

REVIEW

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Neck circumference and its association with cardiometabolic risk factors: a systematic review and meta-analysis

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Abstract

Background: Recently, neck circumference (NC) has been used to predict the risk of cardiometabolic factors. This study aimed to perform a systematic review and meta-analysis to examine: (i) the sensitivity (SE) and specificity (SP) of NC to predict cardiometabolic risk factors and (ii) the association between NC and the risk of cardiometabolic parameters.

Methods: A systematic search was conducted through PubMed/Medline, Institute of Scientific Information, and Scopus, until 2017 based on the search terms of metabolic syndrome (MetS) and cardio metabolic risk factors. Random-effect model was used to perform a meta-analysis and estimate the pooled SE, SP and correlation coefficient (CC).

Results: A total of 41 full texts were selected for systematic review. The pooled SE of greater NC to predict MetS was 65% (95% CI 58, 72) and 77% (95% CI 55, 99) in adult and children, respectively. Additionally, the pooled SP was 66% (95% CI 60, 72) and 66% (95% CI 48, 84) in adult and children, respectively. According to the results of meta-analysis in adults, NC had a positive and significant correlation with fasting blood sugar (FBS) (CC: 0.16, 95% CI 0.13, 0.20), HOMA-IR (0.38, 95% CI 0.25, 0.50), total cholesterol (TC) (0.07 95% CI 0.02, 0.12), triglyceride (TG) concentrations (0.23, 95% CI 0.19, 0.28) and low density lipoprotein cholesterol (LDL-C) (0.14, 95% CI 0.07, 0.22). Among children, NC was positively associated with FBS (CC: 0.12, 95% CI 0.07, 0.16), TG (CC: 0.21, 95% CI 0.17, 0.25), and TC concentrations (CC: 0.07, 95% CI 0.02, 0.12). However, it was not significant for LDL-C.

Conclusion: NC has a good predictive value to identify some cardiometabolic risk factors. There was a positive association between high NC and most cardiometabolic risk factors. However due to high heterogeneity, findings should be declared with caution.

Keywords: Neck circumference, Metabolic syndrome, Cardiometabolic risk factors

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Background

Cardiovascular diseases are dominant cause of death across the world [1]. Obesity is an important risk factor for these threats and other cardiometabolic diseases such as diabetes [2].

The association between body mass index (BMI), waist circumference (WC), and waist-to-hip ratio (WHR), indices of general or central obesity, with increased cardiometabolic risk has been proved in numerous studies [2, 3]. However, these measures need calibrated tools such as scale, or vary throughout a day. In contrast, neck circumference (NC) is easy to measure, constant, and time-saving measure to identify overweight and obese individuals [4, 5]. It has also been shown as a tool associated with central obesity [6], hypertension and other components of metabolic syndrome (MetS) [7]. A recent meta-analysis from six studies in children and adolescents showed that NC was moderately associated with BMI [8]. To our knowledge, there has been no meta-analysis on sensitivity (SE) and specificity (SP) of NC to identify cardiometabolic risk factors, so far. Moreover, the association between NC and cardiometabolic risk factors has not been examined in child population. Accordingly, we performed a systematic review on studies which assessed NC in association with cardiometabolic risk factors, and studies which reported SE and SP of NC to identify cardiometabolic risk factors.

Methods

This study was designed as a systematic review on the association of NC and cardio metabolic risk factors. The main related international electronic data sources of PubMed and the NLM Gateway (for MEDLINE), Institute of Scientific Information (ISI), and Scopus searched systematically. For each, strategies were run separately regarding the detailed practical instruction including filters and refining processes. The medical subject headings, Entry Terms and Emtree options were used to reach the most sensitive search.

The strategy developed based on the search terms of MetS, cardio metabolic risk that included all of related components such as glycemic indices including diabetes mellitus, blood glucose, hemoglobin A1c (HbA1c), homeostatic model assessment (HOMA), insulin resistance (IR), lipid profiles including triglycerides (TG), low density lipoprotein (LDL), high density lipoprotein cholesterol (HDL-C), total cholesterol (TC), anthropometric measures including body mass index (BMI), waist circumference (WC), NC, overweight, generalized and abdominal obesity, and blood pressure (BP) including systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and their sub-components. At next stage these queries added to results for

NC. Data refined for human subject without restriction on language.

We excluded papers of non-population-based studies or those with duplicate citation. For multiple publications of the same population, only the article with largest sample size was included.

The bibliographic information of searched studies saved using Endnote software and four independent reviewers completed all three steps of data refinement, including titles, abstracts and full texts review. Possible disagreements were resolved by third reviewer (M.Qh).

Using Cohen's kappa statistic, agreement between the results of data extraction of two experts (Sh.D, P.Ch) was 0.94. Data were collected through standard forms which contained author's name, publication year, location, and type of study, sample size, age range, sex, measurements details, and interested outcomes.

Risk of bias assessment

Risk of bias for studies which reported diagnostic accuracy of NC for predicting cardiometabolic risk factors was assessed using "quality assessment of diagnostic accuracy studies 2" (QUADAS2) checklist. This checklist includes four main methodological domains of study (sample selection, index test, gold standard, process and timing). According to this checklist studies were categorized as "low risk of bias", "high risk of bias" and "unclear". The quality assessment of observational studies which assessed association between NC and cardiometabolic risk factors was assessed using the Newcastle–Ottawa checklist which is adapted for types of study (cross sectional, case–control, cohort). In this checklist, each study can attain 9 scores for its quality. Four scores for the selection of study groups, two scores for the comparability of the groups, and three scores for the assessment of outcomes. A study with a Newcastle–Ottawa scale score of ≥ 6 was considered as high quality study. Three authors (H.A, M.Z, A.M) independently evaluated the included studies. A third author (M.M) resolved any disagreements between them.

Ethical considerations

The protocol of study was approved by the ethical committee of Alborz University of Medical Science. All reviewed studies were properly cited. For more information about a certain study, we contacted the corresponding authors.

Statistical analysis

The results of diagnostic accuracy of NC to identify MetS was presented as SE, SP and the area under the curve (AUC). The overall (pooled) SE and of SP of NC to identify MetS according to sex and age groups

(pediatric and adult) was estimated using random effect meta-analysis method (using the Der-Simonian and Laird method). Forest plot also was used to present result of meta-analysis schematically.

To examine the overall correlation between NC and cardiometabolic risk factors, when r Pearson was reported a mean transformed correlation using r -to- z transformation procedure was used to obtain Fisher's Z . The standard error was also calculated based on the variance of Fisher's Z . Spearman was also converted Pearson correlation coefficients, using the following formula:

$$r(\text{Pearson}) = 2 * \sin(r(\text{Spearman}) * \pi/6)$$

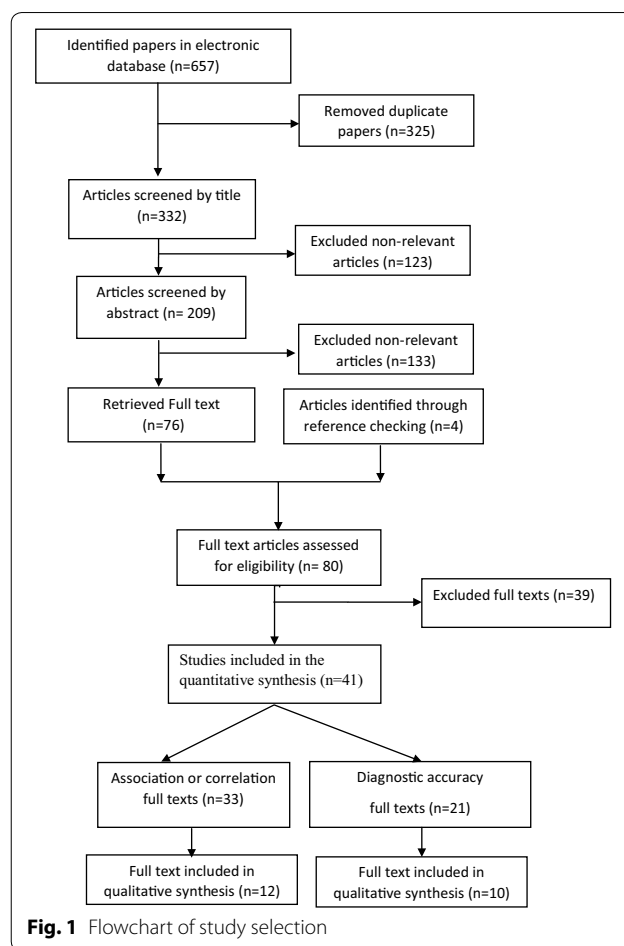
We used Der Simonian and Laird method to pool the correlation coefficients (CC). Between-study heterogeneity was assessed using the I^2 statistic and I^2 more than 50% considered as high heterogeneity. Findings were reported separately for adults and children. When the heterogeneity was high, we stratified the studies according to mean age (more or less than 48 years), sex (men, women, both) and continent (Asian, non-Asian) in adult populations. As the range of age in children was similar among the included studies, only sex and continent was considered for subgroup analysis. Stratification was performed when at least two studies were in each sub group. To assess publication bias when there were more than 10 effect sizes, funnel plots and Begg test was used. However, publication bias for variables with less than 10 effect sizes was examined using Egger test. P -value < 0.05 value was considered statistically significant. All statistical analyses were performed with Stata version 12.0 (STATA Corp, College Station, TX, USA).

Results

Figure 1 shows the selection process of articles. In total, 657 records were obtained using searching through PubMed and the NLM Gateway (for MEDLINE), ISI, and Scopus. Subsequently, 325 duplicates were removed. Articles were screened by title and abstract. In addition, 4 articles were identified through reference checking. A total of 80 full texts were assessed for eligibility and finally, 41 articles were selected. The topic of target studies were categorized as follow:

- i) Studying diagnostic accuracy of high NC for prediction cardiometabolic risk factors (n = 21).
- ii) Studying association between NC and cardiometabolic risk factors (n = 33).

Some studies addressed both of these topics.



Results of qualitative synthesis

A-1: The diagnostic accuracy of high NC to predict cardiometabolic risk factors

A total of 21 articles (including 18 cross-sectional and 3 case-control studies) had reported SE and SP of NC for prediction of cardiometabolic risk factors. They were published between 2010 and 2016 in different countries: China (n=4), Brazil (n=3), USA (n=3), India (n=3), and 1 article in Colombia, Ukraine, Europe, Turkey, Canada, and Egypt. Eleven studies included children and adolescents and the other 10 ones assessed adults (Table 1).

The highest SE values of NC for prediction of MetS was 100 in children and 80 in adults. The maximum SP was 89.5 in children and 91 in adults. The SE values to predict overweight/obesity ranged from 34 to 97 in children, and the SP was between 50 and 94. Only 2 studies included adults [9, 10] wherein SE was between 62 and 87 in men, and 68 and 80 in women. SP was between 62 and 74 in men, and between 65 and 74 in women. In 2 studies which reported SE and SP of NC in the prediction of abdominal obesity [10, 11], SE ranged from 56.1 to

Table 1 Characteristics of the included studies which assessed diagnostic value of high neck circumference to predict cardiometabolic risk factors

Study	Type of study	Country	Target population	Sample size	Sex ratio (M/F)	Age year	Outcome	Diagnostic criteria	Cut-off values for high NC	Age-sex group	SE % (95% CI)	SP % (95% CI)	AUC (95% CI)
Silva, et al [15]	Cross-sectional	Brazil	Healthy	388	169/219	10-19	Insulin resistance	HOMA1-IR \geq 3.87 and HOMA1-IR \leq 4.19 for females. HOMA1-IR \geq 3.85 and HOMA1-IR \geq 3.77 for males	Prepubertal females: > 32.0 cm Pubertal females: > 34.1 cm	Prepubertal females	76.92 (46.2-94.7)	77.50 (61.5-89.1)	0.84 (0.72-0.97)
Goncalves et al. [12]	Cross-sectional	Brazil	Healthy	260	129/131	10-14	BP	High BP: > 95th percentile	Total: 30.2 cm, Male: 30.5 cm, Female: 29.9 cm	Total	80.0	78.4	0.807 (0.754-0.854)
										Female	100.0	69.5	0.908 (0.844-0.951)
										Male	85.7	71.3	0.747 (0.663-0.819)
										Male	54.6	86.4	0.70 (0.613-0.777)
										Both sexes	61.9	59.3	0.616 (0.554-0.676)
	Female	64.5	64.0	0.645 (0.557-0.727)									
	Both sexes	72.7	57.3	0.703 (0.643-0.757)									
	Female	95.7	36.1	0.659 (0.571-0.739);									
	Male	100.0	74.0	p < 0.05 0.902 (0.837-0.947);									
				p < 0.001									

Table 1 (continued)

Study	Type of study	Country	Target population	Sample size	Sex ratio (M/F)	Age year	Outcome	Diagnostic criteria	Cut-off values for high NC	Age-sex group	SE % (95% CI)	SP % (95% CI)	AUC (95% CI)
Torriani et al. [37]	Cross-sectional	USA	Subjects with treated malignancies	303	152/151	18–91	Diabetes	Fasting glucose ≥ 100 mg/dL		Total	0.800	67.5	0.682 (0.621–0.738); $p < 0.001$
							Excess body fat	Body fat 15–25% for females and 10–20% for males		Female	100.0	75.8	0.827 (0.751–0.887); $p < 0.001$
										Total	64.0	65.1	67.6 (0.615–0.733); $p < 0.001$
										Female	67.6	66.7	0.711 (0.625–0.786); $p < 0.001$
										Male	75.0	60.7	0.728 (0.643–0.803); $p < 0.001$
							MetS	NCEP Adult Treatment Panel III	43.6 cm in men and 38.6 cm in women	Male	74 (60, 85)	80 (66, 90)	0.79 (0.70, 0.86)
Formisano et al. [23]	Cross-sectional	Italy, Belgium, Cyprus, Estonia, Germany, Hungary, Spain and Sweden	Healthy	15673	7962/7711	3–10	CMetS	The components used to calculate cMetS score were the same risk factors used in the adult MetS definition. cMetS score > 90 th percentile was considered unfavorable	Male 26.25	Female	74 (60, 85)	91 (80, 97)	0.85 (0.76, 0.91)
										Male 3–4 years	47.5	89.5	0.713 (0.622–0.804)
										4–5 years	58.5	86.4	0.805 (0.740–0.871)

Table 1 (continued)

Study	Type of study	Country	Target population	Sample size	Sex ratio (M/F)	Age year	Outcome	Diagnostic criteria	Cut-off values for high NC	Age-sex group	SE % (95% CI)	SP % (95% CI)	AUC (95% CI)
									27.10	5-6 years	82.0	78.6	0.874 (0.820-0.928)
									27.60	6-7 years	83.2	79.9	0.895 (0.856-0.934)
									28.30	7-8 years	79.6	80.3	0.885 (0.848-0.922)
									28.65	8-9 years	88.1	78.0	0.907 (0.872-0.942)
									30.90	9-10 years	71.4	88.1	0.881 (0.772-0.991)
								Female 24.95		Female 3-4 years	63.6	78.6	0.741 (0.662-0.820)
									25.15	4-5 years	81.4	74.4	0.823 (0.764-0.883)
									26.15	5-6 years	75.0	81.0	0.839 (0.772-0.906)
									26.45	6-7 years	94.7	73.8	0.921 (0.884-0.958)
									27.10	7-8 years	88.6	76.3	0.897 (0.862-0.933)
									27.80	8-9 years	93.6	79.0	0.924 (0.898-0.950)
									29.65	9-10 years	1.00	95.0	0.984 (0.955-1.000)
Pillai et al. [27]	Prospective observational cross-sectional	India	Women with PCOS	121	0/121	12-41	MetS	MetS by IDF	33.35	Female	60.3	70.7	0.7 (0.604-0.794)

Table 1 (continued)

Study	Type of study	Country	Target population	Sample size	Sex ratio (M/F)	Age year	Outcome	Diagnostic criteria	Cut-off values for high NC	Age-sex group	SE % (95% CI)	SP % (95% CI)	AUC (95% CI)
Yan et al. [9]	Cross-sectional	China	Healthy	2092	971/1121	> 65	MetS	MetS by ATP III	33.87	Female	73	69	0.722 (0.631–0.816)
Kurtoglu et al. [24]	Case-control	Turkey	Healthy	581	259/322	5–18	MetS	IDF criteria	38 cm in men and	Male	80	55	0.76
									35 cm in women	Female	75	67	0.73
Cizza et al. [38]	Cross-sectional	USA	Obese	120	28/92	18–50	MetS	IDF criteria	38 cm in men and	Male	87	62	NR
									35 cm in women	Female	80	74	0.766 (0.689–0.882)
de Lucena-Ferretti et al. [20]	Cross-sectional	Brazil	Healthy	1667	751/916	10–17	Overweight	WHO criteria	36 cm in boys and	Male	61.9	85.6	0.766 (0.689–0.882)
									35 cm in girls	Female	60.4	78.15	0.749 (0.683–0.808)
Yang et al. [10]	Cross-sectional	China	Type 2 diabetic patient	3182	1294/1888	20–80	MetS	Chinese Diabetes Society criteria	NO 38 cm	Female	0.54	0.70	0.63
									> 34.25 in boys and > 31.25 in girls	Male	53.3	72.8	0.690 (0.649–0.730)
Yang et al. [10]	Cross-sectional	China	Type 2 diabetic patient	3182	1294/1888	20–80	MetS	Chinese Diabetes Society criteria	> 37.95 in boys and > 32.65 in girls	Male	34.2	94.5	0.712 (0.654–0.770)
									NC 39 cm for men and 35 cm for women	Female	63.8	90.9	0.815 (0.754–0.877)
Yang et al. [10]	Cross-sectional	China	Type 2 diabetic patient	3182	1294/1888	20–80	MetS	Chinese Diabetes Society criteria	NC 39 cm for men and 35 cm for women	Male	42.8	83.8	0.67 (0.63–0.70); p<0.001
									NC 37 cm for men and 35 cm for women	Female	60.0	66.5	0.66 (0.63–0.70); p<0.001
Yang et al. [10]	Cross-sectional	China	Type 2 diabetic patient	3182	1294/1888	20–80	MetS	Chinese Diabetes Society criteria	Central obesity	Male	65.1	73.6	0.77 (0.72–0.82); p<0.001
									WC ≥ 85 cm for men and ≥ 80 cm for women	Female	60.0	66.5	0.66 (0.63–0.70); p<0.001

Table 1 (continued)

Study	Type of study	Country	Target population	Sample size	Sex ratio (M/F)	Age year	Outcome	Diagnostic criteria	Cut-off values for high NC	Age-sex group	SE % (95% CI)	SP % (95% CI)	AUC (95% CI)
Zepeda et al. [39]	Cross-sectional	USA	Healthy	1058	561/497	6–18	Overweight	BMI \geq 24 kg/m ²	NC 38 cm for men and 35 cm for women	Female	64.0	75.9	0.75 (0.72–0.78); p < 0.001
Katz et al. [40]	Cross-sectional	Canada	Healthy	1913	977/936	6–17	High BP	Systolic and/or diastolic BP \geq 95th percentile for age, sex and height	NC > 90 th	Male Female	NR	NR	0.72 (0.69–0.75); p < 0.001 0.73 (0.70–0.75); p < 0.001
Lou et al. [41]	Cross-sectional	China	Healthy	2847	1475/1372	7–12	Overweight/obesity	BMI > 85th percentile CDC	NC > 50th percentile Boys: 25.3–35.5 cm Girls: 24.8–30.5 cm	Total	0.970	0.500	0.75 (0.70–0.81) 0.72 (0.63–0.75) 0.884
							Overweight/obesity	BMI \geq 85th	Boys: 27.4–31.3 cm Girls: 26.3–31.4 cm	Male Female Total	0.803	0.847	NR
Selvan et al. [13]	Cross-sectional	India	Healthy	451	258/193	30–80	MetS	NCEPATP III	> 34.9 cm for men > 31.25 cm for women	Male Female	0.846 0.819	0.843 0.845	0.753 (0.694–0.813) 0.768 (0.687–0.849)
							Type 2 DM	NR	NR	Male Female	NR	NR	0.453 (0.382–0.5324) 0.439 (0.357–0.520)
							Hypertension	NR	NR	Male Female	NR	NR	0.535 (0.465–0.606) 0.501 (0.416–0.586)

Table 1 (continued)

Study	Type of study	Country	Target population	Sample size	Sex ratio (M/F)	Age year	Outcome	Diagnostic criteria	Cut-off values for high NC	Age-sex group	SE % (95% CI)	SP % (95% CI)	AUC (95% CI)
Hatipoglu et al. [25]	Case-control	Turkey	Overweight/ obese children and healthy ones as control	967	475/492	6-18	High TG	BMI ≥ 85th percentile of the BMI reference curve according to local references	Boys: pre-pubertal 29.0 and pubertal 32.5 cm Girls: pre-pubertal 28.0 and pubertal 31.0 cm	Prepubertal male	86.36	82.58	0.889
											(78.5-92.2)	(75.0-88.6)	(0.843-0.926)
Atwa et al. [42]	Cross-sectional	Egypt	Healthy	2762	1327/1435	12-15	Overweight/obesity	BMI > 85th CDC	Men: 29.3-32.3 cm Women: 28.6-30.8 cm	Male Female Total	80.85	76.26	0.877
											(71.4-88.2)	(68.3-83.1)	(0.828-0.916)
											78.95	85.15	0.884
											(68.1-87.5)	(76.7-91.4)	(0.828-0.927)
Luo et al. [11]	Cross-sectional	China	Healthy	1943	783/1160	58 ± 7	MetS	≥ 2 metabolic disorders But without abdominal obesity	NC > 38.5 cm for men NC > 34.5 cm for women	Male Female	83.33	81.42	0.896
											(75.9-89.2)	(75.0-86.8)	(0.857-0.928)
											0.927	0.806	NR
											0.928	0.670	NR
Luo et al. [11]	Cross-sectional	China	Healthy	1943	783/1160	58 ± 7	MetS	≥ 2 metabolic disorders But without abdominal obesity	NC > 38.5 cm for men NC > 34.5 cm for women	Male Female	50.53	67.74	NR
											(45.93-55.12)	(62.23-72.92)	
											48.95	74.85	
											(44.37-53.54)	(71.43-78.07)	
Luo et al. [11]	Cross-sectional	China	Healthy	1943	783/1160	58 ± 7	MetS	≥ 2 metabolic disorders But without abdominal obesity	NC > 38.5 cm for men NC > 34.5 cm for women	Male Female	56.1	83.5	0.781
											58.1	82.5	0.777

Table 1 (continued)

Study	Type of study	Country	Target population	Sample size	Sex ratio (M/F)	Age year	Outcome	Diagnostic criteria	Cut-off values for high NC	Age-sex group	SE % (95% CI)	SP % (95% CI)	AUC (95% CI)
			Diabetes				Diabetes	FPG \geq 6.10 mmol/L and (or) a 2hPG \geq 7.80 mmol/L, and (or) previously diagnosed diabetes		Male	46.33 (41.33–51.38)	59.79 (54.73–64.71)	NR
										Female	43.64 (39.12–48.25)	71.08 (67.53–74.44)	
											48.88 (44.58–53.20)	68.98 (62.78–74.71)	NR
			High BP				High BP	SBP \geq 130 mmHg, and (or) DBP \geq 85 mmHg, and (or) previously diagnosed hypertension serum TG $>$ 1.70 mmol/L		Male	48.88 (44.58–53.20)	68.98 (62.78–74.71)	NR
										Female	42.94 (39.17–46.78)	76.18 (72.14–79.90)	
											52.82 (47.01–58.58)	62.66 (58.17–66.99)	NR
			High TG				High TG	Serum TG \geq 1.70 mmol/L		Male	52.82 (47.01–58.58)	62.66 (58.17–66.99)	NR
										Female	50.73 (45.29–56.16)	71.67 (68.45–74.74)	
											51.45 (44.95–57.92)	60.33 (56.07–64.48)	
Khalangot et al. [14]	Cross-sectional	Ukraine	Healthy (not registered as T2D patients)	196	46/150	>44	DM	HbA1c \geq 6.5%	NO 36.5 cm for women and > 38.5 cm for men	Female	72.2 (46.5–90.3)	62.3 (53.4–70.7)	0.690 (0.815–0.564)
										Male	100 (54.1–100)	38.5 (23.4–55.4)	0.774 (0.682–0.866)
										Total	50.0	76.0	70
Kumar et al. [26]	Cross-sectional	India	Patients who attended medicine clinic in a tertiary care KMC hospital	431	250/181	Males > 35 and females > 40	MetS	ATP 111	Total: 36.5cms Female: 34 Male: 37				

Table 1 (continued)

Study	Type of study	Country	Target population	Sample size	Sex ratio (M/F)	Age year	Outcome	Diagnostic criteria	Cut-off values for high NC	Age-sex group	SE % (95% CI)	SP % (95% CI)	AUC (95% CI)
Gomez-Arbelaez et al. [16]	Cross-sectional	Colombia	Healthy	669	351/318	8–14	MetS	Modified NHANES	29 cm in boys and 28.5 cm in girls	Male	100	45.37	0.74 (0.68–0.78)
										Female	87.50	53.61	0.73 (0.68–0.78)
										Male	52.54	61.19	0.54 (0.49–0.59)
										Female	50.00	62.35	0.57 (0.51–0.62)

NC neck circumference, HOMA homeostatic model assessment, IR insulin resistance, HOMA-IR Homeostasis Model Assessment-Insulin Resistance, HDL-C high density lipoprotein-cholesterol, NCEP National Cholesterol Education Program criteria, cMetS continuous metabolic syndrome, CDS Chinese Diabetes Society, CDC Centers for Disease Control and Prevention, IDF International Diabetes Federation, MetS metabolic syndrome, BMI body mass index, WHO World Health Organization, VFA visceral fat area, DM diabetes mellitus, FBS fasting blood glucose, HbA1c hemoglobin A1c, TG triglycerides, LDL low density lipoprotein, TC total cholesterol, WC waist circumference, BP blood pressure, NR not reported

68.8 and SP ranged from 65.4 to 83.5. In 2 studies which reported SE and SP of NC for prediction of hypertension among children and adolescents, maximum SE and SP were 85 and 71 in boys and 100 and 69 in girls [12]. Only 3 studies assessed SE and SP of NC for the prediction of high TG and low HDL-C [11–13] wherein the highest values of SE and SP were 62 and 71, respectively.

Among 4 studies which assessed SE and SP of NC for prediction of type 2 diabetes [11–14], the maximum values of SE and SP was 80 and 67 in children [12], and 100 and 72 in adults. In studies which assessed insulin resistance [12, 15, 16], two studies reported a SE of 100 in boys, and 50 to 95 in girls. The SP was 42 to 74 in boys, and 36 to 84 in girls.

According to QUADAS-2 checklist, the study methods of all diagnostic accuracy studies met all QUADAS-2 items. However, three studies were classified as “unclear risk” in the domain of “patient selection” (third question of the first domain) [11, 15, 16]. One studies were classified as “high risk” in the first question of the first domain (random sampling method) [9]. Totally, 83.33% of the studies were considered as high quality (low risk of bias) and 91.66% were classified as low concern according to the QUADAS-2 checklist.

A-2: Association between NC and cardiometabolic risk factors

Articles which assessed association between NC and cardiometabolic risk factors were categorized into two sections: articles which assessed cardiometabolic risk factors as binary variables and reported odds ratio (OR) or relative risk (RR) in logistic regression analysis (Table 2), or articles which assessed cardiometabolic risk factors as continuous variables and reported correlation coefficient or Beta coefficient in correlation or linear regression analysis (Table 3).

Table 2 lists characteristics of studies reporting OR/RR of high NC and the risk of cardiometabolic risk factors ($n=13$). Most of them were designed as cross-sectional ($n=10$) and the rest as case-control ($n=2$) or cohort ($n=1$). The studies were carried out in different countries including China ($n=3$), Brazil ($n=3$), Greece ($n=2$), and one study in Ukraine, USA, Iran, Lithuania, and South Korea. In 6 studies, children and adolescents were included, and 7 reports were on adult populations. The articles have been published between 2012 and 2017.

Three studies in adults assessed the OR of high NC in prediction of MetS presence [9, 17, 18]. Among them, Yan et al. found the strongest association between high NC and MetS in both elderly men and women, with ORs of 11.53 and 7.69, respectively [9]. The association between high NC and DM was reported in few studies [9, 14, 18, 19] where in ORs or RRs varied between 1.26 (1.06–1.50) and 2.07 (1.06–4.03).

Three studies reported the association between high NC and obesity. Among children and adolescents, ORs was between 1.07 and 1.70 for the prediction of overweight, and 1.10 to 3.25 for prediction of obesity [20, 21]. Yan et al. found again a strong association between high NC and obesity among elderly men and women, with ORs of 26.26 and 17.16, respectively [9].

In two studies which assessed the association between high NC and high TG [9, 18], the ORs were between 1.16 and 3.06. In regard to high BP, Kuciene et al. [22] found that greater NC was associated with 4 times risk for hypertension. Among adults, Yan et al. [9] found OR of 2.41 and 4.37 in elderly men and women, respectively.

Table 3 shows association studies where both NC and cardiometabolic risk factors were reported continuous variables. A total of 27 studies were found (14 publications included children and adolescents, and 13 studies in adults). Most of them used correlation coefficients, and few ones used beta regression coefficients for statistical analyses. The articles were published between 2010 and 2017. The studies were carried out in different countries including China ($n=6$), India ($n=4$), USA ($n=3$), Turkey ($n=3$), Brazil ($n=2$), Egypt ($n=2$), Greece ($n=2$), and one study in Iran, Canada, Europe, Colombia, and South Korea.

Out of 18 studies which assessed the correlation between NC and BMI, 11 articles included children and adolescents. Significant correlations were found between NC and BMI. The r ranged from 0.38 [21] to 0.88 [12] in adolescents. In adults, r ranged from 0.41 to 0.84 in men and women together.

There was a significant association between WC and NC in all 20 studies (13 reports in children and adolescents, and 8 studies in adults). The r ranged from 0.318 [23] to 0.85 [24, 25] among children and adolescents. In adults, r -values was between 0.45 [26] and 0.75 [27].

Out of 18 studies which reported the correlation between NC and blood pressure, 9 publications were on children and adolescents. A wide range of r was found; from 0.02 [28] to 0.62 [12]. In some studies, the correlation was not significant [13, 28, 29].

Weak correlations was observed between NC and FBS in 12 relevant studies, (r ranged from -0.377 to 0.27 [29, 30]). Eleven studies also reported correlation between fasting insulin, HOMA-IR or both with NC. The r -values for these two variables were very close, ranging from 0.21 to 0.61 [24, 30].

Fourteen studies reported correlation coefficients of blood TC, TG, HDL-C, or LDL-C with NC. Findings of correlation between TC and NC was not conclusive; r -values ranged from -0.27 [12] to 0.302 [24]. Blood TG was positively correlated with NC in all reports [r ranged from 0.06 [12] to 0.409 [24]]. There was negative

Table 2 Characteristics of the included studies which assessed relationship between neck circumference and cardiometabolic risk factors

Study	Country	Type of study	Population	n	Male/fe male	Agey	Diagnostic criteria of outcome	Unit of NC	Sex group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Khalan-got et al. [14]	Ukraine	Cross-sectional	Healthy not registered as T2D patients	196	46/150	>44	HbA1c \geq 6.5%		Both sexes	Gender, BMI	DM	1.43 (1.05–1.96); p=0.024	Adjusted OR (95% CI)	8
Yan et al. [9]	China	Cross-sectional	Healthy	2092	971/1121	>65	According to the 2004 Chinese Diabetes Society (CDS) criteria [1] BMI \geq 25 kg/m ²		Male Female	Age	MetS	11.53 (5.57–23.87) 7.69 (4.91–12.04)	Adjusted OR (95% CI) (Q4/Q1)	7
									Male Female		Obesity	26.26 (11.02–62.57) 17.16 (9.59–30.70)		
									Male Female		HighTG	3.06 (2.06–4.54) 2.01 (1.59–2.56)		
									Male Female		HighBP	2.41 (1.94–3.00) 4.37 (2.81–6.7)		
									Male Female		High FBS	1.89 (1.53–2.34) 1.68 (1.41–2.00)		
Zepeda et al. [39]	USA	Cross-sectional	Healthy	1058	561/497	6–8	Systolic and/or diastolic BP \geq 95th percentile for age, sex and height	NC > 90th percentile	Both sexes	Age, gender and height	High BP	1.59 (1.05–2.40)	Adjusted OR (95% CI)	8
de Luca-Ferrari et al. [20]	Brazil	Cross-sectional	Healthy	1667	751/916	10–17	Overweight and obesity according to the definitions of WHO	\geq 34.25 in boys and \geq 31.25 in girls \geq 37.95 in boys and \geq 32.65 in girls	Both sexes	Sex, age, weight, BMI, WC, pubertal stage, SBP, DBP, % body fat	Over-weight Obesity	1.70 (0.85–3.39) 3.26 (1.00–10.59)	Adjusted OR (95% CI)	7

Table 2 (continued)

Study	Country	Type of study	Population	n	Male/fe male	Agey	Diagnostic criteria of outcome	Unit of NC	Sex group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Pereira et al. [17]	Brazil	Cross-sectional	College students	702	62.7% were women	20–24	NCEP Adult Treatment Panel III	Neck circumference \geq 39 cm for men and \geq 35 cm for women	Both sexes	Sex, age, occupational situation	MetS	5.4 (1.4–22.1)	Adjusted OR (95% CI)	7
Zhou et al. [18]	China	Cross-sectional	Healthy	4201	2508/1693	20–85	MetS according to the IDF criteria Increased TG: (\geq 1.7 mmol/L) Decreased HDL-C (\leq 1.29 mmol/L for women) High BP (SBP > 130 or DBP \geq 85 mmHg) Increased FBS (\geq 5.60 mmol/L)	NC of \geq 37 cm for men and \geq 33 cm for women	Male	Age, BMI, WC and waist to hip ratio	MetS High BP Increased TG Increased FBS MetS	1.29 (1.12–1.48) 1.15 (1.01–1.32) 1.16 (1.02–1.33) 1.26 (1.06–1.50) 1.44 (1.20–1.72)	Adjusted OR (95% CI)	8
Kuciene et al. [22]	Lithuania	Case-control	Case: hypertensive Control: healthy	1947	962/985	12–15	Prehypertension: SBP or DBP \geq 90th and < 95th percentile Hypertension: SBP or DBP \geq 95th percentile	NC at > 90th percentile	Both sexes	Age, sex	High BP Increased TG Increased FBS Decreased HDL-C Prehypertension Hypertension Prehypertension/hypertension	1.22 (1.03–1.46) 1.42 (1.18–1.71) 1.32 (1.06–1.65) 1.29 (1.10–1.51) 2.99 (1.88–4.77) 4.05 (3.03–5.41) 3.75 (2.86–4.91)	Adjusted OR (95% CI)	7

Table 2 (continued)

Study	Country	Type of study	Population	n	Male/fe male	Agey	Diagnostic criteria of outcome	Unit of NC	Sex group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Choet al. [19]	South Korea	Cohort	Healthy	3521	1784/1737	42–71	DM was defined based on the WHO criteria	–1st quartile: men: 35.1 cm Women: 30.7 cm –4th quartile: Men: 40.3 cm Women: 35.2 cm	Male Female	Age, BMI orWC, family history of DM, antihypertensive medication, TG, alanine aminotransferase, hsCRP, PPA, HbA1c, HOMA-IRandIGI, daytime sleepiness	Incidence of diabetes mellitus	1.746 (1.037–2.942) 2.077 (1.068–4.038)	Adjusted RR (95% CI)	8
Guo et al. [43]	China	Cross-sectional	Normal	6802	3631/3171	5–18	According to The Fourth Report on the Diagnosis, Evaluation and treatment of High Blood Pressure in Children and Adolescents	NC ≥ 90th percentile	Normal weight subjects Overweight subjects Obese subjects	Age, gender BMI, WC	Prehypertension	1.439 (1.118–1.853)	Adjusted OR (95% CI)	8
Vallianou et al. [44]	Greece	Cross-sectional	consecutive adults who had visited the 'Pol-ykliniki' General Hospital for a health check-up	490	194/296	18–89	CRP > 0.1 mg/dL	Total	Total	Age and gender years of school, smoking, physical activity status, Diet and alcohol intake	High-SE C-reactive protein	1.161 (0.738–1.826) 0.892 (0.429–1.854) 1.14 (1.05–1.23)	Adjusted OR (95% CI)	7

Table 2 (continued)

Study	Country	Type of study	Population	n	Male/fe male	Agey	Diagnostic criteria of outcome	Unit of NC	Sex group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Kelishadi et al. [21]	Iran	Cross-sectional	School students	23043	11708/11335	6–18	Overweight was considered as BMI between the 85th and 94th centiles for age and sex, obesity as BMI \geq 95th centile; and abdominal obesity as WHtR $>$ 0.5.		Total	Adjusted for age, sex and living area	Over weight General obesity Abdominal obesity	1.07 (1.06–1.08) 1.10 (1.08–1.11) 1.20 (1.18–1.21)	Adjusted OR (95% CI)	7
Zen et al. [45]	Brazil	Case-control	CHD patients	376	242/134	40 years or over	Significant coronary artery disease defined by the presence of stenosis \geq 50% in a major epicardial coronary artery-left anterior descending, circumflex or right coronary artery or their branches with or at least 2.5 mm of diameter	41.6 cm in men and 37.0 cm in women	Total	Age, sex, years at school, smoking, hypertension, HDL-C and diabetes mellitus	Significant coronary stenosis	2.4 (1.1–5.3)	Adjusted OR (95% CI)	7

Table 3 Characteristics of the included studies on correlation between neck circumference and cardiometabolic risk factors

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Kurtoglu et al. [24]	Turkey	Case–control	Healthy	581	259/322	5–18	Prepubertal boys		BMI	$r = 0.759; P < 0.001$	Pearson correlation; n; P-value	7
									SBP	$r = 0.502; P < 0.001$		
									DBP	$r = 0.335; P < 0.001$		
									WC	$r = 0.820; P < 0.001$		
									FBS	$r = 0.172; P = 0.046$		
									Insulin	$r = 0.609; P < 0.001$		
									TC	$r = 0.302; P < 0.001$		
									TG	$r = 0.409; P < 0.001$		
									HDL-C	$r = -0.166; P = 0.056$		
									HOMA-IR	$r = 0.619; P < 0.001$		
							Pubertal boys		BMI	$r = 0.774; P < 0.001$		
									SBP	$r = 0.452; P < 0.001$		
									DBP	$r = 0.472; P < 0.001$		
									WC	$r = 0.833; P < 0.001$		
									FBS	$r = 0.047; P = 0.650$		
									Insulin	$r = 0.325; P < 0.001$		
									TC	$r = 0.467; P < 0.001$		
									TG	$r = 0.380; P < 0.001$		
									HDL-C	$r = -0.304; P < 0.001$		
									HOMA-IR	$r = 0.336; P = 0.001$		
							Prepubertal girls		BMI	$r = 0.783; P < 0.001$		
									SBP	$r = 0.396; P < 0.001$		
									DBP	$r = 0.317; P < 0.001$		
									WC	$r = 0.853; P < 0.001$		
									FBS	$r = 0.210; P = 0.031$		
									Insulin	$r = 0.416; P < 0.001$		
									TC	$r = 0.272; P = 0.005$		

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Silva et al. [15]	Brazil	Cross-sectional	Healthy	388	169/219	10–19	Male	Body fat percent-age and puberty	TG	r = 0.208; P = 0.032	Adjusted Pearson correlation; n; P-value	6
									HDL-C	r = -0.349; P < 0.001		
									HOMA-IR	r = 0.409; P < 0.001		
									BMI	r = 0.778; P < 0.001		
									SBP	r = 0.268; P < 0.001		
									DBP	r = 0.193; P = 0.008		
									WC	r = 0.781; P < 0.001		
									FBS	r = 0.131; P = 0.074		
									Insulin	r = 0.455; P < 0.001		
									TC	r = 0.101; P = 0.170		
									TG	r = 0.201; P = 0.006		
									HDL-C	r = -0.189; P = 0.010		
									HOMA-IR	r = 0.449; P < 0.001		
									BMI Z score	0.58; P < 0.001		
									WC	0.79; P < 0.001		
									SBP	0.47; P < 0.001		
									DBP	0.37; P < 0.001		
FBS	-0.08; P < 0.001											
Fasting insulin	0.29; P < 0.001											
HOMA1-IR	0.29; P < 0.001											
TC	0.08											
LDL-C	0.14											
HDL-C	-0.34; P < 0.001											
TG	0.23; P < 0.01											
BMI Z score	0.48; P < 0.001											
WC	0.64; P < 0.001											
SBP	0.28; P < 0.001											
DBP	0.18; P < 0.01											
FBS	0.08;											

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Age	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Goncalves et al. [12]	Brazil	Cross sectional	Healthy	260	129/131	10–14	Total		Fasting insulin	0.43; P < 0.001		6
									HOMA1-IR	0.41; P < 0.001		
									TC	0.04;		
									LDL-C	0.09;		
									HDL-C	-0.24; P < 0.001		
									TG	0.25; P < 0.001		
									Body fat	0.51; P < 0.001	Pearson correlation; n; P-value	
									WC	0.74; P < 0.001		
									Weight	0.75; P < 0.001		
									BMI	0.88; P < 0.001		
									Waist to height ratio	0.41; P < 0.001		
									WHR	0.14; P < 0.05		
									HOMA-IR	0.35; P < 0.001		
Gomez-Arbelaez et al. [16]	Colombia	Cross-sectional	Healthy	669	351/318	8–14	Total	Age, gender and Tanner stage	Fasting insulin	0.36; P < 0.001		7
									SBP	0.62; P < 0.001		
									DBP	0.29; P < 0.001		
									TC	-0.27; P < 0.001		
									LDL-C	-0.18; P < 0.05		
									HDL-C	-0.27; P < 0.001		
									TG	0.06; P < 0.001		
									FBS	0.815 ± 0.244; P = 0.001	Adjusted Beta ± SE	
									HDL-C	-1.333 ± 0.384; P = 0.001		
									TG	3.887 ± 1.014; P < 0.001		
									SBP	1.719 ± 0.205; P < 0.001		
									DBP	1.305 ± 0.173; P < 0.001		
									Insulin	0.362 ± 0.051; P < 0.001		

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Atwa et al. [42]	Egypt	Cross-sectional	Healthy	2762	1327/1435	12–15	Male		HOMA-IR	0.085 ± 0.011; P < 0.001	Pearson correlation coefficient; p-value	8
Pillai et al. [27]	India	Prospective observational cross-sectional	Women with PCOS	121	0/121	12–41	Female		Weight	r = -0.68; P < 0.001	Pearson correlation coefficients	6
									BMI	r = -0.67; P < 0.001		
									WC	r = -0.72; P < 0.001		
									Weight	r = -0.68; P < 0.001		
									BMI	r = -0.65; P < 0.001		
									WC	r = -0.63; P < 0.001		
Vallianou et al. [44]	Greece	Cross-sectional	Consecutive adults who had visited the 'Polykliniki' General Hospital for a health check-up	490	194/296	18–89	Age, gender, years of school, smoking, physical activity, diet, alcohol intake	SBP	0.97 (0.41–1.54); p = 0.001	Adjusted Beta (95% CI)	7	
								DBP	0.66 (0.31–1.01); P < 0.0001			
								FBS	0.003 (0.001–0.005); p = 0.003			
								HDL-C	-1.37 (-1.77–0.97); p < 0.0001			
								LDL-C	1.15 (-0.05–2.34); p = 0.06			
								TC	1.01 (-0.33–2.35); p = 0.14			
								TG	0.02 (0.01–0.03); p < 0.0001			
								WC	r = -0.78; P < 0.001			
								BMI	r = -0.72; P < 0.001			
								SBP	r = -0.44; P < 0.001			
Zepeda et al. [39]	USA	Cross-sectional	Healthy	1058	561/497	6–18	Male		WC	r = -0.78; P < 0.001	Pearson correlation coefficients; p-value	8

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Luo et al. [11]	China	Cross-sectional	Healthy	1943	783/1160	58 ± 7	Male	Several metabolic and body fat parameters	DBP	r = 0.23; P < 0.001	Adjusted	8
									WHtR	r = 0.25; P < 0.001		
									WC	r = 0.83; P < 0.001		
									BMI	r = 0.71; P < 0.001		
									SBP	r = 0.41; P < 0.001		
									DBP	r = 0.28; P < 0.001		
									WHtR	r = 0.49; P < 0.001		
									Trunk FM	0.444; P < 0.001		
									visceral fat area	0.138; P < 0.001		
									Subcutaneous fat area	0.208; P < 0.001		
Lou et al. [41]	China	Cross-sectional	Healthy	2847	1475/1372	7–12	Male		SBP	0.052; P = 0.039	Pearson correlation coefficient; p-value	8
									Trunk FM	0.519; P < 0.001		
									visceral fat area	0.144; P < 0.001		
									Subcutaneous fat area	0.053; P = 0.032		
									SBP	0.098; P < 0.001		
									Weight	r = 0.841; P < 0.001		
									BMI	r = 0.800; P < 0.001		
									WC	r = 0.809; P < 0.001		
									Weight	r = 0.785; P < 0.001		
									BMI	r = 0.736; P < 0.001		
Selvan et al. [13]	India	Cross-sectional	Healthy	451	258/193	30–80	Age		WC	r = 0.739; P < 0.001	Adjusted Pearson correlation coefficient; p-value	
									WC	r = 0.742; P < 0.001		
									BMI	r = 0.744; P < 0.001		
									SBP	r = 0.106		
									DBP	r = 0.113		
									FBS	r = 0.025		

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Katz et al. [40]	Canada	Cross-sectional	Healthy	1913	977/936	6–17	Healthy-weight male	Age	TC	r = 0.211; P < 0.05	Adjusted Beta (95% CI)	8
									TG	r = 0.365; P < 0.001		
									LDL-C	r = 0.185		
									HDL-C	r = -0.319; P < 0.01		
									WC	r = 0.713; P < 0.001		
									BMI	r = 0.682; P < 0.01		
									SBP	r = 0.172		
									DBP	r = 0.028		
									FBS	r = 0.221		
									TC	r = 0.003		
									TG	r = 0.112		
									LDL-C	r = 0.092		
									HDL-C	r = -0.327; P < 0.01		
									BMI	0.75 (0.62–0.88)		
BMI	0.46 (0.38–0.54)											
WC	0.24 (0.18–0.3)											
WC	0.16 (0.13–0.18)											
BMI	0.42 (0.37–0.47)											
BMI	0.37 (0.26–0.48)											
WC	0.15 (0.12–0.17)											
WC	0.15 (0.13–0.17)											

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of asso- ciation	Quality score
Formisano et al. [23]	Italy, Belgium, Cyprus, Estonia, Germany, Hungary, Spain and Sweden	Cross-sectional	Healthy	15673	7962/7711	3–10	Boys	BMI z-score and country of origin	WC z-score	0.318; P < 0.001	Adjusted Pearson correlation coefficient; p-value	8
									SBPz-score	0.030		
									DBP z-score	-0.017		
									HDL-C z-score	-0.060; P < 0.001		
									TG z-score	0.056; P < 0.001		
									HOMA index	0.068; P < 0.001		
									z-score			
									WC z-score	0.357; P < 0.001		
									SBPz-score	0.050; P < 0.005		
									DBP z-score	-0.011		
									HDL-C z-score	-0.056; P < 0.005		
									TG z-score	0.063; P < 0.001		
									HOMA index	0.111; P < 0.001		
Cizza et al. [38]	USA	Cross-sectional	Obese	120	28/92	18–50	Total	MetS score	r = 0.458; p < 0.001	Pearson correlation coefficient; p-value	6	
								Fasting insulin	r = 0.476; P < 0.001			
								HOMA index	r = 0.461; P < 0.001			
								Visceral fat	r = 0.674; P < 0.001			
								Subcutaneous fat	r = 0.125; P = 0.20			
								Total abdominal fat%	r = 0.482; P < 0.001			

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Yang et al. [10]	China	Cross-sectional	Type 2 diabetic patients	3182	1294/1888	20–80	Male Female		BMI	$r = 0.41; P < 0.0001$ $r = 0.84; P < 0.0001$	Pearson correlation coefficient; p-value	8
Kumar et al. [26]	India	Cross-sectional	Patients who attended medicine	431	250/181	Males > 35 and females > 40	Male Female Total		WC BMI	$r = 0.47; P < 0.0001$ $r = 0.47; P < 0.0001$ $0.492; P < 0.001$	Pearson correlation coefficient;	7
			Clinic in a tertiary care KMC hospital						WC Hip W/H RATIO SBP	$0.453; P < 0.001$ $0.458; P < 0.001$ $-0.005; P = 0.912$ $0.243; P < 0.001$	p-value	
Rao et al. [46]	India	Cross-sectional	Patients who visited medicine OPD of a tertiary care teaching hospital	250	180/70	40–100	Total		DBP FBS TC LDL HDL TG SBP	$0.107; P = 0.027$ $0.166; P < 0.001$ $0.266; P < 0.001$ $0.344; P < 0.001$ $-0.173; P < 0.001$ $0.280; P < 0.001$ $0.194056; P = 0.002$	Pearson correlation coefficient; p-value	6
Li et al. [47]	China	Cross-sectional	Patients who took lower abdomen and neck CT examinations	177	87/90	35–75	Men Women	Age	DBP Visceral adipose tissue (VAT)	$0.176716; P = 0.005$ $r = 0.49, p < 0.001$ $r = 0.25, p = 0.012$	Adjusted Pearson correlation coefficient; p-value	6

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of asso- ciation	Quality score
Zhou et al. [18]	China	Cross-sectional	from the Examination Centre	4201	2508/1693	20–85	Male	Age	Subcutaneous adipose tissue (SAT) SBP	r = 0.59, p < 0.001 r = 0.41, p < 0.001 r = 0.250; p < 0.01	Adjusted Pearson correlation coefficient; p-value	8
							Female		DBP FBG TG HDL-C TC LDL-C SBP DBP FBG TG HDL-C TC LDL-C	r = 0.261; p < 0.01 r = 0.177; p < 0.01 r = 0.240; p < 0.01 r = -0.202; p < 0.01 r = 0.143; p < 0.01 r = 0.088; p < 0.01 r = 0.255; p < 0.01 r = 0.189; p < 0.01 r = 0.180; p < 0.01 r = 0.199; p < 0.01 r = -0.234; p < 0.01 r = 0.039 r = 0.075; p < 0.01 r = 0.576; p = 0.000		
Saka et al. [48]	Turkey	Cross-sectional	Healthy	411	174/237	20–60	Men Women		Body weight WC Hip circumferences BMI	r = 0.702; p = 0.000 r = 0.593; p = 0.000 r = 0.667; p = 0.000 r = 0.568; p = 0.000 r = 0.617; p = 0.000 r = 0.58; p = 0.000 r = 0.688; p = 0.000	Pearson correlation coefficient	7

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Androutsos et al. [28]	Greece	Cross-sectional	Healthy	324	167/157	9–13	Total	Age, gender, Tanner stage, physical activity, and protein-, carbohydrate- and fat-dietary intake	TC	-0.200 ± 0.777	Adjusted (β ± SE)	7
									HDL	-1.713 ± 0.376		
									LDL	1.016 ± 0.669		
									Fasting glucose	0.285 ± 0.217		
									SBP	2.082 ± 0.273		
									DBP	0.465 ± 0.234		
									TG	0.037 ± 0.009		
									Insulin	0.064 ± 0.014		
									HOMA-IR	0.067 ± 0.014		
							Male		TC	r = -0.11	Pearson's correlation coefficient	
									HDL	r = -0.32, p < 0.001		
									LDL	r = 0.04		
									FBS	r = 0.10		
									SBP	r = 0.43, p < 0.001		
									DBP	r = 0.02		
									TG	r = 0.12		
									Insulin	r = 0.23, p < 0.001		
									HOMA-IR	r = 0.23, p < 0.001		
							Female		TC	r = -0.11		
									HDL	r = -0.23, p < 0.001		
									LDL	r = 0.05		
									FBS	r = 0.11		
									SBP	r = 0.43, p < 0.001		
									DBP	r = 0.20, p < 0.05		
									TG	r = 0.22, p < 0.05		
									Insulin	r = 0.35, p < 0.001		
									HOMA-IR	r = 0.36, p < 0.001		

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Age	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Joshipura et al. [49]	San Juan, USA	Cross-sectional	Overweight/obese, non-diabetic Hispanics	1206	54.6% male	40–65	Total	Age, gender, smoking status, physical activity	TC	$r = -0.10$	Adjusted Pearson correlation coefficient; p-value	8
									HDL	$r = -0.27, p < 0.001$		
									LDL	$r = 0.01$		
									FBS	$r = 0.11$		
									SBP	$r = 0.43, p < 0.001$		
									DBP	$r = 0.09$		
									TG	$r = 0.15, p < 0.001$		
									Insulin	$r = 0.26, p < 0.001$		
									HOMA-IR	$r = 0.26, p < 0.001$		
									BMI	$R = 0.66; p < 0.001$		
									WC	$R = 0.64; p < 0.001$		
									% body fat	$R = 0.45; p < 0.001$		
									HOMA-IR	$R = 0.45; p < 0.05$		
FBS	$R = 0.10; p < 0.001$											
HbA1c	$R = 0.28; p < 0.001$											
SBP	$R = 0.18; p < 0.001$											
HDL-C	$R = -0.23; p < 0.001$											
DBP	$R = 0.23; p < 0.001$											
TG	$R = 0.12; p < 0.05$											
Hs-CRP	$R = 0.30; p < 0.001$											
Weight	$0.63; p = 0.001$											
Hassan et al. [29]	Egypt	Cross-sectional case control	50 healthy, 50 obese children	100	52/48	7–12	Metabolic subjects		BMI	$0.239; P = 0.240$	Pearson correlation coefficient; p-value	6
									WC	$0.465; P = 0.017$		
									Waist/Hip	$-0.113; P = 0.582$		
									SBP	$0.289; P = 0.152$		
									DBP	$0.445; P = 0.023$		
									LDL	$0.122; P = 0.551$		
									HDL	$-0.120; P = 0.559$		
									TC	$0.056; P = 0.787$		
									TG	$-0.253; P = 0.212$		

Table 3 continued

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of asso- ciation	Quality score	
Cho et al. [19]	South Korea	Conor t	Healthy	3521	1784/1737	42-71	Non metabolic subjects		FBS	-0.377; P = 0.058	Pearson	8	
									Fasting Insulin	0.219; P = 0.283			
									HOMA-IR	0.113; P = 0.583			
									Weight	0.619; P = 0.001			
									BMI	0.535; P = 0.007			
									WC	0.605; P = 0.002			
									Waist/Hip	-0.203; P = 0.340			
									SBP	0.048; P = 0.823			
									DBP	0.186; P = 0.384			
									LDL	-0.444; P = 0.030			
									HDL	-0.139; P = 0.516			
									TC	-0.221; P = 0.299			
									TG	0.314; P = 0.135			
									FBS	-0.137; P = 0.524			
									Fasting Insulin	0.119; P = 0.580			
									HOMA-IR	0.116; P = 0.591			
									SBP	0.170; P < 0.001			Correlation coef- ficient; p-value
									DBP	0.200; P < 0.001			
									BMI	0.801; P < 0.001			
									WC	0.740; P < 0.001			
Body fat (%)	0.547; P < 0.001												
FPG	0.159; P < 0.001												
HOMA-IR	0.317; P < 0.001												
TG	0.240; P < 0.001												
HDL-C	-0.246; P < 0.001												
SBP	0.203; P < 0.001												
DBP	0.199; P < 0.001												
BMI	0.744; P < 0.001												
WC	0.706; P < 0.001												
Body fat (%)	0.510; P < 0.001												
FPG	0.122; P < 0.001												

Table 3 (continued)

Study	Country	Type of study	Population	n	Male/ female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
Guo et al. [43]	China	Cross-sectional	Normal	6802	3631/3171	5–18	Normal weight	Age, gender, BMI, WC	HOMA-IR TG HDL-C BMI	0.234; P < 0.001 0.256; P < 0.001 −0.223; P < 0.001 r = 0.226; P < 0.001	Adjusted Pearson correlation coefficient; p-value	8
							Overweight		WC SBP DBP BMI WC SBP DBP BMI	r = 0.339; P < 0.001 r = 0.449; P < 0.001 r = 0.328; P < 0.001 r = 0.137; P < 0.001 r = 0.348; P < 0.001 r = 0.459; P < 0.001 r = 0.344; P < 0.001 r = −0.004; P = 0.932		
							Obese		WC SBP DBP BMI	r = 0.635; P < 0.001 r = 0.477; P < 0.001 r = 0.325; P < 0.001 r = 0.700; P < 0.001	Pearson correlation coefficient; p-value	8
Hatipoğlu et al. [25]	Turkey	Case-control	Overweight/obese children and healthy ones as control	967	475/492	6–18	Boys pre-pubertal Girls pre-pubertal		WC	r = 0.821; P < 0.001 r = 0.727; P < 0.001 r = 0.848; P < 0.001		
							Boys Prepubertal Pubertal Girls Prepubertal Pubertal		WC	r = 0.733; P < 0.001 r = 0.839; P < 0.001 r = 0.776; P < 0.001 r = 0.854; P < 0.001		
Kelishadi et al. [21]	Iran	Cross-sectional	School students	23043	11708/11335	6–18	Male	Age, sex and living area	Weight BMI	r = 0.546; p < 0.001 r = 0.389; p < 0.001	Adjusted Pearson correlation coefficient; p-value	7
									WC Waist/Hip Waist/Height	r = 0.491; p < 0.001 r = 0.035; p < 0.001 r = 0.156; p < 0.001		

Table 3 (continued)

Study	Country	Type of study	Population n	Male/female	Agey	Age group	Confounder	Outcome	Measure of effect	Measure of association	Quality score
								Hip	$r = 0.505; p < 0.001$		
						Female		Weight	$r = 0.481; p < 0.001$		
								BMI	$r = 0.387; p < 0.001$		
								WC	$r = 0.456; p < 0.001$		
								Waist/Hip	$r = -0.020; p < 0.001$		
								Waist/Height	$r = 0.222; p < 0.001$		
								Hip	$r = 0.464; p < 0.001$		
						Total		Weight	$r = 0.519; p < 0.001$		
								BMI	$r = 0.384; p < 0.001$		
								WC	$r = 0.479; p < 0.001$		
								Waist/Hip	$r = 0.023; p < 0.001$		
								Waist/Height	$r = 0.188; p < 0.001$		
								Hip	$r = 0.478; p < 0.001$		

correlation between HDL-C and NC in all relevant publications, with r ranging from -0.120 [29] to -0.35 [30]. Weak and mostly not significant correlations between LDL-C and NC were observed.

According to the Newcastle–Ottawa checklist, all selected studies were categorized as high quality study and attained score ≥ 6 according to this scale. Overall, 20% of studies attained 6 scores, 38% of studies attained 7 scores and the rest got the score of 8 (Tables 2 and 3).

Results of quantitative synthesis

B-1: The diagnostic accuracy of high NC to predict MetS

The results of heterogeneity statistics about the SE of high NC to predict MetS according to sex and age groups showed severe heterogeneity in SE existed between studies in male (I^2 : 97.9%; Q test: 335.85, $p < 0.001$), female (I^2 : 91.1%; Q test: 112.26, $p < 0.001$), pediatric (I^2 : 91.1%; Q test: 33.75, $p < 0.001$), adult (I^2 : 96.2%; Q test: 391.78, $p < 0.001$), and overall population (I^2 : 96%; Q test: 479.02, $p < 0.001$). Due to severe heterogeneity between studies, the random effect meta-analysis was used and the pooled SE in male, female, pediatric, adult and overall population was estimated 69% (95% CI 56–83), 67% (95% CI 60–74), 77% (95% CI 55–99), 65% (95% CI 58–72) and 67% (95% CI 61–74), respectively (Additional file 1: Figure S1:A–D). The results of heterogeneity statistics for SP of high NC to predict MetS indicated severe heterogeneity among studies in both sexes and age groups. The random effect meta-analysis showed that the pooled SP in male, female, adult, pediatric and overall population was 64% (95% CI 52, 75), 67% (95% CI 60, 74), 66% (95% CI 60, 72), 66% (95% CI 48, 84) and 66% (95% CI 60, 73), respectively (Additional file 2: Figure S2: E–H).

Publication bias: Begg's test confirmed no publication bias for sensitivity ($p = 0.32$) and specificity ($p = 0.92$) of high NC for predicting MetS.

B-2: The association of NC with glycemic indices in adult populations

FBS: The pooled estimates of 4 studies (seven effect sizes) indicated that there was a significant positive correlation between NC and serum levels of FBS (CC: 0.16, 95% CI 0.13, 0.20). However, the heterogeneity was high (I^2 : 56.0%, $p = 0.03$) (Additional file 3: Figure S3:1). Subgroup analysis based on age, sex and continent are presented in Additional file 4: Table S1. After stratification by continent (Asian, Non-Asian), we found that the association between NC and FBS concentrations in Asian population (CC: 0.19, 95% CI 0.16, 0.22; I^2 : 0, $p = 0.61$) was stronger than Non-Asian (CC: 0.13, 95% CI 0.10, 0.16; I^2 : 28.3%, $p = 0.24$). This parameter attenuated the heterogeneity greater than gender subgroups.

HOMA-IR: The association between NC and HOMA-IR was reported in three studies containing four effect sizes. The overall effect size showed a significant link between NC and HOMA-IR (CC: 0.38, 95% CI 0.25, 0.50) in adult population, while the heterogeneity was high (I^2 : 93.5%, $p = 0.0001$) (Additional file 3: Figure S3:2). Due to limited studies, it was not possible to perform subgroup analysis to find the reason of the heterogeneity.

B-3: The association of NC with lipid profile in adult populations

Based on the overall effect size, in subjects who had higher NC, serum levels of TC was higher than those with smaller one (CC: 0.12, 95% CI 0.05, 0.19; I^2 : 79.2, $p = 0.001$) (Additional file 3: Figure S3:3). After stratification by age, a notable reduction was observed in the heterogeneity (Additional file 4: Table S1). Besides, pooling 8 effect sizes revealed that there was a significant correlation between NC and TG concentrations (CC: 0.23, 95% CI 0.19, 0.28; I^2 : 76.2%, $p = 0.001$) (Additional file 3: Figure S3:4). However, after subgroup analysis the heterogeneity did not attenuate considerably (Additional file 4: Table S1). Meta-analysis on LDL-C concentrations also showed a positive association with NC (CC: 0.14, 95% CI 0.07, 0.22); however, the heterogeneity was high (I^2 : 79.2%, $p = 0.001$) (Additional file 3: Figure S3:5). Subgroup analysis showed that this association in men (CC: 0.13, 95% CI 0.03, 0.22; I^2 : 59.1%, $p = 0.11$) was stronger than women (CC: 0.08, 95% CI 0.03, 0.13; I^2 : 0%, $p = 0.81$).

Publication bias: Egger's test showed no publication bias for FBS ($p = 0.49$), HOMA-IR ($p = 0.57$), TC ($p = 0.92$), TG ($p = 0.93$) and LDL-C ($p = 0.25$).

B-4: The association of NC with glycemic indices in child populations

FBS: From five studies in which the association between NC and FBS concentrations was reported, 12 effect sizes were extracted. The pooled estimates showed that children with greater NC had higher levels of FBS compared to those with smaller one (CC: 0.12, 95% CI 0.07, 0.16; I^2 : 48.4%, $p = 0.03$) (Additional file 5: Figure S4:1). No severe heterogeneity was found for this association.

HOMA-IR: The correlation between NC and HOMA-IR was reported in 6 studies including 11 effect sizes. Based on findings, greater NC was correlated with higher HOMA-IR (CC: 0.27, 95% CI 0.23, 0.31). However, the heterogeneity was considerably high (I^2 : 93.2%, $p = 0.0001$) (Additional file 5: Figure S4:2).

B-5: The association of NC with lipid profile in child populations

The pooled estimates ($n=12$) of five studies showed a significant positive link between NC and TC concentrations (CC: 0.07 95% CI 0.02, 0.12; $I^2:87.8\%$, $p=0.001$), although it was a weak correlation (Additional file 5: Figure S4:3). Findings of six studies also revealed a significant link between NC and TG levels (CC: 0.21, 95% CI 0.17, 0.25; $I^2:61.2\%$, $p=0.001$) (Additional file 5: Figure S4:4). However, no correlation was obtained between NC and LDL-C (CC: 0.01, 95% CI -0.06 , 0.07; $I^2:65.9\%$, $p=0.005$) (Additional file 5: Figure S4:5). Due to limited studies on children, subgroup analyses were not possible.

Publication bias: Begg's test confirmed no publication bias for FBS ($p=0.19$), HOMA-IR ($p=0.38$), TC ($p=0.37$), TG ($p=0.58$) and LDL-C ($p=0.06$).

Discussion

The current systematic review and meta-analysis revealed a positive association of NC, glycemic status and lipid profile in adult and child populations. However, no correlation was observed between NC and LDL-C concentrations in children. In general, due to high heterogeneity the findings should be declared with caution. Moreover, the association between NC and other cardio-metabolic risk factors were significant in most studies. However, because of limited studies drawing a certain decision needs further studies. Although the SE and the SP of NC to predict MetS were greater than about 65% in both child and adult populations, the between-study heterogeneity was considerably high.

To the best of our knowledge, the present study is the first study that examined the association of NC and cardio-metabolic risk factors in all age ranges and determined the SE and the SP of NC to predict MetS. In the present study, subgroup analysis revealed that the link between serum levels of FBS and NC in Asian was stronger than other adult populations. Findings on children populations also showed that the link between NC and FBS was significant only in Asian populations. Additionally, in Asian children the link between insulin resistance and NC was stronger than non-Asians.

These findings showed that race can play a main role in this correlation. Besides, the correlation between NC and LDL-C levels in men was stronger than the correlation in adult women. Therefore, gender can be another factor that affects the association. Energy intake, physical activity level, and menopause status are possible factors that can affect the link. In the present study, some included studies did not control such factors and it is likely to cause bias in the findings.

Another factor in the association between NC and cardio-metabolic risk factors is likely to be study design.

In the present systematic review, design in most studies was cross-section. The weakness of this kind of study is inability to clarify a cause and effect relationship. Prospective cohort studies can shed light on the type of the association.

Although prior studies introduced WC as a good predictor for cardio-metabolic risks [31, 32], it has some limitations. For instance, several sites including midway between rib cage and iliac crest, the lower border of rib cage, and iliac crest umbilicus are used for measuring WC. This resulted in different values for WC. Moreover, time of measurement, the state of expiration and fullness affect the measure [29, 33]. However, NC measurement is easy and accessible. Besides, a unit site for measurement was reported among the studies. NC is measured above the cricoid cartilage and perpendicular to the long axis of the neck [34, 35]. Due to no variation in the measurement of NC, multiple measurements are not needed to be sure about its accuracy.

Compare to BMI, NC has some strength points. NC is measured faster and does not need special tools [9]. Therefore, particularly for epidemiological assessment it seems to be a good predictor. However, due to the high heterogeneity, more studies are needed to clarify its efficacy.

In the present study, we found that the association of NC with obesity, diabetes, hypertension, and MetS were significant in most studies. However, due to limited studies we cannot draw a fix conclusion about these issues. In addition, as there has been no meta-analysis on the SE and the SP of NC as a predictor for MetS, we could not compare our results with previous findings. Based on a systematic review by Arias et al., there was a positive association between NC and adiposity parameters indirectly measured by reference methods including dual-energy x-ray absorptiometry (DXA) and computed tomography (CT) in adult population. However, they reported no study on children in this regard [50].

The mechanisms that explain the association between neck adipose tissue and cardio-metabolic risk factors are not precisely identified. It is likely that high plasma free fatty acids (FFAs) provide a ground for developing metabolic disorders [36]. Increasing in the levels of FFAs can result in oxidative stress and vascular injury [15, 36]. The main releasing rate of systemic FFA is dedicated to upper body subcutaneous fat [5, 36]. Accordingly, NC can be a suitable predictor for CVD risk factors.

The present study has two main limitations: [1] due to cross-sectional design in the most included studies a cause and effect relationship was not clarified. [2] Heterogeneity mostly remained high even after stratification by possible confounders. The main strength of the present

systematic review was to determine the SE and SP of NC in adult and child populations.

Conclusion

Although the SE and the SP of NC to predict MetS were acceptable in both child and adult population, the between-study heterogeneity was considerably high. There is a positive association between NC and glycemic indices, and lipid profile in adult and pre-pubertal populations. However, no correlation was observed between NC and LDL-C concentrations in children. Due to high heterogeneity, the findings should be declared with caution. Although the association between NC and other cardio-metabolic risk factors were significant in most studies, due to limited publications in this regard more prospective cohort studies are needed to clarify these associations.

Additional files

Additional file 1: Figure S1. Forest plot of high neck circumference sensitivity for predicting metabolic syndrome in A) male, B) female, C) children, D) adult population.

Additional file 2: Figure S2. Forest plot of high neck circumference specificity for predicting metabolic syndrome in E) male, F) female, G) children, H) adult population.

Additional file 3: Figure S3. Forest plot of the association of neck circumference and 1) FBS, 2) HOMA, 3) TC, 4) TG, 5) LDL-C in adult population.

Additional file 4: Table S1. Subgroup analysis for the association between neck circumference and cardio-metabolic factors in adult population.

Additional file 5: Figure S4. Forest plot of the association of neck circumference and 1) FBS, 2) HOMA, 3) TC, 4) TG, 5) LDL-C in child population.

Authors' contributions

AAJ, NN, SD, PC, MEA, design and data gathering, SSZ, HA, MZ, AMG, MM design and revision, MQ data analysis. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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References

- Roth GA, Huffman MD, Moran AE, Feigin V, Mensah GA, Naghavi M, et al. Global and regional patterns in cardiovascular mortality from 1990 to 2013. *Circulation*. 2015;132(17):1667–78.
- Handbook of Obesity (2nd Edition)-George A. Bray Claude Bouchard-0824747739-Infoma Healthcare.pdf > .
- Despres JP, Lemieux I, Bergeron J, Pibarot P, Mathieu P, Larose E, et al. Abdominal obesity and the metabolic syndrome: contribution to global cardiometabolic risk. *Arterioscler Thromb Vasc Biol*. 2008;28(6):1039–49.
- Ben-Noun L, Sohar E, Laor A. Neck circumference as a simple screening measure for identifying overweight and obese patients. *Obes Res*. 2001;9(8):470–7.
- Hingorjo MR, Qureshi MA, Mehdi A. Neck circumference as a useful marker of obesity: a comparison with body mass index and waist circumference. *J Pak Med Assoc*. 2012;62(1):36–40.
- Ben-Noun LL, Laor A. Relationship between changes in neck circumference and changes in blood pressure. *Am J Hypertens*. 2004;17(5 Pt 1):409–14.
- Ozkaya I, Tunckale A. Neck circumference positively related with central obesity and overweight in Turkish university students: a preliminary study. *Cent Eur J Public Health*. 2016;24(2):91–4.
- Ma C, Wang R, Liu Y, Lu Q, Liu X, Yin F. Diagnostic performance of neck circumference to identify overweight and obesity as defined by body mass index in children and adolescents: systematic review and meta-analysis. *Ann Hum Biol*. 2017;44(3):223–9.
- Yan Q, Sun D, Li X, Zheng Q, Li L, Gu C, et al. Neck circumference is a valuable tool for identifying metabolic syndrome and obesity in Chinese elder subjects: a community-based study. *Diabetes Metab Res Rev*. 2014;30(1):69–76.
- Luo GR, Yuan SY, Fu HJ, Wan G, Zhu LX, Bu XL, et al. 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*. 2010;33(11):2465–7.
- Luo Y, Ma X, Shen Y, Xu Y, Xiong Q, Zhang X, et al. Neck circumference as an effective measure for identifying cardio-metabolic syndrome: a comparison with waist circumference. *Endocrine*. 2017;55(3):822–30.
- Gonçalves VSS, Faria ERD, Franceschini SDCC, Priore SE. Neck circumference as predictor of excess body fat and cardiovascular risk factors in adolescents. *Revista de Nutrição*. 2014;27(2):161–71.
- Selvan C, Dutta D, Thukral A, Nargis T, Kumar M, Mukhopadhyay S, et al. Neck height ratio is an important predictor of metabolic syndrome among Asian Indians. *Indian J Endocrinol Metab*. 2016;20(6):831.

14. Khalangot M, Gurianov V, Okhrimenko N, Luzanchuk I, Kravchenko V. Neck circumference as a risk factor of screen-detected diabetes mellitus: community-based study. *Diabetol Metab Syndr*. 2016;8(1):12.
15. Silva CdCd, Zambon MP, Vasques ACJ, Rodrigues AMdB, Camilo DF, Antonio MÁR, et al. Neck circumference as a new anthropometric indicator for prediction of insulin resistance and components of metabolic syndrome in adolescents: Brazilian Metabolic Syndrome Study. *Rev Paul Pediatr*. 2014;32(2):221–9.
16. Gomez-Arbelaez D, Camacho PA, Cohen DD, Saavedra-Cortes S, Lopez-Lopez C, Lopez-Jaramillo P. Neck circumference as a predictor of metabolic syndrome, insulin resistance and low-grade systemic inflammation in children: the ACRIES study. *BMC Pediatr*. 2016;16(1):31.
17. Pereira DCR, Araújo MFMD, Freitas RWJFD, Teixeira CRdS, Zanetti ML, Damasceno MMC. Neck circumference as a potential marker of metabolic syndrome among college students. *Rev Lat Am Enfermagem*. 2014;22(6):973–9.
18. J-y Zhou, Ge H, M-f Zhu, L-j Wang, Chen L, Y-z Tan, et al. Neck circumference as an independent predictive contributor to cardio-metabolic syndrome. *Cardiovasc Diabetol*. 2013;12(1):76.
19. Cho NH, Oh TJ, Kim KM, Choi SH, Lee JH, Park KS, et al. Neck circumference and incidence of diabetes mellitus over 10 years in the Korean genome and epidemiology study (KoGES). *Sci Rep*. 2015;5:18565.
20. de Lucena Ferretti R, de Pádua Cintra I, Passos MAZ, de Moraes Ferrari GL, Fisberg M. Elevated neck circumference and associated factors in adolescents. *BMC Public Health*. 2015;15(1):208.
21. Kelishadi R, Djalalinia S, Motlagh ME, Rahimi A, Bahreynian M, Arefirad T, et al. Association of neck circumference with general and abdominal obesity in children and adolescents: the weight disorders survey of the CASPIAN-IV study. *BMJ Open*. 2016;6(9):e011794.
22. Kuciene R, Dulskiene V, Medzioniene J. Association of neck circumference and high blood pressure in children and adolescents: a case-control study. *BMC Pediatr*. 2015;15(1):127.
23. Formisano A, Bammann K, Fraterman A, Hadjigeorgiou C, Herrmann D, Iacoviello L, et al. Efficacy of neck circumference to identify metabolic syndrome in 3–10 year-old European children: results from IDEFICS study. *Nutr Metab Cardiovasc Dis*. 2016;26(6):510–6.
24. Kurtoglu S, Hatipoglu N, Mazicioglu MM, Kondolot M. Neck circumference as a novel parameter to determine metabolic risk factors in obese children. *Eur J Clin Invest*. 2012;42(6):623–30.
25. Hatipoglu N, Mazicioglu MM, Kurtoglu S, Kendirci M. Neck circumference: an additional tool of screening overweight and obesity in childhood. *Eur J Pediatr*. 2010;169(6):733–9.
26. Kumar NV, Ismail MH, Mahesha P, Girish M, Tripathy M. Neck circumference and cardio-metabolic syndrome. *J Clin Diagn Res*. 2014;8(7):MC23.
27. Pillai BP, Kumar H, Jayakumar RV, Alur VC, Sheejamol V. The prevalence of metabolic syndrome in polycystic ovary syndrome in a South Indian population and the use of neck circumference in defining metabolic syndrome. *Int J Diabetes Dev Ctries*. 2015;35(4):469–75.
28. Androutsos O, Grammatikaki E, Moschonis G, Roma-Giannikou E, Chrousos G, Manios Y, et al. Neck circumference: a useful screening tool of cardiovascular risk in children. *Pediatr Obes*. 2012;7(3):187–95.
29. Hassan NE, Atef A, El-Masry SA, Ibrahim A, Al-Tohamy M, Rasheed EA, et al. Is neck circumference an indicator for metabolic complication of childhood obesity? *Open Access Maced J Med Sci*. 2015;3(1):26.
30. Fitch KV, Stanley TL, Looby SE, Rope AM, Grinspoon SK. Relationship between neck circumference and cardiometabolic parameters in HIV-infected and non-HIV-infected adults. *Diabetes Care*. 2011;34(4):1026–31.
31. Savva S, Tornaritis M, Savva M, Kourides Y, Panagi A, Silikiotou N, et al. Waist circumference and waist-to-height ratio are better predictors of cardiovascular disease risk factors in children than body mass index. *Int J Obes*. 2000;24(11):1453.
32. De Koning L, Merchant AT, Pogue J, Anand SS. Waist circumference and waist-to-hip ratio as predictors of cardiovascular events: meta-regression analysis of prospective studies. *Eur Heart J*. 2007;28(7):850–6.
33. Dixon JB, O'Brien PE. Neck circumference a good predictor of raised insulin and free androgen index in obese premenopausal women: changes with weight loss. *Clin Endocrinol*. 2002;57(6):769–78.
34. Hoebel S, Swanepoel M, Malan L. Examining waist and neck circumferences as screening tools for metabolic syndrome in a sub-Saharan Caucasian cohort at three year follow-up: the SABPA prospective cohort. *J Endocrinol Metab Diabetes S Afr*. 2014;19(3):106–12.
35. Preis SR, Massaro JM, Hoffmann U, D'Agostino RB Sr, Levy D, Robins SJ, et al. Neck circumference as a novel measure of cardiometabolic risk: the Framingham Heart study. *J Clin Endocrinol Metab*. 2010;95(8):3701–10.
36. Liang J, Teng F, Liu X, Zou C, Wang Y, Dou L, et al. Synergistic effects of neck circumference and metabolic risk factors on insulin resistance: the cardio-metabolic risk in Chinese (CRC) study. *Diabetol Metab Syndr*. 2014;6(1):116.
37. Torriani M, Gill CM, Daley S, Oliveira AL, Azevedo DC, Bredella MA. Compartmental neck fat accumulation and its relation to cardiovascular risk and metabolic syndrome. *Am J Clin Nutr*. 2014;100(5):1244–51.
38. Cizza G, de Jonge L, Piaggi P, Mattingly M, Zhao X, Lucassen E, et al. Neck circumference is a predictor of metabolic syndrome and obstructive sleep apnea in short-sleeping obese men and women. *Metab Syndr Relat Disord*. 2014;12(4):231–41.
39. Zepeda A, Curcio C, Nafiu O, Prasad Y. Association of neck circumference and obesity status with elevated blood pressure in children. *J Hum Hypertens*. 2013;28(4):263.
40. Katz SL, Vaccani J-P, Clarke J, Hoey L, Colley RC, Barrowman NJ. Creation of a reference dataset of neck sizes in children: standardizing a potential new tool for prediction of obesity-associated diseases? *BMC Pediatr*. 2014;14(1):159.
41. Lou D-H, Yin F-Z, Wang R, Ma C-M, Liu X-L, Lu Q. Neck circumference is an accurate and simple index for evaluating overweight and obesity in Han children. *Ann Hum Biol*. 2012;39(2):161–5.
42. Atwa H, Fiala L, Handoka NM. Neck circumference as an additional tool for detecting children with high body mass index. *J Am Sci*. 2012;8(10):442–6.
43. Guo X, Li Y, Sun G, Yang Y, Zheng L, Xingang Z, et al. Prehypertension in children and adolescents: association with body weight and neck circumference. *Intern Med*. 2012;51(1):23–7.
44. Vallianou NG, Evangelopoulos AA, Bountziouka V, Vogiatzakis ED, Bonou MS, Barbetseas J, et al. Neck circumference is correlated with triglycerides and inversely related with HDL cholesterol beyond BMI and waist circumference. *Diabetes Metab Res Rev*. 2013;29(1):90–7.
45. Zen V, Fuchs FD, Wainstein MV, Gonçalves SC, Biavatti K, Riedner CE, et al. Neck circumference and central obesity are independent predictors of coronary artery disease in patients undergoing coronary angiography. *Am J Cardiovasc Dis*. 2012;2(4):323.
46. Rao KSP, Dinesh PV. Association of blood pressure in adults with selected anthropometric parameters and CRP: a hospital based cross sectional study. *J Evol Med Dent Sci JEMDS*. 2016;5(51):3383–8.
47. Li H-X, Zhang F, Zhao D, Xin Z, Guo S-Q, Wang S-M, et al. Neck circumference as a measure of neck fat and abdominal visceral fat in Chinese adults. *BMC Public Health*. 2014;14(1):311.
48. Saka M, Türker P, Ercan A, Kızıltan G, Baş M. Is neck circumference measurement an indicator for abdominal obesity? A pilot study on Turkish Adults. *Afr Health Sci*. 2014;14(3):570–5.
49. Joshipura K, Muñoz-Torres F, Vergara J, Palacios C, Pérez CM. Neck circumference may be a better alternative to standard anthropometric measures. *J Diabetes Res*. 2016. <https://doi.org/10.1155/2016/6058916>.
50. Arias MT, Martinez-Tellez B, Soto J, Sanchez-Delgado G. Validity of neck circumference as a marker of adiposity in children and adolescents, and in adults: a systematic review. *Nutr Hosp*. 2018;35(3):707–21.

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