

Anthropometric Markers as Cardiovascular Predictors: A Comparison Between Conventional Cut-Off Points and Population Percentiles

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Abstract

Background: Cardiovascular diseases (CVD) are the leading cause of mortality worldwide. An ongoing debate exists regarding the most appropriate methods for assessing adiposity-associated cardiovascular risk in working populations. The aim of the study was to evaluate the association between different anthropometric markers and the development of cardiovascular events in Peruvian workers.

Methods: This is a retrospective cohort study of 10,300 workers (2014 - 2021). Body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHtR), and the WC-BMI index were evaluated as predictors of CVD (myocardial infarction and/or stroke). Population percentiles (75th and 95th) and conventional cut-off points were used. Additionally, conventional cut-off points were employed, such as 0.5 for WHtR, and according to the Adult Treatment Panel III (ATP-III) (≥ 102 cm in men and ≥ 88 cm in women) or International Diabetes Federation (IDF) (≥ 80 cm in men and ≥ 90 cm in women) for abdominal obesity.

Results: Obesity, as measured by BMI, showed a significant association with myocardial infarction (adjusted hazard ratio (aHR): 4.07; 95% confidence interval (CI): 1.08 - 15.4). Very high WC and WHtR (95th percentile) presented a greater risk of total cardiovascular events (aHR: 2.40; 95% CI: 1.12 - 5.12 and aHR: 2.57; 95% CI: 1.17-5.64, respectively), being particularly predictive for stroke (aHR: 4.53; 95% CI: 1.13 - 18.1 and aHR: 4.05; 95% CI: 1.01 - 16.3, respectively). No significant associations were found using conventional cut-off points for WHtR and abdominal obesity.

Conclusions: Central adiposity markers, especially WC and WHtR, were evaluated through population percentiles and were better predictors of cardiovascular events than BMI or conventional cut-off points in the Peruvian working population. These findings support reorienting obesity definitions toward cardiovascular risk assessment using population-specific percentiles rather than relying exclusively on universal adiposity thresholds.

Keywords: Obesity; Cardiovascular risk; Anthropometry; Occupational health; Cardiovascular disease; Retrospective cohort

Introduction

Cardiovascular diseases (CVD) remain the leading cause of mortality worldwide, accounting for approximately 17.9 million deaths annually, according to the World Health Organization [1]. Obesity, traditionally considered a modifiable risk factor for CVD, has experienced a significant increase in the working population during recent decades, with a global prevalence that has tripled since 1975 [2]. This phenomenon has generated substantial debate regarding the most appropriate methods for assessing cardiovascular risk (CVR) associated with adiposity.

Historically, body mass index (BMI) has been considered the gold standard for obesity classification, with universal cut-off points (≥ 25 kg/m² for overweight and ≥ 30 kg/m² for obesity) established primarily in Caucasian populations [3]. However, recent research suggests that measures of central adiposity, such as waist circumference (WC) and waist-to-height ratio (WHtR), might be better predictors of CVR [4, 5]. Nevertheless, cut-off points for these markers have also generated controversy, including those defined by the Adult Treatment Panel III (ATP-III) [6] or the International Diabetes Federation (IDF) [7]. In contrast, the universal cut-off point of 0.5 for WHtR lacks robust validation based on cardiovascular outcomes [8].

Accurate CVR assessment is relevant in the occupational context due to its impact on work productivity and associated healthcare costs. Studies in working populations have demonstrated that different anthropometric markers may have vary-

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ing predictive values depending on the specific characteristics of the studied population [9, 10]. Therefore, it is crucial to establish population-specific cut-off points that allow for more precise CVR identification, considering both traditional criteria and population-specific percentiles.

This situation thus presents an opportunity to reassess anthropometric markers not only from an etiological perspective linking adiposity with atherosclerosis but also from a prognostic approach. Following the PROgnosis RESearch Strategy (PROGRESS) framework [11], this study aligns with prognostic factor research (type II), seeking to identify specific characteristics (in this case, anthropometric markers) that influence cardiovascular outcomes. The findings could lay the groundwork for developing predictive models (type III) that combine these markers with other risk factors to predict individual CVR in working populations.

Materials and Methods

Study design and type

An observational analytical retrospective cohort study was conducted using secondary data from occupational medical evaluations performed between 2014 and 2021 at an occupational health clinic. The study design, analysis, and reporting adhered to the guidelines established by the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement and PROGRESS [11], thus ensuring transparency and methodological quality in the reporting of observational studies [12].

Population, sample, and eligibility criteria

The study population consisted of workers who underwent periodic occupational medical evaluations at the occupational health clinic between 2013 and 2020. To be eligible, participants had to meet the following inclusion criteria: 1) have at least two occupational medical evaluations with a minimum interval of 1 year between them; 2) have complete records of anthropometric measurements in their evaluations; and 3) have complete documentation of relevant sociodemographic variables and medical history.

Specific exclusion criteria were established for each cardiovascular outcome of interest, either the presence of myocardial infarction (MI) and/or stroke. For the incidence analysis, participants who had a history of any previous cardiovascular event at the start of the study, either by self-report or documented medical record, were excluded.

Participant follow-up was conducted through periodic occupational medical evaluations, which could be annual or biennial, according to each company's specific requirements and current labor regulations. When a participant developed any cardiovascular events of interest, they were considered an incident case, and their follow-up was censored for that specific outcome in the subsequent analysis. However, they continued with their routine occupational evaluations.

Variables and measurement

The study's dependent variables were CVD events, defined as MI and/or stroke. These events were evaluated through self-reporting during periodic occupational medical evaluations. The composite outcome (CVD) and its components (MI and stroke) were analyzed independently.

The main independent variables were the different anthropometric markers. Nutritional status was classified according to the World Health Organization (WHO) criteria using BMI: normal weight (≥ 24.9 kg/m²), overweight (25.0 - 29.9 kg/m²), and obesity (≥ 30 kg/m²). Abdominal obesity (AO) was evaluated using three indicators: WC, WHtR, and the WC-BMI index. For these markers, two classification systems were established: 1) based on population distribution, using the 75th (elevated) and 95th (very elevated) percentiles as cut-off points to define elevated and very elevated risk, respectively; and 2) according to conventional criteria, such as 0.5 for WHtR, and according to ATP-III (≥ 102 cm in men and ≥ 88 cm in women) [6] or IDF (≥ 80 cm in men and ≥ 90 cm in women) [7] for AO.

Follow-up time was calculated in years, considering each participant's first occupational medical evaluation as the starting point. Covariables included sociodemographic factors (age, sex), occupational characteristics (type of work (office, physical or manual, customer service or sales, health professional, social services) and work shift (day, night)), and traditional CVR factors (smoking in the last 30 days (yes/no), alcohol consumption in the previous 30 days (yes/no), systolic and diastolic blood pressure, fasting glucose, total cholesterol, and triglycerides).

Procedures

Data collection was conducted during occupational medical evaluations at three distinct times: at the beginning of employment (pre-occupational evaluation), during scheduled periodic examinations, and at the end of employment (retirement evaluation). Each evaluation followed a standardized protocol that included applying a structured questionnaire to collect sociodemographic and occupational information and health history, with special emphasis on personal and family cardiovascular history.

Anthropometric measurements were performed by previously trained nursing staff who were standardized in anthropometric techniques. Weight measurement was performed using calibrated digital scales, with the worker in a bipedal position, wearing light clothing and without footwear. Height was determined using calibrated wall stadiometers, with the participant in an erect position, heels together, and head in the Frankfurt plane. For WC measurement, an inextensible measuring tape was used, placed at the midpoint between the lower edge of the last rib and the upper edge of the iliac crest, with the worker in a standing position and at the end of normal expiration, following international recommendations for body perimeter measurements.

The medical evaluation included a structured clinical interview conducted by occupational physicians. These physi-

cians documented the presence of previous CVD events (MI and/or stroke) through worker self-reporting and review of medical documentation when available. Additionally, modifiable CVR factors such as smoking, alcohol consumption, and occupational characteristics that could influence CVR were recorded, including time in a seated position and work shift.

Data were recorded in a standardized electronic system as part of the occupational clinic's routine protocol, ensuring the quality and consistency of the collected information. No additional specific interventions were performed for research purposes, maintaining the study's observational nature.

Statistical analysis

Data were analyzed using R Studio version 4.1.0. The analysis was structured in three main phases. First, incidence rates of cardiovascular events (total CVD, MI, and stroke) were calculated per 1,000 person-years of follow-up, with their respective 95% confidence intervals (CIs), specifically according to the different categories of anthropometric markers evaluated: BMI (normal weight, overweight, obesity), WC and WHtR (normal, elevated, very elevated according to 75th and 95th percentiles), and the composite WC-BMI index.

Univariate and multivariate Cox regression models were used to evaluate the association between anthropometric markers and cardiovascular event risk. Univariate models were constructed for each anthropometric marker separately, while multivariate models were adjusted for potential confounders, including sex, age (categorized as ≤ 59 years and ≥ 60 years), smoking, and alcohol consumption. Results were presented as crude hazard ratios (cHR) and adjusted hazard ratios (aHR) with their respective 95% confidence intervals.

An additional comparative analysis was performed using conventional cut-off points (ATP-III and IDF for WC and 0.5 for WHtR) to evaluate concordance with results obtained through percentile categorization. Results were visualized using the "gt" package for incidence tables and the "gtsummary" package for regression models.

All analyses were conducted considering a 5% significance level. Data were processed using the R packages tidyverse, survival, gt, and gtsummary. Cox model assumptions, including proportional hazards, were verified through appropriate graphical methods and statistical tests.

Ethical aspects

This study was conducted with the approval of the Universidad Nacional Toribio Rodriguez de Mendoza Research Ethics Committee (CIEI number: 0068). In compliance with data protection and confidentiality regulations, a rigorous process of information anonymization was implemented before analysis, removing all personal and business identifiers that could allow the recognition of participants or organizations involved.

The research was conducted strictly according to the fundamental ethical principles established in the Declaration of Helsinki and international guidelines for good practice in oc-

cupational health research. As part of our commitment to scientific transparency and research reproducibility, the anonymized database and statistical analysis codes are available for consultation and verification in an open-access repository [13].

Results

Main characteristics

Approximately 10,300 workers were analyzed, predominantly male (84.57%), with a mean age of 37.17 ± 11.53 years, where 95.60% were under 60. The majority were employed in physical or manual work (54.49%) and office work (35.45%), with a low proportion of night work (6.56%). Regarding anthropometric indicators, the mean BMI was 27.18 ± 4.02 kg/m², with prevalences of overweight and obesity of 47.73% and 21.98%, respectively. The mean WC was 91.15 ± 10.41 cm, and WHtR was 0.55 ± 0.06 . Using population-specific percentiles, elevated and very elevated AO occurred in 24.79% and 6.62%, respectively, while according to conventional criteria, the prevalence of AO was 20.26% by ATP-III and 61.57% by IDF. Additionally, the prevalence of obesity by WHtR (≥ 0.5) reached 81.76%. The remaining characteristics can be visualized in Table 1.

Incidence and development of CVD according to nutritional status

For total CVD events, an incidence of 1.27 (95% CI: 0.48 - 2.05) per 1,000 person-years was observed in individuals with normal weight, increasing to 2.52 (95% CI: 1.63 - 3.40) in overweight and 3.54 (95% CI: 1.95 - 5.13) in obesity. Obesity was significantly associated with CVD in the crude analysis (cHR: 2.99; 95% CI: 1.43 - 6.25), although this association was attenuated after adjustment for confounding variables. Particularly notable was the association between obesity and MI, where a significant relationship was maintained even after adjustment (aHR: 4.07; 95% CI: 1.08 - 15.4), representing a four-fold higher risk than normal weight. For stroke, although a trend toward higher incidence was observed in obesity (1.68 per 1,000 person-years), the associations did not reach statistical significance (Table 2).

Incidence and development of CVD according to AO

Regarding AO, for total CVD events, the incidence progressively increased from 1.92 (95% CI: 1.28 - 2.57) per 1,000 person-years in the normal group to 5.55 (95% CI: 1.92 - 9.18) in the group with very elevated circumference, maintaining this significant association even after multivariate adjustment (aHR: 2.40; 95% CI: 1.12 - 5.12) (Table 3). The association with stroke was particularly notable, where the very elevated circumference category presented a more than four-fold higher risk (aHR: 4.53; 95% CI: 1.13 - 18.1) compared to the normal category. A similar pattern was observed for MI, where the very elevated category showed a significantly higher risk (aHR: 3.79; 95% CI: 1.17 - 12.2) than the normal category.

Table 1. Study Sample Characteristics

Characteristic	N = 10,300
Sex	
Female	1,589 (15.43%)
Male	8,711 (84.57%)
Age ^a	37.17 (11.53)
Age group	
18 - 59 years	9,847 (95.60%)
60 years or older	453 (4.40%)
Occupation type	
Office	3,651 (35.45%)
Physical or manual	5,612 (54.49%)
Customer service or sales	62 (0.60%)
Health professional	243 (2.36%)
Social services	732 (7.11%)
Night shift work	
No	9,624 (93.44%)
Yes	676 (6.56%)
Smoking status	
No	6,031 (58.55%)
Yes	4,269 (41.45%)
Alcohol consumption	
No	5,143 (49.93%)
Yes	5,157 (50.07%)
Body mass index ^a	27.18 (4.02)
Abdominal waist ^a	91.15 (10.41)
Waist-to-height ratio	0.55 (0.06)
Waist-BMI	25.12 (6.40)
Nutritional status	
Normal weight	3,120 (30.29%)
Overweight	4,916 (47.73%)
Obesity	2,264 (21.98%)
Abdominal obesity (percentile)	
Normal	7,065 (68.59%)
Elevated	2,553 (24.79%)
Very elevated	682 (6.62%)
WHtR-defined obesity (percentile)	
Normal	7,162 (73.31%)
Elevated	2,074 (21.23%)
Very elevated	534 (5.47%)
WC-BMI-defined obesity (percentile)	
Normal	7,486 (72.68%)
Elevated	2,271 (22.05%)
Very elevated	543 (5.27%)
Abdominal obesity (ATP-III)	

Table 1. Study Sample Characteristics - (continued)

Characteristic	N = 10,300
No	8,213 (79.74)
Yes	2,087 (20.26)
Abdominal obesity (IDF)	
No	3,958 (38.43)
Yes	6,342 (61.57)
WHtR-defined obesity (≥ 0.5)	
No	1,879 (18.24)
Yes	8,421 (81.76)

Data were shown in n (%). ^aMean (SD). BMI: body mass index; WC: waist circumference; WHtR: waist-to-height ratio; ATP-III: Adult Treatment Panel III; IDF: International Diabetes Federation; SD: standard deviation.

Incidence and development of CVD according to WHtR-defined obesity

The WHtR was shown to be a strong predictor of cardiovascular events. For total CVD events, a marked increase in incidence was observed from 1.84 (95% CI: 1.21 - 2.47) per 1,000 person-years in the normal category to 7.14 (95% CI: 2.48 - 11.81) in the very elevated category, with this association remaining significant after multivariate adjustment (aHR: 2.57; 95% CI: 1.17 - 5.64) (Table 4). Very elevated WHtR showed particularly strong associations with both stroke (aHR: 4.05; 95% CI: 1.01 - 16.3) and MI (aHR: 4.20; 95% CI: 1.26 - 14.0), indicating approximately four times higher risk compared to the normal category for both outcomes.

Incidence and development of CVD according to the WC-BMI index-defined obesity

Regarding the WC-BMI index, it showed a particular pattern of association with cardiovascular events. For total CVD events, a significant increase was observed in the elevated category with an incidence of 3.98 (95% CI: 2.32 - 5.65) per 1,000 person-years compared to 1.91 (95% CI: 1.29 - 2.54) in the normal category, maintaining the association after adjustment (aHR: 1.81; 95% CI: 1.05 - 3.11) (Table 5). The most notable association was observed with MI, where the elevated category presented a three-fold higher risk (aHR: 3.10; 95% CI: 1.23 - 7.76) compared to the normal category. However, unlike other anthropometric markers, the elevated category did not show significant associations with any cardiovascular outcomes studied.

Cardiovascular event risk according to conventional AO criteria (ATP-III - IDF) and classical WHtR

In the complementary analysis using conventional criteria for AO, weaker associations were observed compared to the population percentile categorization. AO, according to ATP-

Table 2. Incidence Rates and Development of CVD According to Body Mass Index Categories

	Nutritional status	Incidence rate ^a (95% CI)	Number of events	Person-years	cHR	aHR ^b
CVD	Normal weight	1.27 (0.48 - 2.05)	10	7,902.36	Ref.	Ref.
	Overweight	2.52 (1.63 - 3.40)	31	12,317.15	1.91 (0.96, 3.78)	1.23 (0.61, 2.47)
	Obesity	3.54 (1.95 - 5.13)	19	5,371.76	2.99 (1.43, 6.25)	1.87 (0.89, 3.95)
Stroke	Normal weight	0.38 (0.01 - 0.81)	3	7,902.36	Ref.	Ref.
	Overweight	0.73 (0.25 - 1.21)	9	12,317.15	0.67 (0.20, 2.33)	0.46 (0.13, 1.65)
	Obesity	1.68 (0.58 - 2.77)	9	5,371.76	2.13 (0.65, 7.00)	1.44 (0.42, 4.88)
MI	Normal weight	0.63 (0.08 - 1.19)	5	7,902.36	Ref.	Ref.
	Overweight	0.41 (0.05 - 0.76)	5	12,317.15	2.01 (0.54, 7.42)	1.51 (0.40, 5.72)
	Obesity	1.12 (0.22 - 2.01)	6	5,371.76	5.28 (1.43, 19.5)	4.07 (1.08, 15.4)

^aIncidence rate is expressed per 1,000 person-years. ^bAdjusted for sex, age, tobacco use, and alcohol consumption. Categories: normal (< 75th percentile), elevated (75th - 95th percentile), very elevated (> 95th percentile). CVD: cardiovascular events; MI: myocardial infarction; cHR: crude hazard ratio; aHR: adjusted hazard ratio; 95% CI: 95% confidence interval; Ref.: reference category.

Table 3. Incidence Rates and Development of CVD According to Abdominal Obesity

	Abdominal obesity	Incidence rate ^a (95% CI)	Number of events	Person-years	cHR	aHR ^b
CVD	Normal	1.92 (1.28 - 2.57)	34	17,690.21	Ref.	Ref.
	Elevated	2.71 (1.42 - 3.99)	17	6,280.14	1.58 (0.88, 2.84)	1.25 (0.69, 2.26)
	Very elevated	5.55 (1.92 - 9.18)	9	1,620.93	3.54 (1.69, 7.43)	2.40 (1.12, 5.12)
Stroke	Normal	0.68 (0.29 - 1.06)	12	17,690.21	Ref.	Ref.
	Elevated	0.80 (0.10 - 1.49)	5	6,280.14	2.80 (0.93, 8.38)	2.36 (0.78, 7.15)
	Very elevated	2.47 (0.05 - 4.89)	4	1,620.93	5.87 (1.51, 22.9)	4.53 (1.13, 18.1)
MI	Normal	0.40 (0.10 - 0.69)	7	17,690.21	Ref.	Ref.
	Elevated	0.96 (0.19 - 1.72)	6	6,280.14	1.41 (0.49, 4.01)	1.22 (0.42, 3.53)
	Very elevated	1.85 (0.00 - 3.95)	3	1,620.93	4.89 (1.56, 15.3)	3.79 (1.17, 12.2)

^aIncidence rate is expressed per 1,000 person-years. ^bAdjusted for sex, age, tobacco use, and alcohol consumption. Categories: normal (< 75th percentile), elevated (75th - 95th percentile), very elevated (> 95th percentile). CVD: cardiovascular events; MI: myocardial infarction; cHR: crude hazard ratio; aHR: adjusted hazard ratio; 95% CI: 95% confidence interval; Ref.: reference category.

Table 4. Incidence Rates and Development of CVD According to WHtR-defined Obesity

	WHtR-defined obesity (percentile)	Incidence rate ^a (95% CI)	Number of events	Person-years	cHR	aHR ^b
CVD	Normal	1.84 (1.21 - 2.47)	33	17,924.96	Ref.	Ref.
	Elevated	2.54 (1.16 - 3.91)	13	5,126.92	1.55 (0.81, 2.96)	1.19 (0.61, 2.30)
	Very elevated	7.14 (2.48 - 11.81)	9	1,260.29	4.76 (2.26, 10.0)	2.57 (1.17, 5.64)
Stroke	Normal	0.67 (0.29 - 1.05)	12	17,924.96	Ref.	Ref.
	Elevated	0.59 (0.00 - 1.25)	3	5,126.92	2.51 (0.81, 7.72)	2.03 (0.64, 6.39)
	Very elevated	3.17 (0.06 - 6.28)	4	1,260.29	6.44 (1.70, 24.4)	4.05 (1.01, 16.3)
MI	Normal	0.45 (0.14 - 0.76)	8	17,924.96	Ref.	Ref.
	Elevated	0.98 (0.12 - 1.83)	5	5,126.92	1.07 (0.30, 3.81)	0.89 (0.25, 3.26)
	Very elevated	2.38 (0.00 - 5.07)	3	1,260.29	6.18 (1.98, 19.3)	4.20 (1.26, 14.0)

^aIncidence rate is expressed per 1,000 person-years. ^bAdjusted for sex, age, tobacco use, and alcohol consumption. Categories: normal (< 75th percentile), elevated (75th - 95th percentile), very elevated (> 95th percentile). CVD: cardiovascular events; WHtR: waist-to-height ratio; MI: myocardial infarction; cHR: crude hazard ratio; aHR: adjusted hazard ratio; 95% CI: 95% confidence interval; Ref.: reference category.

Table 5. Incidence Rates and Development of CVD According to WC-BMI Index-Defined Obesity

	WC-BMI-defined obesity (percentile)	Incidence rate ^a (95% CI)	Number of events	Person-years	cHR	aHR ^b
CVD	Normal	1.91 (1.29 - 2.54)	36	18,816.91	Ref.	Ref.
	Elevated	3.98 (2.32 - 5.65)	22	5,525.04	2.36 (1.38, 4.02)	1.81 (1.05, 3.11)
	Very elevated	1.60 (0.01 - 3.82)	2	1,249.33	1.07 (0.26, 4.45)	0.85 (0.20, 3.55)
Stroke	Normal	0.53 (0.20 - 0.86)	10	18,816.91	Ref.	Ref.
	Elevated	1.63 (0.56 - 2.69)	9	5,525.04	2.65 (0.94, 7.47)	2.14 (0.75, 6.13)
	Very elevated	1.60 (0.01 - 3.82)	2	1,249.33	2.34 (0.30, 18.5)	1.98 (0.25, 15.8)
MI	Normal	0.48 (0.17 - 0.79)	9	18,816.91	Ref.	Ref.
	Elevated	1.09 (0.22 - 1.95)	6	5,525.04	3.68 (1.49, 9.11)	3.10 (1.23, 7.76)
	Very elevated	0.80 (0.01 - 2.37)	1	1,249.33	4.37 (0.95, 20.1)	3.84 (0.83, 17.9)

^aIncidence rate is expressed per 1,000 person-years. ^bAdjusted for sex, age, tobacco use, and alcohol consumption. Categories: normal (< 75th percentile), elevated (75th - 95th percentile), very elevated (> 95th percentile). CVD: cardiovascular events; BMI: body mass index; WC: waist circumference; MI: myocardial infarction; cHR: crude hazard ratio; aHR: adjusted hazard ratio; 95% CI: 95% confidence interval; Ref.: reference category.

III criteria (aHR: 1.43; 95% CI: 0.89 - 2.59) and IDF (aHR: 1.50; 95% CI: 0.83 - 2.71) showed trends toward increased cardiovascular event risk, although these associations did not reach statistical significance after adjustment. Similarly, the conventional cut-off point of WHtR ≥ 0.5 also did not show a significant association with cardiovascular events (aHR: 1.23; 95% CI: 0.54 - 2.76) (Table not shown).

Discussion

Main findings

In this occupational cohort study, we found that different anthropometric markers show distinctive patterns of association with cardiovascular events, highlighting the importance of considering multiple adiposity measures in CVR assessment. Particularly notable was the finding that central adiposity indicators, especially WC and WHtR categorized by population percentiles, showed more robust associations with cardiovascular events than traditional BMI or conventional cut-off points for AO.

An especially relevant finding was identifying specific risk patterns according to the type of cardiovascular event. Our analysis showed that while obesity measured by BMI was significantly associated with MI (aHR: 4.07; 95% CI: 1.08 - 15.4), central adiposity markers, particularly WC and WHtR above the 95th percentile, demonstrated stronger and more consistent associations with both total cardiovascular events (aHR: 2.40; 95% CI: 1.12 - 5.12 and aHR: 2.57; 95% CI: 1.17 - 5.64, respectively) and stroke (aHR: 4.53; 95% CI: 1.13 - 18.1 and aHR: 4.05; 95% CI: 1.01 - 16.3, respectively). Furthermore, these population-specific percentile cut-offs showed stronger associations than conventional criteria, suggesting they might be more appropriate for CVR stratification in our population.

Controversies with cut-off points

The traditional concept of obesity has been based on excess

body fat. However, the widespread adoption of BMI as the standard for its diagnosis presents significant limitations, as the initially established cut-off points lack a solid scientific foundation directly linking them to body fat percentage. As Ho-Pham et al [14] point out in their critical analysis, even WHO never formally established specific body fat percentage thresholds to define obesity, despite this being erroneously cited in the scientific literature for decades. This is understandable, given the inherent challenges of establishing universal cut-off points across diverse global populations. Body composition and fat distribution patterns vary significantly across ethnic groups, geographical regions, and populations, making worldwide standardization particularly challenging. This reality strengthens our argument for the use of population-specific percentiles in CVR assessment, as they better reflect the anthropometric characteristics of the target population.

WC emerged as a more specific alternative for evaluating central adiposity because BMI does not distinguish between fat and lean mass. However, paradoxically, the established cut-off points for WC were derived from its correlation with BMI, with ATP-III using a BMI of 30 kg/m² and IDF of 25 kg/m² as references [15]. In other words, an indicator whose validity for defining obesity was questionable from its origin was used as a reference standard. Following this same line, WHtR adopted the cut-off point 0.5 based primarily on systematic reviews [16]. However, its application results in obesity prevalences close to 80% in some populations, which seems implausible from an epidemiological and clinical perspective [17].

This situation poses a fundamental dilemma: defining obesity based on body fat percentage would require sophisticated measurement methods such as computed tomography, which are impractical for population screening. Therefore, we propose that the definition of obesity should be reoriented toward its association with CVR rather than being based exclusively on adipose tissue quantity. Under this approach, using population-specific percentiles for different anthropometric markers could offer a more rational alternative for establishing clinically relevant cut-off points.

Anthropometric markers and CVD

In the present study, BMI was not an anthropometric risk marker for CVD development, either generally or specifically for MI or stroke. The literature related to this topic has shown controversial results. While BMI has traditionally been used as the primary marker to define obesity, it presents important diagnostic limitations. A recent meta-analysis by Oguntade et al [5] that included over 1 million adults demonstrated strong positive associations between adiposity markers and heart failure risk, with a relative risk of 1.42 (95% CI: 1.40 - 1.42) per 5 kg/m² increase in BMI, 1.28 (95% CI: 1.26 - 1.31) per 10-cm increase in WC, and 1.33 (95% CI: 1.28 - 1.37) per 0.1-unit increase in waist-hip ratio. Notably, the association with adiposity was stronger for heart failure with preserved ejection fraction than for heart failure with reduced ejection fraction, suggesting different mechanisms may be involved in the etiopathogenesis of heart failure subtypes. These limitations highlight the importance of WC, which has proven to be a significant predictor of CVR even after adjusting for BMI. Indeed, a recent international consensus has emphasized the need to consider WC as a “vital sign” in clinical practice [15].

BMI's main limitation lies in its inability to distinguish between fat and lean mass. This deficiency is particularly relevant given that adipose tissue distribution, rather than total quantity, determines cardiometabolic risk. A recent population-based cohort study by Su et al [4] explored the relationship between WC and both CVD morbidity and all-cause mortality in metabolically healthy individuals. The adjusted logistic regression model indicated that a 10-cm increase in WC was associated with a 1.45-fold higher prevalence of CVD. As a categorical variable, there was a significant upward trend in CVD incidence across quartiles of WC, with adjusted odds ratios (95% CI) of 2.41 (1.13 - 5.53) for Q2, 2.65 (1.18 - 6.39) for Q3, and 2.53 (0.9 - 7.44) for Q4, compared to Q1. Furthermore, the Cox regression analysis revealed that each 10-cm increase in WC contributed to an approximately 8% increase in all-cause mortality, even in metabolically healthy individuals. This evidence suggests that BMI alone might not adequately stratify CVR, especially in individuals with atypical body composition, and underscores the importance of routine WC measurement for effective CVD risk management, regardless of metabolic health status.

On the other hand, WC has proven to be an important anthropometric marker for CVD development, including MI and stroke. This finding is consistent with evidence showing that WC emerged as a complementary or alternative marker to BMI under the premise that fat distribution, especially central adiposity, is more relevant than total adiposity for CVR.

A meta-analysis by Jayedi et al [18] examining 72 prospective cohort studies with over 2.5 million participants demonstrated a strong positive linear association between WC and all-cause mortality. The study found that each 10-cm increase in WC was associated with a 11% higher risk of all-cause mortality (hazard ratio (HR): 1.11, 95% CI: 1.08 - 1.13), with stronger associations observed in younger adults and women. Moreover, compared with the optimal WC (defined as the *na-*

dir of the curve), the estimated decreases in life expectancy for men with WCs of 90 cm, 100 cm, 110 cm, and 120 cm were 1.7, 3.1, 4.4, and 5.7 years, respectively. For women with WCs of 80 cm, 90 cm, 100 cm, and 110 cm, the corresponding decreases were 1.4, 2.6, 3.8, and 5.0 years, respectively. Moreover, data from prospective cohorts in Latin America have shown that specific WC cut-off points (≥ 89 cm in men and ≥ 86 cm in women) are associated with a 1.76- and 1.41-fold increase in the risk of major cardiovascular events and incident diabetes, respectively [19].

A recent international consensus has emphasized the need to consider WC as a “vital sign” in clinical practice, given its importance for CVR assessment [15]. A recent cross-sectional study by Suwala et al [20] investigating the predictive capacity of anthropometric measures for CVR found that both BMI and WC independently predicted above-average increased CVR (odds ratio: 1.10 - 1.27). Interestingly, the study revealed gender-specific differences in the predictive accuracy of these measurements: in males, BMI was a more accurate predictor (area under the curve (AUC) = 0.816), while in females, WC demonstrated superior predictive capacity (AUC = 0.739). The researchers proposed novel thresholds for these anthropometric measures: a BMI of 27.6 kg/m² was associated with a 3.3 - 5.3 times increased risk of CVD depending on gender, while WC thresholds of 93 cm in women and 99 cm in men corresponded to a 3.8 - 4.8-fold higher risk. These findings suggest that although measurement protocols may vary, the predictive capacity of WC for cardiovascular events remains robust, especially when gender-specific considerations are incorporated.

Furthermore, the present investigation found that WHtR above the 95th percentile presented a significant risk for CVD, specifically for MI and stroke, when analyzed separately. Notably, this association was not found with the 75th percentile or with the traditional cut-off point of 0.5, which questions the universal validity of this latter value.

The 0.5 cut-off point for WHtR has been widely adopted as a universal value, primarily based on evidence from European, American, and Asian populations. While several studies have validated this cut-off point in these populations, as demonstrated by the analysis of Health Survey for England data, where WHtR ≥ 0.5 showed better predictive capacity than the BMI-WC matrix for cardiometabolic risk [21], there is growing evidence questioning its universal applicability, especially in Latin America.

A comprehensive systematic review and meta-analysis by Savva et al [22] examining 107 studies with over 3.9 million participants found that optimal WHtR threshold values vary significantly according to the specific condition being predicted: 0.53 - 0.55 for diabetes, 0.51 - 0.54 for CVD, and 0.50 - 0.52 for hypertension, suggesting that a single universal cut-off point might be overly simplistic. Although the weighted average value across populations approximated 0.52, this primarily reflects data from European, North American, and East Asian populations, with limited representation from Latin American cohorts. Recent research in Latin American populations has demonstrated demographically distinct optimal thresholds. For instance, a study of Chilean adults by Petermann-Rocha et al [23] identified optimal cut-points of 0.56 for men and 0.58 for

women for cardiometabolic risk. These regional variations underscore the importance of population-specific anthropometric thresholds for clinical practice.

Thus, while WHtR appears to be the most important indicator for long-term CVD risk, classical cut-off points might significantly overestimate risk in Latin American populations. Therefore, there is a need to investigate cut-off points based on CVR, possibly using population-specific percentiles.

Public health importance of the study

Our findings have important public health implications and propose a fundamental reconsideration of obesity. The traditional definition based primarily on body fat percentage could evolve toward one more oriented to CVR, considering that different anthropometric indices capture distinct aspects of cardiometabolic risk.

The results of this study transcend the simple association between adiposity and CVR, positioning themselves within the framework of prognostic, even etiological research. The evaluated anthropometric markers, especially those based on population percentiles, could constitute valuable prognostic factors for developing future predictive models. Unlike the traditional etiological approach that explains the relationship between adiposity and atherosclerosis, our findings support the prognostic utility of these markers for predicting future cardiovascular events.

Using different anthropometric measurements could significantly improve CVR assessment in clinical practice. While BMI and WC have been traditional pillars in clinical evaluation, incorporating WHtR as a complementary measure could identify at-risk individuals who currently go unnoticed with conventional metrics. This prognostic perspective could complement existing prediction tools, considering that most current models either do not use any anthropometric marker or primarily rely on BMI as the sole anthropometric marker [20, 24]. The incorporation of central adiposity measures with population-specific cut-off points could improve the predictive capacity of future CVR models in Latin American working populations.

WHtR offers significant public health advantages in terms of practical implementation: it is easy to measure, requires no specialized equipment, and provides a simple and memorable health message. However, the variability in optimal cut-off points suggests the need to develop population-specific recommendations, particularly in Latin America, where our findings indicate that traditional cut-off points might not be appropriate. These results lay the groundwork for future research to develop predictive models integrating multiple anthropometric markers for more accurate CVR prediction in specific populations.

Strengths and limitations

Among the main strengths of this study are its retrospective cohort design with a large database from occupational health

surveillance ($n = 10,300$), extended follow-up period (2014 - 2021), and simultaneous evaluation of multiple anthropometric markers under standardized protocols. However, it also presents important limitations addressed during its development: 1) While cardiovascular events were initially identified through self-reporting, the occupational health setting provided additional verification through medical documentation review and mandatory occupational health reassessments following such major health events, mitigating potential reporting biases. Additionally, these serious health conditions (MI and stroke) require formal medical documentation for occupational records and often lead to work absences and workplace accommodations, enhancing the reliability of their reporting; 2) While the population was predominantly male (84.57%), this reflects the reality of the studied labor sector and analyses were adjusted for sex to control potential biases, in addition to performing stratified analyses when possible; 3) Although direct information on diet and physical activity was not collected, proxy variables such as type of work (administrative vs. manual) and time in seated position were included, providing indirect information about occupational physical activity level; 4) The potential “healthy worker effect” is an inherent limitation of occupational studies, however, the long follow-up period and inclusion of workers from various sectors and occupations helped capture greater variability in the studied population’s health status.

Conclusions and recommendations

This study demonstrates that central adiposity markers, particularly WC and WHtR evaluated through population-specific percentiles, serve as superior prognostic indicators of CVD compared to BMI or conventional cut-off points in the Peruvian working population. The findings reveal that percentile categorization, especially the 95th percentile, exhibits stronger associations with cardiovascular events than traditional ATP-III, IDF criteria, or the standard 0.5 cut-off point for WHtR. These findings support the implementation of routine anthropometric measurements in occupational health evaluations and underscore the necessity of developing population-specific cut-off points for Latin American populations. Future research directions should focus on incorporating central adiposity measures into CVR calculators and validating these findings through additional prospective studies across diverse working populations in the region. Implementing these evidence-based approaches could enhance early identification and prevention of cardiovascular events in occupational settings, particularly in Latin American contexts where conventional cut-off points may not be optimal.

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Conflict of Interest

The authors declare no conflict of interest.

Informed Consent

Informed consent was not required for this study.

Author Contributions

Victor Juan Vera-Ponce: conceptualization, investigation, methodology, resources, writing - original draft, writing - review and editing. Joan A. Loayza-Castro: methodology, software, data curation, formal analysis, writing - review and editing. Fiorella E. Zuzunaga-Montoya and Luisa Erika Milagros Vasquez-Romero: investigation, project administration, writing - original draft, writing - review and editing. Lupita Ana Maria Valladolid-Sandoval: investigation, methodology, writing - original draft, writing - review and editing. Jhosmer Ballena-Caicedo: validation, visualization, supervision, writing - original draft, writing - review and editing. Witre Omar Padilla: investigation, methodology, resources, writing - original draft, writing - review and editing. Carmen Ines Gutierrez De Carrillo: methodology, supervision, funding acquisition, writing - review and editing.

Data Availability

The data supporting this study's findings have been deposited in Figshare and can be accessed at <https://doi.org/10.6084/m9.figshare.27098296.v1>.

Abbreviations

CVD: cardiovascular diseases; BMI: body mass index; WC: waist circumference; WHtR: waist-to-height ratio; CVR: cardiovascular risk; MI: myocardial infarction; AO: abdominal obesity; ATP-III: Adult Treatment Panel III; IDF: International Diabetes Federation; HR: hazard ratio; aHR: adjusted hazard ratio; cHR: crude hazard ratio; CI: confidence interval; WHO: World Health Organization; SD: standard deviation

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