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Exploring the Associations of Neck Circumference, Blood Pressure, CRP, and Insulin Resistance on the Visceral Adiposity Index: Insights from a Cross-Sectional Study

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Abstract: Background: The visceral adiposity index (VAI) is a composite marker designed to quantify visceral adiposity and its metabolic implications. It integrates anthropometric (such as waist circumference and BMI) and metabolic parameters (including triglyceride levels and HDL cholesterol), providing a more comprehensive assessment of visceral fat distribution than traditional measures alone. Higher VAI values are indicative of increased visceral adiposity and have been linked to heightened cardiovascular risk and metabolic disturbances. In recent years, understanding the complex interplay between metabolic factors and cardiovascular health has become increasingly important. Methods: This cross-sectional study delves into the influence of neck circumference (NC), blood pressure (BP), C-reactive protein (CRP), and insulin resistance on the VAI among outpatient cardiology patients, offering insights into sex-specific disparities and the utility of VAI as a diagnostic tool for assessing visceral adiposity and associated cardiovascular risks. Results: The sample comprised 268 outpatient cardiology patients (152 men, 116 women). Men, averaging 55.4 years old (SD = 14.4), exhibited significantly higher VAI values than women, with robust correlations found between VAI and markers of insulin resistance (Insulin: $\rho = -0.167$, $p = 0.006$; HOMA-IR: $\rho = -0.163$, $p = 0.007$). Analysis across VAI quartiles highlighted distinct patterns, revealing lower NC and elevated systolic blood pressure (SBP) values in higher VAI categories. Despite these associations, multiple linear regression controlling for age and sex demonstrated a limited predictive capacity of NC, BP, CRP, and lipid profiles on VAI (R2 range: 0.001–0.011). Conclusions: These findings underscore sex-specific disparities and suggest that VAI serves as a modest yet valuable tool in assessing visceral adiposity and associated cardiovascular risks.

Keywords: insulin resistance; visceral adiposity index; cardiovascular diseases; cardiovascular risk; waist circumference; Brazilian population

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1. Introduction

Cardiovascular diseases (CVDs) exert a significant toll on public health systems due to their elevated mortality rates that cause a substantial impact globally. Annually, an estimated 17.9 million people worldwide develop CVDs. Consequently, there has been an intensified exploration of risk factors in this context, with obesity emerging as an independent predictor. Considering that obesity significantly contributes to CVDs, it is crucial to establish preventive measures and early diagnostic tools for assessing adiposity rates in individuals at risk. Visceral adiposity, characterized by the ectopic accumulation of fat and dysfunctional adipose tissue (AT), serves as a key marker. Presently, the visceral adiposity index (VAI) proves valuable as an identification tool for predicting AT dysfunction due to its simplicity and non-invasive nature. As a gender-specific marker that combines anthropometric data and lipid profiles, VAI can be widely employed to evaluate the cardiovascular risk associated with dysfunctional AT accumulation [1,2]. The objective of this cross-sectional study is to analyze the influence of neck circumference, blood pressure (BP), C-reactive protein (CRP), and insulin resistance parameters on the VAI in Brazilian adults attending a cardiology outpatient clinic.

2. Materials and Methods

2.1. Study Design

This research constituted an analytical observational study employing a cross-sectional design, with the participation of 268 individuals from the University Hospital of the University of Marília. The inclusion criteria comprised individuals seeking routine cardiovascular care consultations at the Cardiology Unit or those exhibiting active cardiovascular symptoms.

2.2. Study Population

The participants in this study consist of a diverse group of volunteers, adults and elderly individuals of both genders, with ages ranging from 20 to 89 years. It is noteworthy that the records of pregnant and lactating women were intentionally excluded to maintain the focus and integrity of the research.

2.3. Anthropometric and Biochemical Analysis

The anthropometric variables collected and analyzed were weight, height, waist circumference (WC), neck circumference (NC), and body mass index (BMI). Anthropometric measurements were taken and recorded by trained professionals using the measurement techniques as preconized by Lohman et al. [3] and Gibson [4].

BMI was calculated by dividing weight in kilograms by the square of height in meters, classified according to World Health Organization (WHO) standards [5]. WC values were assessed according to WHO classification [6]. The interpretations of NC values were based on the study conducted by Stabe et al. [7].

The variables collected for biochemical analysis included fasting blood glucose levels (FBG), serum high-density lipoprotein cholesterol (HDL-c), serum triglycerides (TG), total cholesterol (TC), serum insulin levels (INS), and CRP. Serum low-density lipoprotein cholesterol (LDL-c) levels were determined using Friedewald's formula for all included participants [8]. The Homeostatic Model Assessment for Insulin Resistance (HOMA-IR) was calculated for all included patients using FBG and INS blood levels [9,10].

2.4. Calculation of VAI

Sex-specific equations were employed to calculate the VAI for all study participants. Key parameters used in this calculation included WC, BMI, TG, and HDL-c. The VAI formulas integrated two anthropometric parameters (BMI in kg/m^2 and WC in cm) along with two biochemical parameters (TG and HDL-c in mmol/L) [1].

$$VAI_{MEN} = [WC/\{39.68 + (1.88 * BMI)\}] * (TG/1.03) * (1.31/HDL\text{-}c)$$

$$VAI_{WOMEN} = [WC/\{36.58 + (1.89 * BMI)\}] * (TG/0.81) * (1.52/HDL\text{-}c)$$

2.5. Statistical Analysis

Quantitative variables were summarized using mean, standard deviation (SD), and 95% confidence interval. VAI data were also stratified by quartile distribution across the entire sample and by sex for group comparisons. Normality was assessed using the Kolmogorov–Smirnov test with Lilliefors correction, and correlations among quantitative variables were evaluated using Spearman's rank correlation coefficient. The homogeneity of variances was verified using Levene's test. Student's *t*-test or Welch's test was applied to compare two independent means, depending on the assumption of variance homogeneity. For comparisons involving more than two independent means, one-way ANOVA followed by Bonferroni post hoc test was utilized when necessary. Multiple linear regression analysis using the Enter method was performed to explore the impact of independent variables on VAI, with model goodness-of-fit assessed using R-squared. Statistical significance was set at 5%, and all analyses were conducted using SPSS software (version 27.0).

3. Results

The study sample, comprising 152 men and 116 women attending a cardiology outpatient clinic, exhibited various characteristics related to cardiometabolic health. Among men, the mean age was 55.4 years (SD = 14.4), with a mean BMI of 29.7 kg/m^2 (SD = 5.4) and a WC of 101.6 cm (SD = 16.0). NC averaged 40.6 cm (SD = 4.0), while systolic blood pressure (SBP) was 130.3 mmHg (SD = 16.6), and diastolic blood pressure (DBP) was 82.8 mmHg (SD = 10.2). Additionally, markers such as CRP (4.3 mg/dL, SD = 5.1), TC (185.5 mg/dL, SD = 45.3), HDL-c (47.1 mg/dL, SD = 13.3), and LDL-c (110.3 mg/dL, SD = 39.2) were measured. Although fewer in number, the women in the sample displayed comparable distributions across these variables, with notable differences observed in NC, TC, and LDL-c levels between the sexes. These findings underscore the diverse parameters influencing cardiometabolic risk profiles in this outpatient population and are presented in Table 1.

Table 1. Comparison of the mean and standard deviation (SD) of study variables in relation to sex for the sample (*n* = 268).

Variables	Men (*n* = 152)	Women (*n* = 116)	*p*-Value
	Mean ± SD	Mean ± SD	
Age	55.4 ± 14.4	58.3 ± 12.8	0.077 **
BMI (kg/m^2)	29.7 ± 5.4	29.7 ± 6.2	0.977
WC (cm)	101.6 ± 16.0	100.3 ± 12.8	0.465 **
NC (cm)	40.6 ± 4.0	36.1 ± 3.5	0.000
SBP (mmHg)	130.3 ± 16.6	127.4 ± 18.2	0.180
DBP (mmHg)	82.8 ± 10.2	81.0 ± 11.0	0.157
CRP (mg/dL)	4.3 ± 5.1	5.0 ± 4.9	0.250
TC (mg/dL)	185.4 ± 45.3	198.1 ± 46.6	0.027
HDL-c (mg/dL)	47.0 ± 13.3	46.1 ± 15.5	0.606
LDL-c (mg/dL)	110.3 ± 39.2	120.4 ± 41.4	0.042
HbA1C (%)	5.9 ± 1.2	5.9 ± 1.0	0.914
FBG (mg/dL)	107.7 ± 32.5	102.3 ± 19.7	0.092 **
Insulin (µIU/mL)	13.6 ± 13.2	16.3 ± 19.2	0.180
HOMA-IR	3.7 ± 3.9	4.4 ± 5.7	0.264
VAI	6.2 ± 4.7	6.5 ± 6.6	0.661

** *p*-value calculated by the Welch test for data that did not meet the assumption of homogeneity of variances by the Levene test. VAI is a sex-specific mathematical equation based on WC, BMI, TG, and HDL-c levels that indirectly expresses visceral adipose dysfunction associated with cardiometabolic risk. HOMA -IR is an index to assess insulin resistance based on serum glucose and insulin levels in fasting.

Table 2 presents the correlation analysis of the VAI with various study variables across the total sample and stratified by sex. Notably, INS ($\rho = -0.167$, $p = 0.006$) and HOMA-IR

(ρ = −0.163, $p = 0.007$) demonstrated significant negative correlations with VAI, suggesting a stronger relationship with insulin resistance parameters in the overall sample.

Table 2. Analysis of the VAI correlation with study variables in the total sample and by sex.

Variables	VAI											
	Men (n = 152)				Women (n = 116)				Total (n = 268)			
	ρ	p-Value	CI95%		ρ	p-Value	CI95%		ρ	p-Value	CI95%	
			LL	UL			LL	UL			LL	UL
Age	0.065	0.427	−0.100	0.226	−0.041	0.661	−0.227	0.148	0.018	0.774	−0.106	0.141
NC (cm)	0.005	0.953	−0.159	0.169	−0.153	0.101	−0.331	0.036	−0.057	0.352	−0.179	0.067
SBP (mmHg)	0.114	0.162	−0.051	0.273	0.179	0.054	−0.009	0.355	0.145	0.017 *	0.022	0.264
DBP (mmHg)	0.105	0.200	−0.060	0.264	0.176	0.058	−0.012	0.352	0.135	0.026 *	0.012	0.254
CRP (mg/dL)	0.110	0.179	−0.055	0.269	0.015	0.874	−0.173	0.202	0.064	0.298	−0.060	0.186
TC (mg/dL)	−0.147	0.071	−0.303	0.017	−0.001	0.994	−0.188	0.187	−0.084	0.171	−0.205	0.040
LDL-c (mg/dL)	−0.159	0.051	−0.314	0.005	0.049	0.604	−0.140	0.234	−0.072	0.241	−0.193	0.052
HbA1C (%)	−0.102	0.212	−0.261	0.063	−0.078	0.407	−0.261	0.111	−0.102	0.095	−0.223	0.022
FBG (mg/dL)	−0.130	0.110	−0.288	0.035	−0.074	0.428	−0.258	0.115	−0.110	0.072	−0.230	0.013
Insulin (µIU/mL)	−0.218	0.006 *	−0.369	−0.057	−0.093	0.319	−0.276	0.096	−0.167	0.006 *	−0.285	−0.045
HOMA-IR	−0.213	0.008 *	−0.364	−0.051	−0.090	0.337	−0.273	0.099	−0.163	0.007 *	−0.281	−0.041

p-value calculated by Spearman correlation test. Spearman's Rho correlation coefficient (ρ). * Indicates significant correlation for p-value < 0.050. 95% confidence interval (CI95%) with lower limit (LL) upper limit (UL).

Table 3 presents the median and quartile distribution of VAI values across the total sample and stratified by sex. In the total sample (n = 268), the 25th, median, and 75th percentiles for VAI were 3.24, 4.82, and 7.86, respectively. Among men (n = 152), these values were 3.10, 4.83, and 8.30, and among women (n = 116), they were 3.38, 4.79, and 7.45. These results indicate that VAI values tended to be higher in men compared to women, with variations observed across quartiles, reflecting differing distributions of visceral adiposity within the studied population.

Table 3. Median and quartile distribution of VAI values in the total sample and by sex.

	Men (n = 152)			Women (n = 116)			Total (n = 268)		
	25th	Median	75th	25th	Median	75th	25th	Median	75th
VAI	3.10	4.83	8.30	3.38	4.79	7.45	3.24	4.82	7.86

VAI is a sex-specific mathematical equation based on WC, BMI, TG, and HDL-c levels that indirectly expresses visceral adipose dysfunction associated with cardiometabolic risk. First quartile (25th). Third quartile (75th).

Table 4 presents the comparison of the mean and SD of the study variables across categories of VAI values categorized by quartile distribution and stratified by sex. Among participants in the <25th percentile VAI category (n = 67), the mean NC was significantly lower at 36.8 cm (SD = 3.7), denoted by 'a', compared to those in the 25th to 75th percentile category (n = 135) with an NC of 39.0 cm (SD = 4.7), and >75th percentile category (n = 66) with an NC of 39.9 cm (SD = 3.7), indicated by 'b' ($p < 0.001$). SBP showed a significant increase across VAI quartiles, with those in the >75th percentile category having the highest SBP (133.0 mmHg, SD = 17.2) compared to the <25th percentile (124.8 mmHg, SD = 18.3) and 25th to 75th percentile categories (129.3 mmHg, SD = 16.5) (p = 0.023). These findings highlight the association of NC and SBP with varying levels of visceral adiposity, underscoring potential cardiovascular risk factors within the study cohort.

Table 5 presents the results of multiple linear regression analyses investigating the impact of various study variables, adjusted for sex and age, on the VAI. The models display low R-squared values (R^2) ranging from 0.001 to 0.011, indicating that the included variables collectively explain only a small proportion of the variance in VAI. These findings suggest that factors beyond those examined in this study may play a more substantial role in influencing visceral adiposity levels within the study population.

Table 4. Comparison of the mean and standard deviation (SD) of the study variables in relation to the categories of VAI values by quartile distribution considering sex.

Variables	VAI Quartile						*p*-Value
	<25th (*n* = 67)		25th to 75th (*n* = 135)		>75th (*n* = 66)		
	Mean	SD	Mean	SD	Mean	SD	
Age	57.3	13.6	56.3	13.4	57.0	14.9	0.864
NC (cm)	36.8 [a]	3.7	39.0 [b]	4.7	39.9 [b]	3.7	<0.001 *
SBP (mmHg)	124.8 [a]	18.3	129.3	16.5	133.0 [b]	17.2	0.023 *
DBP (mmHg)	79.7	10.5	82.8	10.8	83.0	10.0	0.105
CRP (mg/dL)	4.2	3.9	5.1	5.1	4.0	5.7	0.246
TC (mg/dL)	199.3	51.0	190.7	42.4	183.0	47.7	0.126
LDL-c (mg/dL)	121.8	42.8	114.2	38.3	108.5	41.3	0.161
HbA1C (%)	5.9	0.8	5.9	1.3	5.8	1.0	0.798
FBG (mg/dL)	99.8	16.9	108.1	31.8	105.4	27.4	0.137
Insulin (μIU/mL)	16.7	16.6	15.2	18.5	12.0	8.2	0.230
HOMA-IR	4.4	5.0	4.2	5.3	3.3	3.3	0.395

* indicates significant difference between means using one-way ANOVA test for p-value ≤ 0.050. Different superscript letters indicate significant difference between means by Bonferroni post hoc test for p-values ≤ 0.050.

Table 5. Multiple linear regression analysis for the effect of study variables controlled by sex and age on VAI.

Variable		B	CI95%		Model	
Dependent	Independent		IL	UL	*p*-Value	R^2
VAI	(Constant) NC (cm)	11.232 −0.110	2.523 −0.288	19.942 0.069	0.628	0.007
VAI	(Constant) SBP (mmHg)	4.019 0.017	−2.123 −0.022	10.162 0.056	0.795	0.004
VAI	(Constant) DBP (mmHg)	3.154 0.037	−3.141 −0.027	9.449 0.101	0.658	0.006
VAI	(Constant) CRP (mg/dL)	6.257 0.006	2.873 −0.129	9.640 0.142	0.962	0.001
VAI	(Constant) TC (mg/dL)	8.221 −0.010	3.782 −0.025	12.660 0.005	0.587	0.007
VAI	(Constant) LDL-c (mg/dL)	7.962 −0.014	4.075 −0.031	11.849 0.003	0.416	0.011
VAI	(Constant) HbA1C (%)	8.112 −0.343	3.519 −0.943	12.705 0.257	0.671	0.006
VAI	(Constant) FBG (mg/dL)	7.251 −0.010	3.175 −0.035	11.326 0.015	0.821	0.003
VAI	(Constant) Insulin (μIU/mL)	6.613 −0.020	3.230 −0.062	9.997 0.023	0.774	0.004
VAI	(Constant) HOMA-IR	6.589 −0.075	3.233 −0.217	9.945 0.066	0.709	0.005

Regression coefficient (B). 95% confidence interval (CI95%) with lower limit (LL) upper limit (UL) for B.

In summary, significant correlations were observed exclusively in males and the overall sample concerning the VAI. Among males, correlations were significant only for INS and HOMA-IR. In the total sample, significant correlations with VAI were noted not only for insulin and HOMA-IR but also for SBP and DBP. However, these correlations were modest, prompting further exploration with additional analytical models. Analysis across VAI quartile categories revealed lower NC and SBP values among individuals below the first quartile (<25th) for VAI. Subsequent multiple linear regression analysis, controlling

for covariates such as sex and age, indicated no discernible effect of the investigated variables on VAI values. These findings suggest that the relationships involving NC, blood pressure, CRP, TC, LDL-c, and insulin resistance parameters with VAI are weak and may not reflect clinically significant associations for estimating these parameters. Nevertheless, VAI continues to demonstrate associations with the impact of obesity (WC and BMI) and dyslipidemia (TG and HDL-c) on cardiovascular risk.

4. Discussion

Our correlation analyses highlighted intriguing associations between VAI and various metabolic markers. Notably, significant negative correlations were observed between VAI and insulin resistance indices (INS and HOMA-IR) in the overall sample, specifically among males, suggesting a stronger relationship between visceral adiposity and insulin dysregulation in men. This might be possible because men presented slight but not significant (p = 0.092) increased FBG levels of 107.7 ($\pm$1.2) compared to 102.3 ($\pm$19.7) in women. When categorizing participants by quartiles of VAI, significant differences in NC and SBP emerged, particularly among individuals in higher VAI quartiles. This finding underscores visceral adiposity's potential role in influencing central obesity (reflected by NC) and cardiovascular health markers (such as SBP), further substantiating the complex interrelationships between adiposity distribution and cardiometabolic risk. Our study contributes valuable insights into the nuanced relationships between visceral adiposity and cardiometabolic health markers. While confirming sex-specific differences in adiposity distribution and metabolic outcomes, our findings underscore the need for further research to elucidate additional factors influencing visceral adiposity and its implications for cardiovascular risk assessment and management strategies.

Gu et al. [11] conducted a comprehensive study on the relationship between VAI and prediabetes. Key findings indicate that both VAI and WC independently increase the risk of prediabetes. Specifically, in males, increased VAI with normal WC and normal VAI with increased WC were associated with higher odds ratios (ORs) for prediabetes. In females, similar patterns were observed with increased VAI and normal WC, as well as normal VAI and increased WC. Our results indicated significant negative correlations between VAI and insulin resistance parameters such as HOMA-IR, which occurred in the overall sample, specifically among males. This is particularly interesting because VAI in Gu et al.'s study did not appear to correlate more specifically with a distinct sex. Our results might have been possible because men presented slight but not significant increased FBG levels of 107.7 compared to 102.3 in women.

Pekgor et al. [12] investigated the relationship between HOMA-IR and VAI levels in obese patients, emphasizing their association with Metabolic Syndrome (MetS) and insulin resistance. The study established VAI as a significant indicator for identifying patients with MetS, with a cutoff value of 2.205.

Jafari and colleagues [13] explored the correlation between insulin resistance indices and CVD incidence over 5 and 10 years in a cohort of healthy adults. The study identified the lipid accumulation product (LAP), TG–glucose index (TyG), and VAI as significant predictors of CVD risk. Our study demonstrated VAI as a significant predictor of differences in NC and SBP, particularly among individuals in higher VAI quartiles. Our findings specifically complement Jafari and colleagues' results because we underscore the VAI's influence in central obesity, which is reflected by NC, and cardiovascular health markers, which is reflected by SBP, demonstrating and substantiating the VAI as a more confident adiposity measurement to calculate cardiovascular risk.

With regard to lipid assessments, Jabłonowska-Lietz et al. [14] conducted an investigation into the potential of VAI as a reliable predictor for lipid abnormalities among 106 obese adults. The results revealed significant associations between several anthropometric indicators and VAI estimated by bioimpedance. Notably, the VAI, WC, and waist-hip ratio (WHR) emerged as robustly correlated with glucose and lipid abnormalities in the obese population. Conversely, VAI and BMI exhibited correlations with total fat mass

percentage (FM%). Furthermore, WC, WHR, and VAI demonstrated correlations with total body weight.

Goldani et al. [15] explored the VAI's utility in predicting MetS components among elderly individuals in Brazil. The analysis of associations among biochemical and MetS components revealed direct and significant correlations of BMI, weight, and VAI with blood glucose, HDL-c, and TG. In another Brazilian investigation, researchers explored the use of VAI for predicting components of MetS, focusing on a younger population.

Schuster et al. [16] conducted a cross-sectional study into the applicability of VAI in forecasting MetS components in young adults. The results revealed correlations between VAI and glucose, HDL-c, and TG in females. VAI correlated with glucose, HDL-c, TG, and DBP among males. Elevated VAI was associated with an increased risk of abdominal obesity, hypertriglyceridemia, and low HDL-c. Among obesity indicators, VAI exhibited a larger area under the curve (AUC) for increased TG and low HDL-c.

Agius et al. [17] investigated the discriminatory value of anthropometric and biochemical variables in predicting insulin resistance, determining its optimal cutoff points. Their data showed that LAP, VAI, TG, and WC all discriminated insulin resistance in both men and women with high power. Other authors investigated the discriminative power of VAI and other anthropometric indices to assess cardiovascular events in patients with metabolic dysfunction associated with steatotic liver disease (MASLD) [18]. Their results indicated VAI as the worst indicator compared to HOMA-IR and LAP since these indicators demonstrated the best accuracy in detecting MASLD. These results are prominent because insulin resistance is closely associated with the development and progression of MASLD [19]. More recently, Ishfaq et al. [20] found a positive correlation between VAI and visceral body fat among metabolically obese normal-weight individuals, demonstrating the VAI's reliability to assess visceral body fat in metabolically healthy obese volunteers successfully despite significant changes in biochemical laboratory tests.

Future studies should explore broader metabolic parameters and longitudinal outcomes to enhance our understanding of visceral adiposity's implications for cardiovascular health. Researchers must also examine the suitability and dependability of VAI across a broad spectrum of populations, considering variables such as age, ethnicity, geographical location, and regional susceptibilities. Additionally, scientists must thoroughly explore the intricate mechanisms that establish the connection between VAI and inflammation, delving into the molecular pathways and cellular interactions that underline this association. Finally, researchers must comprehensively explore the genetic factors that influence VAI, thereby unraveling the heritability patterns inherent in this index.

5. Conclusions

This study provides compelling insights into the intricate relationships between anthropometric measures, cardiometabolic markers, and the VAI in a diverse outpatient cardiology population. Our findings underscore significant sex-specific variations, with men exhibiting higher VAI values and stronger correlations with insulin resistance markers compared to women. NC and SBP emerged as notable indicators of visceral adiposity across VAI quartiles, highlighting their potential role in cardiovascular risk assessment. However, multiple linear regression analysis revealed that NC, BP, CRP, and lipid profiles collectively explain only a minimal proportion of VAI variance.

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