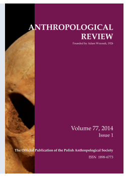
Anthropological Review • Vol. 79(3), 347–365 (2016)

DE GRUYTER OPEN

ANTHROPOLOGICAL REVIEW
Available online at: https://doi.org/10.1515/anre-2016-0025



Neck circumference as a screening measure of overweight/obesity among Indian adults

Nitish Mondal[1], Jaydip Sen[2], Kaushik Bose[3,4], Ruplin Timungpi[1], Moniram Kathar[1], Sarlongki Hanse[1]

[1]Department of Anthropology, Assam University, Diphu Campus, Diphu, District: Karbi Anglong 782460, Assam, India
[2]Department of Anthropology, University of North Bengal, P.O.: NBU, District: Darjeeling, 734013, West Bengal, India
[3]Department of Anthropology, Vidyasagar University, Medinipur 721102, West Bengal, India
[4]Unit of Anthropology, Polish Academy of Sciences, Wrocław, Poland

ABSTRACT: Neck circumference (NC) is an anthropometric measurement of differentiating body fat distributions and a marker of upper subcutaneous adiposity. The present study highlights the association and importance of NC as a suitable proxy screening measure of overweight/obesity as compared to the conventional anthropometric variables used among Indian adults. The present community based cross-sectional study was undertaken among 1169 Karbi adults (males: 625; females: 544) residing in Karbi Anglong district of Assam, Northeast India, who were selected through a multistage stratified random sampling method. Height, weight, waist circumference (WC), hip circumference (HC) and NC were recorded using standard procedures. The body mass index (BMI) was calculated and prevalence of overweight/obesity was assessed using standard cut-offs. The prevalence of obesity using BMI (≥25.00 kg m^{-2}) was 15.52% and 15.26% among males and females, respectively ($p \geq 0.05$).The prevalence of obesity using NC was observed to be significantly higher among males (48.80%) than females (19.12%) ($p<0.01$). The binary logistic regression analysis showed that NC predicted obesity over the conventional anthropometric variables with reasonable accuracy ($p<0.01$). The ROC-AUC analysis showed a relatively greater significant association between BMI, WC and HC and NC for obesity ($p<0.01$). Thus, NC appears to be a potentially simple, easy-to-use screening measure for predicting obesity among adults. Further studies are required to validate its use for screening of obesity among other ethnic populations in India.

KEY WORDS: Neck circumference; Body Mass Index; Overweight; Obesity; Waist circumference; Northeast India; Anthropometry; Public Health

Introduction

Obesity or the accumulation of excess body adiposity is considered to be a complex disease of the diverse etiology (Binks 2016) and is a result of a complex combination of an "obesogenic environment" (Mendes et al. 2013). This complex envi-

Original Article Received: December 2, 2015; Accepted for publication: June 15, 2016
DOI: 10.1515/anre- 2016-0025

ronment consists of genetic (Sitek et al. 2014; Rosset et al. 2016), socio-economic (Chung et al. 2016; Kowalkowska et al. 2016), nutritional (Gurnani et al. 2015; Binks 2016) and psychological (Czegledi 2016; Kelley et al. 2016) factors. Obesity is becoming a major public health issue in both the developed and developing countries as it contributes to numerable preventable, non-communicable diseases and related mortalities and morbidities (Huxley et al. 2010; Misra and Khurana 2011; WHO 2011; Akin and Nienaber 2015). Its prevalence is considered to be one of the most blatantly visible, yet most neglected public health problem that requires urgent interventions (WHO 2013). Recent studies have reported that global obesity trends and its related problems are one of the major health issues among adults in both the developed and developing countries (Popkin and Slining 2013; Morgen and Sørensen 2014). Although, there are several technologically advanced methods to assess total and regional body adiposity (Wells 2010; Sen and Mondal 2012; Al-Bachir and Ahhmad, 2016), anthropometric measurements and indices are more widely used in population studies on overweight/obesity. Their main advantages are their safe use, non-invasive, inexpensive and easy applicability. These anthropometric measures play significant roles in clinical and public health screening and surveillance of with respect to overweight/obesity (WHO, 2000; Dudeja et al. 2001; Das and Bose 2006; Sarkar et al. 2009; Misra and Khurana, 2011; Huxley et al. 2011; Sen et al. 2013; Mondal and Sen 2014; Rengma et al. 2015).

One of the most widely utilized index is the body mass index (BMI). It is used to describe greater adiposity as compared to excess body weight relative to height, although it does not depict regional body adiposity distribution (Wells 2010; Sen and Mondal 2013; Mondal and Sen 2014). There is a large amount of scientific literature on the assessment of overweight and obesity among adult using this anthropometric index and here the recent studies of Das and Bose (2006), Sarkar et al. (2009), Chopra et al. (2013), Sen et al. (2013), Shafaghi et al (2014), Anuradha et al. (2015), Rengma et al. (2015) and Kowalkowska et al. (2016) are mentionable. It is now an established fact that a BMI value of $\geq$25.00 kg m^{-2} is a major risk factor for a wide range of metabolic diseases such as cardio-vascular diseases (Mandviwala et al. 2016), hypertension (Kelly et al. 2015), type II diabetes (Bhowmik et al. 2014) and certain types of cancers (Argolo et al. 2015). Studies have also suggested that waist circumference (WC) along with waist-hip ratio (WHR) and to a lesser extent waist-height ratio (WC/height), can also be utilized to accurately describe body fat distributions and subsequent morbidity and mortality among adults (Onat et al. 2009; Huxley et al. 2010; WHO, 2011; Chakraborty et al. 2011; Feng et al. 2012; Mondal and Sen 2014; Cheong et al. 2014). It has been opined that an individual is generally defined to be healthy by measuring his/her WC and/or WHR (Onat et al. 2009; Huxley et al. 2011; WHO 2011). The prevalence of high mortality and morbidity was observed to be greater at lower BMI values and smaller WC values among Asian populations (WHO Expert Consultation 2004; Pan and Yeh 2008; Low et al. 2009; Huxley et al. 2011; WHO 2011; Misra and Khurana 2011). Several studies have reported that the proposed cut-offs may be needed to be lowered for different ethnic populations of Asia (WHO Expert Consultation 2004; Low et al. 2009; WHO 2011).

Neck circumference (NC) is a relatively new potential proxy anthropometric measurement that can be utilized to differentiate between normal and excess body fat distribution and considered to be a marker of upper body subcutaneous adipose tissue distribution (Ben-Noun and Laor 2003, 2006; Onat et al. 2009; Yang et al. 2010; Hingorjo et al. 2012; Aswathappa et al. 2013; Özkaya and Tunçkale 2016). Studies have reported significant associations between NC and the conventional anthropometric variables (such as BMI, WC and WHR) during the assessment of obesity and metabolic disorders among adults (Ben-Noun and Laor 2006; Onat et al. 2009; Hingorjo et al. 2012; Adamu et al. 2013; Aswathappa et al. 2014; Özkaya and Tunçkale 2016). Studies have further observed that higher NC values were associated with increased risk of type-2 diabetes and hypertension (Noun and Laor 2003; Yang et al. 2010; Aswathappa et al. 2013), cardiovascular diseases (Sjöström et al. 1997; Ben-Noun and Laor 2006; Fink et al. 2006) and metabolic disorders (Sjöström et al. 1997; Ben-Noun and Laor 2006; Onat et al. 2009; Yang et al. 2010; Stabe et al. 2013; Wang et al. 2015). Studies have reported significant associations between NC and conventional anthropometric variables (such as BMI, WC and WHR) during the assessment of obesity and metabolic disorders among adults (Ben-Noun and Laor 2006; Onat et al. 2009; Hingorjo et al. 2012; Adamu et al. 2013; Aswathappa et al. 2013, 2014; Stabe et al. 2013; Assyov et al. 2016).

The advantages of NC are its simplicity and low cost. It also provides very good inter- and intra- observer reliability and requires minimum effort from the observer and the subject (LaBerge et al. 2009). Therefore, NC could be potentially used as a quick and easy-to-apply anthropometric screening tool in large-scale population investigations over conventionally used anthropometric variables to assess overweight/obesity. However, such population-based studies on the relation between NC and obesity are still lacking for adult populations especially among Asian and Indian populations. The objectives of the present study were two-fold. The first was to assess the prevalence of excess adiposity using conventional anthropometric variables along with NC among an Indian adult population. The second was to assess the relation and reliability of NC as a screening measure of overweight/obesity as compared to the routinely used conventional anthropometric adiposity variables of excess adiposity in the population under study.

Materials and Methods

Study area and subjects

India consists of a large number of ethnic and indigenous elements having enormous amounts of ethnic and genetic diversity (Indian Genome Variation Consortium 2008). It is a vast country with varied geographical conditions where body composition varies with race, sex and geographical locations. With a population of more than 1.22 billion, the Indian population consists of 4693 communities with several thousand endogamous groups. The present community based cross-sectional study has been carried out among 1169 adults (males: 625; females: 544) belonging to the indigenous tribal Karbi population of Karbi

Anglong, Assam, Northeast India. Ethnically, the Karbi is an endogamous Mongoloid tribal population belonging to the Tibeto-Burman linguistic family group and occupying the districts of Karbi Anglong, Dima Hasao, Kamrup, Marigaon, Nagaon, Golaghat, Karimganj, Lakhimpur and Sonitpur in the state of Assam and the states of Arunachal Pradesh, Meghalaya and Nagaland, all located in the North-eastern region of India. However, they are mostly concentrated in the district of Karbi Anglong (25°33′ N to 26°35′ N latitude and 92°10′ E to 93°50′ E longitude). This district is the largest among the 32 districts of the state of Assam and covers an area of 10,434 sq km. According the National Census of 2011, the district had a population of 9,56,313 individuals (males: 4,90,167; females: 4,66,146) with an average literacy rate of 69.25% (males: 76,14%; females: 62.00%). The sizable number and widespread distribution of the Karbi population were the two sole criteria for selecting this population for the present study. A total of 14 Karbi dominated villages were covered in the course of this study. These villages were situated ~15–20 km from of the town of Diphu, the district headquarters of Karbi Anglong.

The participants were selected using a multi-stage stratified sampling method. In the first stage, households of those individuals belonging to the Karbi population were identified based on their surnames and physical characters. The data were subsequently verified from the governmental records. In the second stage, purposive random sampling was utilized to select the individuals to be included in the study. A total of 1290 adult Karbi individuals in the age group of 20–49 years (males: 690; females: 600) were approached to participate in the study. All the subjects were apparently healthy and devoid of any physical deformity. They had no previous histories related to medical and surgical episodes and were not suffering from any diseases during the time of data collection. The individuals with enlargement of the thyroid gland, goitre and neck deformity and those exhibiting any abnormality were excluded from the study. Pregnant, post-partum and lactating women were also excluded. These exclusions were done so as to avoid selection bias. Age of the individuals was recorded from the birth certificates, voter identity cards and other official documents issued by the Government. The objectives of the study were explained to them in a simple, yet in a detailed manner. Finally, 1169 of them (males: 625; females: 544) voluntarily agreed to participate in the study. The overall participation rate was 90.62%. The data was recorded from the concerned household of the subjects. An informed consent was obtained from each participant. Consents were also obtained from the local village level authorities and headmen prior to the collection of data. The necessary clearances were obtained prior to the commencement of the study, which was conducted in accordance with the ethical guidelines for human experimental research as laid down in the Helsinki Declaration (Touitou et al. 2004). The study was conducted during the period from August 2012 to May 2013.

Anthropometric measurements recorded

The anthropometric measurements were recorded following the standard procedures of Hall et al. (2007). Weight was recorded with the subject standing motionless on a portable digital weighing machine (Libra®, Edryl-India, Tiswadi, Goa) to the nearest 0.10 kg. The measurement was taken wearing minimum clothing without any footwear. Height was measured using an anthropometer rod (GPM type, Galaxy Informatics, New Delhi) to the nearest 0.10 cm with the subject standing in erect position on a flat surface and the head oriented in the Frankfort horizontal plane. The WC was measured midway between the iliac crest and lower margin of the ribs with the subject remaining in the standing position. Hip circumference (HC) was measured at the maximum elevation of buttocks wearing minimum clothes (WHO 2011). The NC was measured as the minimum distance around the neck with the neck held in a vertical position with the eye facing forward. It was measured with the help of a non-stretchable Gullick tape to the nearest 0.10 cm. This measurement was carefully recorded by identifying the uppermost level of the margin of the thyroid cartilage (Adam's apple) (Fink 2012). Care was taken not to involve the shoulder and neck muscles (Trapezius) during recording the measurement. The instruments were regularly checked for their accuracy in measurements so as to reduce errors during the collection of the measurements.

The technical error of measurement (TEM) was calculated to check the consistency and reliability of the intra-observer and inter-observer measurements in connection with the anthropometric measurements following the method of Ulijaszek and Kerr (1999). This particular method involves the calculation of observer differences and the subsequent determination of the coefficient of reliability (R). The value of 'R' value has a range from 0 (not reliable) to 1 (complete reliability). The formula for calculating TEM is as follows:

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

The formula for calculating R is as follows:

$R = \{1 - (TEM)^2/SD^2\}$, SD being the standard deviation of all the measurements.

For analysis of TEM, a total 50 adult Karbi individual aged 20–49 years were selected from the town of Diphu using simple random sampling. Their height, WC, HC and NC were measured by three of the authors (RT, MK and SH). The values of 'R' were subsequently determined from TEM. Very high values of 'R' (>0.975) were obtained for all four anthropometric measurements. As these values were appreciably higher than the cut-off value of 0.95 as suggested by Uljaszek and Kerr (1999), the measurements recorded by these three authors were considered to be reliable, reproducible and free from any observer bias. Subsequently, all the measurements for the present study were recorded by them. Measurements for the present study involved two consecutive readings for height, WC, HC and NC for each subject, and the means being noted.

Assessment of adiposity

The BMI was calculated using the following standard equation of WHO (2000):

$BMI = Weight/Height^2 \ kg \ m^{-2}$.

The population-specific proposed lower cut-offs for Asian populations were used to determine overweight and obesity because of greater variability in adiposity-related morbidities in lower BMI among Asian adults (WHO Expert Consultation 2004; Low et al. 2009;

WHO 2011). The prevalence of obesity (BMI $\geq$25.00 kg m^{-2}) was assessed using the proposed cut-offs for Asia-Pacific populations (WHO 2000). A WC value of $\geq$90.0 cm and ≥80.0 cm, as recommended by WHO (2010), was used to define regional obesity among the males and females respectively. Using WHR (WC/HC) obesity was defined as ≥0.90 cm for males and ≥0.80 cm for females (Deurenberg-Yap et al. 2001; Obesity in Asia Colloboration 2007). The value of ≥0.50 as proposed by Hsieh and Muto (2004) for WC/height was also used to define adiposity. The NC cut-offs points of ≥36.0 cm (males) and ≥32.0 cm (females) was used to assess overweight/ obesity, as proposed by Aswathappa et al. (2014).

Statistical analysis

The data were statistically analysed using the Statistical Package for Social Science (SPSS version, 17.0). A p value of <0.05 was considered to be statistically significant, while $p\geq0.05$ was considered to be statistically not significant. Normality was tested using the Shapiro-Wilk test for each of the anthropometric variables. Independent sample t-test was done to assess mean differences with respect to the anthropometric variables between sexes. Pearson correlation coefficient (r) analysis was done to study the relationship between the variables. Chi-square analysis was performed to assess sex-differences in the prevalence of excess adiposity. A binary logistic regression (BLR) analysis was employed to derive the 'likelihood ratio' and 'R-square statistics' so as to identify the better predictor model for estimation of obesity (BMI ≥25.00 kg m^{-2}) using the conventional anthropometric variables of adiposity. The BLR provides a probability of obesity assessment based on the maximum likelihood approach. Logistic regression models were derived as; y = β 1 X x1 + β 2 X x2 + … + β n X xn + b. The values of 'β_1' through 'β_n' where the β coefficients for each variable, 'x_1' through 'x_n' denoted the different variables, and 'b' was the constant. The likelihood ratio of model summary statistic measured how poorly the model predicted the decisions, where the smaller the statistic was considered to be the better predictor of the model. A receiver-operating characteristic (ROC) curve was plotted for determination of the efficacy of the screening variables for correctly identifying individuals on the basis of their classification by the reference test. The ROC curve is a plot of the true positive rate (sensitivity) against the false positive rate (1-specificity). In the present study, the specificity and sensitivity were calculated to test the predictive accuracy and reliability of anthropometric variables for obesity using BMI (≥25.00 kg m^{-2}). Similarly, the ROC curve was also performed for estimation of a positive rate against the false positive rate for conventional anthropometric against the overweight/obese category as determined using NC. Those classified as overweight were coded as 1 and normal coded as 0 against the predictor variables. The 95% Confidence Intervals (CIs) of the area under the normalized ROC (AUC-ROC) curve was also calculated to ascertain the best surrogate anthropometric measurements with BMI and NC against the conventional anthropometric variables. The values of the AUC curve analysis could be between '0' and '1'. A value of '0' indicates that the screening measure did not perform well, whereas the value of '1' denotes a perfect performance. The AUC value of 0.50 mean the diagnostic test is not better than by chance, hence, values >0.50 were more desirable.

Results

The age and sex-specific range and descriptive statistics of anthropometric variables are presented in Table 1. The overall mean age was observed to be higher among males (29.45±7.94 years) than females (25.63 ±7.36 years) ($p<0.01$). The mean values of weight, height, NC, WC and WHR were observed to be significantly higher among males than females ($p<0.01$), whereas the mean values of WC/ height were higher among females ($p<0.01$). The mean values HC were slightly higher in females than males, but the difference was not statistically significant ($p>0.05$). The mean BMI value was slightly higher, but statistically not significant among males (22.33± 3.37 kg m^{-2}) than females (22.03± 3.31 kg m^{-2}) ($p>0.05$). The Shapiro-Wilk test for normality was not statistically significant ($p>0.05$) for each of the anthropometric variables. Using the independent-sample t-test analysis, the sex-specific mean differences were observed to be statistically significant with respect to age, height, weight, NC, WC, WHR, and WC/height ratio ($p<0.01$), but not in the case of HC, and BMI ($p>0.05$) (Table 1). Among males, the age-specific mean differences were observed to be statistically significant with respect to age, height, WC, HC, WHR and WC/height ($p<0.01$). In case of females, the age-specific mean differences were observed to be statistically significant with respect to age, WC, WC/height ($p<0.01$) and HC ($p<0.05$) (Table 1).

Pearson's correlation analysis was done to find out the association between anthropometric variables with BMI and NC among males and females (Table 2). The correlation coefficient analysis showed a positive, statistically significant ($p<0.01$) correlation of weight with BMI and NC among males (r= 0.870 and r= 0.567) and females (r= 0.905 and r= 0.668), with the correlation coefficient also found significant between height and NC in males (r= 0.254) and females (r= 0.285) ($p<0.01$). The results showed a positive, statistically significant (p<0.01) correlations of BMI with NC (r= 0.498), WC (r= 0.421), HC (r= 0.393) WHR (r= 0.144) and WC/height (r= 0.433) among male individuals. The correlation coefficient was also statistically significant ($p<0.01$) between NC and WC (r = 0.578), NC and HC (r= 0.562), NC and WHR (r = 0.157) and NC and WC/height (r = 0.451). The results of Pearson's correlation analysis, among female individuals also showed significant positive correlations ($p<0.01$) of BMI with NC (r= 0.587), WC (r= 0.687), HC (r= 0.644), WHR (r= 0.399) and WC/height (r= 0.705). The correlation coefficient was also statistically significant ($p<0.01$) between NC and WC (r= 0.569), NC and HC (r= 0.574), NC and WHR (r= 0.285) and NC and WC/ height (r= 0.502) (Table 2).

Assessment of central and regional adiposity

The prevalence of excess adiposity among the Karbi individuals is presented in Table 3. The prevalence of obesity using BMI (≥25.00 kg m^{-2}) was 15.52% and 15.26% among males and females, respectively (p≥0.05). Using WC, the prevalence of excess regional/central adiposity was significantly greater among females than males (24.82% vs. 4.32%, p<0.01). In

Table 1. Descriptive statistics (mean± SD), range of age and anthropometric variables/indices among the Karbi individuals

Anthropometric variables/ indices	Males (N=625)						Females (N=544)						Sex difference (t-test)
	20–29 year	30–39 years	40–49 years	Overall	Range	F-value	20–29 year	30–39 years	40–49 years	Overall	Range	F-value	
Age (years)	23.65 ±2.71	33.94 ±2.87	43.84 ±3.21	29.45 ±7.94	20.0–49.0	2140.70**	22.34 ±2.79	33.29 ±3.00	44.40 ±3.95	25.63 ±7.36	20.00–49.00	1441.36**	25.77**
Weight (kg)	57.94 ±9.90	57.22 ±8.66	58. 19 ±11.52	57.77 ±9.81	40.00–92.00	0.43	49.34 ±7.32	50.86 ±10.07	51.29 ±11.70	49.70 ±8. 19	40.00–87.00	2.01	15.13**
Height (cm)	161.70 ±6.85	159.64 ±6.57	159.24 ±5.58	160.75 ±6.68	138.50–183.00	8.64**	150.16 ±5.01	149.98 ±6.04	150.37 ±4.70	150.15 ±5.12	140. 20–164.50	0.08	30.09**
Neck circumference (NC) (cm)	35.88 ±2.50	36.16 ±3.02	35.75 ±3.46	35.94 ±2.81	29.50–46.60	0.85	29.73 ±2.26	30.07 ±3.06	30.43 ±2.82	29.84 ±2.44	21.50–39.00	2.12	39.36**
Waist circumference (WC) (cm)	75.44 ±5.35	77.29 ±6.92	79.21 ±10.12	76.52 ±6.82	57.50–108.00	13.11**	73.45 ±9.38	76.39 ±11.48	77.31 ±13.68	74.16 ±10.17	54.80–104.80	5.03**	4.23**
Hip circumference (HC) (cm)	85.64 ±5. 19	86.61 ±7.55	88.37 ±8. 19	86.32 ±6.49	60.00–119.00	6.78**	86.59 ±7.96	88.71 ±9.36	88.76 ±9.71	87.05 ±8.34	65.10–115.80	3.07*	−1.80
Waist/ Hip circumference Ratio (WHR)	0.88 ±0.05	0.89 ±0.04	0.89 ±0.05	0.89 ±0.05	0.58–1.28	5.29**	0.85 ±0.06	0.86 ±0.07	0.87 ±0.08	0.85 ±0.06	0.65–0.99	2.63	9.78**
Waist circumference/ Height Ratio (WC/ height)	0.47 ±0.03	0.48 ±0.05	0.49 ±0.06	0.48 ±0.04	0.35–0.67	23.83**	0.49 ±0.06	0.51 ±0.07	0.52 ±0.09	0.49 ±0.07	0.35–0.77	4.87**	−5.59**
Body Mass Index (BMI) (kg/m^2)	22.13 ±3.29	22.46 ±3.17	22.87 ±3.95	22.33 ±3.37	17.52–32.21	1.96	21.88 ±3.07	22.55 ±3.79	22.59 ±4.44	22.03 ±3.31	17.26–35.52	1.95	1.54

**p*<0.05, ***p*<0.01, ±SD= stanadard deviation

Table 2. Pearson correlation analysis between anthropometric variables/indices among the Karbi individuals

Anthropometric variables/indices	Males (N=625)		Females (N=544)	
	Body mass index (BMI)	Neck circumference (NC)	Body mass index (BMI)	Neck circumference (NC)
Weight	0.870*	0.567*	0.905*	0.668*
Height	–0.058	0.254*	–0.051	0.285*
Neck circumference (NC)	0.498*	–	0.587*	–
Hip circumference (HC)	0.393*	0.562*	0.644*	0.574*
Waist circumference (WC)	0.421*	0.578*	0.687*	0.569*
Waist/ Hip circumference Ratio (WHR)	0.144*	0.157*	0.399*	0.285*
Waist circumference/Height Ratio (WC/Height)	0.433*	0.451*	0.705*	0.502*
Body Mass Index (BMI)	–	0.498*	–	0.587*

*$p<0.01$ (Two-tailed Correlation analysis)

Table 3. Prevalence of excess adiposity assessed using the conventional anthropometric variables/ indices among the Karbi individuals

Anthropometric variable/indices	Prevalence of excess adiposity		Sex difference (χ^2-value)
	Males (N=625)	Females (N=544)	
Body Mass Index (BMI): obesity	97 (15.52)	83 (15.26)	0.01
Waist circumference (WC): central obesity	27 (4.32)	135 (24.82)	77.10*
Waist/ Hip circumference ratio (WHR): central obesity	270 (43. 20)	423 (77.76)	36.66*
Waist / Height ratio (WC/ height): central obesity	138 (22.08)	229 (42.10)	28.11*
Neck circumference (NC): overweight/obesity	305 (48.80)	104 (19.12)	55.78*

*$p<0.01$, Values in parenthesis indicates percentage

WHR and WC/height description the rate of obesity of women (77.76% and 42.10%) was assigned to men (43. 20% and 22.08%) and conversely ($p<0.01$). Using NC, the prevalence of obesity was observed to be significantly higher among the male (48.80%) as compared to the female (19.12%) individuals ($p<0.01$).

Binary logistic regression analysis of the anthropometric variables against obesity

A BLR analysis was employed to derive the 'likelihood ratio' and 'R-square statistics' to identify the better predictor model for the estimation of obesity (BMI ≥25.00 kg m^{-2}) using the anthropometric variables of adiposity among the individuals (Table 4). Among male individuals, NC appeared to be a better predictor in terms of likelihood of obesity followed by WC ($p<0.01$). The better model predictive values were observed to be in WC/ height ratio followed by WC among female individuals ($p<0.01$). A relative predictability was shown by NC to assess obesity in comparison to the other conventional anthropometric variables among females using the BLR analysis ($p<0.01$). An acceptable accuracy for the prediction of obesity was also observed

Table 4. Binary logistic regression analysis to predict the anthropometric variables/ indices of obesity assessed using BMI (≥25.00 $kgm^{-2\dagger}$) among the Karbi individuals

Sex	Anthropometric variables/ indices	B	Constant	Wald	P	Likelihood statistics	Cox and Snell R^2 statistics	Nagelkerke R^2 statistics
Males (N=625)	Neck circumference (NC) (cm)	0.389	–15.98	61.12	0.000	453.58	0.128	0.222
	Waist circumference (WC) (cm)	0.130	–11.83	54.16	0.000	470.86	0.104	0.180
	Hip circumference (HC) (cm)	0.131	–13.22	42.98	0.000	482.89	0.087	0.150
	Waist/Hip circumference ratio (WHR)	8.733	–9.49	11.85	0.000	526.30	0.021	0.036
	Waist circumference/Height ratio (WC/height)	19.168	–11.03	53.55	0.000	473.35	0.100	0.174
Females (N=544)	Neck circumference (NC) (cm)	0.503	–17.15	65.41	0.000	374.38	0.153	0.266
	Waist circumference (WC) (cm)	0.144	–13.02	87.86	0.000	333. 19	0.215	0.374
	Hip circumference (HC) (cm)	0.175	–17.59	87.67	0.000	337.55	0. 208	0.363
	Waist/Hip circumference ratio (WHR)	13.564	–13.48	44.45	0.000	423.15	0.074	0.128
	Waist circumference/Height ratio (WC/height)	23.589	–14.03	90.02	0.000	322.63	0.230	0.400

† WHO, 2000 cut-off

for variables of HC and WHR among both sexes based on the BLR analysis ($p<0.01$).

ROC-AUC analysis of the anthropometric variables against BMI

The results of the ROC-AUC analysis to ascertain dependency and appropriateness of the anthropometric variables plotted against obesity (BMI ≥ 25.00 kg m^{-2}) is shown in Table 5. The results indicated that the best predictor of obesity (according to the criterion of BMI ≥ 25.00 kg m^{-2}) in men is NC (AUC 0.76, 95%CI 0.69–0.82), and in women WC/height (0.84, 95%CI 0.78–0.89). In both sexes HC (AUC 0.83 in females and AUC 0.69 in males) and WC (AUC 0.82 in females and AUC 0.69 in males) were also very good predictors of obesity ($p<0.01$). A slightly weaker surrogate of obesity in both sexes was WHR (AUC 0.71 in women and AUC 0.65 on men) ($p<0.01$). The comparison of AUC-ROC analysis of the NC, WC and HC as surrogate variables

Table 5. Receiver operating curve−Area under curve analysis (ROC-AUC) of anthropometric variables/ indices plotted against BMI (≥25.00 $kg/m^{2\dagger}$) among the Karbi individuals

Anthropometric variables/indices	Males	Females
Neck circumference (NC) (cm)	0.755* (0.69–0.82)	0.787* (0.73–0.85)
Waist circumference (WC) (cm)	0.689* (0.62–0.76)	0.823* (0.77–0.88)
Hip circumference (HC) (cm)	0.691* (0.62–0.76)	0.832* (0.77–0.89)
Waist/Hip circumference ratio (WHR)	0.654* (0.59–0.72)	0.713* (0.65–0.78)
Waist circumference/Height ratio (WC/height)	0.637* (0.57–0.71)	0.838* (0.78–0.89)

*$p<0.01$, Values in parentheses indicates 95% confidence interval of ROC-AUC
†WHO, 2000 cut-offs

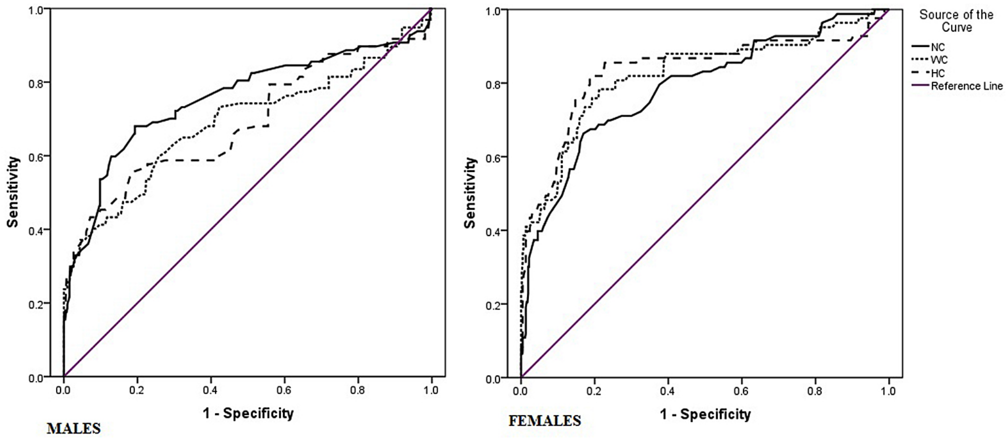


Fig. 1. Receiver operating curve analysis characteristics related to obesity (BMI ≥25.00 kg m^{-2}) with NC, WC and HC

of excess adiposity against BMI (BMI ≥ 25.00 kg m^{-2}) among males and the females is displayed separately in Figure 1.

ROC-AUC analysis of the anthropometric variables against NC

The results of the ROC-AUC analysis showing dependency and the appropriateness of the anthropometric variables for assessment of overweight/obesity plotted against NC in both sexes are shown in Table 6. The prevalence of overweight/obesity was classified using the proposed cut-offs for NC among Indian populations by Aswathappa et al. (2014). The NC has been tested as an alternative measure of excess adiposity and results showed that the BMI and HC showed the best surrogate variables of overweight/obesity among males and females individual ($p<0.01$). Similarly, a significant ($p<0.001$) greater association was observed with BMI among

Table 6. Receiver operating curve-Area under curve analysis (ROC-AUC) of the anthropometric variables/indices plotted against neck circumference among the Karbi individuals

Anthropometric variables indices	Overweight/Obesity	
	Males (≥36 cm)†	Females (≥32 cm)†
Body Mass Index (BMI) (kg/m²)	0.7 20* (0.68–0.76)	0.830* (0.78–0.88)
Waist circumference (WC) (cm)	0.714* (0.67–0.75)	0.761* (0.71–0.82)
Hip circumference (HC) (cm)	0.7 19* (0.68–0.76)	0.775* (0.73–0.83)
Waist/Hip circumference ratio (WHR)	0.560* (0.52–0.61)	0.660* (0.60–0.72)
Waist circumference/Height ratio (WC/height)	0.624* (0.58–0.67)	0.747* (0.69–0.80)

*$p<0.01$, Values in parentheses indicate 95% confidence interval of ROC-AUC
† Cut-offs as proposed by Aswathappa et al. (2014)

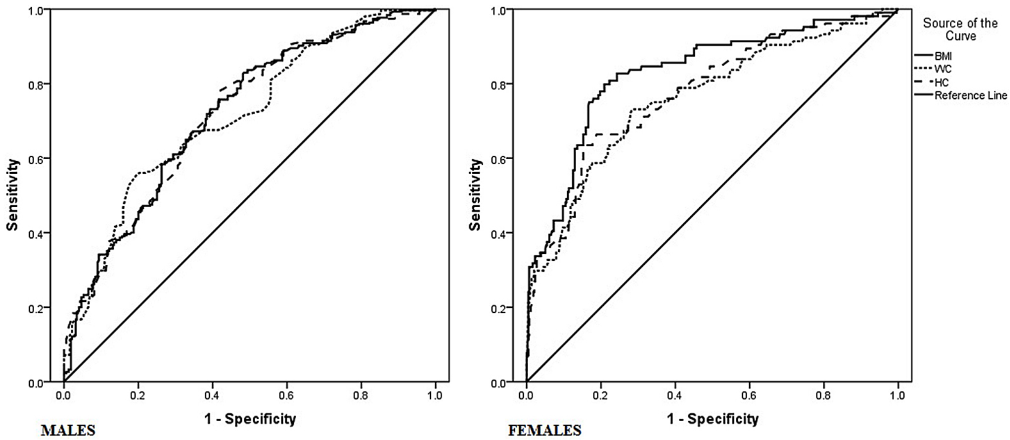


Fig. 2. Receiver operating curve analysis characteristics related to overweight/obesity assessed using NC (≥36.0 cm/≥32.0 cm) with BMI, WC and HC

males (AUC 0.72, 95%CI 0.68–0.76) and females (AUC 0.83, 95%CI 0.78–0.88). The HC showed greater association with NC among males (AUC 0.72, 95%CI 0.68–0.76) and females (AUC 0.78, 95%CI 0.73–0.83) ($p<0.01$). Similarly, WC showed a significant ($p<0.001$) association with obesity among males (AUC 0.71, 95%CI 0.67–0.75) and females (AUC 0.76, 95%CI 0.71–0.82) (p<0.05). A comparative AUC-ROC analysis of BMI, WC and HC as surrogate variables of overweight/obesity (≥36.0 cm/≥32.0 cm) against NC among male and female individuals is presented separately in Figure 2.

Discussion

In this study, the population-specific proposed lower cut-offs for Asian populations were used to determine the overweight and obesity because of the greater variability in adiposity-related morbidities in lower BMI among Asian adults (WHO Expert Consultation 2004; Low et al. 2009; WHO 2011; Misra and Khurana 2011). An ideal measure of obesity would be an index that reflects the degree of adiposity, in a unified way across the sex/gender, age and populations and is associated with adverse health risks. However, such a measure does not exist in practical situations. The conventional anthropometric variables (such as BMI, WC, WHR and WC/height) are widely recommended and used for the assessment of obesity due to their potential independent associations with major metabolic disorders and obesity related mortalities and morbidities in adults (Dudeja et al. 2001; Das and Bose 2006; Deepa et al. 2009; Low et al. 2009; Onat et al. 2009; WHO 2011). Current knowledge argues against using unified BMI cut-offs to define overweight/obesity in various ethnic groups, especially in Asian origin ethnic groups or populations (WHO Expert Consultation 2004; WHO 2011; Misra and Khurana 2011). However, it is not clear where to draw the demarcation, because the relationship between excess adiposity, metabolic disorders and several other non-communicable diseases are on a continuum that varies in degree among different ethnic populations.

Therefore, the population-specific relative risks in pre-disposition to regional/central adiposity, thereby increased risks of developing metabolic disorders in different ethnic populations (such as Asian Indian) are very crucial owing to greater variations of body-adiposity and/or BMI (WHO Expert Consultation 2004; Pan and Yeh 2008; Low et al. 2009; WHO, 2011; Misra and Khurana 2011).

Several population-specific studies have suggested using population specific cut-off points due to higher levels of body fat percentages and abdominal adipose tissues among the Asian populations. Therefore, the present study has used the newly proposed BMI cut-off points for the adult Asian populations so as to determine obesity (BMI $\geq$25.00 kg m^{-2}) (WHO 2000; WHO expert consultation 2004). Studies investigating the body composition and its association with health outcomes in Asian populations have analysed and reported greater body adiposity percentages in Asians at a lower BMI, as well as an increased prevalence of regional adiposity as compared to Europeans population (Pan and Yeh 2008; Low et al. 2009; WHO 2011; Misra and Khurana 2011). The Asian populations also appear to have increased metabolic disorder risks at lower regional adiposity (e.g. WC and WHR) than their European counterparts at lower BMI levels (WHO Expert Consultation 2004; Pan and Yeh 2008; Low et al. 2009; Misra and Khurana 2011; Mondal and Sen 2014). Therefore, there is an urgent need for appropriate proxy anthropometric variables (such as NC) over the conventionally used ones for the assessment of population-specific risks of overweight/obesity owing to the greater population diversity. Several studies have recently tried to introduce the use of NC as a simple screening measure of overweight/obesity and its associations with increased metabolic disorder risks in adults (Ben-Noun et al. 2001; Ben-Noun and Laor 2006; Onat et al. 2009; Hingorjo et al. 2012; Aswathappa et al. 2013, 2014; Stabe et al. 2013; Wang et al. 2015; Özkaya and Tunçkale, 2016).

The present study showed an existence of strong associations between NC and conventional anthropometric variables for obesity (such as BMI, WC, HC and WHR) among adults. Positive associations of NC with BMI, WC, HC, WHR and WC/height among adults of both sexes are also indicated ($p<0.01$) (Table 2). Several researchers have reported similar associations of NC with BMI, WC, HC and WHR (Fink et al. 2006; Ben-Noun and Laor 2006; Onat et al. 2009; Hingorjo et al. 2012; Adamu et al. 2013; Aswathappa et al. 2013, 2014; Wang et al. 2015; Özkaya and Tunçkale 2016). Furthermore, studies reported that NC has a potential role to surpassing excess adiposity marker over the conventional anthropometric measures (e.g., BMI, WC and WHR) in metabolic disorders (Onat et al. 2009; Yang et al. 2010; Adamu et al. 2013; Aswathappa et al. 2013; Wang et al. 2015; Assyov et al. 2016). The BMI has also shown a reasonably good correlation with the other conventional anthropometric variables of excess adiposity in adults (Dudeja et al. 2001; Das and Bose 2006; Sarkar et al. 2009; Hingorjo et al. 2012; Aswathappa et al. 2013). Therefore, it was opined that BMI can be used to determine and monitor changes in the prevalence of overweight/obesity (Dudeja et al. 2001; Das and Bose 2006; Onat et al. 2009; Sen et al. 2013; Mondal and Sen 2014; Rengma et al. 2015). Recent studies have reported that NC has a potential role to play as an excess adiposity marker over the conventional anthropometric variables in metabolic disorders in adults (Onat et al. 2009; Yang et al. 2010; Aswathappa et al. 2013; Adamu et al. 2013; Wang et al. 2015; Assyov et al. 2016). The present study also showed a high prevalence of overall and regional adiposity using the conventional anthropometric variables (such as BMI, WC, WHR and WC/height) among adults (Table 3). This is in conformity with other similar Indian studies that have observed the existence of a greater proportion and variations both overall and regional adiposity ($p<0.05$) using these conventional anthropometric variables among female individuals (Dudeja et al. 2001; Das and Bose 2006; Deepa et al. 2009; Sarkar et al. 2009; Aswathappa et al. 2014; Mondal and Sen 2014). It is generally attributed that Indians have more body adiposity both total and in the abdominal region with less fat-free mass, skeletal muscle and bone mineral than all other ethnic groups (Deepa et al. 2009; Misra and Khurana 2011; Kalra et al. 2013; Mondal and Sen 2014). The present study has also observed positive associations of the conventional anthropometric variables used to define excess adiposity between BMI, WC, HC and NC. Conventional anthropometric variables such as WC, WHR and WC/height predicted specifically intra-abdominal and regional adiposity risk associations with hypertension, cardiovascular diseases, diabetes and other non-communicable diseases (Dudeja et al. 2001; Hsieh and Muto 2004; Onat et al. 2009; Huxley et al. 2010; Feng et al. 2012; Adamu et al. 2013; Bhowmik et al. 2014; Cheong et al. 2014).

The present study has identified the use of NC as a relatively valid parameter for the assessment of excess adiposity among adults using BLR and ROC-AUC analysis (Tables 4 and 5). The results of the 'likelihood' and R^2-statistics suggested that NC showed a reasonable and reliable predictive accuracy in the assessment of excess adiposity or overweight/obesity among both sexes over the conventionally used anthropometric variables. In the search of alternate anthropometric variable(s) of obesity (BMI $\geq$25.00 kg m^{-2}) assessment over the conventional anthropometric measurements (such as WC, HC, WHR and WC/height) and NC showed similar predictive associations in both BLR and AUC-ROC analysis among the adult individuals (Tables 4 and 5). The use of NC in combination with the conventional anthropometric variables separates the effects of visceral and subcutaneous mass and adiposity distribution on metabolic indicators (Sjöström et al. 1997). The association of the anthropometric variables with NC also showed that BMI, WC and HC are the best surrogate variables of excess adiposity (BMI $\geq$25.00 kg m^{-2}) (Fig. 1). Ben-Noun et al (2001), while comparing NC with BMI, observed the accuracy of NC to determine overweight/obesity to be 91.0% to 95.0% among males and 97.0% to 98.0% among females. The present study has observed that BMI and HC with NC have the relatively greater predictability in assessing overweight/obesity among adult males (72.0% and 71.9%) and females (83.0% and 77.5%) (Table 6).

Therefore, NC has the potential to be used as an alternative, straightforward, low cost and practical screening indicator of adiposity among adults, especially in large population based investigations. Studies have recommended the use of NC due to its good predictive nature in excess adiposity (Laakso et al. 2002; Hingorjo et al. 2012; Aswathappa et al. 2014). The present study also confirms the relative use and predictability of NC as an easy screening measure of excess adiposity pattern related to BMI, WC and HC among adults (Fig. 2). Furthermore, several researchers have reported different population-specific cut-offs to assess the prevalence of excess adiposity using NC (Ben-Noun and Laor 2006; Yang et al. 2010; Hingorjo et al. 2012; Aswathappa et al. 2014). Such discrepancy with the results in cut-offs estimation could be attributed to different diagnostic standards and/or population variations. The present study assessed the overweight/obesity prevalence among using the derived cut-offs of NC among the Indian population (Aswathappa et al. 2014). A similar cut-offs of NC >35.5 cm (in men) and >32 cm (in women) reported to assess overweight/obesity prevalence among Asian origin adults (Hingorjo et al. 2012). Additionally, NC is generally inexpensive and is easier to obtain than other anthropometric measures of body adiposity (such as WC, HC, BMI and WHR) and has a good predictive reliability (Onat et al. 2009; Aswathappa et al. 2014). However, a specific methodological issue needs to be addressed here. This is the absence of any established guidelines to define the anatomical location of the measurement of NC. It could be above the cricothyroid cartilage (Hall et al. 2007) or at the upper level of the margin of the thyroid cartilage (Frank, 2012) or just below the laryngeal prominence (Preis et al. 2010). Hence, although the specific outcome of any population-specific and clinical investigations could be improved by using simple and appropriate anthropometric variables such as NC, larger studies are needed to validate the results (Puri et al. 2013).

Conclusion

This study has highlighted the fact that obesity is becoming a major health issue in Indian populations. It has also been observed that NC is a better potential clinical screening tool for predicting obesity among adults. It shows a strong association with the prevalence of obesity and therefore, is reasonable to consider it as an independent screening measure of the assessment of excess adiposity. The results show the consistency of NC to assess overweight/obesity as compared to the conventional anthropometric variables. As the conventional anthropometric variables also showed significant relationships with NC when the latter was utilized to assess excess adiposity, hence, NC could be used as a simple and convenient measure to evaluate the overweight/obesity over the conventionally used anthropometric measures. Further studies should be conducted to derive precise population-specific NC cut-offs values for larger populations (such as Asian Indian) to generalize the magnitude of obesity with a simple anthropometric measurement.

Acknowledgements

The help and co-operation of the local authorities, village headmen, participants and Department of Anthropology, Assam University, Diphu Campus are acknowledged.

Author contribution

NM: Concept, design, statistical analysis, writing of the manuscript.
JS: Concept, design, statistical analysis, writing of the manuscript.

KB: Concept, design, statistical analysis, writing of the manuscript.
RT: Data collection.
MK: Data collection.
SH: Data collection.

Conflict of interest

The Authors declare that there is no conflict of interests.

Corresponding author

Dr. Nitish Mondal, Department of Anthropology, Assam University, Diphu Campus, Diphu, Karbi Anglong 782462, Assam, India, e-mail address: nitishanth@gmail.com

References

Adamu LH, Asuku AY, Taura MG, Tela IA, Datti S, Imam A. 2013. Neck circumference: An upcoming tool of adiposity indices. Niger J Basic Clin Sci 10:82–5.

Akin I, Nienaber CA. 2015. "Obesity paradox" in coronary artery disease. World J Cardiol 7:603–8.

Al-Bachir M, Ahhmad H. 2016. Detecting overweight and obesity among young Syrian boys based on skinfold thickness. Anthropol Rev 79:35–46.

Anuradha RK, Sathyavathi RB, Reddy TM, Hemalatha R, Sudhakar G, Geetha P, Reddy KK. 2015. Effect of social and environmental determinants on overweight and obesity prevalence among adolescent school children. Indian J Endocr Metab 19:283–7.

Argolo DF, Iyengar NM, Hudis CA. 2015. Obesity and Cancer: Concepts and Challenges. Indian J Surg Oncol 6:390–8.

Assyov Y, Gateva A, Tsakova A, Kamenov Z. 2016. A comparison of the clinical usefulness of neck circumference and waist circumference in individuals with severe obesity. Endocr Res 6:1–9.

Aswathappa J, Garg S, Kutty K, Shankar V. 2013. Neck circumference as an anthropometric measure of obesity in diabetics. N Am J Med Sci 5:28–31.

Aswathappa J, Garg S, Kutty K, Shankar V. 2014. Utility of neck circumference, a simple and novel measure as anthropometric marker of obesity in adults. World J Pharmacy Pharm Sci 3:1618–29.

Ben-Noun L, Laor A. 2003. Relationship of neck circumference to cardiovascular risk factors. Obes Res 11:226–31.

Ben-Noun L, Laor A. 2006. Relationship between changes in neck circumference and cardiovascular risk factors. Exp Clin Cardiol 11:14–20.

Ben-Noun L, Sohar E, Laor A. 2001. Neck circumference as a simple screening measure for identifying overweight and obese patients Obes Res 9:470–7.

Bhowmik B, Munir SB, Ahmed KR, Siddiquee T, Diep LM, Wright E, Hassan Z, Debnath PR, Mahtab H, Azad Khan AK, Hussain A. 2014. Anthropometric indices of obesity and type 2 diabetes in Bangladeshi population: Chandra Rural Diabetes Study (CRDS). Obes Res Clin Pract 8:e201–98.

Binks M. 2016. The Role of the Food Industry in Obesity Prevention. Curr Obes Rep 5: 201–7.

Chakraborty R, Bose K, Kozieł S. 2011. Waist circumference in determining obesity and hypertension among 18–60 years old Bengalee Hindu male slum dwellers in Eastern India. Ann Hum Biol 38:669–75.

Cheong KC, Ghazali SM, Hock LK, Yusoff AF, Selvarajah S, Haniff J, Zainuddin AA, Ying CY, Lin KG, Rahman JA, Shahar S, Mustafa AN. 2014. Optimal waist circumference cut-off values for predicting cardiovascular risk factors in a multi-ethnic Malaysian population. Obes Res Clin Pract 8:e154–62.

Chopra SM, Misra A, Gulati S, Gupta R. 2013. Overweight, obesity and related non-communicable diseases in Asian Indian girls and women. Eur J Clin Nutr 67:688–96.

Czeglédi E. 2016. Options for stress management in obesity treatment. Orv Hetil 157:260–7.
Das M, Bose K. 2006. Presence of high rates of overweight and obesity among adult Marwaris of Howrah, West Bengal, India. Coll Antropol 30:81–6.
Deepa M, Farooq S, Deepa R, Manjula D, Mohan V. 2009. Prevalence and significance of generalized and central body obesity in an urban Asian Indian population in Chennai, India (CURES: 47). Eur J Clin Nutr 63:259–67.
Deurenberg-Yap M, Chew SK, Lin VF, Tan BY, van Staveren WA, Deurenberg P. 2001. Relationships between indices of obesity and its co-morbidities in multi-ethnic Singapore. Int J Obes Relat Metab Disord 25:1554–62.
Dudeja V, Misra A, Pandey RM, Devina G, Kumar G, Vikram NK. 2001. BMI does not accurately predict overweight in Asian Indians in northern India. Br J Nutr 86:105–12.
Feng RN, Zhao C, Wang C, Niu YC, Li K, Guo FC, Li ST, Sun CH, Li Y. 2012. BMI is strongly associated with hypertension, and waist circumference is strongly associated with type 2 diabetes and dyslipidemia, in northern Chinese adults. J Epidemiol 22:317–23.
Fink B, Manning JT, Neave N. 2006. The 2nd–4th digit ratio (2D:4D) and neck circumference: implications for risk factors in coronary heart disease. International Journal of Obesity 30:711–4.
Fink B. 2012. Neck circumference: its usage in medicine and biology. In Handbook of Anthropology: Physical Measures of Human Form in Health and Disease, V.R. Preedy (eds), Springer Science, 665–75.
Freitag Luglio H. 2016. Genetic Variation of Fatty Acid Oxidation and Obesity, A Literature Review. Int J Biomed Sci 12:1–8.
Gurnani M, Birken C, Hamilton J. 2015. Childhood Obesity: Causes, Consequences, and Management. Pediatr Clin North Am 62:821–40.
Hall JG, Allanson JE, Gripp KW, Slavotinek AM. 2007. Handbook of Physical Measurements. New York: Oxford University Press.
Hingorjo MR, Qureshi MA, Mehdi A. 2012. Neck circumference as a useful marker of obesity: A comparison with body mass index and waist circumference. J Pak Med Assoc 62:36–40.
Hsieh SD, Muto T 2004. A simple and practical index for assessing the risk of metabolic syndrome during the routine heath checkups. Nippon Rinsho 62:1143–49.
Huxley R, Mendis S, Zheleznyakov E, Reddy S, Chan J. 2010. Body mass index, waist circumference and waist:hip ratio as predictors of cardiovascular risk--a review of the literature. Eur J Clin Nutr 64:16–22.
Indian Genome Variation Consortium. 2008. Genetic landscape of the people of India: A canvas for disease gene exploration. J Genet 87:3–20.
Kalra S, Mercuri M, Anand SS. 2013. Measures of body fat in South Asian adults. Nutr Diabetes 3:e69. doi: 10.1038/nutd.2013.10.
Kelley CP, Sbrocco G, Sbrocco T. 2016. Behavioral Modification for the Management of Obesity. Prim Care 43:159–75.
Kelly RK, Magnussen CG, Sabin MA, Cheung M, Juonala M. 2015. Development of hypertension in overweight adolescents: a review. Adolesc Health Med Ther 6:171–87.
Kowalkowska J, Poínhos R, Franchini B, Afonso C, Correia F, Pinhão S, Vaz de Almeida MD, Rodrigues S. 2016. General and abdominal adiposity in a representative sample of Portuguese adults: dependency of measures and socio-demographic factors' influence. Br J Nutr 115:185–92.
Laakso M, Matilainen V, Keinänen-Kiukaanniemi S. 2002. Association of neck circumference with insulin resistance-related factors. Int J Obes Relat Metab Disord 26:873–5.
LaBerge RC, Vaccani JP, Gow RM, Gaboury I, Hoey L, Katz SL. 2009. Inter- and intra-rater reliability of neck circumference

measurements in children. Pediatr Pulmonol 44:64–9.

Low S, Chin MC, Ma S, Heng D, Deurenberg-Yap M. 2009. Rationale for redefining obesity in Asians. Ann Acad Med Singapore 38:66–9.

Mandviwala T, Khalid U, Deswal A. 2016. Obesity and Cardiovascular Disease: a Risk Factor or a Risk Marker? Curr Atheroscler Rep 18:21. doi: 10.1007/s11883-016-0575–4.

Mendes LL, Nogueira H, Padez C, Ferrao M, Velasquez-Melendez G. 2013. Individual and environmental factors associated for overweight in urban population of Brazil. BMC Public Health 13:988. doi: 10.1186/1471–2458–13–988.

Misra A, Khurana L. 2011. Obesity-related non-communicable diseases: South Asians vs White Caucasians. Int J Obes (Lond) 35:167–87.

Mondal N, Sen J. 2014. Role of anthropometry in assessment of excess adiposity and metabolic disorders in Asian Indians. In: K Bose and R Chakraborty, editors. Public Health in 21st Century: Health consequences of human central obesity. New York: Nova Biomedical, 71–83.

Morgen CS, Sørensen TI. 2014. Obesity: Global trends in the prevalence of overweight and obesity. Nat Rev Endocrinol 10:513–4.

Obesity in Asia Collaboration. Huxley R, Barzi F, Lee CM, Lear S, Shaw J, Lam TH, Caterson I, Azizi F, Patel J, Suriyawongpaisal P, Oh SW, Kang JH, Gill T, Zimmet P, James PT, Woodward M. 2007. Waist circumference thresholds provide an accurate and widely applicable method for the discrimination of diabetes. Diabetes Care 30:3116–8.

Onat A, Hergenç G, Yüksel H, Can G, Ayhan E, Kaya Z, Dursunoğlu D. 2009. Neck circumference as a measure of central obesity: associations with metabolic syndrome and obstructive sleep apnea syndrome beyond waist circumference. Clin Nutr 28:46–51.

Özkaya İ, Tunçkale A. 2016. Neck Circumference Positively Related with Central Obesity and Overweight in Turkish University Students. Cent Eur J Public Health 24:91–4.

Pan WH, Yeh WT. 2008. How to define obesity? Evidence-based multiple action points for public awareness, screening, and treatment: an extension of Asian-Pacific recommendations. Asia Pac J Clin Nutr 17:370–4.

Popkin BM, Slining MM. 2013. New dynamics in global obesity facing low- and middle-income countries. Obes Rev 142:11–20.

Preis SR, Massaro JM, Hoffmann U, D'Agostino RB Sr, Levy D, Robins SJ, Meigs JB, Vasan RS, O'Donnell CJ, Fox CS. 2010. Neck circumference as a novel measure of cardiometabolic risk: the Framingham Heart study. J Clin Endocrinol Metab 95:3701–10.

Puri G, Scott G, Gan SK. 2013. Can neck circumference be used as a tool to identify the metabolic syndrome and insulin resistance? Practical Diabetes 30:184–5.

Rengma MS, Sen J, Mondal N. 2015. Socio-Economic, Demographic and Lifestyle Determinants of Overweight and Obesity among Adults of Northeast India. Ethiop J Health Sci 25: 199–208.

Rosset I, Strapagiel D, Sitek A, Majewska M, Ostrowska-Nawarycz L, Żądzińska E. 2016, Association of FTO and TMEM18 polymorphisms with overweight and obesity in the population of Polish children. Anthropological Review 79:17–33.

Sarkar D, Mondal N, Sen J. 2009. Obesity and blood pressure variations among the Bengali Kayastha population of North Bengal, India. J Life Sci 1:35–43.

Sen J, Mondal N, Dutta S. 2013. Factors affecting overweight and obesity among urban adults: a cross-sectional study. Epidemiol Biostatistics Pub Health 10:e8741–1–8.

Sen J, Mondal N. 2013. Fat mass and fat-free mass as indicators of body composition among Bengalee Muslim children. Ann Hum Biol 40:286–93.

Shafaghi K, Shariff ZM, Taib MN, Rahman HA, Mobarhan MG, Jabbari H. 2014. Parental body mass index is associated with adolescent overweight and obesity in Mashhad, Iran. Asia Pac J Clin Nutr 23:225–31.

Sitek A, Rosset I, Strapagiel D, Majewska M, Ostrowska-Nawarycz L, Żądzińska E. 2014. Association of FTO gene with obesity in Polish schoolchildren. Anthropological Review 77:33–44.

Sjöström CD, Lissner L, Sjöström L. 1997. Relationships between changes in body composition and changes in cardiovascular risk factors: the SOS Intervention Study. Swedish Obese Subjects. Obes Res 5:5 19–30.

Stabe C, Vasques AC, Lima MM, Tambascia MA, Pareja JC, Yamanaka A, Geloneze B. 2013. Neck circumference as a simple tool for identifying the metabolic syndrome and insulin resistance: results from the Brazilian Metabolic Syndrome Study. Clin Endocrinol (Oxf) 78:874–81.

Touitou Y, Portaluppi F, Smolensky MH, Rensing L. 2004. Ethical principles and standards for the conduct of human and animal biological rhythm research. Chronobiol Int 21:161–70.

Ulijaszek SA, Kerr DA. 1999. Anthropometric measurement error and the assessment of nutritional status. Br J Nutr 82:165–77.

Wang X, Zhang N, Yu C, Ji Z. 2015. Evaluation of neck circumference as a predictor of central obesity and insulin resistance in Chinese adults. Int J Clin Exp Med 8: 19107–13.

Wells JCK. 2010. The evolutionary biology of human body fatness: thrift and control. Cambridge: Cambridge University Press.

WHO Expert Consultation. 2004. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. Lancet 363:157–63.

World Health Organization (WHO). 2000. The Asia Pacific Perspective, Redefining obesity and its treatment. Geneva: World Health Organization.

World Health Organization (WHO). 2011. Waist circumference and waist–hip ratio: report of a WHO expert consultation, Geneva, 8–11 December 2008.

World Health Organization (WHO). 2013. Controlling the global obesity epidemic-The challenge. Avalable at:http://www.who.int/nutrition/topics/obesity/en/; [Accessed March 15 2013].

Yang GR, Yuan SY, Fu HJ, Wan G, Zhu LX, Bu XL, Zhang JD, Du XP, Li YL, Ji Y, Gu XN, Li Y. 2010. Beijing Community Diabetes Study Group. Neck circumference positively related with central obesity, overweight, and metabolic syndrome in Chinese subjects with type-2 diabetes: Beijing Community Diabetes Study 4. Diabetes Care 33:2465–7.