Int J Clin Exp Med 2015;8(10):19107-19113
www.ijcem.com /ISSN:1940-5901/IJCEM0008329

Original Article

Evaluation of neck circumference as a predictor of central obesity and insulin resistance in Chinese adults

Xuhong Wang[1,2], Ning Zhang[1,2], Caiguo Yu[1,2], Zhili Ji[3]

[1]*Beijing Key Laboratory of Diabetes Prevention and Research, Beijing, China; Departments of* [2]*Endocrinology,* [3]*General Surgery, Beijing Lu He Hospital, Capital Medical University, China*

Received March 23, 2015; Accepted October 14, 2015; Epub October 15, 2015; Published October 30, 2015

Abstract: Objectives: To evaluate whether neck circumference (NC) could be used as a valid and effective method for identifying obesity and insulin resistance (IR) in Chinese adults. Methods: A total of 3307 adults aged 20-65 years were randomly recruited from two communities of Tongzhou, Beijing. Height, weight, waist circumference (WC), hip circumference (HC), neck circumference (NC), blood pressure, fasting plasma glucose (FPG), fasting serum insulin (FINS), total cholesterol (TC), serum triglyceride (TG), High-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C) and Urinary albumin (UAlb) were measured. Pearson correlation coefficient was used to explore the relationship between NC and other measurements. Furthermore, the best cutoff values of NC for central obesity identification were determined by applying the receiver operating characteristic (ROC) curve analysis. Results: NC correlated positively with BMI, SBP and WC In both sexes. Both WC and NC correlated significantly positively with IR. A positive correlation between NC and FPG as well as a negative correlation between NC and HDL were found in obese men. NC≥38.5 cm for men and ≥34.5 cm for women were determined to be the best cutoff levels for identifying subjects with central obesity, with 82.9% accuracy for men and 79.9% accuracy for women. Conclusions: NC correlated positively with BMI and WC in both genders, indicating that NC could be used as a valid marker for both overall obesity and central obesity. In addition, measuring NC was shown to be a useful test for IR identification. Large number of NC is suggested to be associated with high risk of developing metabolic disorders, such as diabetes and dyslipidemia.

Keywords: Neck circumference, predictor, central obesity, insulin resistance

Introduction

Obesity has become a health epidemic all over the world, the definition and classification of which are constantly changing with relevant studies in depth. The body mass index (BMI, weight divided by the square of height, kg/m^2) is found with correlation of the amount of body fat, and widely used to define overweight and obesity [1, 2]. However, BMI does not directly measure body fat, or even implicate the distribution of fat in that the criteria using BMI for obesity determination varies in different populations [3-5]. Jean Vague first brought up the idea that body shape and/or fat distribution correlate with obesity in 1956 [6]. Following his thought, numerous methods, with the combination of BMI or not, have been developed to better define obesity in different populations, such as waist circumference (WC), waist/hip ratio, mid-upper arm circumference, subscapular/triceps ratio and neck circumference (NC) [7, 8].

NC measurement has been proved as a simple screening method to identify overweight and obese people in the Israeli population, which indicates upper body fat distribution and onset of central obesity [9, 10]. It is also documented that NC, as another predictor of visceral obesity, is more significantly associated with insulin resistance (IR) than WC in the European population [11]. However, whether NC can be a valid indicator for identifying central obesity and IR has not been investigated in the Chinese population.

In the current study, we demonstrated that measuring NC is also a practical and effective way to identify people with central obesity and IR in both Chinese men and women. Further-

Table 1. General characteristics of study subjects

	Normal-weight		Overweight		Obese	
	Male (n=383)	Female (n=664)	Male (n=475)	Female (n=887)	Male (n=286)	Female (n=612)
BMI (kg/m²)	21.8±1.5	21.8±1.6	26.9±1.1	26.0±1.1	30.7±3.0	30.9±3.2
NC (cm)	36.9±7.5	34.1±2.1	39.7±73.6	36.1±4.3	42.1±3.3	38.5±4.9
WC (cm)	84.1±7.5	80.9±7.4	93.9 ±6.1	90.3±6.9	103.4±8.4	100.0±9.1
HC (cm)	94.0±6.1	92.8±6.0	100.6±5.8	99.6±6.2	107.5±8.4	107.9±8.2
FPG (mmol/L)	5.4±1.7	5.2±1.5	5.6±1.8	5.2±1.6	5.9±1.9	5.7±1.9
FINS (mIU/L)	32.1±42.1	43.2±42.0	48.3±36.2	56.9±39.7	90.5±26.8	72.5±46.4
TC (mmol/L)	4.8±1.0	4.8±0.9	4.8±6.9	5.1±1.0	4.9±1.0	5.1±1.0
TG (mmol/L)	1.36±1.5	1.4±1.0	2.0±2.0	1.9±2.0	2.6±3.0	2.1±1.8
HDL (mmol/L)	1.5±0.5	1.4±0.3	1.3±0.4	1.4±0.4	1.2± 5.0	1.3±0.7
LDL (mmol/L)	2.8±0.9	2.9±0.8	2.9±0.7	3.1±0.8	3.0±0.7	3.1±0.8
UAlb (μmol/L)	314.0±78.3	238.9±59.2	338.7±84.7	267.0±63.0	350.1±81.9	290.1±72.0
HOMA-IR	8.5±13.4	10.3±15.0	12.5±13.9	14.2±12.6	19.6±22.3	18.7±16.7

Note: BMI, Body Mass Index; NC, Neck Circumference; WC, Waist Circumstance; HC, Hip Circumference; FPG, Fasting Plasma Glucose; FINS: Fasting serum INSulin; TC: Total Cholesterol; TG, Triglyceride; HDL, High-Density Lipoprotein; LDL, Low-Density Lipoprotein; UAlb, Urinary Albumin; HOMA-IR, Homeostatic Model Assessment of Insulin Resistance.

more, we also determined the best cutoff values of NC that would be useful for identifying central obesity and IR among Chinese adults.

Methods

Study population and sampling method

A multistage, stratified, simple random sampling design was used to select participants from 2 neighborhood communities in Tongzhou. The communities were chosen to represent the variety of economic development and geographical distribution. A total of 3307 subjects aged 20-65 years were recruited in the study. Subjects with history of thyroid disorders or neck tumors were excluded.

Data collection

Information on social-demographic characteristics (age, gender, occupation, education level, etc.), physical activity, family history of diabetes, medical history and diet habits was collected by trained interviewers using questionnaires. Physical examination was also done, and height, weight, WC, HC and NC were measured according to the standard protocols of the China Chronic Disease and Risk Factor Surveillance 2010 [12]. BMI was calculated by dividing weight in kilograms by height in meters squared. Blood pressure test was repeated three times after each 5-minute rest at a sitting position and the lowest reading was used in the study. Waist circumference was measured at a midpoint between the lowest rib and iliac crest using a flexible tape, with the subject standing. Hip circumference was measured by wrapping the flexible tape around the greatest circumference of the buttock, with a standing position. Neck circumference was measured below the thyroid cartilage (underneath the Adam's apple in men) in the front, and at the level of the mid cervical spine at the back using a flexible tape, with the subject standing.

Blood samples were collected from all participates to determine FPG, FINS, TC, TG, HDL-C and LDL-C after an overnight fast of 10 hours at least. A HITACHI 7020 automatic biochemical analyzer was used to test the concentration of FPG, TC, TG, HDL and LDL in the blood samples. FINS were determined by radioimmunoassay with the test kit provided by China Institute of Atomic Energy. UAlb was detected via a scattering immunoturbidimetric assay, using an Array 360 CE Protein Analyzer (Beckman Instruments Inc.). The Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) was calculated according to the formula: FPG (mmol/L) x FINS (mIU/L) / 22.5.

Diagnostic criteria

According to the criteria in 2000 China Health and Nutrition Survey [13], normal weight was defined as BMI between 18.5 kg/m^2 and 24.0 kg/m^2. Overweight was defined as BMI between

Table 2. Relationship between NC and other anthropometric measurements by gender

Variable	NC (cm)			
	Men		Women	
	r	*P*	*r*	*P*
BMI (Kg/m^2)	0.52	<0.01	0.41	<0.01
WC (cm)	0.49	<0.01	0.32	<0.01
SBP (mmHg)	0.20	<0.01	0.13	<0.01

Note: BMI, Body Mass Index; WC, Waist Circumstance; SBP, Systolic Blood Pressure.

Table 3. Relationship between HOMA-IR and NC/WC by gender

Variable	HOMA-IR			
	Men		Women	
	r	*P*	*r*	*P*
NC (cm)	0.18	<0.01	0.29	<0.01
WC (cm)	0.24	<0.01	0.47	<0.01

Note: HOMA-IR, Homeostatic Model Assessment of Insulin Resistance; NC, Neck Circumference; WC, Waist Circumstance.

Table 4. Relationship between NC and other anthropometric measurements by gender

Variable	NC (cm)			
	Men		Women	
	r	*P*	*r*	*P*
FPG (mmol/L)	0.25	<0.01	0.06	>0.01
HDL (mmol/L)	-0.12	<0.05	-0.01	>0.01

Note: NC, Neck Circumference; FPG, Fasting Plasma Glucose; HDL, High-Density Lipoprotein.

24.0 kg/m^2 and 28 kg/m^2. And obesity was defined as BMI of 28 kg/m^2 or higher. Central obesity was defined as waist circumference of 85 cm or larger in males and 80 cm or larger in females [5].

Statistical analysis

All the continuous variables were presented as mean ± standard deviation. Pearson correlation coefficient was used to explore the relationship between NC and other anthropometric measurements. For the purpose of normal distribution, logarithmic transformation was applied to HOMA-IR in all statistical analyses. Receiver operator characteristic (ROC) curve analysis was performed to determine the accuracy of NC in predicting central obesity and to find out the optimal cutoff values for identifying central-obese adults. The maximum value of the Youden's index was used as the criterion for selecting the optimal cutoff values of NC. Two-sided *P* value was used with the significance level of 0.05. All of the analyses were performed with SPSS Statistics 17.0 for Windows (SPSS Inc.).

Results

Of the 3307 study subjects, 1144 subjects were male, and 2163 female. A total of 1047 subject participants were with normal weight, 1362 participants were overweight and 898 were obese. The average BMI for normal-weight, overweight and obese men were 21.8, 26.9 and 30.7, respectively. For women, the numbers were 21.8, 26.0 and 30.9. The average NC was 36.9 cm, 39.7 cm and 42.1 cm for normal-weight, overweight and obese men, and 34.1 cm, 36.1 cm and 38.5 cm for women in the corresponding groups. Normal-weight, overweight and obese men had an average WC of 84.1 cm, 93.9 cm and 103.4 cm. Normal-weight, overweight and obese women had an average WC of 80.9 cm, 90.3 cm and 100.0 cm. As expected, NC, WC, HC, FPG, FINS, TC, TG, LDL, UAlb and HOMA-IR all increased with BMI, and HDL decreased as BMI declined, in both genders (**Table 1**). Subjects with obesity had the highest NC, WC, HC, FPG, FINS, TC, TG, LDL, UAlb, HOMA-IR and the lowest HDL among the three groups.

In both sexes, NC correlated positively with BMI (r=0.52, P<0.01 in men and r=0.41, P<0.01 in women), SBP (r=0.20, P<0.01 in men and r=0.13, P<0.01 in women) and WC (r=0.47, P<0.01 in men and r=0.32, P<0.01 in women) (**Table 2**). Both WC and NC correlated significantly positively with HOMA-IR (WC: r=0.24, P<0.01 in men and r=0.47, P<0.01 in women; NC: r=0.18, P<0.01 in men and r=0.29, P<0.01 in women) (**Table 3**). After stratifying the subjects by BMI and gender, we found a positive correlation between NC and FPG and a negative correlation between NC and HDL in obese men. However, such correlation was not seen in obese women (**Table 4**).

Using the ROC Curve Analysis, NC≥38.5 cm for men and ≥34.5 cm for women were determined to be the best cutoff levels for identifying sub-

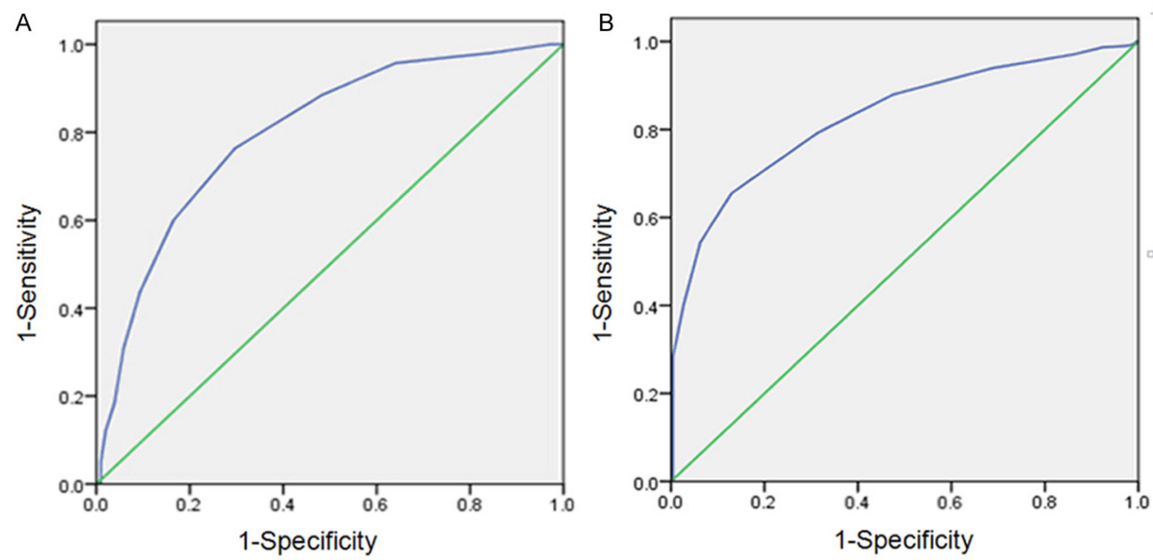

Figure 1. The receiver operating characteristic (ROC) curves for men and women to identify central obesity. A. ROC curve for NC in women. B. ROC curve for NC in men. NC, neck circumference.

jects with central obesity (WC≥85 cm for men and ≥80 cm for women), with 82.9% accuracy for men and 79.9% accuracy for women (AUC was 0.829 for men and 0.799 for women). The ROC curves for men and women were shown in **Figure 1A**, **1B**, separately.

Discussion

Various methods are available for identifying obesity, such as BMI, waist and waist-hip ratio. Among those methods, WC was used as the most common index to determine central obesity. However, WC alone as the criterion of central obesity is inadequate to tell whether it is caused by abdominal subcutaneous adipose tissue or visceral adipose tissue. The visceral adipose tissue mass, instead of the subcutaneous adipose tissue mass, was significantly correlated with IR, type 2 diabetes and cardiovascular diseases, demonstrated by previous studies [14-17]. In addition, upper-body subcutaneous adipose tissue, estimated by NC, was also found to be associated with type 2 diabetes and IR [18, 19]. Therefore, in addition to WC, NC could also be used as a simple, quick method for identifying obesity and insulin resistance. Our study confirmed this conclusion by demonstrating the positive correlation between HOMA-IR and both WC and NC in both genders.

In this study, NC correlated well with other anthropometric measurements in identifying overweight and obese population. NC correlated positively and significantly with BMI and WC in both genders, indicating that NC could be used as a valid marker for both overall obesity and central obesity. In addition, the correlation between NC and HOMA-IR was stronger in women than that in men, which may be related with the gender difference in fat metabolism [20]. Moreover, NC correlated positively with FPG and negatively with HDL in obese men, indicating a higher risk of developing metabolic disorders in that population. However, similar correlation was not found in obese women. Further studies are needed to explore this issue.

Based on our analyses, we determined NC≥ 38.5 cm for men and ≥34.5 cm for women as the best cutoff values for identifying the subjects with central obesity, with 82.9% accuracy for men and 79.9% accuracy for women. These results were slightly different from the cutoff values reported by a recent study in China. According to the study, NC≥37 cm for men and ≥35 cm for women were the best cutoff values for identifying population with central obesity. This discrepancy may be explained by the use of different study subjects. The participants were selected randomly from two communities in this study while a group of diabetes patients were recruited in the study mentioned above.

Disclosure of conflict of interest

None.

Address correspondence to: Zhili Ji, Department of General Surgery, Beijing Lu He Hospital, Capital Medical University, 82, South Xinhua Road, Tongzhou District, Beijing 101149, China. E-mail: jizhili@medmail.com.cn

References

[1] Brodie DA. Techniques of measurement of body composition. Part I. Sports Med 1988; 5: 11-40.

[2] Deurenberg P. Methods for determining fat mass and fat distribution. Acta Paediatr Suppl 1992; 383: 53-7; discussion 58.

[3] Sturm R. Increases in morbid obesity in the USA: 2000-2005. Public Health 2007; 121: 492-6.

[4] Kanazawa M, Yoshiike N, Osaka T, Numba Y, Zimmet P, and Inoue S. Criteria and classification of obesity in Japan and Asia-Oceania. World Rev Nutr Diet 2005; 94: 1-12.

[5] Zhou BF; Cooperative Meta-Analysis Group of the Working Group on Obesity in China. Predictive values of body mass index and waist circumference for risk factors of certain related diseases in Chinese adults--study on optimal cut-off points of body mass index and waist circumference in Chinese adults. Biomed Environ Sci 2002; 15: 83-96.

[6] Vague J. The degree of masculine differentiation of obesities: a factor determining predisposition to diabetes, atherosclerosis, gout, and uric calculous disease. Am J Clin Nutr 1956; 4: 20-34.

[7] Hatipoglu N, Mazicioglu MM, Kurtoglu S, and Kendirci M. Neck circumference: an additional tool of screening overweight and obesity in childhood. Eur J Pediatr 2010; 169: 733-9.

[8] Locke AE, Kahali B, Berndt SI, Justice AE, Pers TH, Day FR, Powell C, Vedantam S, Buchkovich ML, Yang J, Croteau-Chonka DC, Esko T, Fall T, Ferreira T, Gustafsson S, Kutalik Z, Luan J, Mägi R, Randall JC, Winkler TW, Wood AR, Workalemahu T, Faul JD, Smith JA, Hua Zhao J, Zhao W, Chen J, Fehrmann R, Hedman ÅK, Karjalainen J, Schmidt EM, Absher D, Amin N, Anderson D, Beekman M, Bolton JL, Bragg-Gresham JL, Buyske S, Demirkan A, Deng G, Ehret GB, Feenstra B, Feitosa MF, Fischer K, Goel A, Gong J, Jackson AU, Kanoni S, Kleber ME, Kristiansson K, Lim U, Lotay V, Mangino M, Mateo Leach I, Medina-Gomez C, Medland SE, Nalls MA, Palmer CD, Pasko D, Pechlivanis S, Peters MJ, Prokopenko I, Shungin D, Stančáková A, Strawbridge RJ, Ju Sung Y, Tanaka T, Teumer A, Trompet S, van der Laan SW, van Setten J, Van Vliet-Ostaptchouk JV, Wang Z, Yengo L, Zhang W, Isaacs A, Albrecht E, Ärnlöv J, Arscott GM, Attwood AP, Bandinelli S, Barrett A, Bas IN, Bellis C, Bennett AJ, Berne C, Blagieva R, Blüher M, Böhringer S, Bonnycastle LL, Böttcher Y, Boyd HA, Bruinenberg M, Caspersen IH, Ida Chen YD, Clarke R, Daw EW, de Craen AJ, Delgado G, Dimitriou M, Doney AS, Eklund N, Estrada K, Eury E, Folkersen L, Fraser RM, Garcia ME, Geller F, Giedraitis V, Gigante B, Go AS, Golay A, Goodall AH, Gordon SD, Gorski M, Grabe HJ, Grallert H, Grammer TB, Gräßler J, Grönberg H, Groves CJ, Gusto G, Haessler J, Hall P, Haller T, Hallmans G, Hartman CA, Hassinen M, Hayward C, Heard-Costa NL, Helmer Q, Hengstenberg C, Holmen O, Hottenga JJ, James AL, Jeff JM, Johansson Å, Jolley J, Juliusdottir T, Kinnunen L, Koenig W, Koskenvuo M, Kratzer W, Laitinen J, Lamina C, Leander K, Lee NR, Lichtner P, Lind L, Lindström J, Sin Lo K, Lobbens S, Lorbeer R, Lu Y, Mach F, Magnusson PK, Mahajan A, McArdle WL, McLachlan S, Menni C, Merger S, Mihailov E, Milani L, Moayyeri A, Monda KL, Morken MA, Mulas A, Müller G, Müller-Nurasyid M, Musk AW, Nagaraja R, Nöthen MM, Nolte IM, Pilz S, Rayner NW, Renstrom F, Rettig R, Ried JS, Ripke S, Robertson NR, Rose LM, Sanna S, Scharnagl H, Scholtens S, Schumacher FR, Scott WR, Seufferlein T, Shi J, Vernon Smith A, Smolonska J, Stanton AV, Steinthorsdottir V, Stirrups K, Stringham HM, Sundström J, Swertz MA, Swift AJ, Syvänen AC, Tan ST, Tayo BO, Thorand B, Thorleifsson G, Tyrer JP, Uh HW, Vandenput L, Verhulst FC, Vermeulen SH, Verweij N, Vonk JM, Waite LL, Warren HR, Waterworth D, Weedon MN, Wilkens LR, Willenborg C, Wilsgaard T, Wojczynski MK, Wong A, Wright AF, Zhang Q; LifeLines Cohort Study, Brennan EP, Choi M, Dastani Z, Drong AW, Eriksson P, Franco-Cereceda A, Gådin JR, Gharavi AG, Goddard ME, Handsaker RE, Huang J, Karpe F, Kathiresan S, Keildson S, Kiryluk K, Kubo M, Lee JY, Liang L, Lifton RP, Ma B, McCarroll SA, McKnight AJ, Min JL, Moffatt MF, Montgomery GW, Murabito JM, Nicholson G, Nyholt DR, Okada Y, Perry JR, Dorajoo R, Reinmaa E, Salem RM, Sandholm N, Scott RA, Stolk L, Takahashi A, Tanaka T, Van't Hooft FM, Vinkhuyzen AA, Westra HJ, Zheng W, Zondervan KT; ADIPOGen Consortium; AGEN-BMI Working Group; CARDIOGRAMplusC4D Consortium; CKDGen Consortium; GLGC; ICBP; MAGIC Investigators; MuTHER

Consortium; MIGen Consortium; PAGE Consortium; ReproGen Consortium; GENIE Consortium; International Endogene Consortium, Heath AC, Arveiler D, Bakker SJ, Beilby J, Bergman RN, Blangero J, Bovet P, Campbell H, Caulfield MJ, Cesana G, Chakravarti A, Chasman DI, Chines PS, Collins FS, Crawford DC, Cupples LA, Cusi D, Danesh J, de Faire U, den Ruijter HM, Dominiczak AF, Erbel R, Erdmann J, Eriksson JG, Farrall M, Felix SB, Ferrannini E, Ferrières J, Ford I, Forouhi NG, Forrester T, Franco OH, Gansevoort RT, Gejman PV, Gieger C, Gottesman O, Gudnason V, Gyllensten U, Hall AS, Harris TB, Hattersley AT, Hicks AA, Hindorff LA, Hingorani AD, Hofman A, Homuth G, Hovingh GK, Humphries SE, Hunt SC, Hyppönen E, Illig T, Jacobs KB, Jarvelin MR, Jöckel KH, Johansen B, Jousilahti P, Jukema JW, Jula AM, Kaprio J, Kastelein JJ, Keinanen-Kiukaanniemi SM, Kiemeney LA, Knekt P, Kooner JS, Kooperberg C, Kovacs P, Kraja AT, Kumari M, Kuusisto J, Lakka TA, Langenberg C, Le Marchand L, Lehtimäki T, Lyssenko V, Männistö S, Marette A, Matise TC, McKenzie CA, McKnight B, Moll FL, Morris AD, Morris AP, Murray JC, Nelis M, Ohlsson C, Oldehinkel AJ, Ong KK, Madden PA, Pasterkamp G, Peden JF, Peters A, Postma DS, Pramstaller PP, Price JF, Qi L, Raitakari OT, Rankinen T, Rao DC, Rice TK, Ridker PM, Rioux JD, Ritchie MD, Rudan I, Salomaa V, Samani NJ, Saramies J, Sarzynski MA, Schunkert H, Schwarz PE, Sever P, Shuldiner AR, Sinisalo J, Stolk RP, Strauch K, Tönjes A, Trégouët DA, Tremblay A, Tremoli E, Virtamo J, Vohl MC, Völker U, Waeber G, Willemsen G, Witteman JC, Zillikens MC, Adair LS, Amouyel P, Asselbergs FW, Assimes TL, Bochud M, Boehm BO, Boerwinkle E, Bornstein SR, Bottinger EP, Bouchard C, Cauchi S, Chambers JC, Chanock SJ, Cooper RS, de Bakker PI, Dedoussis G, Ferrucci L, Franks PW, Froguel P, Groop LC, Haiman CA, Hamsten A, Hui J, Hunter DJ, Hveem K, Kaplan RC, Kivimaki M, Kuh D, Laakso M, Liu Y, Martin NG, März W, Melbye M, Metspalu A, Moebus S, Munroe PB, Njølstad I, Oostra BA, Palmer CN, Pedersen NL, Perola M, Pérusse L, Peters U, Power C, Quertermous T, Rauramaa R, Rivadeneira F, Saaristo TE, Saleheen D, Sattar N, Schadt EE, Schlessinger D, Slagboom PE, Snieder H, Spector TD, Thorsteinsdottir U, Stumvoll M, Tuomilehto J, Uitterlinden AG, Uusitupa M, van der Harst P, Walker M, Wallaschofski H, Wareham NJ, Watkins H, Weir DR, Wichmann HE, Wilson JF, Zanen P, Borecki IB, Deloukas P, Fox CS, Heid IM, O'Connell JR, Strachan DP, Stefansson K, van Duijn CM, Abecasis GR, Franke L, Frayling TM, McCarthy MI, Visscher PM, Scherag A, Willer CJ, Boehnke M, Mohlke KL, Lindgren CM, Beckmann JS, Barroso I, North KE, Ingelsson E, Hirschhorn JN, Loos RJ, Speliotes EK. Genetic studies of body mass index yield new insights for obesity biology. Nature 2015; 518: 197-206.

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

[10] Ben-Noun LL and Laor A. Relationship between changes in neck circumference and changes in blood pressure. Am J Hypertens 2004; 17: 409-14.

[11] Yang L, Samarasinghe YP, Kane P, Amiel SA, and Aylwin SJ. Visceral adiposity is closely correlated with neck circumference and represents a significant indicator of insulin resistance in WHO grade III obesity. Clin Endocrinol (Oxf) 2010; 73: 197-200.

[12] CCDC, China Chronic Disease and Risk Factor Surveillance 2010. 2010, Chinese Center for Disease Control and Prevention (CCDC): http://ghdx.healthdata.org/record/china-chronic-disease-and-risk-factor-surveillance-2010.

[13] CHNS, China Health and Nutrition Survey 2000. 2000: http://www.phsciencedata.cn/Share/ky_sjml.jsp?id=15883803-f005-408e-b4c9-f13697f5a19f.

[14] Pouliot MC, Despres JP, Nadeau A, Moorjani S, Prud'Homme D, Lupien PJ, Tremblay A, and Bouchard C. Visceral obesity in men. Associations with glucose tolerance, plasma insulin, and lipoprotein levels. Diabetes 1992; 41: 826-34.

[15] Lemieux S, Prud'homme D, Nadeau A, Tremblay A, Bouchard C, and Despres JP. Seven-year changes in body fat and visceral adipose tissue in women. Association with indexes of plasma glucose-insulin homeostasis. Diabetes Care 1996; 19: 983-91.

[16] Fujimoto WY, Bergstrom RW, Boyko EJ, Chen KW, Leonetti DL, Newell-Morris L, Shofer JB, and Wahl PW. Visceral adiposity and incident coronary heart disease in Japanese-American men. The 10-year follow-up results of the Seattle Japanese-American Community Diabetes Study. Diabetes Care 1999; 22: 1808-12.

[17] Banerji MA, Faridi N, Atluri R, Chaiken RL, and Lebovitz HE. Body composition, visceral fat, leptin, and insulin resistance in Asian Indian men. J Clin Endocrinol Metab 1999; 84: 137-44.

[18] Grunfeld C, Rimland D, Gibert CL, Powderly WG, Sidney S, Shlipak MG, Bacchetti P, Scherzer R, Haffner S, Heymsfield SB. Association of upper trunk and visceral adipose tissue volume with insulin resistance in control and HIV-infected subjects in the FRAM study. J Acquir Immune Defic Syndr 2007; 46: 283-90.

[19] Preis SR, Pencina MJ, D'Agostino RB Sr, Meigs JB, Vasan RS, and Fox CS. Neck circumference and the development of cardiovascular disease risk factors in the Framingham Heart Study. Diabetes Care 2013; 36: e3.

[20] Blaak E. Gender differences in fat metabolism. Curr Opin Clin Nutr Metab Care 2001; 4: 499-502.