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Revisión

Correlation and comparison between different measurement sites of waist circumference and cardiovascular risk in children: a systematic review and meta-analysis

Correlación y comparación entre diferentes lugares de medición de la circunferencia de la cintura y el riesgo cardiovascular en niños: revisión sistemática y metaanálisis

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Abstract

Background: waist circumference (WC) is a component of metabolic syndrome (MetS) and an excellent marker for the risk of cardiovascular disease (CVD) in children. This study aimed to provide information on the anatomical measurement sites of WC and their comparative correlation with MetS and its components in children.

Methods: the literature search included papers published between January 2005 and September 2023 that met the following criteria: pediatric patients (2-18 years), WC measurement at different anatomical sites (≥ 2), and CVD risk by MetS. The quality of each study was determined using the STROBE and modified GRADE scales. The meta-analysis evaluated the $WC_{iliac\text{-}crest}$ and WC_{middle}.

Results: five observational studies (total population: 1,224) were included. WC was measured at 2-4 anatomical sites. In all studies, the correlations between different WC measurement sites and CVD risk were similar. The STROBE assessment ranged from 12-20/22 and the GRADE was A for all the articles. The meta-analysis showed that the heterogeneity (I^2 test) of the $WC_{iliac\text{-}crest}$ and WC_{middle} with CVD variables was substantial.

Conclusion: All WC measurement sites showed adequate correlation with CVD risk, with some small individual differences. WC_{narrow} and $WC_{umbilucus}$ have adequate consistency and could be excellent alternatives in daily clinical practice because of their ease of measurement. Further studies are needed to evaluate the correlation between different WC measurement sites and CVD risk in children stratified according to pubertal stage and sex.

Keywords:

Waist circumference.
Pediatric obesity.
Cardiovascular risk.
Metabolic syndrome.

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Resumen

Antecedentes: la circunferencia de la cintura (CC) es un componente del síndrome metabólico (SM) y un excelente marcador de riesgo cardiovascular (RCV). El objetivo de este estudio fue proporcionar información sobre los sitios de medición anatómica de la CC en niños y su correlación comparativa con el SM y sus componentes.

Métodos: búsqueda bibliográfica incluyó artículos entre enero 2005 y septiembre 2023 con los siguientes criterios: niños (2-18 años), CC medida en ≥ 2 sitios anatómicos y SM. La calidad de cada estudio se evaluó con las escalas STROBE y GRADE modificada. El metaanálisis evaluó la CC cresta iliaca y CC media.

Resultados: se incluyó cinco estudios observacionales (población total: 1224). Todos los estudios mostraron similares correlaciones entre los diferentes sitios de medición de CC y el RCV. La evaluación STROBE fue de 12-20/22 y GRADE fue A en todos los artículos. El metaanálisis mostró que la heterogeneidad (prueba I^2) de la CC cresta ilíaca y la CC media con las variables de RCV fue significativa.

Conclusión: todos los sitios de medición de la CC mostraron una correlación adecuada con el RCV, con algunas pequeñas diferencias. CC estrecha y CC umbilical tienen una consistencia adecuada y podrían ser excelentes alternativas en la práctica clínica diaria debido a la facilidad de medición. Se necesitan más estudios para evaluar la correlación entre diferentes sitios de medición de la CC y el riesgo de RCV en niños estratificados según la etapa puberal y el sexo.

Palabras clave:

Circunferencia de la cintura. Obesidad pediátrica. Riesgo cardiovascular. Síndrome metabólico.

INTRODUCTION

Waist circumference (WC) is the main indicator of abdominal adiposity and reflects the amount of visceral adipose tissue (VAT). Therefore, it is considered the best measurement for detecting patients at risk of cardiovascular disease (CVD) (1). CVD risk assessment in children with obesity has gained relevance because it may predict increased mortality in adulthood owing to coronary heart disease and stroke (2). Obesity in children is associated with type 2 diabetes *mellitus* (T2DM), dyslipidemia, arterial hypertension, non-alcoholic fatty liver disease, genu valgum, and obstructive sleep apnea (3). The pathophysiological mechanisms that lead to an increased risk of developing CVD with early atherosclerosis in patients with obesity (4) are related to increased insulin resistance (IR) (5) and activation of chronic inflammation (6). The CVD risk in children is assessed based on the presence of metabolic syndrome (MetS). The "Third Report of the National Cholesterol Education Program (NCEP) in Adults Panel of Treatment III" (7) defined MetS when a patient has three of the following components: abdominal obesity measured by WC, increased triglyceride (TG), decreased high-density cholesterol (HDL), hypertension, and fasting hyperglycemia or T2DM (8).

The detection of CVD risk factors is perform with WC measurement in the routine physical exam. Although this evaluation is practical and simple; several recommendations should be made for each anatomical measurement site (Fig. 1). The WC at the narrowest visual abdominal part (WC_{narrow}) was initially described by Lohman et al. (9) and later by the International Society for the Advancement of Kinanthropometry (ISAK) (10), the WC at the midpoint between the lower rib and the top of the iliac crest (WC_{middle}) by the World Health Organization (WHO) (11), and the WC above the border of the iliac crest ($WC_{iliac\text{-}crest}$) by the National Health and Nutrition Examination Survey (NHANES) (12). WC at the level of the umbilicus ($WC_{umbilicus}$) was described by Croft et al. (13) and Eisenmann et al. (14). WC_4 was unusual and described by Rudolf et al. (15).

Interestingly, the anatomical WC measurement site was not based on comparative correlation studies between different WC measurement sites and cardiovascular risk. The objective of this review is to evaluate anatomical WC measurement sites and their comparative correlation with other MetS components in children.

METHODS

The study protocol was registered in the Prospero ID CRD42023454847.

SEARCH STRATEGY

The literature search was conducted by AMBT, without language restriction in Lilacs, MEDLINE/PubMed, Web of Science, and Scopus databases on October 2023. Papers published between January 2005 and August 2023 were included. The PICO framework was used to develop search strategies and ensure comprehensive and bias-free searches: Population: Patients between 2-18 years. Intervention: WC measurement. Comparison: WC measurement at different anatomical sites (≥ 2). Diagnostic outcomes: CVD risk or other MetS components.

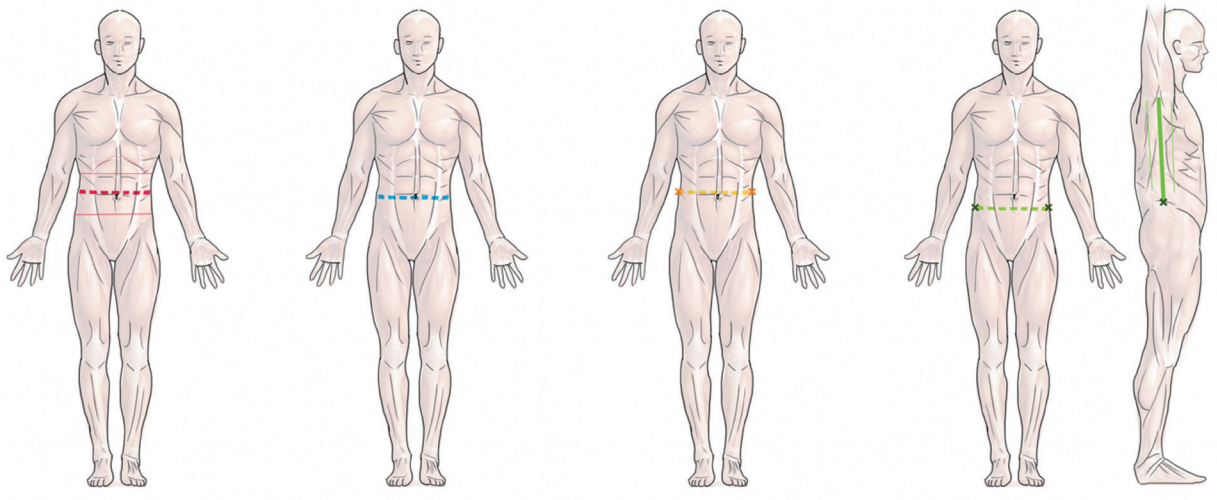
The combination of the boolean descriptors were: "Waist circumference" AND ("measurement anatomical sites" OR "Waist circumference AND pediatric OR cardiometabolic risk factor"). "Waist circumference" AND ("measurement anatomical sites" OR "Waist circumference AND pediatric OR metabolic syndrome"). "Waist circumference measurement sites" and "metabolic syndrome."

ELIGIBILITY CRITERIA

Observational studies that had ≥ 2 anatomical sites of WC and their correlation with MetS or other components of MetS.

STUDY QUALITY AND RISK OF BIAS ASSESSMENT

Eligible studies were assessed by two investigators independently (RGM and DBML). Any divergence was resolved by a third evaluator (LFMR). The quality of each study was determined using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist (22 items) (16). The modified



WC_{middle}	$WC_{umbilicus}$	WC_{narrow}	$WC_{iliac\ crest}$
WHO (37,38)	Croft et al. (13)	ISAK (10)	NHANES (12)
Stand with arms relaxed on the sides. Measurement at the level of the mid-axillary line and the midpoint between the lower border of the last rib and the upper border of the iliac crest.	Standing. Tape measurement at navel level.	Standing with arms crossed over the chest. The examiner faces him and takes measurements at the narrowest level between the 10th rib and iliac crest. If it is not evident, the midpoint is taken.	Stand with arms crossed and hands on opposite shoulders. The examiner should be on the patient's right side. Measurement at the intersection of the mid-axillary line with the upper border of the iliac crest.

Figure 1.

WC measurement recommendations (WHO: World Health Organization; ISAK: International Standards for Anthropometric Assessment, United Kingdom; NHANES: National Health and Nutrition Examination Survey).

Grading of Recommendations Assessment, Development, and Evaluation (GRADE) scale (Table I) was applied, considering A (good), B (moderate), and C (low) when the paper characteristics were complete, partial, or non-specific, respectively.

THE STRATEGY OF DATA SYNTHESIS

The methodology of the systematic review followed the Cochrane Manual guidelines (17), and was adjusted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (18).

STATISTICAL ANALYSES

Meta-analysis was performed with Jamovi 2.2.5 version (by EELH and MLEV) using WC coefficients of correlation with components of MetS included in 4/5 articles. Bosy-Westphal et al. (19) were excluded because they included both children and adults. The WC measurements included in the meta-analysis were the $WC_{iliac\text{-}crest}$ and WC_{middle}. Other WC measurements were

Table I. GRADE evaluation of the of the scientific articles

GRADE score for the characteristics of the paper: A. Completely described B. Partially described C. Not described
Characteristics described in the paper:
Inclusion and exclusion criteria
Methods of sample selection
Stratified by sex, social group, or lifestyle
Baseline valued described
WC measurement method description
Definition of cardiovascular risk or MetS and its components
Bias or confounders taken in account
Statistical analysis applied

GRADE: Grading of Recommendations, Assessment, Development and Evaluation; WC: waist circumference; MetS: metabolic syndrome.

excluded because there were only two publications of each one. A random effects model was used to fit the data. Analysis was performed using the Fisher r-to Z-transformed correlation coefficient. Heterogeneity was estimated using the Cochran Q test and I^2 statistic. If $I^2 > 50$ % or $p < 0.1$, heterogeneity of the results was considered. Studentized residuals and Cook distances were used to determine whether the studies were outliers or influential in the model context. Studies with a studentized residual larger than the $100 \times (1 - 0.05 / [2 \times k])$ th percentile of a standard normal distribution were considered potential outliers. Studies with Cook's distance greater than the median and six times the interquartile range of Cook´s distance were considered influential. The Begg and Muzumbar rank correlation test and Egge's regression test, using the standard error of the observed outcomes as a predictor, were used to verify the funnel plot asymmetry.

RESULTS

From 3,680 non-duplicate records, ten studies were selected because they evaluated ≥ 2 WC anatomical sites. After the full texts were reviewed, five studies were excluded because they did not include MetS components (Fig. 2). Finally, we included five studies with 1,224 children (5-18 years old) of both sexes: Hitze et al. (20) and Bosy-Westphal et al. (19) (both in the German group), Johnson et al. (21), Harrington et al. (22), and López et al. (23). Table II presents the characteristics of the studies. Bosy-Westphal et al. studied prepubertal and pubertal children and adults. Except for the study by López et al. (23), all other studies divided their results by sex. Harrington et al. (22) assessed children according to ethnicities(21). Each article measured WC at to 2-4 anatomical sites, which showed adequate reproducibility. WC of the inferior margin of the ribs (WC_{rib}) was measured in the German group (19,20). The WC at the level of the umbilicus ($WC_{umbilicus}$) and WC_{narrow} was measured by Johnson et al. (21) and Harrigton et al. (22). WC was measured four centimeters (cm) above the umbilical scar (WC_4) and was evaluated by Hitze et al. (20). The $WC_{iliac\text{-}crest}$ and WC_{middle} were measured in all studies included in this review.

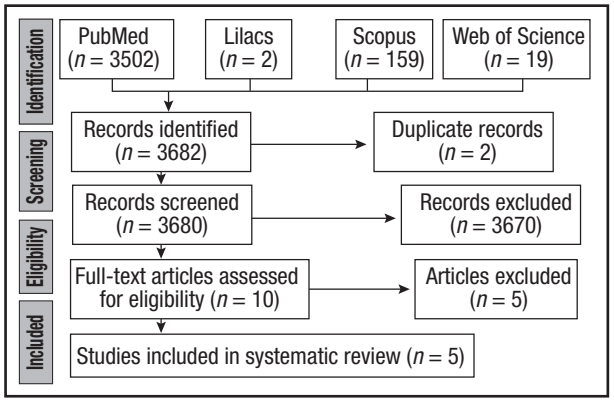


Figure 2.
Flow diagram of search results.

All studies evaluated WC while standing but with different arm positions: hanging freely (19,20) or crossing over the chest (21).

STATISTICAL EVALUATION IN THE INCLUDED STUDIES

Pearson's correlation was performed between each WC measurement site and MetS components in all articles. In some cases, adjustments for age (19,22), ethnicity (21), or logarithmic transformation of variables are necessary (19-23). The prevalence of obesity and MetS differed between these studies (21-23). Johnson et al. (21) described a different prevalence of MetS according to each definition criterion: the modified National Cholesterol Education Program (NCEP) (24), International Diabetes Federation (IDF) (25), and Cook et al. (26). López et al. (23) described MetS according to the IDF (Table II).

DIFFERENCES BETWEEN WC MEASUREMENT SITES

The studies showed that the magnitude of WC (cm) was different in measurement sites and that there were inherent to sex, ethnicity and puberal stage (20). The correlation between the magnitude of all WCs was strong (r = 0.93-0.99).

WC MEASUREMENT SITES AND METS

In Hitze et al. (20), in the female (F) group, all WC measurements showed positive correlations with systolic blood pressure (SBP), diastolic blood pressure (DBP), TG, glucose, and Homeostatic Model Assessment for Insulin Resistance (HOMA-IR), but they did not show any correlation with total cholesterol (TC) and low-density cholesterol (LDL). In the male (M) group, all WC measurements were positively correlated with DBP, LDL, and HOMA-IR. They did not show any correlation with the SBP, TG, TC, or glucose levels.

Bosy-Westphal et at. (19) showed that the WC measurement correlation at all anatomical measurement sites was adequate with abdominal fat, but it was better with subcutaneous adipose tissue (SAT) than with VAT. In prepubertal M, the relationship between the $WC_{iliac\text{-}crest}$ with VAT and HOMA-IR was lower than that in the other WC.

In Johnson et al. (21) the correlation coefficient showed a significant positive association between all WC measurement sites and the SBP, DBP, and HOMA-IR. The TG levels were positively correlated with WC_{narrow} and $WC_{middle.}$ Correlation between CVD risk variables and WC_{narrow} or WC_{middle} was slightly higher. The correlation between MetS and CVD risk was similar for all WC measurements, with only differences. According to the IDF definition of MetS, WC_{narrow} and WC_{middle} were significantly associated with MetS, and the number of MetS components. According to Cook's

definition of MetS, there was no association between MetS and all WC; however, WC_{narrow} and WC_{middle} showed significant odds ratios (OR) with the number of MetS components. For the definition of MetS according to the NCEP, an association was observed between MetS and WC_{narrow} or WC_{middle} but not with $WC_{iliac\text{-}crest}$ or $WC_{umbilicus}$.

Harrington et al. (22) evaluated the age-controlled correlation between WC and logVAT was significant in all the groups. The correlation between all anatomical measurement sites and MetS components was good, except for the glucose levels in the white-M and AA-F groups. There was no correlation between any WC measurement site and DBP in the white-M.

López et al. (23) reported a statistically significant correlation between WC_{middle} and $WC_{iliac\text{-}crest}$ and SBP, DBP, TG, and HDL levels. Glucose levels showed a low correlation with all WCs measurements.

The STROBE scale yielded a result between 12 and 20 points for 22 items. The modified GRADE scale results for all included articles were A (good evidence) (Table II).

META-ANALYSIS

Figure 3 shows the results of the meta-analysis. The random-effects model showed that the correlation of $WC_{iliac\text{-}crest}$ and WC_{middle} with the average variables of MetS differed significantly from 0. The $WC_{iliac\text{-}crest}$ and WC_{middle} I^2 test in all evaluations with the CVD risk variables showed heterogeneity: HDL (66.4 %, $p = 0.028$ and 69.12 %, $p = 0.019$), TG (77.96 %, $p = 0.006$ and 68.78 %, $p = 0.028$), SBP (94.68 %, $p < 0.001$ and 95.7 %, $p < 0.001$), and DBP (90.09 %, $p < 0.001$ and 90.56 %, $p < 0.001$). Glucose presented low heterogeneity in both WC (0 %, $p < 0.634$; 0 %, $p < 0.722$). In the studentized analysis, López et al. (23) presented atypical values for HDL, SBP, and DBP for WC_{middle} and $WC_{iliac\text{-}crest}$. Glucose analysis in both WC and TG in WC_{middle} showed no outliers. Hitze et al. (20) showed the possibility of an outlier in the correlation between WC_{middle} and TG levels. Cook's evaluation showed that none of the studies could be considered influential on any of the variables studied. Egge's regression analysis and Begg's rank correlation tests did not indicate asymmetry in the components of MetS evaluated; therefore, the construction of the funnel graph (Fig. 3) with a few studies generated the possibility of bias.

DISCUSSION

This review shows that the studies included had adecuate comparative correlation between all WC measurement sites and other MetS components except glucose which shows a low correlation. It provides an advantage because measurements are easier at certain anatomical points depending on the characteristics of each patient.

The correlation coefficient evaluation in this meta-analysis shows no difference in the correlation between WC_{middle} or $WC_{iliac\text{-}crest}$ and other MetS components. Studies carried out in different countries have shown that measuring WC_{middle} can predict the presence of MetS in pediatric patients (27,28). WC is considered a good predictor of MetS because it is positively correlated with MetS (29). A review in adult patients reported that there was no substantial difference in the WC measurement site protocols in terms of cardiovascular morbidity, and mortality (30).

We were not able to perform stratified analyses by sex, age, pubertal stage or ethnicity, because data were insufficient. Children are in constant development: this modifies the correlation between WC measurements at different anatomical sites and other MetS components. Fat distribution is very similar between girls and boys in their first childhood years, and then changes at puberty, the beginning of sexual development (31,32). Other studies have already shown these differences by sex in abdominal fat distribution, and some indicate that the presence of obesity does not seem to modify this distribution; that is, the WC_{narrow} is the smallest and the $WC_{umbilicus}$ is the largest (33). Furthermore, it is possible that the fat deposits distribution by ethnic group may contribute to different cardio-metabolic risk (34).

Some studies included in this review defined the overwaist at all anatomical sites using percentiles created for WC_{middle}. This may have modified their results because each WC anatomical measurement site should have specific percentile value. This is important when evaluating a clinical measurement that constitutes a diagnostic tool for MetS, and to avoid bias. We did not find percentile values for WC_{rib} in the literature, and there are only few population studies for the $WC_{umbilicus}$ (14) and WC_{narrow} (35,36).

In children and adolescents, all definitions of MetS (IDF, Cook, and ATP III) consider the same components, but there is great variability due to lack of standardization of the cut-off points. Similary, the frecuency of WC $\geq 90^{th}$ percentile varies according to the WC measurement site and the MetS definition used, modifying therapeutic decisions. The lack of consensus on the WC measurement site in children underestimates or overestimates the CVD risk, as reported in research studies on MetS.

All studies reviewed followed appropriate measurement techniques and standardization, although each author differed in the arms position. The subject's position standing upright with arms relaxed on both sides was described by Lohman et al. (9) to measure WC_{narrow} and by the WHO to measure WC_{middle} (37,38). Patients standing with arms crossed over their chest and hands on their shoulders were described by NHANES (12) to measure the $WC_{iliac\text{-}crest}$ and by ISAK (10) to measure WC_{narrow} (20-22). Thus, Lennie et al. (39) found significant differences in WC measurements performed at different positions in adults. There have been no studies on this topic in the pediatric population. In the smallest or very restless children, arms crossed on the chest and hands on the shoulders are more comfortable and provide more stability.

Technical difficulties in locating bony anatomical references in children with obesity are uncomfortable for patients (15); therefore, WC_{narrow} and $WC_{umbilicus}$ facilitate waist measurement. Some children with significant abdominal subcutaneous tissue have a hanging position at the umbilicus, which modifies the umbilical scar position.

Table II. Structured summary of the results of the included studies

Author, year		Hitze et al., 2008	Bosy-Westphal et al., 2009	Johnson et al., 2010	Harrington et al., 2013	López et al., 2016
Journal name (JRI)		*Obes Facts* (3.9)	*J Nutr* (4.2)	*J. Pediat* (3.7)	*Pediatr Obes* (3.42)	*Endoc Pract* (3.86)
Country-City		Germany-Kiel	Germany-Kiel	Canada-Edmonton	USA-Louisiana	Mexico-CDMX
n		180	234 (prepuberal 74, puberal 160)	73	371 (White 178, AA 193)	366
Inclusion criteria	Age (median or range)	13.2 ± 3.7 years	11.97 years (prepuberal, 9.05 years; puberal, 14.9 years)	8 to 17 years	5 to 18 years	10 to 18 years
	% Female	50.5	50.5	56.2	52.83	48.9
Exclusion criteria		Use of drugs that influence the results	Use of drugs that influence the results	Not indicated	Race other than white or AA	Genetic or endocrine obesity and drugs that influence the results
Measurement sites of WC	WC_{rib}	✓	✓			
	WC_{middle}	✓	✓	✓	✓	✓
	$WC_{iliac\ crest}$	✓	✓	✓	✓	✓
	WC_{narow}			✓	✓	
	$WC_{umbilicus}$			✓	✓	
	WC_4	✓				
WC measurement	Anthropometric tape	Nonelastic (no brand indicated)	Nonelastic (no brand indicated)	Spring-loaded (FitSystems) (Calgary, Alberta, Canada)	Not indicated	Nonstretchable fiberglass (no brand indicated)
	Position of the patient	Stand with arms hanging freely	Standing	Standing with arms crossed over the chest. Mirror to see that the tape measure did not slip down the back	Standing with arms relaxed at their sides	WHO and NHANES measuring method
	Precision and accuracy of their measurements	4 trained observers. Each observer simultaneously performed the measurements of the 4 sites. Intraobserver CV: WC_{narrow} 0.6 %, WC_4 1.5 %, WC_{middle} 1.1 %, $WC_{iliac\ crest}$ 0.7 %. Inter-observer CV: WC_{narrow} 1 %, WC4 1.9 %, WC_{middle} 1.9 %, $WC_{iliac\ crest}$ 3.1 %	4 trained nutritionists. CV intra observer e interobserver: WCnarrow 0.59 y 1.29 %; WCiliac crest 1.43 y 2.64 % y WCmiddle 1.19 y 2.52 %	The same clinical performed all measurements of WC sequentially 2 times. If they differed > 0.5 cm, a third sequence was taken	3 trained technicians. Interobserver and intraobserver CV: 0.98 and 0.99	Measurements were performed by a pediatric obesity specialist and a pediatric endocrinologist. Interobserver CV ±0.41 cm with kappa 0.95-0.98 at the different WC sites

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Table II (Cont.). Structured summary of the results of the included studies

Author, year		Hitze et al., 2008	Bosy-Westphal et al., 2009	Johnson et al., 2010	Harrington et al., 2013	López et al., 2016
Definition WC > 90th		WC_{middle} (31)	Not considered	*Fernández et al.* (32) ($WC_{iliac\ crest}$)	*Fernández et al.* (32) ($WC_{iliac\ crest}$)	*Fernández et al.* (32) ($WC_{iliac\ crest}$), *Klünder et al.* (33) (W_{middle})
Definition of MetS		Not assessed	Not assessed	MetS and its components were evaluated without WC with the definitions of IDF, NCEP and by Cook et al.	MetS components: HDL ≤ 45 mg/dL, TG ≥ 75 mg/dL (5-9 years) or ≥ 90 mg/dL (10-18 years). Fasting hyperglycemia ≥ 100 mmol/L). Hypertension = SBP or DBP ≥ 90th for age, sex, and height. Defined MetS when they had ≥ 2 components except WC	MetS according to IDF if they had 3 components (except WC): TG ≥ 150 mg/dL), HDL < 40 mg/dL) (M and F) and in ≥ 16 years in M < 40 mg/dL and in F < 50 mg/dL, glucose ≥ 100 mg/dL, arterial hypertension if SBP and/or DBP ≥ 130/85 mmHg
Study design		Cross-sectional, observational	Cross-sectional observational. Children and adults analyzed comparatively and separately	Cross-sectional observational in children with obesity (BMI ≥ 85th)	Cross-sectional, observational	Cross-sectional, observational in children with and without obesity
Sample size calculation		Not indicated	Not indicated	Not indicated	400	Not indicated
Statistical analysis	Correlation of each WC with components of MetS	Pearson correlation. Comparison between correlations was performed with the Meng et al. test	The strength of the correlation coefficients was compared with Meng's method. For the correlation between WC and CVD risk, the data were adjusted for age	Pearson correlation. Evaluated the association between BMI and MetS components. Both controlled for age, sex, and ethnicity	Pearson correlation, controlled for age	Pearson correlation
	Others	Variables with a non-normal distribution (SBP, DBP, TG, HDL, and glucose) were adjusted	TG, HOMA-IR levels were normalized by logarithmic transformation	Logistic regression to calculate the OR of MetS and increase in its components related to WC and BMI Z. All variables were adjusted for age and ethnicity	The difference between WC in cm was compared by repeated-measures ANOVA and Turkey post-hoc tests. VAT was adjusted	We determined the ROC curve to see the WC ≥ P 90th of both measurements and the waist-to-height ratio > 0.5 with the CVD risk variables
Prevalence of overweight/obesity		12.2 % with overweight (F:11 %, M:13.5 %)	Puberty: F: 26.1 %, M: 26.3 %. Prepuberty: F: 0 %, M:7.7 %	All with BMI > 85th, 95 % of children with BMI > 95th)	Obesity according: IOTF: 28 %, CDC: 33.4 %	Overweight: 24 %. Obesity: 55 %
Prevalence of MetS		Not evaluated	Not evaluated	NCEP: F: 39 %, M: 34 %. IDF: F: 43.9 %, M: 50 %. Cook: F: 39 %, M: 56.8 %	13.8 % (M White: 19 %, M AA: 10 %, F White: 16.9 % a F AA: 9.7 %)	IDF: 32.80 %

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Table II (Cont.). Structured summary of the results of the included studies

Author, year		Hitze et al., 2008	Bosy-Westphal et al., 2009	Johnson et al., 2010	Harrington et al., 2013	López et al., 2016
Differences between WC measurement sites		$WC_{rib} < WC_4 < WC_{middle} < WC_{iliac-crest}$ ($r > 0.93$, $p < 0.01$). WC_{rib} and WC_4 (cm) were lower in F. WC_{middle} and $WC_{iliac-crest}$ did not show differences between sexes. Prevalence WC ≥ 90th F and M was: WC_{rib}: 13.2 % and 15.7 %, WC_4: 14.3 % and 19.1 %, WC_{middle}: 18.7 % and 22.5 % and $WC_{iliac-crest}$: 37.4 % and 30.3 %	WC (cm) in prepuberty and puberty was: $WC_{rib} > WC_{middle} > WC_{iliac-crest}$ ($p < 0.001$)	WC (cm) by sex: M: $WC_{umbilicus} > WC_{iliac-crest} > WC_{middle} > WC_{narrow}$. WC_{narrow} *vs* $WC_{iliac-crest}$ ($p < 0.01$), or *vs* WCumbilicus ($p < 0.08$) and not significant *vs* WC_{middle}. F: $WC_{umbilicus} > WC_{iliac-crest} > WC_{middle} > WC_{narrow}$. WC_{narrow} was significantly different from all WC. Correlation between all WC: r = 0.93-1, $p < 0.0001$	WC (cm): White F $WC_{umbilicus} > WC_{iliac-crest} > WC_{middle} > WC_{narrow}$ ($p < 0.05$). White M and AA F no significant difference between $WC_{iliac-crest}$, and $WC_{umbilicus}$ AA M WC_{narrow} was statistically smaller. WC ≥ 90th = WC_{narrow}: 20.7 %, WC_{middle}: 29.6 %, $WC_{iliac\,crest}$: 31.5 %, and $WC_{umbilicus}$: 31.1 % (evaluated with percentile values of $WC_{iliac-crest}$)	All group: High SBP 7.7 %, fasting hyperglycemia 10.7 %, high TG 37.4 %., low HDL 56.4 %
Correlation of each WC with MetS components		F: All WC had positive correlation with SBP, DBP, TG, glucose, HOMA-IR and negative correlation with HDL. Not correlated: TC y LDL. M: All WC had positive correlation with DBP, LDL, HDL and HOMA-IR. Not correlation: SBP, TG, TC and glucose. The difference between correlation coefficients was significant ($p < 0.05$) in: F: $WC_{iliac-crest}$ *vs* WC_{rib} with the variable TG. M: $WC_{iliac-crest}$ *vs* WC_{rib}, WC_4 and WC_{middle} with LDL showed positive correlation ($p < 0.01$)	In all groups the correlation between all WC with SAT (r = 0.65-0.76) showed better correlation than VAT (r = 0.75 to 0.89). Correlation in prepubertal and pubertal between all WC with VAT was 0.73-0.87, with SBP 0.73-0.93 and similar with cardiovascular risk (numerical data not shown in the paper). Prepubertal M: correlation between $WC_{iliac-crest}$ with VAT (r = 0.65) and HOMA-IR (r = 0.13, $p < 0.05$); were lower than the other WC (WC_{middle} with VAT r = 0.76, and WC_{middle} with HOMA-IR r = 0.45, WC_{rib} and VAT r = 0.76 and WC_{rib} with HOMA-IR r = 0.33	Correlation between all WC with: SBP (r = 0.40-0.48), DBP (r = 0.37-0.46), Insulin (r = 0.43-0.63), HOMA-IR (r = 0.43-0.62). TG had positive correlation with WC_{narrow} and WC_{middle}. Correlation among WC_{narrow} and WC_{middle} was slightly stronger with CVD risk variables. Association of MetS for IDF: WC_{narrow} (OR 2.18; IC 1.23-3.85; $p = 0.007$) and WC_{middle} (OR 1.81; IC 1.06-3.09; $p = 0.03$); showed higher risk of MetS and number of MetS components. MetS - Cook definition: MetS was not associated with any WC; but it was associated with the number of components in WC_{narrow} (OR 2.10; IC 1.28-3.44; $p = 0.003$), WC_{middle} (OR 1.83; CI 1.13-2.98; $p = 0.01$). MetS-NCEP: was associated in WC_{narrow} (OR 3.80; CI 1.28-11.33; $p = 0.02$), and WC_{middle} (OR 3.24; CI 1.08-9.72; $p = 0.04$)	Correlation between all WC measurement sites: 0.97 to 0.99 (between all groups and by race and sex). Age-controlled correlation beatween WC and log VAT was significant in all groups: white and black M = 0.81-0.86, white F and AA = 0.87-0.89. Correlation of all WC with MetS components was strong except glucose for white M and AA-F. In AA-M the correlation between glucose with WC_{narrow} was lower but not with other WC. There was no correlation between all WC with DBP in white-M	Correlation between WC_{middle} was significant with SBP 0.72, DBP 0.63, glucose 0.13, TG 0.42 and HDL -0.46. Correlation between $WC_{iliac-crest}$ with: SBP 0.71, DBP 0.61, glucose 0.12, HDL -0.455. Sensitivity WC > 90th for WC_{middle} and $WC_{iliac-crest}$: Hypertension 88.9 and 81.5, hyperglycemia 64.1 and 59, hypertriglyceridemia 64.4 and 64.4, low HDL 63.1 and 65.1 and to identify ≥ 2 components of MetS was 67.9 and 68.8, respectively. The AUC for $WC_{middle} > 90^{th}$ and $WC_{iliac-crest} > 90^{th}$: hypertension (0.69 and 0.64), low HDL (0.62 and 0.62) and ≥ 2 components of MetS (0.617 and 0.608)
	STROBE	16	16	From 12 to 18	20	From 16 to 19
Evaluations of the quality of evidence	GRADE	A	A	A	A	A

JRI: journal rank indicator; AA: African American; WHO: World Health Organization; NCHS: National Center of Health Statistics; CV: coefficient of variation; MetS: metabolic syndrome; IDF: International Diabetes Federation; NCEP: National Cholesterol Education Program; HDL: high density lipoprotein cholesterol; TG: triglycerides; SBP: systolic blood pressure; DBP: diastolic blood pressure; M: male(s); F: female(s); BMI: body mass index; CVD: cardiovascular disease; HOMA-IR: Homeostatic Model Assessment for Insulin Resistance; OR: odds ratio; VAT: visceral adipose tissue; NPV: negative predictive value; PPV: positive predictive value. BMI: body mass index; IOTF: International Obesity Task Force; CDC: Centers for Disease Control and Prevention; NHANES: National Health and Nutrition Examination Survey; TC: total cholesterol; LDL: low-density lipoprotein cholesterol; SAT: subcutaneous adipose tissue; CI: confidence interval; AUC: area under the curve; STROBE: Strengthening the Reporting of Observational studies in Epidemiology; GRADE: Grading of Recommendations; Assessment; Development and Evaluation.

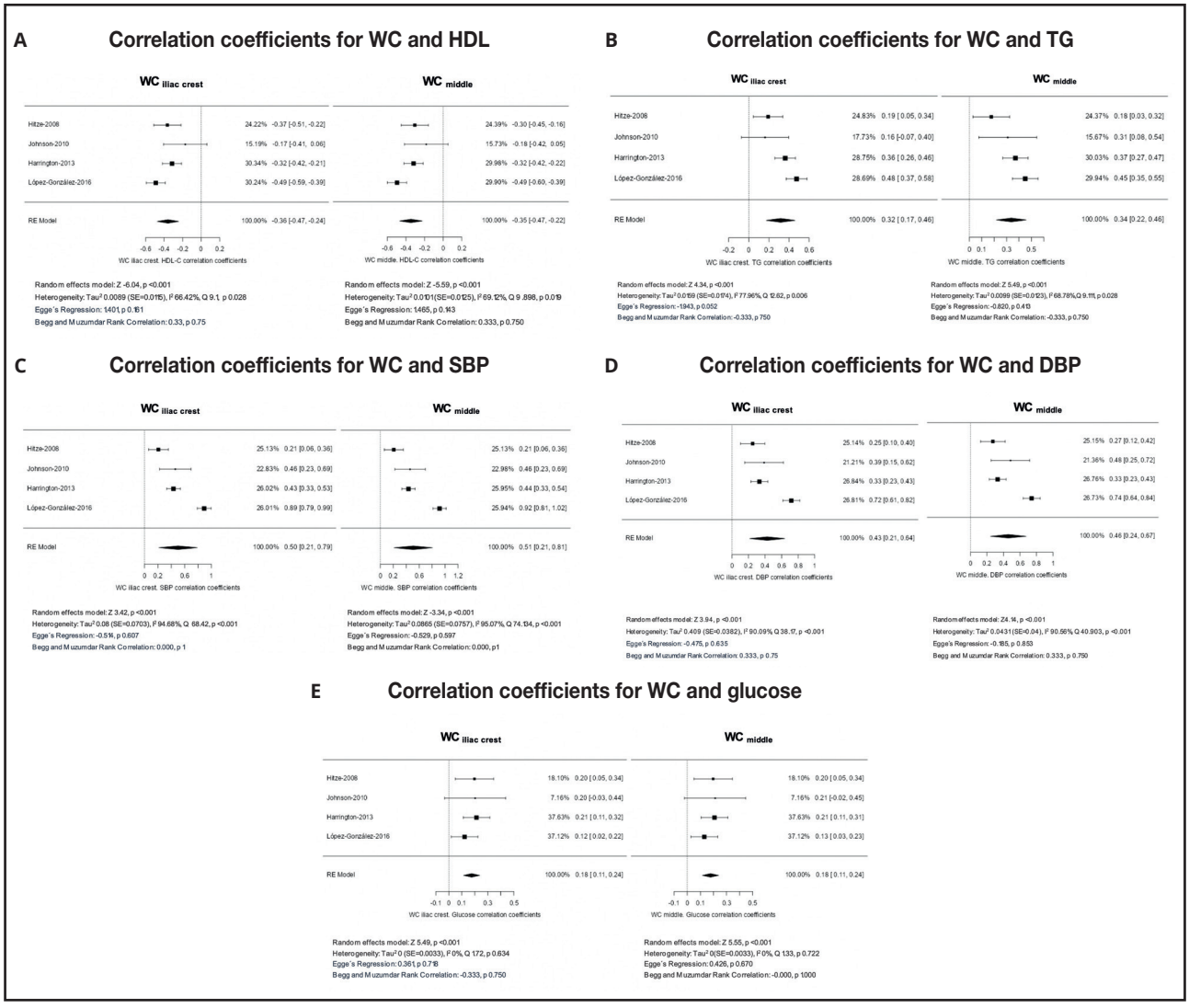

Figure 3.

Meta-analysis of correlation coefficients for $WC_{iliac\text{-}crest}$, WC_{middle}, and MetS components (WC: waist circumference; $WC_{iliac\text{-}crest}$: waist circumference measured above the iliac crest; WC_{middle}: waist circumference measured between the floating rib and the iliac crest; MetS: metabolic syndrome; HDL: high-density lipoprotein cholesterol; TG: triglycerides; SBP: systolic blood pressure; DBP: diastolic blood pressure) (Supplementary material: https://www.nutricionhospitalaria.org/anexos/05144-01.pdf).

However, this measurement may still be significant due to the prominence of the abdomen. In daily pediatric practice, WC is measured by physicians, nutritionists, pediatricians, and nurses. Work team training is essential to ensure precision in the technique and the anatomical site of measurement.

In table III, we summarize the strengths and weaknesses of each WC measurement site in children that can be better adapted to daily clinical practice according to training in measurement techniques and the characteristics of children.

A major limitation of our results is related to the fact that only few studies have assessed the correlation between different anatomical WC measurement sites and MetS in children and adolescents. This draws attention, considering that WC is the most relevant point for CVD risk exploration in clinical practice. Therefore, this systematic review should be the starting point for future studies on the specific characteristics of CVD risk according to age and sex at different measurement sites. It is essential to create specific percentiles for each WC measurement site for each ethnic group or population.

CONCLUSIONS

There is similar and adequate correlation between all WC measurement sites and other MetS components in the included studies, regardless the anatomical site of measurement. However, there are differences by age, pubertal development, and

Table III. Strengths and weaknesses of WC measurement sites

Measurement site	Strengths	Weaknesses
WC_{middle}	Established measurement protocol. Percentile tables in different ethnic populations. Good correlation with MetS	Difficulty in locating the anatomical point. Measurement can be uncomfortable and requires more time
$WC_{iliac\text{-}crest}$	Established measurement protocol. Percentile tables in different ethnic populations. Good correlation with MetS	Difficulty in locating the anatomical point. Difficult to stabilize the tape measure on a curved skin surface
WC_{rib}	Anatomical site location can be easy to locate and measure	No established measurement protocol. Not commonly used. May underestimate WC measurement
WC_{4}	Less comfortable and easier to locate in overweight or obese patients	No established measurement protocol. Not commonly used. The point of measurement can be at different sites on the abdomen, which can give a lot of variability
$WC_{umbilicus}$	Description of measurement protocol. Tables of percentiles in different ethnic population	Modification of umbilical scar location by adipose tissue descent in patients with obesity
WC_{narrow}	Established measurement protocol. Percentile tables in different ethnic populations. Good correlation with MetS	It is an anatomical site that may be difficult to visualize in some patients

ethnicity that have not yet been clearly defined.

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