95% CI: 0.81-0.86) and females (AUC 0.88, 95%CI: 0.85-0.89) ($p<0.01$). The cut-offs of NC were observed to be 36.0 cm and 38.0 cm (in males) and 30.9 cm and 33.0 cm (in females) for BMI ≥25.00 kgm^{-2} and BMI ≥30.00 kgm^{-2}, respectively.
Conclusion: Further studies should be undertaken to determine and validate the existing and/or newly proposed cut-offs among larger samples for pan-Indian cut-offs for the assessment of overweight and obesity and related risks of non-communicable diseases and metabolic disorders using NC.

Key words: BMI, Neck circumference, Waist circumference, Overweight, Obesity, Anthropometry, North-east India, Public health.

INTRODUCTION

Upper body fat distribution has long been recognised to relate to increase risks of hypertension, cardiovascular disease, type-II diabetes and metabolic disorders. Neck circumference (NC) is a relatively new anthropometric measurement of differentiating body fat distributions and proposed as a proxy measurement of upper body subcutaneous tissue distributions[1-9]. Researchers have tried to establish that upper body fat distributions relate to greater NC and could have an association with increased risks of type-II diabetes and hypertension [1,6,10], cardiovascular diseases [2,11,12] and metabolic disorders [2,5,6,7,9]. Currently, there are several technologically advanced methods (such as bioelectrical impedance analysis, dual-energy X-ray absorptiometry and magnetic resonance imaging) to assess total and regional body adiposity but the application of non-invasive, inexpensive and easy to apply anthropometric measurements are usually observed to be more realistic and widely accepted in both clinical and epidemiological research [13,14]. Several researchers have reported positive associations between conventional anthropometric measures of overweight and obesity {such as body mass index (BMI), waist circumference (WC) and waist-hip-ratio (WHR)} with NC among adults [3,4,5,7,8,9,11,15,16,17,18,19,20].

The BMI is considered as a better surrogate anthropometric measure of adiposity that measures adiposity in terms of excess weight gain relative to height rather than excess body fat [13,14,21]. However, BMI does not distinguish between specific regional distribution and weight associated with actual body composition with body adiposity. Generally BMI values of ≥25.00 kgm^{-2} and ≥30.00 kgm^{-2} have been recommended for overweight and obesity among adults, respectively [24,25]. Recently, a redefined the criteria of overweight (≥23.00 kgm^{-2}) and obesity (≥25.00 kgm^{-2}) have been revised for "Asian" populations due to the reason that increased co-morbidities and health risk factors related to excess adiposity occurred at lower BMI levels among Asian populations [21,22,24,25]. It is believed that BMI ≥25.00 kgm^{-2} is a major risk factor for a wide range of diseases such as cardiovascular diseases, type-II diabetes and certain site specific cancers including colorectal and breast cancer [21,22,23,24]. Moreover, general complications arises in case of similar body fat distributions among different ethnic populations due to body proportions variations with BMI, which could be the reason among Asian populations [24,25].

Several studies have reported use of NC as an easy-to-use, proxy anthropometric screening measurement of overweight and obesity [1,2,4,6,8,10,12,20]. Researchers have also reported that NC has the potential to surpass conventional anthropometric measures (e.g., BMI and WC) as a powerful marker of adiposity distribution, cardio-metabolic syndrome disorders and insulin resistance [1,5,6,14,26]. The assessment of regional accumulation of excess adiposity, especially in the upper body segment is considered a better predictor of obesity related complications including hypertension, diabetes, and cardiovascular diseases [1,5]. Recently, some population based studies from India have also tried to establish the relationship of NC with regional adiposity, metabolic disorders, cardiovascular diseases and related co-morbidities among Asian Indian populations [1,27,28].

Therefore, the identification of relative risks of excess adiposity and their co-morbidities have become a priority for investigators in clinical research. It is evident that the advantage of NC is that it is a relatively simple, inexpensive measure and provides very good inter- and intra-observer reliability and requires minimum effort from the examiner and the examinee [5,29]. Moreover, NC could be potentially used as a quick and easy-to-apply anthropometric screening tool in population and clinical studies in preference to other anthropometric variables (such as BMI and WC). However, very few clinical based studies have tried to establish this relationship and determined population specific cut-offs to assess overweight and obesity in adults using NC [1,4,5,6,30]. These population specific cut-off studies are almost absent among Asian Indian population. Hence, identification of alternate anthropometric measurement (e.g., NC) in determining overweight and obesity is of paramount importance to establish appropriate population specific cut-offs. Given the above, objectives of the present study were to identify the reliability of use of NC as a screening measure and to determine appropriate population specific cut-offs of overweight and obesity in Asian Indian populations.

METHODS

Study Area and Subjects

India consists of a large number of ethnic and indigenous elements having enormous amounts of ethnic and genetic diversity [31]. With a population of more than 1.22 billion, it is now recognized that the Indian population consists of 4693 communities with several thousand endogamous groups. The present community based cross-sectional study has been conducted among adult individuals belonging to a heterogeneous tribal and non-tribal population of Karbi Anglong (25^{0}33' N to 26^{0}35' N latitude and 92^{0}10' E to 93^{0}50' E longitude) district of Assam, Northeast India. A total of 26 villages/ habitats situated ~15-40 km from Diphu town of Karbi Anglong was covered. The data were collected during August 2012 to March 2014.

The subjects were included using a multistage-stratified sampling method. In the first stage, households were identified. In the second-stage, a simple random sampling was used to select the individuals. A total of 2000 (males: 1000; females: 1000) adult individuals in the age group of 20 to 49 years were approached to participate in this study. Of them, 1830 (males: 914; females: 916) voluntarily agreed to participate in the same. The overall participation rate was 91.50%. Age of the individuals was recorded from the birth certificates and relevant official documents. An informed consent was taken from each subject, local village level authorities and headmen prior to data collection. The necessary research clearance was obtained prior to the commencement of the study, and the study was conducted in accordance with the ethical guidelines for human experimental research as laid down in the Helsinki Declaration [32].

Socioeconomic and demographic data (e.g. education, occupation and monthly family income) were collected using a structured schedule. Socioeconomic status (SES) was evaluated using a modified version of the scale of Kuppuswamy [33]. This scale allows determination of socioeconomic status based on a score calculated from education, occupation and household income. It was subsequently observed that all the selected individuals were belonged to a lower to middle SES group. The subjects were apparently healthy, devoid of any physical deformity, previous histories related to medical and surgical episodes and not suffering from any diseases at the time of data collection. Pregnant, post-partum and lactating females were excluded.

Anthropometric Measurements Recorded

Anthropometric measurements were recorded following standard procedures [34]. Weight was recorded to the nearest 0.1 kg with the participant standing motionless on a portable digital weighing scale. The measurement was taken wearing minimum clothing without any footwear. Height was measured to the nearest 0.1 cm with the participant standing in erect position on a flat platform with the head oriented in the Frankfort horizontal plane using an anthropometer rod. The WC was measured midway between the iliac crest and lower margin of the ribs with the participant in the standing position. The NC measured as distance around the neck in a horizontal plane at the level of the most prominent portion of the thyroid cartilage (Adam's apple) with the head held erect (in the resting position) and eyes facing forward [18,30,34]. Care was taken not to involve the shoulder and neck muscles (Trapezius) during recording the measurement. Two consecutive readings were recorded for height, weight WC and NC, and the means were noted. The instruments used were calibrated before and during the period of data collection to reduce the systematic error.The technical error of measurement (TEM) was utilized to check consistency of the data. The TEM is an accuracy index and measures the standard deviation between intra-observer and inter-observer measures [35]. The TEM was calculated using the following equation:

$TEM=\sqrt{(\sum D^2/2N)}$, D=difference between the measurements, N= number of individuals measured.

The coefficient of reliability (R) was determined from TEM following the standard procedure [35]. The 'R' value ranges from 0 (not reliable) to 1 (complete reliability). The value of R was calculated using the following equation:

$R=1-(TEM)^2/SD^2$, SD= standard deviation of all measurements.

For analysis of TEM, a total 50 adult individual other than those selected for the present study were selected from the town of Diphu using a method of simple random sampling. Height, weight, WC and NC were recorded from them by two of the randomly selected authors who were trained in the anthropometry techniques during field settings. A very high value of 'R' (>0.975) was obtained for all anthropometric measurements and values were appreciably higher than the cut-off value of 0.95 as specified by Ulijaszek and Kerr [35]. Therefore, the measurements recorded were considered to be reliable, reproducible and free from any observer bias. The measurements in the present study were subsequently obtained by five of the authors (RT, MK, SH, ST and AS). The systematic errors due to the shift in the style or landmark interpretations or between instruments were also tested using a standard procedure [36]. Similarly, differences in the anthropometric measurements were evaluated with repeated measures and sessions using one-way ANOVA and the mean differences were observed to be statistically not significant ($p>0.05$).

Assessment of Excess Adiposity

Using BMI, proposed redefined classification for the Asia-Pacific populations was used to classify the different adiposity levels (e.g., BMI >23.00 kgm^{-2}, BMI >25.00 kgm^{-2}, BMI >27.50 kgm^{-2} and BMI >30.00 kgm^{-2}) [24,25].

Statistical Analysis

The data were statistically analysed using Statistical Package for Social Science (SPSS version, 17.0). A p value of <0.05 was considered to be statistically significant. Homogeneity of variance was tested using Levene's test of equality of variance. For all variables, the p-value was observed to be statistically not significant ($p>0.05$) thus showing that variances were same for both the groups in connection with all the variables. Normality was tested using the Shapiro–Wilk test for each of the variables sex-wise, and p-values observed to be statistically not significant ($p>0.05$). Independent sample t-test was done to determine mean differences between sexes in the anthropometric variables. The Pearson correlation coefficient (r) analysis was utilized to understand the relations between adiposity variables among both sexes.

Linear regression analysis was done to assess the best anthropometric predictive of BMI and the coefficient of determination (R^2) and standard error of estimate (SEE) were calculated for NC and WC. Chi-square (χ^2) analysis was done to assess sex differences in prevalence of different levels of adiposity.

A binary logistic regression (BLR) analysis was employed to derive the 'Wald statistics' and 'R-square statistics' to identify the better predictor model for estimation of adiposity levels (e.g., BMI ≥23.00 kgm^{-2}, ≥25.00 kg m^{-2}, ≥27.50 kgm^{-2} and ≥30.00 kgm^{-2}) [24]. The BLR provides a probability of obesity assessment based on the maximum likelihood approach. Logistic regression models were derived as; $y = \beta 1 X x_1 + \beta 2 X x_2 + \ldots\ldots. + \beta n X x_n + b$. The values of β 1'through β n' where the β coefficients for each variable, 'x1' through 'xn' denoted the different variables and b' was the constant. The 'Wald statistics' and 'R-square statistics' of model summary statistic measured how well the model predicted the decisions, where the smaller statistic was considered to be a poor predictor of the model.

Receiver-operating characteristic (ROC) curve was plotted for determination of the efficacy of the screening measures for correctly identifying individuals on basis of their classification by the reference test [37]. The ROC curve is a plot of the true positive rate (sensitivity) against the false positive rate (1- specificity). Youden Index (YI) was calculated as: (sensitivity + specificity − 1). The YI and associate cut-offs for different BMI cut-off values were compared to find out the optimal cut-off values for NC. In the present study, the specificity and sensitivity were calculated against adiposity levels [24]. Those individuals observed to be above the excess adiposity levels of BMI cut-offs were coded as '0' and those who were normal coded as '1' against the predictor variables separately. The 95% Confidence Intervals (CIs) of the normalised area under curve of ROC (AUC-ROC) was also calculated to ascertain the best surrogate anthropometric predictor for excess adiposity. The AUC-ROC value of 0.50 means the diagnostic test is not better than by chance, hence, values >0.50 are thus more desirable [37].

RESULTS

Sex-specific subject distributions, range, descriptive statistics and 95% CI of mean of anthropometric variables among adults are presented in Table 1. The mean values of weight, height and NC were observed to be significantly greater among males than females ($p<0.05$). The mean BMI value was found to be similar in males and females ($p>0.05$). The mean NC was observed to be significantly greater among males than females ($p<0.001$). Utilizing t-test analysis, significant sex differences were documented for height, weight and NC ($p<0.001$) (Table 1). The Pearson correlation coefficient (r) analysis of BMI, WC and NC showed significant associations in both sexes ($p<0.001$). A positive correlation was obtained between BMI and NC (r= 0.468 in males; r=0.470 in females, $p<0.001$). A strong correlation was observed between BMI and WC (r =0.479 in males; r=0.600 in females, $p<0.001$). A strong positive correlations were also found between NC and WC (r =0.505 in males, r=0.486 in females, $p<0.001$).

The linear regression analysis showed that the NC was considered to be a significantly ($p<0.01$) better predictor variable of BMI in both males (R^2=0.229) and females (R^2=0.360) than WC (R^2=0.219, in males; R^2=0.221 in females). The sex-specific variation (e.g., SEE) around the regression lines for each sex was significantly greater for NC in males, but found lower among females as compared to the WC (Figure 1).

Prevalence of Adiposity

Prevalence of overweight (BMI ≥25.00 kgm^{-2}) (males: 9.0%; females: 13.5%) was observed to be greater than

TABLE 1. Sex-specific, descriptive statistics (mean ±SD), range, 95% CI of mean and mean differences among the individuals.

VARIABLES	MALES (N=914)		FEMALES (N=916)		SEX DIFFERENCE	
	MEAN ±SD (95%CI)	RANGE	MEAN ±SD (95%CI)	RANGE	T-TEST	p
Height (cm)	161.76 ±5.83 (161.38-162.13)	141.20-179.30	151.21±5.02 (150.89-151.53)	140.00-164.50	41.48	0.000
Weight (kg)	59.00 ±8.67 (58.44-59.57)	40.00-94.00	51.50 ±7.52 (51.00-51.98)	40.00-87.00	19.79	0.000
WC (cm)	77.03 ±6.01 (76.64-77.42)	57.50-108.00	76.50 ±8.60 (75.94-77.05)	54.80-108.50	1.54	0.125
NC (cm)	35.33 ±2.50 (35.17-35.50)	27.90-46.60	30.44 ±2.44 (30.28-30.60)	21.50-45.70	42.38	0.000
BMI (kgm^{-2})	22.51±2.81 (22.37-22.63)	18.04-34.21	22.49±2.85 (22.31-22.68)	18.11-35.52	0.17	0.863

SD: standard deviation; values in parentheses indicate the 95% CI of mean obesity (BMI ≥25.00 kgm^{-2}) (male: 4.4%; females: 2.3%). Using the cut-offs of BMI ≥23.00 kgm^{-2} and 27.50 kgm^{-2} the prevalence were 24.2% and 3.1% (for males) and 22.7% and 3.5% (for females) respectively. Sex differences in prevalence of adiposity were observed to be statistically insignificant (p>0.05) in BMI ≥23.00 kgm^{-2} (χ^2=0.334), BMI ≥25.00 kgm^{-2} (χ^2=2.441) and BMI ≥27.50 kgm^{-2} (χ^2=2.286), with the only exception being observed in BMI ≥25.00 kgm^{-2} (χ^2=6.165) (p<0.05).

Binary logistic regression analysis of the anthropometric variable against excess adiposity

A binary logistic regression (BLR) analysis was employed to derive the 'Wald statistics' and 'R-square statistics' to identify the better predictor model for estimation of adiposity levels using adiposity measurements (Table 2). The NC appeared to be a better predictor in terms of 'Wald statistics' (61.63 vs. 39.27) and 'R-square statistics' (0.083 vs.0.037) in higher adiposity levels (e.g., BMI ≥30.00 kgm^{-2}) as compared with WC (p<0.001) but exception observed in BMI ≥23.00 kgm^{-2} (p<0.001) among males. Similarly, the 'Wald statistics' were observed to be significantly higher at ≥25.00 kgm^{-2} and ≥27.50 kgm^{-2}. Better BLR model predictive values in terms of 'Wald statistics' were observed in WC than NC at all adiposity levels of ≥23.00 kgm^{-2} (145.20 vs. 119.72), ≥25.00 kgm^{-2} (125.61 vs. 98.94), ≥27.50 kgm^{-2} (97.54 vs. 62.54) and ≥30.00 kgm^{-2} (55.23 vs 33.99) among females (p<0.001). The values of coefficient of determination (R^2) were observed to be higher in WC than NC for both sexes, except in higher adiposity levels (BMI ≥27.50 kgm^{-2} and BMI ≥30.00 kgm^{-2}) among males. In all the cases, the BLR coefficients were observed to be statistically significant in both sexes in all adiposity levels (p<0.001).

FIGURE 1. Linear regression analysis between BMI, NC and WC; the excess adiposity measures variation (SEE) around the regression lines for both sexes were found to be greater for NC and WC comparison with BMI.

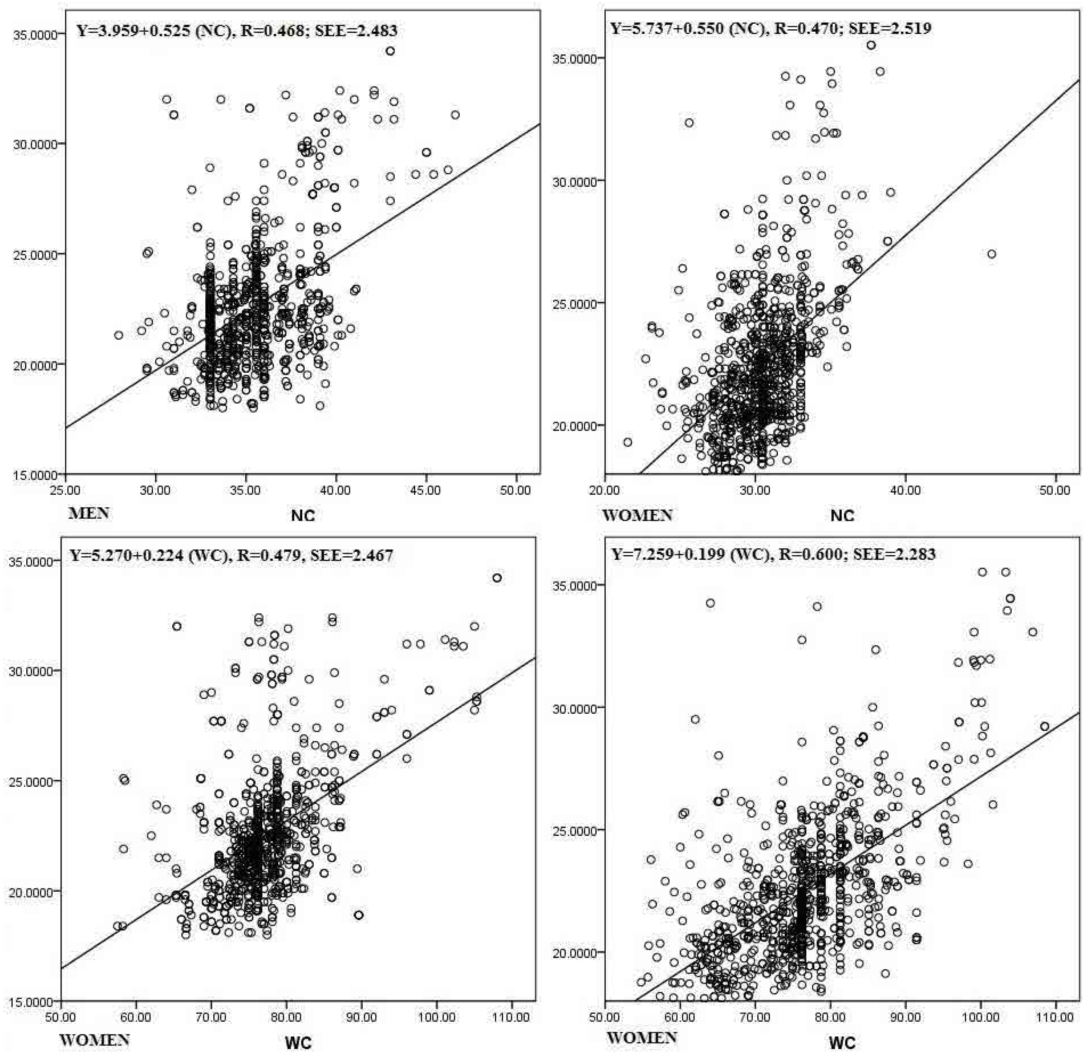

FIGURE 2. Receiver operating curve (ROC) analysis for NC and WC: the ROC is represented be the solid line and dotted line is reference line, the area under curve (AUC) shows a) NC was found greater association with greater adiposity BMI≥27.5 kgm⁻² and BMI≥30.0 kgm⁻²) WC shows significantly greater association with the BMI≥23.0 kgm⁻² and BMI≥25.0 kgm⁻² than NC.

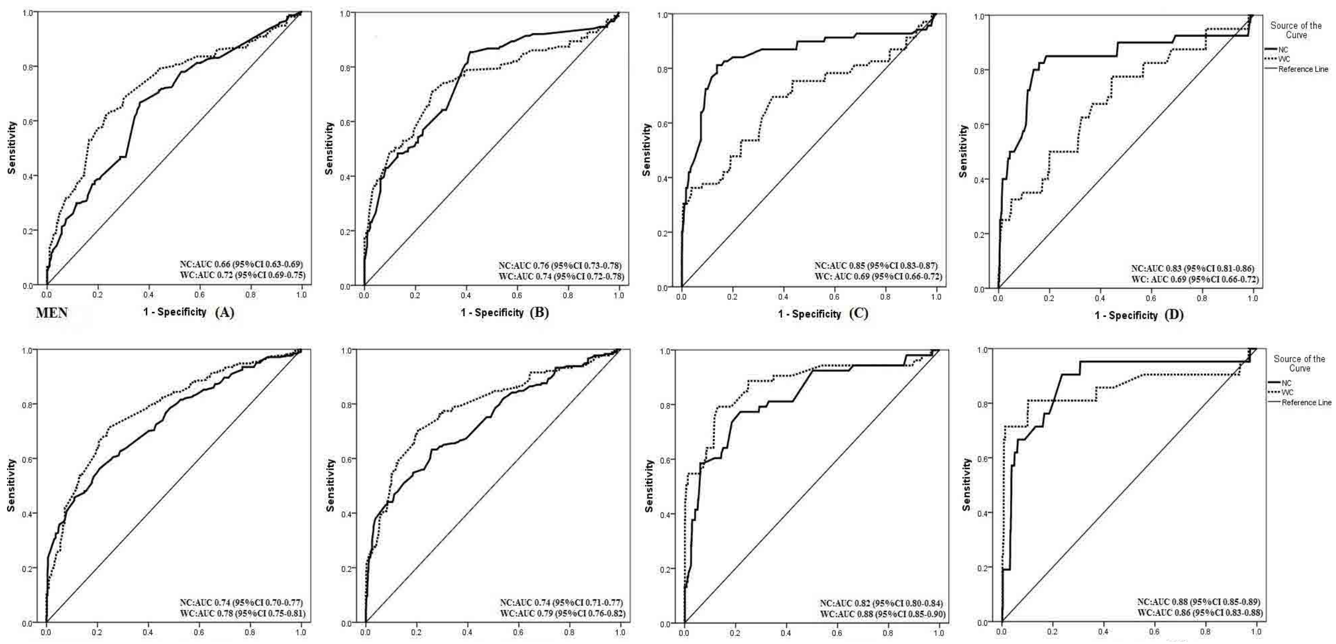

TABLE 2. Binary logistic regression analysis to predict the anthropometric determinants of body adiposity among the individuals

Adiposity levels	Variable	Males (N=914)						Females (N=916)					
		Constant	B	S.E.B	Wald	R² *	P	Constant	B	S.E.B	Wald	R² *	p
BMI≥23.00 kgm⁻²	WC (cm)	12.43	–0.156	0.017	85.82	0.128	0.000	11.55	–0.146	0.012	145.20	0.215	0.000
	NC (cm)	9.72	–0.264	0.031	73.05	0.088	0.000	13.29	–0.424	0.039	119.72	0.163	0.000
BMI≥25.00 kgm⁻²	WC (cm)	15.92	–0.182	0.019	89.90	0.136	0.000	13.32	–0.150	0.013	125.61	0.181	0.000
	NC (cm)	16.14	–0.403	0.040	99.34	0.126	0.000	15.27	–0.445	0.045	98.94	0.133	0.000
BMI≥27.50 kgm⁻²	WC (cm)	14.10	–0.146	0.018	64.35	0.076	0.000	19.65	–0.204	0.021	97.54	0.148	0.000
	NC (cm)	25.71	–0.629	0.066	91.26	0.150	0.000	18.83	–0.506	0.064	62.54	0.081	0.000
BMI≥30.00 kgm⁻²	WC (cm)	12.43	–0.118	0.019	39.27	0.037	0.000	20.04	–0.193	0.027	53.23	0.074	0.000
	NC (cm)	22.05	–0.514	0.065	61.63	0.083	0.000	19.87	–0.504	0.087	33.99	0.043	0.000

*WC= Waist circumference; NC= Neck circumference; * Cox and Snell*

Receiver Operating Curve-Area under Curve (ROC-AUC) Analysis of adiposity measures

The comparison of ROC-AUC to ascertain the dependency and appropriateness of NC and WC as a screening measure of adiposity were tested against BMI cut-offs of BMI≥23.00 kgm⁻², BMI≥25.00 kgm⁻², BMI≥27.50 kgm⁻² and BMI≥30.00 kgm⁻² (Figure 2). The results showed that NC seems to have significantly (p<0.01) better predictive value in greater adiposity (BMI≥30.00 kgm⁻²) among both males (AUC 0.83) and females (AUC 0.88), but WC seems to have significantly (p<0.01) better association with lower adiposity (BMI≥23.00 kgm⁻²) among males (AUC 0.72) and females (AUC 0.78). The predictive values for BMI ≥25.00 kgm⁻² and ≥27.50 kgm⁻² were found to be significantly (p<0.01) greater in males (AUC 0.76and AUC 0.85) for NC. However, this association was observed to be significantly (p<0.01) lower in females (AUC 0.74and AUC 0.82) as compared to WC (AUC 0.79 and AUC 0.88) (Figure 2).

ROC-AUC analysis performed to ascertain the YI, optimal cut-offs along with the sensitivity, specificity values of the derived cut-offs and appropriateness of NC were described against excess different adiposity levels of BMI ≥23.00 kgm⁻², BMI ≥25.00 kgm⁻², BMI ≥27.50 kgm⁻² and ≥BMI 30.00 kgm⁻² (Table 3). The results indicated that BMI cut-off ≥25.00 kgm⁻² was observed to be 36.0 cm with the YI being 0.44 and 30.9 cm with the YI being 0.37 for males and females respectively. Similarly, the cut-off for BMI 30 kgm⁻² was 38.0 cm and 33.0 cm for males

TABLE 3. Receiver Operating Curve (ROC)- Area Under Curve (AUC) curve analysis for different adiposity risks assessed using BMI (kgm^{-2}) and neck circumference and suggested cut-offs of NC (cm) among the individuals.

Adiposity level	Sex	AUC	95% CI of AUC	p	Youden Index		Sensitivity (%)	Specificity (%)	Optimal cut-off
					Youden Index J	Associate cut-off			
BMI≥23.00 kgm^{-2}	Males	0.66	0.63-0.69	0.001	0.30	≤ 35.1	65.7	57.0	35.5
	Females	0.74	0.71-0.77	0.001	0.35	≤31.1	64.3	67.1	30.4
BMI≥25.00 kgm^{-2}	Males	0.76	0.73-0.78	0.001	0.44	≤ 35.1	73.9	59.9	36.0
	Females	0.74	0.71-0.77	0.001	0.37	≤31.2	66.3	65.5	30.9
BMI≥27.50 kgm^{-2}	Males	0.85	0.83-0.87	0.001	0.66	≤37.5	85.2	81.2	37.3
	Females	0.82	0.80-0.85	0.001	0.55	≤31.8	83.0	66.0	32.1
BMI≥30.00 kgm^{-2}	Males	0.83	0.81-0.86	0.001	0.67	≤37.5	86.3	77.5	38.0
	Females	0.88	0.85-0.90	0.001	0.67	≤31.8	86.8	70.3	33.0

CI= Confidence interval

and females respectively. The highest YI was observed to be 0.67 for both sexes. The cut-offs for ≥23.00 kgm^{-2} and ≥27.50 kgm^{-2} was estimated to be 35.5 cm with the YI being 0.30 and 37.3 cm with YI being 0.66 (in males) and 30.4 cm with the YI being 0.36 and 32.1 cm with the YI being 0.55 (in females), respectively.

DISCUSSION

The prevalence of health risks related to increasing BMI is continuous and the interpretations are generally graded to risk-factor of numerous preventable non-communicable diseases. There has been a growing debate on whether it is imperative to develop different population specific BMI cut-offs due to the increasing evidence of the mortality and morbidity variations and excess body fat distribution [22]. Several studies have confirmed that the proportion of "Asian people" with a high risk of type-II diabetes and cardiovascular disease are substantially greater at BMI levels lower than the existing cut-offs for overweight (≥25.00 kgm^{-2}) and obesity (≥30.00 kgm^{-2}) [22,24,25]. Therefore, a redefined the criteria of lower BMI for overweight (≥23.00 kgm^{-2}) and obesity (≥25.00 kgm^{-2}) among "Asian" populations associated with co-morbidities and health risk factors have been proposed [25]. The WHO Expert Consultation has advocated that as a large proportion of "Asian populations" exhibit high risks of type-II diabetes and cardiovascular diseases, the current BMI cut-off should be retained as the international classification and recommended for the purpose of public health action [24]. Therefore, BMI cut-offs of ≥23.00 kgm^{-2}, ≥27.50 kgm^{-2}, ≥32.50 kgm^{-2} and ≥37.50 kgm^{-2} could be considered and proposed by which countries could make decisions for redefining obesity for the purpose of taking public health action [24]. Comparisons show that Asian Indians have more total and abdominal body fat compared to their European counterparts with a similar BMI [22,23]. Several population specific cut-offs have been proposed to identify the obesity and metabolic disorders based on WC and BMI [24,25]. Therefore, these widely used conventional anthropometric measures pose serious ambiguity in general rationalization and acceptability of single cut-off owing to large population/ ethnic variations.

In the present study, an attempt has been made to identify the reliability and acceptability of NC as a valid parameter over the conventionally used anthropometric measures (e.g., BMI and WC) for adiposity assessment and to estimate the sex-specific cut-offs among adult Asian Indian population. Studies have suggested the use of NC in combination with anthropometric measures separates the effects of visceral and subcutaneous body fat-mass and excess adiposity distributions [5,8,10,12,15,20]. Results of the present study have indicated positive associations of NC with BMI and WC in both sexes ($p<0.01$). Several researchers have reported similar significant associations of NC with BMI and WC [2,3,4,5,8,20]. Results of the linear regression analysis showed that NC was the best predictor variables of BMI than WC (Figure 1). This was indicative of a strong association between NC and widely used conventional anthropometric measures of obesity (e.g., BMI and WC). Several studies have reported that NC could be a better anthropometric measurement in assessments of overweight and obesity [1,4,5,6,8,18,20]. Ben-Noun et al. [30], while comparing NC with BMI, found the accuracy of NC measurement to determine overweight and obesity to be 91.0%-95.0% for men and 97.0%-98.0% for women. The BLR analysis showed that NC has relatively better and acceptable predictive advantage over WC in the assessment of adiposity among adults (Table 2). Laakso et al. [12] reported that NC is good predictive measures for clinical screening of obesity related disorder. Similarly, Hingorjo et al. [4] reported that the NC is a useful, simple and easy-to-use anthropometric measures to define overweight and obesity comparison to

BMI and WC. Therefore, the NC could be used as an alternative indicator of adiposity assessment among adults.

The results of ROC-AUC analysis for cut-offs estimations showed that NC ≥36.0 cm and ≥30.9 cm (for overweight, BMI ≥25.00 kgm^{-2}) and 38.0 cm and 33.0 cm (for obesity, BMI ≥23.00 kgm^{-2}) could be utilized for males and females, respectively (Table 3). It has been shown that NC >37.0 cm (in males) and NC >34.0 cm (in females) is probably the best cut-offs points to determine subjects with central obesity [6]. Hingorjo et al. [4] has reported the cut-off values of overweight and obesity was >35.5 cm and >37.5 cm (in males) cm 32.0 cm and 33.5 cm (in females) respectively. A NC >37.0 cm and >39.5 cm (in males) and ≥34.0 cm and ≥36.5 cm (in females) was used in some studies to assess the adiposity of overweight and obesity respectively [18,30]. Lindarto et al. [38] reported that the best NC cut-off for males and females that indicated overweight/obesity were ≥37.0 cm and ≥33.5 cm among Indonesian, respectively. Aswathappa et al. [1] reported that NC of >36.0 cm in diabetics and >37.0 cm in non-diabetics were the best cut-off values to determine subjects with central obesity among Indian adults. The risk of central obesity is more in diabetics at lesser NC (>36.0 cm) compared to non-diabetics (>37.0 cm) individuals. Similarly, Yang et al. [6] have also reported an NC of >39.0 cm (in males) and >35.0 cm (in females) as the cut-offs observed to have best associations in individuals having metabolic syndrome. Onat et al. [5] reported similar cut-offs points of 39.0 cm (in males) and 35.0 cm and 35.5 cm respectively (in females) as corresponding to metabolic syndrome and obstructive sleep apnea [5]. Similar study reported that the optimal NC cut-off to determine metabolic syndrome were >38 cm (in men) and >34 cm (in women) [39]. Moreover, these cut-off levels require a more comprehensive evaluation for the assessment of overweight or obesity status to identify the possible related co-morbidities in populations.

Existing reviews suggest that NC has relatively greater selective advantages over widely used anthropometric adiposity measures (e.g., BMI and WC) due to their major operational research limitations [8,21,23]. Results of the present study showed that NC seems to have a better potential for determination of overweight and obesity and could be used as an inexpensive straightforward measure with less consumption of time both in clinical and epidemiological studies [5,29]. Furthermore, differently defined cut-offs for use of NC for assessing adiposity has been reported in different reported studies [2,4,6]. Such discrepancies with the results relating to cut-off estimations could be attributed to different diagnostic standards and/or population variations including this present study. However, a specific methodological issue that needs to be addressed here relates to the absence of any established guidelines to define the anatomical location of the measurement of NC. The measurement could be above the cricothyroid cartilage [34,40] or at the upper level of the margin of the thyroid cartilage [18] or just below the laryngeal prominence [26]. Hence, although the specific outcome of any population specific and clinical studies could be improved by using simple and appropriate anthropometric variables such as NC, larger studies are needed to validate the results [19].

CONCLUSION

The present study has described NC as a potential screening measure over conventionally used anthropometric measures (e.g., BMI or WC) that have good inter-reliability, acceptability and could be used as screen the excess adiposity. Furthermore, NC could be very useful for assessment of total and regional adiposity and related manifestation in clinical and co-mobidity related studies owing to the population specific cut-offs related issues over conventionally used anthropometric measures (e.g., BMI and WC). It has shown a strong positive association with the excess adiposity and reasonable to consider as an independent practical screening measure of assessment of adiposity in large scale population studies. The proposed cut-offs were found to be similar to other reported cut-offs and would be helpful to identify the magnitude of overweight and obesity among both Asian Indian adults and non-Asian populations as well. Although, there is a paucity of the population specific cut-offs for NC to classify overweight and obesity in adults. Further studies should be undertaken to determine and validate the existing and/or newly proposed cut-offs among larger samples for pan-Indian cut-offs for assessment of overweight and obesity and related risks of non-communicable diseases and metabolic disorders using NC.

Acknowledgement

The authors acknowledged the help and cooperation of local and village level authorities, participants and Department of Anthropology, Assam University.

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