Antrocom Online Journal of Anthropology vol. 17. n. 1 (2021) 185-196– ISSN 1973 – 2880

Antrocom Journal of Anthropology

journal homepage: http://www.antrocom.net

Neck circumference as an alternative measure of central obesity among pre-hypertensive adults

Susmita Roy, Shreyasi Roy and Prof. Jaydip Sen

Department of Anthropology, North Bengal University, Raja Rammohanpur, Shivmandir. Darjeeling-734013. West Bengal, India.

KEYWORDS

neck circumference, central obesity, pre-hypertensive

ABSTRACT

There is a dearth of cut-offs of neck circumference (NC) to define central obesity among pre-hypertensive adults. Primary aim is to find the association of NC and waist circumference (WC) among pre-hypertensive adults and to find optimal cut-offs of NC to predict central obesity among pre-hypertensive adults. The present cross-sectional study was conducted among 666 adults (aged 20-49 years) belonging to the Bengalee Hindu Caste Population and residing in West Bengal. Height, weight, WC, NC and blood pressure were measured. Linear regression analysis was performed to find the association of NC and WC. Receiver Operating Characteristic (ROC) curve analysis was performed to yield optimal cut-offs of NC for predicting central obesity among pre-hypertensive adults. NC and WC showed a strong correlation among both pre-hypertensive adult males (r=0.732) and females (r=0.748). The optimal cut-offs of NC to define central obesity among the subjects were ≥37.1 cm for males and ≥33.8 cm for females. The area under curve (AUC) was .755 for males and .779 for females. NC can be used as an alternate anthropometric measure to define central obesity among pre-hypertensive adults.

Introduction

Central obesity (CO, also called abdominal obesity) refers to the accumulation of fat in the abdominal region resulting in increased waist size. Henceforth, waist circumference (WC) is a well-accepted measure for the screening of CO. Expert groups from different research organizations such as International Diabetes Federation (IDF), National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III) and World Health Organisation (WHO) have reported different cut-offs for WC suitable for determining metabolic syndrome (Alberti *et al.* 2005; Grundy *et al.* 2005). However, there exist several limitations of WC. There is no unanimity regarding the standard method of measuring WC which results in different techniques and locations of its measurement thereby yielding varying values of WC (Verweji *et al.* 2012). Position, meals, and respiration could all affect the measurement of WC (Agarwal *et al.* 2009). Also, the measurement requires removal of clothes which may be inconvenient in some cases. Owing to such limitations of WC, many researchers prefer to use neck circumference (NC) for assessing CO of individuals. As enunciated by the term itself, NC refers to the measurement of circumference of the neck. The technique of measuring NC is simpler and less time-consuming and requires no special tools except a non-stretchable measuring tape. NC is considered as a relatively new potential proxy anthropometric measurement utilized to differentiate normal and excess body fat distribution (Özkaya and Tunçkale 2016). Several studies have consistently shown the association of NC and WC among general adult population (Özkaya and Tunçkale 2016; Hingorjo *et al.* 2012; Mondal *et al.* 2016; Mondal *et al.* 2017; Alzeidan *et al.* 2019).

Please cite this article as: Susmita Roy, Shreyasi Roy and Prof. Jaydip Sen. Neck circumference as an alternative measure of central obesity among pre-hypertensive adults. *Antrocom J. of Anthropology 17-1 (2021) pp. 185-196.*

Who are pre-hypertensive individuals?

Pre-hypertension is the intermediate stage between hypertension and normal blood pressure. Based on the Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (Chobanian *et al.* 2003), prehypertension can be defined as not being on antihypertensive drugs or having systolic blood pressure (SBP) between 120 and 130 mmHg or diastolic blood pressure (DBP) between 80 to 89 mmHg. The concept of prehypertension was introduced as the novel guideline for the management of blood pressure.

Why were pre-hypertensive subjects chosen?

CO is a major concern for pre-hypertensive subjects, especially among adults. This is because CO tends to increase with age in both sexes (Lemieux *et al.* 1996) and this eventually increases the risk for blood pressure elevation (Singh *et al.* 2011). Mounting evidences have claimed that pre-hypertensive adults have higher WC compared to normotensives (Senthil and Krishnadasa 2016; Rafan *et al.* 2018; Yilmazel 2017; Hu *et al.* 2017; Isezuo *et al.* 2011). Additionally, mean WC was observed to increase across the gradient of blood pressure from normo-tension through pre-hypertension to hypertension (Ferguson *et al.* 2008; Isezuo *et al.* 2011). Pre-hypertensive adults with CO had higher odds to develop hypertension (Hu *et al.* 2017; Pitsavos *et al.* 2008). A very recent Chinese cohort study among pre-hypertensive adults revealed that a WC gain >5.0% was associated with a risk to hypertension (Qin *et al.* 2020). The study also claimed that there existed a linear association between percentage of WC gain and risk of progression from pre-hypertension to hypertension. Studies have proved that WC, in comparison to BMI, has better prediction for hypertension risk (Luo *et al.* 2014). However, WC sometimes becomes uneasy to measure due to several reasons mentioned earlier.

A thorough literature search using "Pubmed" database has yielded a paucity of studies on the issue of NC, WC and pre-hypertension among different population groups from India. Not much attention has been paid to pre-hypertension and there is paucity of information on magnitude and risk factors associated with pre-hypertension in the country (Parthaje *et al.* 2016). Previous studies in India in the last few decades have reported varying prevalence of pre-hypertension ranging from 17–47% among adults (Yadav *et al.* 2008; Debbarma *et al.* 2015). However, they have mostly been limited to specific population sub-groups and in certain geographical pockets (Tripathy *et al.* 2017).

It has been recently opined that NC is a simple, non-invasive procedure to detect pre-hypertension (Rajagopalan and Balaji 2017). Early identification of pre-hypertension will help in reducing the incidence of hypertension among adults in the near future, thereby significantly reducing the hypertension-related health-related burden in the country. As a result, the present authors found it worthwhile to measure NC and WC, and to find out their associations among pre-hypertensive adult individuals. Keeping this view in mind, the following objectives have been framed for the present study:

i. to find the association between NC and WC;
i. to find the cut-offs of NC for screening CO among the pre-hypertensive adults belonging to the Bengalee Hindu Caste Population (BHCP).

Materials and Methods

Source of data

The present cross-sectional study was conducted among 666 adult individuals belonging to the BHCP (aged between 20-49 years) and residing in Siliguri sub-division under the district of Darjeeling, West Bengal, India. The selection of this age-group has been made based on the fact that

pre-hypertension was more prevalent among the selected age-group (Badakhsh *et al.* 2015; Choi *et al.* 2006; Ishikawa *et al.* 2008; Pang *et al.* 2008; Rahmanian and Shojaie 2012).

The subjects were selected using a multi-stage stratified sampling technique. In the first stage, the households of the subjects belonging to the BHCP were identified based on the surnames, physical and cultural features. In the second stage, adult population of aforementioned age-group were identified and approached for the study. Initially, 1339 individuals were approached to participate in the study. However, 673 subjects were excluded based on the following inclusion and exclusion criteria:

Inclusion criteria

i. Subjects who were apparently healthy and devoid of any physical deformities;
ii. Subjects who were pre-hypertensive;
iii. Subjects belonging to the selected age-group;
iv. Subjects who voluntarily participated in the study.

Exclusion criteria

i. Subjects having previous histories pertaining to medical and surgical episodes;
ii. Subjects having normal range of blood pressure and high blood pressure;
iii. Subjects with enlargement of thyroid gland, goitre and neck deformity and those exhibiting any abnormality;
iv. Pregnant, post-partum and lactating women;
v. Subjects consuming antihypertensive drugs;
vi. Subjects with any missing data.

Hence, finally, the study comprised of 666 subjects. Of those 666 subjects, 300 (45.05%) were females and 366 (54.95%) were males. The study was in accordance with the ethical guidelines for human experimental research as laid down in the Helsinki Declaration (Touitou *et al.* 2004).

Types of data recorded

Anthropometric measurements of height, weight, WC and NC of the subjects were recorded according to standard procedures of Weiner and Lourie (1969). Blood pressure was measured after the subject was allowed to rest for 15 minutes. The readings were taken thrice for each individual on left arm with the aid of mercury sphygmomanometer by auscultatory method. The subjects were also enquired about their history of medication for blood pressure.

A most commonly used indicator of precision or rather accuracy index called Technical Error of Measurement (TEM) was utilized (Perini *et al.* 2005). For the calculation of inter-observer TEM, height, weight, WC and NC were recorded from 50 subjects, other than those selected for the study. The measurements were taken thrice on each individual by the first and second authors (SR and SR). The TEM was calculated based on the following formula:

TEM [$TEM=\sqrt{(\sum D^2/2N)}$, D=difference between the measurements and N= number of individuals measured] (Goto and Mascie-Taylor, 2007).

The coefficient of reliability (R) which estimates the proportion of variance in a measured population that is free from measurement error was subsequently calculated by the following equation:

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

Very high values of R (> 0.975) were obtained for the inter-observer TEM analysis. All the values of R were appreciably higher than the accepted cut-off value of 0.95 as suggested by Ulijaszek and Kerr (1999). Hence, the anthropometric measurements recorded were considered to be reliable and reproducible and the TEM values were not incorporated for further statistical consideration.

Statistical procedures

The data obtained in the present study was statistically analyzed using statistical constants and relevant statistical tests. The statistical analyses were performed utilizing the software named IBM SPSS (Statistical Package for Social Sciences) Statistics (version 23.0, SPSS Inc., Chicago, IL) and p-values <0.05 and <0.001 were considered as statistically significant. Descriptive statistics were utilized to frame the age-wise and sex-wise mean and standard deviations of the recorded variables. Independent samples t-test was performed to yield the sex-specific differences among the variables. One way analysis of variance (ANOVA) was utilized to identify the mean differences among the anthropometric variables with respect to the different age- groups. For convenience in data handling, the subjects were classified into 3 groups [20-29 years (males=142, females=125), 30-39 years (males=121; females=105) and 40-49 years (males==103; females=70)].

Linear regression analysis was performed to yield the association of WC and NC in both the sexes. Scatter plot was also drawn to get a clear view of the linear association between WC and NC. Receiver Operating Characteristic (ROC) curve analysis was performed to find the best cut-offs of NC for determining CO. For cut-offs of WC for CO, NCEP ATP III protocol was relied upon. According to the modified NCEP ATP III, the cut-off points of WC should be ethnic specific where individuals of Asian origin should use the cut-off of 90 cm in men and 80 cm in women. Areas under ROC curve (AUC) were recorded for both sexes using a 95% confidence interval (CI). A value of $p < 0.05$ on the two-tail test was considered statistically significant. Sensitivity and specificity were also noted down. The optimal cut-off points were determined by the point of convergence of sensitivity and specificity, by simultaneously maximizing the two. The Youden's Index (*J*) which is the maximum potential effectiveness of a biomarker was used to determine the optimal sex-specific cut-off levels of NC that would correlate with CO.

Results

The age- and sex-specific descriptive statistics of the recorded parameters are portrayed in Table 1. The overall mean age was observed to be higher among males (35.40±7.92 years) compared to females (33.94±7.41 years). The overall mean values of BMI (22.15±4.89 kg/m^2 vs 21.71±3.98 kg/m^2), NC (35.62±3.34 cm vs 31.62±2.6cm) and WC (88.48±12.21 vs 82.87±7.66 cm) were observed to be higher among males compared to females. Among males, age-specific mean differences were observed to be statistically significant with respect to age, NC, SBP and DBP whereas among females, the differences were statistically significant with respect to age, NC, WC, SBP and DBP. Based on independent sample t-test, the sex-specific mean differences were statistically significant in NC, WC ($p<0.001$) and SBP ($p<0.05$). However, the mean differences were statistically insignificant in BMI and DBP ($p>0.05$).

Linear regression analysis yielded that NC and WC have a strong correlation (Figure 1) where r=0.748 in females and r=.732 in males (Table 2). The ROC curve analysis for the prediction of CO by NC yielded AUC values of 0.755 and 0.779 for males and females respectively (Figure 2). The

best possible NC cut-offs along with high sensitivity, high specificity and highest Youden's index were found to be 37.1 cm and 33.8 cm for males and females respectively.

Discussion

The present paper is a preliminary report of a bio-anthropological investigation undertaken among pre-hypertensive adults of BHCP group. Pre-hypertension is a cautionary signal and guiding mark for both patients as well as health professionals to take intervention measures with regard to lifestyle (Chobanian *et al.* 2003). Obesity which is a dreadful factor at this stage can increase the risk of health related cardiovascular and metabolic disorders. The present study has focussed on CO which involves fat accumulation in the waist region. WC is the main indicator of abdominal fat accumulation with which same risk factors related to obesity are frequently associated (Janssen *et al.* 2004). Nevertheless, owing to some limitations, several studies prefer to use NC to define CO or increasing WC among the subjects. However, there exists a dearth of cut-offs for NC to define CO among pre-hypertensive adults. The present study has attempted to find optimal cut-offs of NC to predict CO among the aforementioned group of people.

The present study has found a moderate correlation between NC and WC (r=0.732 in males; r=0.748 in females). The correlation coefficients in the present study were higher compared to other studies (Table 3). The ROC curve analysis gave optimal NC cut-offs for predicting CO among pre-hypertensive males and females. The AUC were 0.755 and 0.779 in males and females respectively which proves that the diagnostic test was fair. The details of the analysis were compared with similar other studies (Table 4). Table 3 and Table 4 clarify that the present study would be a valuable adjunct to the similar existing studies.

Generally, people are concerned when they are found to have hypertension. However, they put little emphasis during their pre-hypertensive stage as they are usually unaware of the health status (Isezuo *et al.* 2010; Wang and Wang, 2004). As always said, *prevention is better than cure!* This calls for an urgent need of a public health programme to improve awareness, detection, management, prevention and lifestyle modification during pre-hypertensive stage.

In order to prevent and/or delay hypertension and other cardiovascular diseases, pre-hypertensive subjects should act as a potential target population for the promotion of lifestyle modifications, including losing weight, increasing physical activities, adopting DASH (Dietary Approaches to Stop Hypertension) eating plan, and moderating alcohol consumption. Clinical trials have proved that that these interventions have significantly lowered BP and most of them have been able to prevent the development of hypertension (Zhang and Li 2011). All non-pharmacological interventions for pre-hypertension treatment mentioned above are also found to reduce WC. WC could be used in health promotion programmes to identify individuals who should seek and be offered weight management (Lean *et al.* 1995). The DASH eating plan ensures a healthy flexible balanced diet for pre-hypertensive patients, which is designed to maintain a low sodium intake. This diet plan, in addition, will eventually aid in reducing WC as high sodium intake leads to greater WC (Yi and Kansagra 2014). WC reduction is very crucial step for early prevention of hypertension (Luo *et al.* 2013). Reduction in WC will lead to reduction in NC as they both are positively correlated (Table 3). Circumstances where measuring WC of individuals become a doubtful or problematic issue, NC measurements could yield the status of CO among the pre-hypertensive subjects. The NC cut-offs (≥37.1 cm in males and ≥33.8 cm in females) in the present study could aid in discriminating centrally obese pre-hypertensive subjects. This could act as a preliminary cautionary signal to put a check on the health management.

The present study had some limitations. Primarily, it is a cross-sectional study and as such causal pathways underlying the reported associations could not be ascertained. India being a country with diverse populations, the results needs to be ratified on other population groups.

Conclusion

Pre-hypertension is the preliminary stage that have higher conversion rate to become hypertension. Obesity (in the form of general and/or CO) in this crucial step can be dangerous. Monitoring obesity at this earlier stage can put a big full stop to big issues in the later stages of life. The present study observed NC to be strongly correlated with WC among pre-hypertensive subjects. NC≥37.1 cm and ≥33.8 cm were found to be the best cut-offs for determining CO among pre-hypertensive males and females respectively. Hence, the present study concluded that NC could be considered as an alternative to WC measurement in screening of CO. Early identification of pre-hypertension cases will undoubtedly help in the reduction of the incidence of hypertension among adults in the near future. This, in turn, will significantly reduce the hypertension-related health-related burden in the country.

Acknowledgement *The authors acknowledge the financial support extended by the University Grants Commission, Government of India in the form of Senior Research Fellowship [UGC-Ref. No. 617/(NET-JULY 2016)] to the second author (SR).*

Disclosure Statement *The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.*

References

Agarwal, S. K., Misra, A., Aggarwal, P., Bardia, A., Goel, R., Vikram, N. K., Wasir, J. S., Hussain, N., Ramachandran, K., Pandey, R. M., (2009). "Waist circumference measurement by site, posture, respiratory phase, and meal time: implications for methodology". *Obesity (Silver Spring, Md.)* 17(5):1056–1061.

Alberti, K. G., Zimmet, P., Shaw, J., Idf Epidemiology Task Force Consensus Group, (2005). "The metabolic syndrome--a new worldwide definition". *Lancet (London, England)* 366(9491): 1059–1062.

Alzeidan, R., Fayed, A., Hersi, A. S., Elmorshedy, H., (2019). "Performance of neck circumference to predict obesity and metabolic syndrome among adult Saudis: a cross-sectional study". *BMC obesity* 6:13. Available: <https://doi.org/10.1186/s40608-019-0235-7> (Accessed on January 9, 2020).

Ang, N. S., Raboca, J. C., (2014). "Neck Circumference as a Screening Measure for Abdominal Obesity and its Association with Metabolic Syndrome among High Risk Filipino Patients in Makati Medical Center - a Pilot Study". *Journal of the ASEAN Federation of Endocrine Societies* 26(2): 150.

Anothaisintawee, T., Sansanayudh, N., Thamakaison, S., Lertrattananon, D., Thakkinstian, A., (2019). "Neck Circumference as an Anthropometric Indicator of Central Obesity in Patients with Prediabetes: A Cross-Sectional Study". *BioMed Research International* 2019: 4808541.

Badakhsh, M. H., Malek, M., Aghili, R., Ebrahim Valojerdi, A., Khamseh, M.E., (2015). "Prehypertension; patient awareness and associated cardiovascular risk factors in an urban population in Iran". *Medical Journal of the Islamic Republic of Iran* 29:290.

Chobanian, A. V., Bakris, G. L., Black, H.R., Cushman, W. C., Green, L. A., Izzo, J. L. Jr., Jones, D. W., Materson,

B. J., Oparil, S., Wright, J. T. Jr., Roccella, E. J., Joint National Committee On Prevention, Detection, Evaluation, And Treatment Of High Blood Pressure., (2003). "Seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure". *Hypertension* 42(6):1206-1252.

Choi, K. M., Park, H. S., Han, J. H., Lee, J. S., Lee, J., Ryu, O. H., Lee, K. W., Cho, K. H., Yoon, D., Baik, S. H., Choi, D. S., Kim, S. M., (2006). "Prevalence of prehypertension and hypertension in a Korean population: Korean National Health and Nutrition Survey 2001". *Journal of Hypertension* 24(8):1515-1521.

Debbarma, A., Bhattacharjya, H., Mohanty, A., Mog, C., (2015). "Prevalence of pre-hypertension and its relationship with body mass index among the medical students of Agartala Government Medical College". *International Journal of Research in Medical Sciences* 3(5): 1097-1101.

Ferguson, T. S., Younger, N. O., Tulloch-Reid, M. K., Wright, M. B., Ward, E. M., Ashley, D. E., Wilks, R. J., (2008). "Prevalence of prehypertension and its relationship to risk factors for cardiovascular disease in Jamaica: analysis from a cross-sectional survey". *BMC Cardiovascular Disorders* 8:20.

Goto, R., Mascie-Taylor, C. G. N., (2007). "Precision of measurement as a component of human variation". *Journal of Physiological Anthropology* 26: 253-256.

Grundy, S. M., Cleeman, J. I., Daniels, S. R., Donato, K. A., Eckel, R. H., Franklin, B. A., Gordon, D. J., Krauss, R. M., Savage, P. J., Smith, S. C. Jr., Spertus, J. A., Costa, F., American Heart Association, National Heart, Lung, And Blood Institute., (2005). "Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement". *Circulation* 112(17):2735-2752.

Hingorjo, M. R., Qureshi, M. A., Mehdi, A., (2012). "Neck circumference as a useful marker of obesity: a comparison with body mass index and waist circumference". *The Journal of Pakistan Medical Association* 62(1):36-40.

Hu, L., Huang, X., You, C., Li, J., Hong, K., Li, P., Wu, Y., Wu, Q., Bao, H., Cheng, X., (2017). "Prevalence and Risk Factors of Prehypertension and Hypertension in Southern China". *PLoS One* 12(1):e0170238.

Isezuo, S. A., Sabir, A. A., Ohwovorilole, A. E., Fasanmade, O. A., (2011). "Prevalence, associated factors and relationship between prehypertension and hypertension: a study of two ethnic African populations in Northern Nigeria". *Journal of Human Hypertension* 25(4):224-230.

Ishikawa, Y., Ishikawa, J., Ishikawa, S., Kayaba, K., Nakamura, Y., Shimada, K., Kajii, E., Pickering, T. G., Kario, K., Jichi Medical School Cohort Investigators Group, (2008). "Prevalence and determinants of prehypertension in a Japanese general population: the Jichi Medical School Cohort Study". *Hypertension Research* 31(7):1323-1330.

Janssen, I., Katzmarzyk, P. T., Ross, R., (2004). "Waist circumference and not body mass index explains obesity-related health risk". *The American Journal of Clinical Nutrition* 79(3):379-384.

Lean, M. E., Han, T. S., Morrison, C. E., (1995). "Waist circumference as a measure for indicating need for weight management". *BMJ* 311(6998):158-161.

Lemieux, S., Prud'homme, D., Tremblay, A., Bouchard, C., Després, J. P., (1996). "Anthropometric correlates to changes in visceral adipose tissue over 7 years in women". *International Journal of Obesity and Related Metabolic Disorders* 20(7):618-624.

Luo, W., Guo, Z., Hu, X., Zhou, Z., Mingwu, Zhang L., Liu J., (2013). "A prospective study on association between 2 years change of waist circumference and incident hypertension in Han Chinese". *International Journal of Cardiology* 167(6):2781-2785.

Luo, W., Chen, F., Guo, Z., Wu, M., Hao, C., Zhou, Z., Yao, X., (2014). "Comparison of the Suitability of 2 Years Change in Waist Circumference and Body Mass Index in Predicting Hypertension Risk: A Prospective Study in Chinese-Han". *Iran Journal of Public Health* 43(9):1212-20.

Mondal, N., Sen, J., Bose, K., Timungpi, R., Kathar, M., Hanse, S., (2016). "Neck circumference as a screening measure of overweight/obesity among Indian adults". *Anthropological Review* 79(3): 347–365.

Mondal, N., Timungpi, R., Kathar, M., Hanse, S., Teronpi, S., Timung, A., Bose, K., Sen, J., (2017). "Cut-off point estimation of neck circumference to determine overweight and obesity among Asian Indian adults". *Epidemiology Biostatistics and Public Health* 2017; 14(2): e-12310-1.

Özkaya, İ., Tunçkale, A., (2016). "Neck Circumference Positively Related with Central Obesity and Overweight in Turkish University Students: A Preliminary Study". *Central European Journal of Public Health* 24(2):91-94.

Pang, W., Sun, Z., Zheng, L., Li, J., Zhang, X., Liu, S., Xu, C., Li, J., Hu, D., Sun, Y., (2008). "Body mass index and the prevalence of prehypertension and hypertension in a Chinese rural population". *Internal Medicine* 47(10):893-897.

Parthaje, P. M., Unnikrishnan, B., Thankappan, K. R., Thapar, R., Fatt, Q. K., Oldenburg, B., (2016). "Prevalence and Correlates of Prehypertension Among Adults in Urban South India". *Asia Pacific Journal of Public Health* 28(1 Suppl):93S-101S.

Pei, X., Liu, L., Imam, M.U., Lu, M., Chen, Y., Sun, P., Guo, Y., Xu, Y., Ping, Z., Fu, X., (2018). "Neck circumference may be a valuable tool for screening individuals with obesity: findings from a young Chinese population and a meta-analysis". *BMC Public Health* 18:529.

Perini, T. A., De Oliveira, G. L., Ornellas, J. S., De Oliveira, F. P., (2005). "Technical error of measurement in anthropometry". *Revista Brasileira de Medicina do Esporte* 11: 86-90.

Pitsavos, C., Chrysohoou, C., Panagiotakos, D. B., Lentzas, Y., Stefanadis, C., (2008). "Abdominal obesity and inflammation predicts hypertension among prehypertensive men and women: the ATTICA Study". *Heart Vessels* 23(2):96-103.

Qin, P., Chen, Q., Wang, T., Chen, X., Zhao, Y., Li, Q., Zhou, Q., Guo, C., Liu, D., Tian, G., Wu, X., Qie, R., Han, M., Huang, S., Liu, L., Li, Y., Hu, D., Zhang, M., (20200. "Association of 6-year waist-circumference change with progression from prehypertension to hypertension: the Rural Chinese Cohort Study". *Journal of Human Hypertension.* Available: <https://doi.org/10.1038/s41371-020-0322-8> (Accessed on January 9, 2020).

Qureshi, N. K., Hossain, T., Hassan, M. I., Akter, N., Rahman, M. M., Sultana, M. M., Ashrafuzzaman, S. M., Latif, Z. A., (2017). "Neck circumference as a marker of overweight and obesity and cut-off values for Bangladeshi adults". *Indian Journal of Endocrinology and Metabolism* 21:803-808.

Rafan, S. N., Zakaria, R., Ismail, S. B., Muhamad, R., (2018). "Prevalence of prehypertension and its associated factors among adults visiting outpatient clinic in Northeast Malaysia". *Journal of Taibah University Medical Sciences* 13(5):459-464.

Rahmanian, K., Shojaie, M., (2012). "The prevalence of pre-hypertension and its association to established cardiovascular risk factors in south of Iran". *BMC Research Notes* 5:386.

Rajagopalan, A., Balaji, N., (2017). "Association of Neck Circumference and Obesity with Blood Pressure among Adolescents in Urban and Rural Population in North Tamil Nadu". *Journal of Natural Science, Biology and Medicine* 8(2):144-149.

Senthil, S., Krishnadasa, S. N., (2016). "Prehypertension and Its Determinants in Apparently Healthy Young Adults". *Journal of Clinical and Diagnostic Research* 10(9):CC05-CC08.

Singh, R. B., Fedacko, J., Pella, D., Macejova, Z., Ghosh, S., De, Amit K., Begom, R., Tumbis, Z. A., Haque, M., Vajpeyee, S. K., De, Meester F., Sergey, C., Agarwalo, R., Muthusamy, V. V., Five City Study Group, Gupta, A. K., (2011). "Prevalence and risk factors for prehypertension and hypertension in five Indian cities". *Acta Cardiologica* 66(1):29-37.

Touitou, Y., Portaluppi, F., Smolensky, M. H., Rensing, L., (2004). "Ethical principles and standards for the conduct of human and animal biological rhythm research". *Chronobiology International* 21:161–170.

Tripathy, J. P., Thakur, J. S., Jeet, G., Chawla, S., Jain, S., (2017). "Alarmingly high prevalence of hypertension and pre-hypertension in North India-results from a large cross-sectional STEPS survey". *PLoS One* 12(12):e0188619.

Ulijaszek, S. J., Kerr, D. A., (19990. "Anthropometric measurement error and the assessment of nutritional status". *The British Journal of Nutrition* 82:165–177.

Verweji, L. M., Terwee, C. B., Proper, K. I., Hulshof, C. T., Van Mechelen, W., (2013). "Measurement error of waist circumference: gaps in knowledge". *Public Health Nutrition* 16(2):281-288.

Wang, Y., Wang, Q. J., (2004). "The prevalence of prehypertension and hypertension among US adults according to the new joint national committee guidelines: new challenges of the old problem". *Archieves of Internal Medicine* 164(19):2126-2134.

Weiner, J. S., Lourie, J. A., (1969). Human Biology: A Guide to Field Methods. International Biological Program (IBP), Hand Book No. 9. Blackwell Scientific Publications, Oxford-Edinburgh.

Yadav, S., Boddula, R., Genitta, G., Bhatia, V., Bansal, B., Kongara, S., Julka, S., Kumar, A., Singh, H. K., Ramesh, V., Bhatia, E., (2008). "Prevalence & risk factors of pre-hypertension & hypertension in an affluent north Indian population". *The Indian Journal of Medical Research* 128(6):712-20.

Yi, S. S., Kansagra, S. M., (2014). "Associations of sodium intake with obesity, body mass index, waist circumference, and weight". *American Journal of Preventive Medicine* 46(6):e53-e55.

Yilmazel, G., (2017). "Prehypertension prevalence and its association with neck and abdominal obesity in disease-free young adults". *Acta Medica Mediterranea* 33(2): 329-334.

Zhang, W., Li, N., (2011). "Prevalence, Risk Factors, and Management of Prehypertension". *International Journal of Hypertension* 2011: 605359.

Tables and Figures

Table 1. Descriptive statistics of the recorded variables

Parameters	Males (N=366)					Females (N=300)					Sex differences (t-test)
	20-29 years	30-39 years	40-49 years	Overall	F-value	20-29 years	30-39 years	40-49 years	Overall	F-value	
Age (years)	26.25±1.61	35.74±2.81	44.22±2.16	35.40±7.92	1986.68**	25.19±2.21	33.61±2.22	43.01±3.21	33.94±7.41	1174.50**	2.436*
BMI (kg/m^2)	22.31±3.01	22.99±2.11	22.45±2.16	22.15±4.89	2.571	22.01±2.16	22.46±2.17	22.59±2.07	21.71±3.98	2.084	1.592
NC (cm)	34.62±3.11	36.99±2.87	35.23±1.91	35.62±3.34	25.585**	30.97±4.08	31.99±2.39	31.59±1.41	31.62±2.6	3.222*	17.05**
WC (cm)	88.22±6.11	88.06±5.98	89.19±7.12	88.48±12.21	1.011	81.12±4.11	83.52±5.76	83.98±6.60	82.87±7.66	8.628**	6.92**
SBP (mm Hg)	123.5±2.5	124.5±2.0	123.0±3.5	124.0±3.5	9.320**	123.0±3.5	125.5±1.5	124.5±3.5	125.5±3.0	18.309**	1.955*
DBP (mm Hg)	84.5±2.0	84.0±3.5	83.0±2.5	83.8±2.9	9.224**	83.5±2.5	83.0±3.5	84.5±2.0	83.5±3.5	6.079*	1.210

***p<0.001, *p<0.05*

Table 2. Linear regression analysis of waist circumference by neck circumference

Females

Summary of fit

$r = .748$ $r^2 = .560$

Parameter Estimates

	Estimate	Std. error	p-value
Intercept	50.618	1.592	.000
NC	.906	.046	.000

Males

Summary of fit

$r = .732$ $r^2 = .535$

Parameter Estimates

	Estimate	Std. error	p-value
Intercept	55.485	2.203	.000
NC	1.329	.063	.000

Table 3. Correlation between waist circumference and neck circumference conducted by various studies

Study	Location	Subjects	Correlation
Mondal *et al*., 2016	Assam, India	Karbi adult individuals	r=0.578 (males); r=0.569 (females) (p<0.01)
Mondal *et al*., 2017	Assam, India	Karbi adult individuals	r=0.505 (males); r=0.486 (females) (p<0.001)
Qureshi *et al*., 2017	Bangladesh	Adult	r=0.61 (males); r=0.46 (females) (p<0.001)
Anothaisintawee *et al*., 2019	Thailand	Prediabetic adult patients	r=0.62 (p<0.0001)
Ang and Raboca, 2014	Philippines	High-risk adult patients	r=0.74 (p<0.0001)
Pie et al., 2018	China	Undergraduates aged 18-25 years	r=0.626 (males); r=0.604 (females) (p<0.05)
Present study	West Bengal, India	Prehypertensive adults	r=0.732 (males); r=0.748 (females) (p<0.0001)

Table 4. Comparison of estimates of ROC curve analysis conducted by different studies in finding NC cut-offs for screening central obesity

Study	Location	Characteristics of population	Sex	Cut-offs	Sensitivity	Specificity	AUC
Pie et al., 2018	China	Undergraduates aged 18-25 years	Males	37.1 cm	76.7%	74.1%	0.835
			Females	32.6 cm	83.3%	87.8%	0.863
Ang and Raboca, 2014	Philippines	High-risk adult patients	Males	40cm	62.07%	90.09%	0.831
			Females	33.8 cm	67.59%	85.56%	
Qureshi et al., 2017	Bangladesh	Adult	Males	35.25 cm	-	-	0.83
			Females	31.25 cm	-	-	0.65
Anothaisintawee et al., 2019	Thailand	Prediabetic adult patients	Males	38 cm	67%	84%	0.8138
			Females	32 cm	79%	73%	0.8180
Present study	India	Prehypertensive adults	Males	37.1 cm	74.42%	64.18%	0.755
			Females	33.8 cm	71.79%	74.72%	0.779

Figure 1. Scatter plot showing association of waist circumference and neck circumference

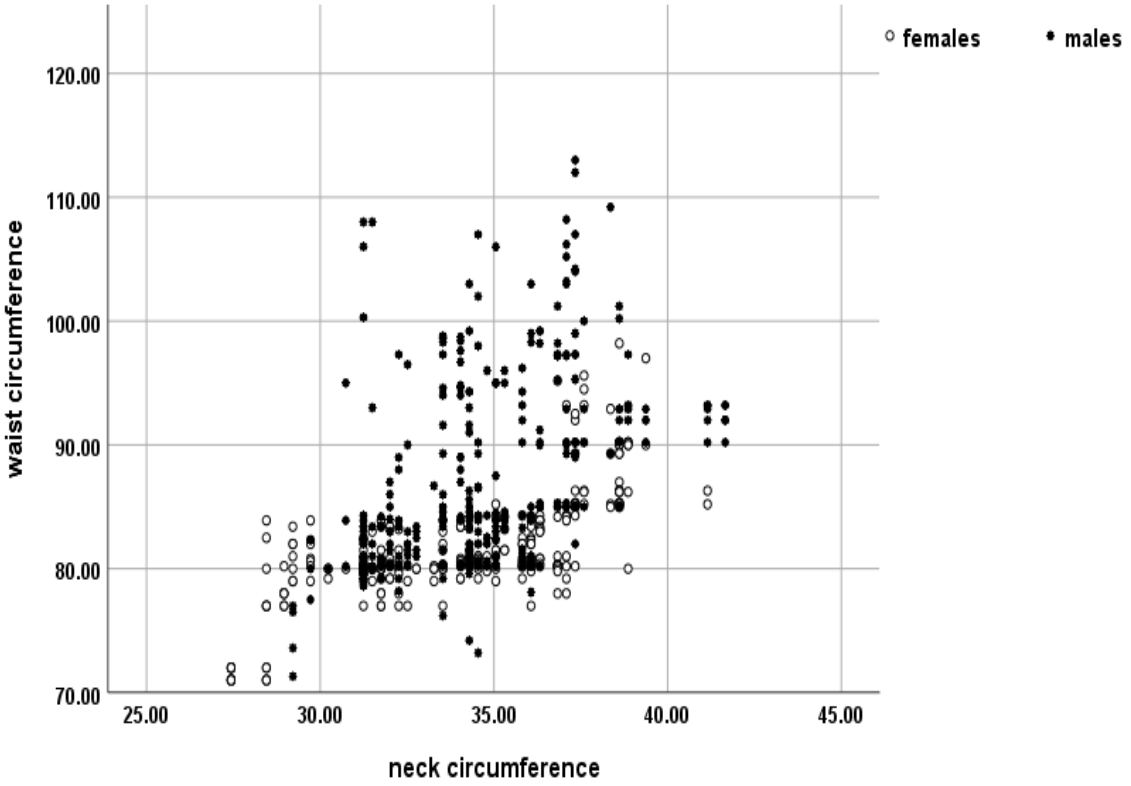
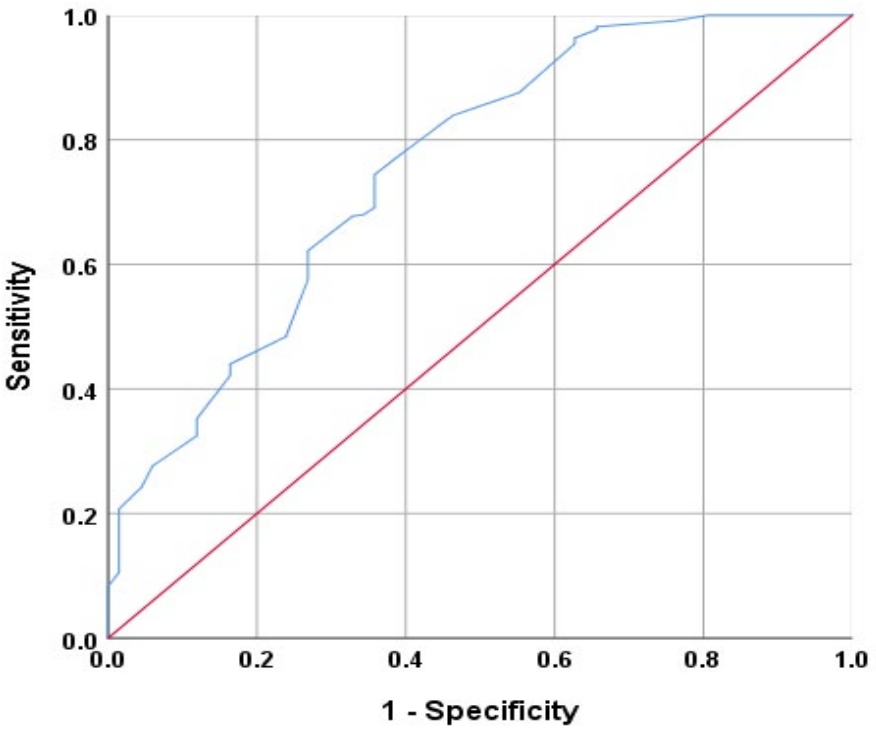


Figure 2. ROC curve analysis to find optimal cut-offs of neck circumference to define central obesity among pre-hypertensive (a) males [AUC=0.755 (95% CI: 0.738-0.773; S.E.: 0.01; p<0.001)] and (b) females [AUC= 0.779 (95% CI: 0.748-0.811; S.E.: 0.01; p<0.001)]

a)



b)