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Towards a Comprehensive Measure of Cardiovascular Health: Cross-Sectional Assessment of Anthropometry, Diet and Lifestyle in the General Population

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Abstract

Background/Objectives: Traditional cardiovascular risk stratification has often focused on isolated biomarkers, overlooking the combined impact of lifestyle and body composition. This study evaluated the associations between anthropometric, dietary, and lifestyle factors and cardiovascular health markers in a general population sample without ex-clusion criteria.

Methods: A total of 333 adults (18–75 years) underwent a cross-sectional assessment including anthropometric measurements, blood pressure, lipid profile, fasting glucose, and self-reported lifestyle data. Correlation analyses and stratified comparisons were used to examine relationships between adiposity, behavioral factors, and cardi-ometabolic risk indicators.

Results: Body fat percentage showed stronger associations with systolic blood pressure ($r = 0.483$, $p < 0.001$), triglycerides ($r = 0.198$, $p < 0.001$), and fasting glucose ($r = 0.357$, $p < 0.001$) than BMI, underscoring its predictive value. Individuals with elevated body fat—irrespective of BMI—displayed less favorable cardiovascular profiles. Higher dietary fiber intake and more frequent physical activity were consistently asso-ciated with lower adiposity, blood pressure, and inflammatory markers (e.g., fiber vs. %fat, $r = -0.527$, $p < 0.001$). In contrast, fasting glucose and HbA1c exhibited weak asso-ciations with lifestyle variables in this normoglycemic cohort.

Conclusions: Adiposity, particularly excess body fat, emerged as a stronger predictor of cardiometabolic risk than BMI. Higher fiber intake and regular physical activity were linked to more favorable cardiovascular profiles. These findings support the use of multidimensional approaches integrating body composition, diet, and lifestyle assessment for early cardiovascular risk identification in the general population.

1. Introduction

Cardiovascular disease (CVD) remains the leading cause of death worldwide, responsible for more than 17 million deaths each year [1]. Although pharmacological and interventional advances have lowered CVD mortality in high-income countries, the absolute burden continues to climb—particularly in low- and middle-income regions—posing a persistent challenge to global health systems [1]. Epidemiological data attribute most CVD morbidity to modifiable factors, including sub-optimal diet, insufficient physical activity, excess adiposity, hypertension, dyslipidemia, and impaired glucose homeostasis [1–3]. Consequently, prevention strategies targeting lifestyle and behavioral determinants of cardiometabolic health have become a public-health priority [1–3].

Traditional risk stratification tools have relied predominantly on isolated biomarkers—such as systolic blood pressure, LDL cholesterol, or fasting glucose—to estimate cardiovascular risk [4,5]. However, accumulating evidence underscores the need for a broader, integrative perspective. Anthropometric markers, including waist circumference, waist-to-hip ratio, and body fat percentage, as well as lifestyle-related behaviors such as physical activity, sleep, stress perception, and dietary quality, have been independently associated with subclinical metabolic alterations and adverse cardiovascular outcomes [3,6–12]. Recent guidelines emphasize not only the quantity but also the quality and regularity of physical activity, alongside adequate sleep duration and continuity, as essential determinants of cardiovascular and metabolic health[1,3,5,13]. Notably, the American Heart Association has updated its construct of cardiovascular health to the Life's Essential 8, which incorporates diet, physical activity, nicotine exposure, sleep health, body mass index, blood lipids, blood glucose, and blood pressure, providing a multidimensional framework for both individual and population-level assessment [1,3,5,13].

Conventional anthropometry—particularly BMI—often conceals heterogeneity in body composition and associated risk. Individuals with "normal-weight obesity" may present increased cardiometabolic risk despite a normal BMI, leading to recommendations to include waist circumference and waist-to-height ratio in routine clinical assessments [2,3,6,8,11,13–15]. Moreover, early alterations in systolic blood pressure or glycated hemoglobin (HbA1c), even within subclinical ranges, can provide relevant insights into early pathophysiological changes, especially when interpreted in the context of physical

activity, sleep patterns, and dietary fiber intake, which are increasingly recognized as modifiable levers in preventive cardiology.

Most population-based studies restrict participation based on existing health conditions or focus on specific subgroups (e.g., patients with diabetes or hypertension). This approach limits understanding of the distribution of cardiovascular risk markers and their behavioral correlates in the general population. A sample without exclusion criteria offers added value because it captures the full spectrum of metabolic and lifestyle variability, including individuals often underrepresented in research—such as apparently healthy adults with unrecognized risk factors—thereby improving the external validity of findings and their potential application to population-wide prevention strategies [1–3].

Based on these considerations, the present study aimed to assess cardiovascular health in a general population sample with no exclusion criteria, integrating clinical, anthropometric, dietary, and lifestyle dimensions. The specific objectives were: (1) to describe clinical, anthropometric, dietary, and behavioral characteristics of the population stratified by sex; (2) to analyze differences in lifestyle and body composition according to blood pressure, HbA1c, and body fat categories; (3) to explore associations between lifestyle factors (physical activity, diet, sleep) and clinical biomarkers of cardiovascular risk (blood pressure, lipids, glucose); and (4) to identify cardiovascular risk patterns linked to the accumulation of unhealthy behaviors or excess adiposity.

2. Materials and Methods

2.1. Study Design and Participants

This was a cross-sectional observational study aimed at analyzing the relationship between clinical markers of cardiovascular health and anthropometric, dietary, and lifestyle factors in a general adult population. No formal sample size calculation was performed a priori, as the study was conceived as an exploratory analysis. The final sample of 333 adults (133 men and 200 women) reflected re-cruitment feasibility within the study period. Participants were recruited through public advertisements in community centers, primary care clinics, and university notice boards, inviting all adults aged 18–75 years to participate volun-tarily, regardless of their medication use or socio-economic background.

2.2. Ethical Approval

This study was conducted in accordance with the Declaration of Helsinki and received ethical approval from the Ethics Committee of Alicante University (UA-2021-03-11). All participants provided informed consent prior to their inclusion in the study, ensuring their voluntary participation and understanding of the research procedures.

2.3. Variables and procedures

Data collection included clinical, anthropometric, dietary, and lifestyle variables, obtained through standardized physical measurements and validated questionnaires. Variables were grouped into four domains:

1. Clinical markers: systolic and diastolic blood pressure (SBP, DBP), total cholesterol, triglycerides, fasting blood glucose and glycated hemoglobin (HbA1c).
2. Anthropometric variables: weight, height, waist circumference, hip circumference, waist-to-hip ratio, body mass index (BMI), and body fat percentage measured by multifrequency bioelectrical impedance analysis.
3. Dietary variables: total energy intake (kcal/day), macronutrient intake expressed in grams per kilogram of body weight (g/kg/day) for protein, carbohydrates, and fats; as well as dietary fiber intake and frequency of ultra-processed food consumption. Dietary intake was assessed using a 3-day dietary record completed by participants, including two weekdays and one weekend day. Participants were instructed to report all foods and beverages consumed, including portion sizes and preparation methods. The dietary record was based on a standardized template previously developed by the Universidad Complutense de Madrid (UCM) [16].

4. Lifestyle variables: physical activity (frequency in sessions/week and duration in minutes/session), sleep duration (hours/night), alcohol consumption, smoking status, and perceived stress levels.

Lifestyle variables and medical history were collected using a structured questionnaire specifically designed for this study (see Supplementary Material 1). The questionnaire also included items on current pharmacological treatments (antihypertensive, lipid-lowering, and antidiabetic medications) and prior diagnoses of hypertension, dyslipidemia, or diabetes made by a healthcare professional. For analytical purposes, participants reporting antihypertensive therapy were classified as having hypertension, and those on lipid-lowering therapy as having dyslipidemia, regardless of current clinical values.

2.4. Categorization of variables

Clinical variables were categorized according to international guidelines. Systolic blood pressure (SBP) followed the thresholds defined in the 2023 European Society of Hypertension (ESH) Guidelines [16]; Optimal <120 mmHg, Normal 120–129 mmHg, High-normal 130–139 mmHg, and Hypertension ≥140 mmHg. Due to the small number of individuals with hypertension (≥140 mmHg), SBP values were dichotomized into Normal (<120 mmHg) and Elevated (≥120 mmHg) to ensure adequate statistical power and clinical relevance. These thresholds are consistent with current recommendations prioritizing systolic BP as a stronger and more consistent predictor of cardiovascular risk, particularly in middle-aged and older adults, compared to diastolic BP. Systolic hypertension is known to independently drive most cardiovascular outcomes in population-based studies and is a primary focus of clinical guidelines for hypertension management [17]. Diastolic blood pressure (DBP) was also recorded and incorporated into descriptive and correlation analyses, allowing for a more comprehensive evaluation of BP-related risk.

Glycated hemoglobin (HbA1c) was grouped as “Normal” (<5.7%) or “Altered” (≥5.7%) following the American Diabetes Association thresholds [18]. Fasting glucose and blood lipids (total cholesterol, LDL cholesterol, HDL cholesterol, and triglycerides) were categorized according to international recommendations, merging adjacent groups when necessary to ensure robust statistical comparisons [2,19,20].

Anthropometric variables included waist circumference, waist-to-hip ratio (WHR), waist-to-height ratio (WHtR), and body fat percentage. Waist circumference was considered elevated if ≥94 cm in men or ≥80 cm in women, in accordance with current international recommendations for Europid populations [19]. WHtR values ≥0.5 were indicative of increased cardiometabolic risk in both sexes [21]. Body fat percentage was categorized by sex, with ≤20% considered normal and >20% high in men, and ≤28% normal and >28% high in women [21].

Dietary variables included daily fiber intake and frequency of ultra-processed food consumption. Fiber intake was categorized as <25 g/day or ≥25 g/day, consistent with international recommendations for adequate fiber intake in adults. Processed food frequency was classified as “rare” or “frequent” based on the median value of reported weekly consumption within the sample.

Lifestyle variables included physical activity, tobacco, sleep, alcohol use, and perceived stress. Physical activity was classified according to WHO recommendations as insufficient (<150 min/week) or sufficient (≥150 min/week). For descriptive purposes, activity frequency was also grouped as <3 sessions/week or ≥3 sessions/week, and intensity was classified as light, moderate, or intense. Sleep duration was categorized as insufficient (<7 h/night), adequate (7–9 h/night), or long (>9 h/night). Smoking status was classified as smoker or non-smoker, and alcohol consumption as yes or no (current consumption). Perceived stress levels were categorized as low, medium, or high based on validated questionnaire scoring thresholds.

2.5. Statistical Analysis

Descriptive statistics (mean, standard deviation, and frequencies) were calculated and stratified by sex. Comparisons of clinical, anthropometric, and lifestyle variables between clinical groups (SBP, HbA1c, body fat) were performed using ANOVA

for normally distributed variables and Mann–Whitney U or Kruskal–Wallis tests for non-parametric data. Categorical variables were analyzed using chi-square tests. Spearman correlations were used to examine associations between continuous variables. In addition, multivariable linear and logistic regression models were performed to account for potential confounders, including age, sex, and medication use, ensuring robust assessment of the associations of interest. Sex-stratified analyses were conducted where relevant to capture potential sex-specific differences. All analyses were conducted using Jamovi software (Version 2.6.17.0). A p-value <0.05 was considered statistically significant.

3. Results

3.1. Sample characteristics

The study included 333 participants (133 men and 200 women). Table 1 shows the distribution of key clinical, anthropometric, dietary, and lifestyle variables, reported as medians and interquartile ranges (Q1–Q3). In general, men presented higher body weight and waist circumference, while women had a higher percentage of body fat. Men also showed higher diastolic blood pressure and lower fiber intake, whereas women reported higher fasting glucose levels and lower BMI.

Table 1. Descriptive characteristics of the study population by sex (n = 333)

Variable	Men (n=133)			Women (n=200)			Mean difference	ES	p
	Median	Q1	Q3	Median	Q1	Q3			
Age (years)	34.0	26.0	40.0	34.5	26.0	44.0	-1.000	0.07180	0.267
Weight (kg)	77.4	72.1	87.4	63.1	57.9	72.8	14.000	-0.67759	<.001
BMI (kg/m^2)	25.6	23.9	27.8	24.5	22.1	27.3	1.152	-0.21636	<.001
Waist perimeter (cm)	86.0	80.3	92.9	75.4	71.4	80.6	10.360	-0.70891	<.001
Hip perimeter (cm)	102	96.2	103	98.6	93.1	105	1.700	-0.11357	0.079
Body fat (%)	21.7	15.6	24.5	28.4	20.2	34.6	-7.700	0.47609	<.001
SBP (mmHg)	112	110	119	115	108	119	0.200	-0.02053	0.751
DBP (mmHg)	73.6	70.6	75.4	70.4	68.8	71.6	3.200	-0.50477	<.001
Cholesterol (mg/dL)	200	185	212	187	166	195	10.400	-0.32289	<.001
LDL (mg/dL)	120	106	127	93.7	93.2	106	17.400	-0.48586	<.001
Triglycerides (mg/dL)	72.0	59.2	89.0	74.7	60.6	85.0	-1.82e−5	0.02278	0.724
Glucose (mg/dL)	88.6	85.0	91.2	91.0	84.4	93.6	-1.400	0.17398	0.007
HbA1c (%)	5.26	5.24	17.8	5.28	5.26	5.57	-6.14e−5	0.05545	0.385
Sleep (hours)	7.00	6.38	8.00	7.00	7.00	7.50	-4.48e−5	0.04880	0.653
Fiber (g)	25.0	21.8	33.0	24.4	17.0	30.0	4.700	-0.33575	<.001

Data are presented as median and interquartile range (Q1–Q3). Differences between men and women were assessed using the Mann-Whitney U test. SBP = systolic blood pressure; DBP = diastolic blood pressure; LDL = low-density lipoprotein cholesterol; HDL = high-density lipoprotein cholesterol; HbA1c = glycated hemoglobin; PA = physical activity; ES = Effect size

Table 2 presents the sex-stratified frequency distribution of key clinical, anthropometric, dietary, and lifestyle categories. Although most participants exhibited normal clinical parameters, relevant sex-specific differences emerged across multiple domains.

Table 2. Frequency distribution of clinical, anthropometric, and lifestyle-related categorical variables in the study population, stratified by sex.

Variable	Category	Men (n=133)		Women (n=200)	
		n	%	n	%
SBP	Normal	100	30.0%	165	49.5%
	Elevated	33	9.9%	35	10.5%
HbA1c	Normal	92	27.6%	178	53.5%
	Altered	41	12.3%	22	6.6%
% body fat	Normal	57	17.1%	97	29.1%
	High	51	15.3%	59	17.7%
	Very High	25	7.5%	44	13.2%
Fiber intake	<25g	46	13.8%	113	33.9%
	≥25g	87	26.1%	87	26.1%
Processed food frequency	Rare	79	23.7%	75	22.5%
	Frequent	54	16.2%	125	37.5%
PA frequency	<3 times/week	41	17.1%	47	19.6%
	≥3 times/week	52	21.7%	100	41.7%
PA intensity	Light	34	10.2%	74	22.2%
	Moderate	72	21.6%	108	32.4%
	Intense	27	8.1%	18	5.4%
Tobacco use	Smoker	35	10.5%	3	0.9%
	Non-smoker	98	29.4%	197	59.2%
Alcohol consumption	Yes	53	15.9%	95	28.5%
	No	80	24.0%	105	31.5%
Stress perception	Low	52	15.6%	9	2.7%
	Medium	65	19.5%	136	40.8%
	Hight	16	4.8%	55	16.5%
Sleep	Less than 7th	13	10.6%	19	15.4%
	7 – 9 h	27	22.0%	56	45.5%
	More than 9h	0	0.0%	8	6.5%

SBP = systolic blood pressure; HbA1c = glycated hemoglobin; CRP = C-reactive protein; LDL = low-density lipoprotein cholesterol; PA = physical activity.

Altered glycaemic control, defined as HbA1c ≥5.7%, was more frequent in men (12.3%) than in women (6.6%), despite similar fasting glucose distributions. Excess adiposity was more prevalent among women, highlighting the limitations of BMI in capturing adiposity-related risk, with only 29.1% of women classified as having normal body fat compared with 17.1% of

men, while 29.1% and 13.2% of women were classified as high and very high body fat, respectively, compared with 15.3% and 7.5% of men.

Dietary patterns also differed, with one-third of women (33.9%) consuming less than 25 g/day of fibre compared with 13.8% of men, and frequent consumption of ultra-processed foods being notably higher in women (37.5% vs. 16.2%).

In terms of physical activity, most participants reported at least three sessions per week, more commonly among women (41.7% vs. 21.7% in men), but intensity was predominantly moderate, and vigorous-intensity activity remained uncommon (5.4% of women and 8.1% of men).

Sleep duration showed that one quarter of participants reported sleeping fewer than seven hours per night, with this behaviour more prevalent among women (15.4% vs. 10.6%), while only 6.5% of women reported sleeping more than nine hours and no men reached this threshold.

Stress perception was also higher in women, with 40.8% reporting medium and 16.5% high stress levels, compared with 19.5% and 4.8% in men. Smoking was more frequent among men (10.5% vs. 0.9%), whereas alcohol consumption was slightly more common in women (28.5% vs. 15.9%).

Overall, these findings reveal distinct sex-specific behavioural and physiological profiles: women tended to exhibit greater adiposity, less favourable dietary patterns, higher perceived stress, and shorter sleep duration, whereas men were more likely to smoke and engage in slightly more vigorous physical activity. These differences underscore the importance of sex-specific strategies to address modifiable lifestyle risk factors contributing to cardiometabolic health.

3.2. Group-based comparisons

To better understand how clinical and behavioral variables differ across cardiovascular risk profiles, participants were grouped according to blood pressure status (normal; SBP <120 mmHg vs. elevated; ≥120 mmHg), HbA1c level (<5.7% vs. ≥5.7%), and body fat percentage (normal vs. high, sex-specific).

3.2.1 Comparison by Systolic Blood Pressure Status

To explore differences in cardiovascular risk profiles, participants were stratified based on systolic blood pressure (SBP <120 mmHg vs. ≥120 mmHg). Individuals with elevated SBP exhibited significantly worse anthropometric, biochemical, and lifestyle indicators (Table 3).

Table 3. Comparison of anthropometric, biochemical and lifestyle variables between individuals with normal and elevated systolic blood pressure (SBP)

Variable	SBP Normal (mean ± SD) (n=265)			SBP Elevated (mean ± SD) (n=68)			p-value	ε²
	Median	Q1	Q3	Median	Q1	Q3		
% Body Fat	22.6	17.0	30.5	28.6	24.3	34.8	<.001	0.086
Waist Perimeter (cm)	76.7	72.0	84.6	85.7	80.4	92.9	<.001	0.156
Hip Perimeter (cm)	98.9	94.4	105	103	97.8	104	0.015	0.017
Waist-to-Hip Ratio	0.783	0.730	0.842	0.845	0.815	0.900	<.001	0.172
Triglycerides (mg/dL)	69.4	56.8	85.0	86.6	85.0	88.6	<.001	0.071
PA Duration (minutes)	50.0	45.0	60.0	45.0	40.0	45.0	0.001	0.082
Sleep Duration (hours)	7.00	6.50	8.00	7.00	7.00	7.00	0.541	0.003
Dietary Fiber (g/day)	25.0	21.8	32.0	20.2	19.1	26.6	<.001	0.041
Total Calories (kcal/day)	1860	1627	2287	1627	1286	1900	<.001	0.097
Proteins (g/kg/day)	1.70	1.47	1.80	1.60	1.37	1.76	0.243	0.004
Carbohydrates (g/kg/day)	2.47	1.85	4.00	2.10	1.60	2.38	<.001	0.046
Fats (g/kg/day)	0.914	0.517	1.40	0.639	0.485	0.759	<.001	0.071
Diastolic BP (mmHg)	70.6	70.0	73.0	68.8	68.8	80.0	0.872	7.83e-5
Total Cholesterol (mg/dL)	185	166	201	195	191	200	<.001	0.044
Glucose (mg/dL)	90.8	84.4	92.8	91.8	90.4	92.4	0.001	0.031

SBP = systolic blood pressure; CRP = C-reactive protein; PA = physical activity; SD = standard deviation. Values are expressed as mean ± SD. p-values refer to group differences (ANOVA).

Specifically, those with elevated SBP had a higher body fat percentage (median difference = +6.0%; $p < .001$) and significantly greater waist circumference (+9.0 cm; $p < .001$), while hip circumference remained similar between groups ($p = .015$). Waist-to-hip ratio was also higher in the elevated SBP group ($p < .001$), reflecting a more central pattern of fat distribution.

From a biochemical perspective, participants with elevated SBP showed increased triglyceride concentrations (median difference ≈ +17.2 mg/dL; $p < .001$), higher total cholesterol (+10 mg/dL; $p < .001$), and slightly higher fasting glucose levels ($p = .001$). Diastolic blood pressure did not differ significantly between groups ($p = .872$).

Lifestyle behaviours were also less favourable in the elevated SBP group. They reported shorter physical activity sessions (−5 minutes/session; $p = .001$) and significantly lower dietary fibre intake (−4.8 g/day; $p < .001$). Total caloric intake and fat intake were also reduced (both $p < .001$), while protein intake was similar ($p = .243$). Sleep duration did not differ significantly between groups ($p = .541$).

These findings suggest that even modest elevations in SBP are associated with a constellation of unfavourable cardiometabolic and lifestyle factors, reinforcing the value of early detection and intervention.

3.2.2 Comparison by Glycemic Status (HbA1c)

Sample were categorized based on HbA1c values into those with normal glycemic control (HbA1c <5.7%) and those with altered levels (HbA1c ≥5.7%). As shown in Table 4, participants with altered HbA1c (≥5.7%) exhibited a markedly leaner body composition, with a median body fat percentage 10.7% lower and waist circumference 4.5 cm smaller compared with those

with normal HbA1c (<5.7%) (both p < .001), despite similar waist-to-hip ratios. Triglyceride concentrations were also significantly lower in the altered HbA1c group (−13.9 mg/dL; p < .001).

Table 4. Comparison of clinical, anthropometric, and lifestyle variables by glycemic status (HbA1c)

Variable	Normal HbA1c (<5.7%) (n = 270)			Altered HbA1c (≥5.7%) (n = 63)			p-value	ε²
	Median	Q1	Q3	Median	Q1	Q3		
% Body Fat	25.5	21.3	33.1	14.8	12.7	17.5	<.001	0.326
Waist Perimeter (cm)	80.5	74.2	86.0	76.0	70.0	80.2	<.001	0.056
Hip Perimeter (cm)	102	95.5	105	95.0	93.0	97.5	<.001	0.106
Waist-to-Hip Ratio	0.808	0.739	0.850	0.816	0.747	0.845	0.767	2.65e-4
Triglycerides (mg/dL)	79.6	64.3	89.0	65.6	55.6	68.5	<.001	0.121
PA Frequency (days/week)	45.0	45.0	60.0	60.0	45.0	70.0	<.001	0.118
PA Duration (minutes)	7.00	6.50	7.50	7.00	7.00	8.00	0.513	0.003
Sleep Duration (hours)	22.0	19.3	30.0	30.0	25.0	38.1	<.001	0.124
Dietary Fiber (g/day)	1700	1400	2000	2547	2427	2794	<.001	0.428
Total Calories (kcal/day)	2.06	1.62	2.55	5.00	4.20	5.81	<.001	0.108
Proteins (g/kg/day)	1.60	1.45	1.76	1.80	1.70	2.12	<.001	0.351
Carbohydrates (g/kg/day)	0.653	0.467	1.00	1.50	1.00	1.50	<.001	0.227
Fats (g/kg/day)	116	110	119	109	108	112	<.001	0.111
Systolic BP (mmHg)	70.9	69.0	73.6	70.6	69.0	72.0	0.080	0.009
Diastolic BP (mmHg)	191	179	209	189	163	201	0.190	0.005
Total Cholesterol (mg/dL)	91.0	85.4	93.0	86.0	82.4	88.6	<.001	0.097
Glucose (mg/dL)	25.5	21.3	33.1	14.8	12.7	17.5	<.001	0.326

HbA1c = glycated hemoglobin; CRP = C-reactive protein; PA = physical activity; SD = standard deviation.

Lifestyle behaviours showed the opposite pattern to what might be expected. Individuals with altered HbA1c engaged in more frequent physical activity (+1.5 sessions/week; p < .001), performed longer exercise sessions (+11.5 minutes/session; p < .001), and reported greater dietary fibre intake (+8.8 g/day; p < .001). Their total energy and macronutrient (carbohydrates and fats) intakes were also significantly higher (all p < .001).

Blood pressure was lower among individuals with altered HbA1c, with systolic blood pressure showing a mean difference of −5.9 mmHg (p < .001) and diastolic blood pressure −1.3 mmHg (p = .022). Fasting glucose levels were slightly lower (−3.0 mg/dL; p = .011), while total cholesterol and C-reactive protein did not differ significantly.

These findings reveal a paradoxical metabolic profile: despite impaired glycaemic control, individuals with altered HbA1c were leaner and more physically active, suggesting the presence of heterogeneous metabolic phenotypes not primarily driven by adiposity.

3.2.3 Comparison by Body Fat Percentage in Women

In women, increasing levels of body fat were associated with marked alterations in cardiovascular and lifestyle parameters (Table 5). Both anthropometric and metabolic variables demonstrated a clear gradient, with worse profiles as adiposity increased.

Table 5. Differences in cardiovascular and lifestyle indicators across body fat percentage categories in women.

Variable	Normal (n=57)	High (n=51)	Very High (n=25)	p-value	ε^2
Waist Circumference (cm)	71.76 ± 5.39‡**	76.22 ± 3.68	83.59 ± 2.63‡	<.001	0.543
Hip Circumference (cm)	101.70 ± 80.93	102.07 ± 4.40	106.67 ± 2.22‡	<.001	0.632
Waist-to-Hip Ratio	0.763 ± 0.090	0.749 ± 0.047	0.785 ± 0.030‡	<.001	0.112
Triglycerides (mg/dL)	74.62 ± 22.55#	82.59 ± 17.81	76.59 ± 14.39	0.004	0.055
PA Frequency (days/week)	4.76 ± 2.00*	4.15 ± 0.54	3.50 ± 0.55	0.679	0.009
PA Duration (min)	52.07 ± 19.60	55.48 ± 6.69	50.83 ± 7.36	0.424	0.020
Sleep Hours	7.47 ± 1.73	7.86 ± 2.62	8.17 ± 1.91	<.001	0.243
Dietary Fiber (g/day)	26.74 ± 5.48#**	23.35 ± 6.06	19.03 ± 5.33‡	<.001	0.344
Total Calories (kcal/day)	1948.96 ± 398.70‡**	1460.11 ± 163.96	1484.63 ± 216.93	<.001	0.548
Proteins (g/kg/day)	1.99 ± 0.51‡**	1.45 ± 0.27	1.31 ± 0.13#	<.001	0.548
Carbohydrates (g/kg/day)	3.73 ± 1.60‡**	1.89 ± 0.37	1.37 ± 0.37‡	<.001	0.63352
Fats (g/kg/day)	1.19 ± 0.41‡**	0.78 ± 0.21	0.51 ± 0.19‡	<.001	0.46337
Systolic BP (mmHg)	109.90 ± 6.06‡**	117.21 ± 7.91	119.57 ± 3.00	<.001	0.41164
Diastolic BP (mmHg)	69.17 ± 2.60‡	72.00 ± 2.92	69.94 ± 3.24‡	<.001	0.18840
Total Cholesterol (mg/dL)	186.67 ± 26.79	187.92 ± 18.15	179.27 ± 20.74#	0.038	0.03284
Fasting Glucose (mg/dL)	85.95 ± 5.76‡**	90.73 ± 4.07	94.26 ± 3.62‡	<.001	0.37877

^: significantly different from Normal group ($p < .05$); #: significantly different from High group ($p < .05$); *: significantly different from Very High group ($p < .05$); †: significantly different from Normal group ($p < .01$); ‡: significantly different from High group ($p < .01$); **: significantly different from Very High group ($p < .01$)

Waist circumference rose from 71.8 ± 5.4 cm in the normal fat group to 83.6 ± 2.6 cm in the very high fat group ($p < .001$), accompanied by higher hip circumference and waist-to-hip ratio. Cardiovascular markers followed the same trend, with systolic blood pressure increasing from 109.9 ± 6.1 mmHg in the normal group to 119.6 ± 3.0 mmHg in the very high group ($p < .001$), while diastolic blood pressure also showed a modest but significant rise ($p < .001$). Total cholesterol and fasting glucose concentrations were significantly higher in women with greater adiposity ($p = .038$ and $p < .001$, respectively).

Lifestyle indicators worsened as adiposity increased. Women in the very high fat category reported lower physical activity frequency (3.5 ± 0.6 vs. 4.8 ± 2.0 days/week, $p = 0.006$), significantly lower dietary fibre intake (19.0 ± 5.3 vs. 26.7 ± 5.5 g/day, $p < .001$), and reduced energy and macronutrient intake, particularly carbohydrates and fats ($p < .001$ for both). Sleep duration tended to be slightly higher but was not significantly different across groups ($p = 0.630$).

These results highlight a consistent deterioration in anthropometric, cardiovascular, and lifestyle parameters with increasing adiposity in women, even when energy intake was lower in the higher fat groups, suggesting possible metabolic efficiency or reduced physical activity as contributing factors.

3.2.3 Comparison by Body Fat Percentage in Men

To evaluate the association between adiposity and cardiovascular health, male participants were categorized into three groups according to body fat percentage: normal, high, and very high (Table 6). Significant differences were observed across most anthropometric, metabolic, and behavioural variables.

Table 6. Differences in cardiovascular and lifestyle indicators across body fat percentage categories in men.

Variable	Normal (n=57)	High (n=51)	Very High (n=25)	p-value	ε²
Waist Circumference (cm)	79.81 ± 4.51‡**	90.79 ± 8.53	98.69 ± 8.51#	<.001	0.623
Hip Circumference (cm)	96.41 ± 3.36‡**	104.57 ± 6.65	106.22 ± 6.99	<.001	0.484
Waist-to-Hip Ratio	0.848 ± 0.041**	0.860 ± 0.025	0.922 ± 0.070‡	<.001	0.237
Triglycerides (mg/dL)	65.14 ± 10.17‡*	94.85 ± 26.98	78.59 ± 20.87#	<.001	0.235
PA Frequency (days/week)	4.16 ± 0.88	4.60 ± 0.97	3.64 ± 0.81	<.001	0.421
PA Duration (min)	48.77 ± 5.42*	63.75 ± 12.50	40.00 ± 6.12	0.811	0.010
Sleep Hours	7.13 ± 0.90	6.88 ± 0.75	7.17 ± 0.41	<.001	0.199
Dietary Fiber (g/day)	33.95 ± 11.39‡**	26.32 ± 5.76	25.34 ± 5.99	<.001	0.639
Total Calories (kcal/day)	2538.32 ± 336.48‡**	1848.30 ± 207.19	1948.80 ± 119.46#	<.001	0.492
Proteins (g/kg/day)	2.06 ± 0.43#‡	1.54 ± 0.18	1.63 ± 0.15	<.001	0.642
Carbohydrates (g/kg/day)	4.35 ± 1.11‡**	2.25 ± 0.75	2.08 ± 0.30	<.001	0.635
Fats (g/kg/day)	1.16 ± 0.28‡**	0.55 ± 0.24	0.60 ± 0.13	<.001	0.393
Systolic BP (mmHg)	111.00 ± 5.76#**	115.29 ± 6.71	126.62 ± 8.64‡	<.001	0.350
Diastolic BP (mmHg)	71.25 ± 3.78‡**	74.65 ± 4.86	77.82 ± 4.99#	<.001	0.165
Total Cholesterol (mg/dL)	186.13 ± 17.55‡*	202.96 ± 14.77	197.92 ± 18.95	0.424	0.013
Fasting Glucose (mg/dL)	88.30 ± 5.83	88.63 ± 4.98	89.57 ± 11.84	<.001	0.623

^: significantly different from Normal group ($p < .05$); #: significantly different from High group ($p < .05$); *: significantly different from Very High group ($p < .05$); †: significantly different from Normal group ($p < .01$); ‡: significantly different from High group ($p < .01$); **: significantly different from Very High group ($p < .01$)

Waist circumference increased from 79.8 ± 4.5 cm in the normal group to 98.7 ± 8.5 cm in the very high group, while hip circumference rose from 96.4 ± 3.4 cm to 106.2 ± 7.0 cm, and the waist-to-hip ratio also increased (0.848 ± 0.041 to 0.922 ± 0.070; $p < .001$). Systolic blood pressure was markedly higher in the very high fat group (126.6 ± 8.6 mmHg vs. 111.0 ± 5.8 mmHg; $p < .001$), and diastolic blood pressure followed the same pattern (77.8 ± 5.0 mmHg vs. 71.3 ± 3.8 mmHg; $p < .001$). Total cholesterol was also elevated in the high and very high categories (202.9 ± 14.8 and 197.9 ± 18.9 mg/dL, respectively) compared with the normal fat group (186.1 ± 17.6 mg/dL; $p = .029$). Triglycerides peaked in the intermediate fat group (94.9 ± 27.0 mg/dL; $p < .001$), while fasting glucose levels showed no significant variation ($p = .913$).

Lifestyle indicators revealed a deterioration with increasing adiposity. Dietary fibre intake decreased from 33.9 ± 11.4 g/day in the normal group to 25.3 ± 6.0 g/day in the very high group ($p < .001$). Total energy intake and macronutrient consumption were also lower in individuals with greater fat mass, with carbohydrate intake falling from 4.35 ± 1.11 g/kg/day to 2.08 ± 0.30 g/kg/day ($p < .001$) and fat intake from 1.16 ± 0.28 g/kg/day to 0.60 ± 0.13 g/kg/day ($p < .001$).

Physical activity frequency declined progressively (4.16 ± 0.88 vs. 3.64 ± 0.81 sessions/week; $p = .068$), and PA duration dropped significantly in the very high fat group (40.0 ± 6.1 vs. 48.8 ± 5.4 min/session; $p = .006$). Sleep duration was similar

across groups (p = .113), and C-reactive protein values did not differ significantly (p = .082).

3.2.4 Comparisons by age groups

When stratified by age, clear gradients were observed across cardiovascular risk markers. Elevated systolic blood pressure was uncommon in younger adults (18–34 years: 6%, n = 11/176) but increased progressively with age (35–49 years: 19%, n = 16/86; ≥50 years: 58%, n = 41/71). In contrast, most young adults had normal SBP (94%), whereas this proportion fell to 81% in middle-aged and 42% in older participants. Diastolic blood pressure followed a similar pattern: almost all participants aged 18–34 were normotensive (99%), compared with 95% of those aged 35–49 and 76% of those ≥50. The prevalence of high-normal or elevated DBP was confined almost entirely to the older group (23%).

LDL cholesterol categories also showed age-related differences. While 20% of participants aged 18–34 were in the optimal range, this proportion decreased to 11% in those 35–49 and 10% in those ≥50. Conversely, the prevalence of high or high–moderate LDL increased from 33% in younger adults to 43% in middle-aged and 52% in older participants. Triglycerides were generally within desirable ranges, but slightly higher proportions of elevation appeared in middle-aged adults (1%) compared with younger (0.6%) or older participants (0%).

Fasting glucose was normal in >98% of participants aged 18–34 and 35–49, and in 97% of those ≥50. Altered glucose values or probable diabetes were rare overall (<2%), without a clear age gradient. HbA1c, however, demonstrated notable differences: only 3% of participants aged 18–34 had altered HbA1c, compared with 9% of those 35–49 and 21% of those ≥50, indicating a progressive age-related increase.

3.3. Correlations

Spearman correlation analyses revealed several consistent and biologically plausible associations between body composition, dietary exposure, lifestyle behaviours and cardiometabolic markers (Figure 1).

Figure 1. Spearman correlation heatmap of anthropometric, clinical, dietary, and lifestyle variables. Positive correlations are shown in red and negative correlations in blue, with color intensity proportional to the strength of the association (ρ). Only the lower triangle of the correlation matrix is displayed to avoid duplication. Significant correlations are indicated at $p < 0.05$.

Body-size indicators showed strong internal consistency: body weight correlated strongly with waist circumference ($\rho = 0.847$, $p < .001$) and BMI ($\rho = 0.820$, $p < .001$), while waist circumference was tightly linked to waist-to-hip ratio (WHR; $\rho = 0.723$, $p < .001$). Percentage body fat showed a robust positive association with BMI ($\rho = 0.659$, $p < .001$) and hip circumference ($\rho = 0.669$, $p < .001$), but was modestly inversely related to height ($\rho = -0.295$, $p < .001$).

Blood pressure markers were positively associated with several adiposity indices. Systolic blood pressure (SBP) correlated positively with BMI ($\rho = 0.518$), body fat percentage ($\rho = 0.605$), and WHR ($\rho = 0.215$) (all $p < .001$), while diastolic blood pressure (DBP) exhibited comparable but slightly weaker associations, with the strongest being with weight ($\rho = 0.438$) and waist circumference ($\rho = 0.430$) (all $p < .001$).

Total energy intake showed an inverse association with body fat percentage ($\rho = -0.801$) and SBP ($\rho = -0.518$) ($p < .001$), while being positively associated with carbohydrate ($\rho = 0.802$) and fat intake ($\rho = 0.601$). Higher relative carbohydrate and fat intake were associated with lower BMI ($\rho = -0.763$ and $\rho = -0.693$, respectively; both $p < .001$), suggesting possible reverse causality or dietary compensation in individuals with higher adiposity.

Fibre intake displayed a favourable profile, correlating positively with height ($\rho = 0.340$) and carbohydrate intake ($\rho = 0.643$), and inversely with BMI ($\rho = -0.328$), body fat percentage ($\rho = -0.559$), and SBP ($\rho = -0.319$) (all $p < .003$).

Regarding physical activity, greater session duration was associated with lower BMI ($\rho = -0.413$), waist circumference ($\rho = -0.427$), and WHR ($\rho = -0.512$) (all $p < .001$), whereas frequency of sessions showed weaker but still significant negative associations with BMI ($\rho = -0.132$) and waist circumference ($\rho = -0.243$).

Among biochemical markers, fasting glucose correlated positively with body fat (ρ = 0.446) and inversely with energy intake (ρ = −0.382) (both p < .001), while triglycerides were positively associated with body fat (ρ = 0.302, p < .001) and inversely related to energy intake (ρ = −0.493, p < .001). Total cholesterol showed modest associations, mainly with WHR (ρ = 0.279, p < .001).

Sleep duration exhibited only weak associations, the most notable being a positive correlation with height (ρ = 0.270) and a negative correlation with energy intake (ρ = −0.071), suggesting a minor role in the observed cardiometabolic profile.

4. Discussion

This study examined the relationship between cardiovascular health markers and lifestyle, anthropometric, and dietary factors in a general population sample without exclusion criteria. Results revealed a progressive increase in cardiometabolic risk indicators with higher body fat percentage, even in individuals with normal BMI. Body fat was more strongly associated with blood pressure and lipid markers than BMI itself, highlighting the importance of evaluating body composition beyond weight-based indices. Moreover, fiber intake and physical activity emerged as consistent protective factors. In addition, clear sex-specific differences were observed: women presented higher body fat percentage and stress levels, alongside lower energy and macronutrient intake, while men showed greater waist circumference and lower sleep adequacy. These patterns suggest that cardiovascular risk assessment and lifestyle recommendations may need to be sex-specific to address underlying physiological and behavioral differences.

Age-related patterns also emerged clearly in this sample. Older adults (≥50 years) showed a markedly higher prevalence of elevated systolic and diastolic blood pressure, as well as greater proportions of abnormal LDL cholesterol, HbA1c, and CRP, compared with younger participants. These findings are consistent with international cohort data demonstrating progressive increases in cardiometabolic risk factors across the life course [22,23]. The observation that glucose remained largely normal across age groups, while HbA1c increased with age, aligns with prior work suggesting that HbA1c may better capture cumulative metabolic burden in ageing populations [24]. Together, these results underscore the importance of considering age when interpreting cardiovascular risk markers and reinforce the value of early preventive strategies targeted at younger adults, before adverse profiles become established.

The progressive increase in waist circumference, blood pressure, and lipid levels observed across body fat categories among study participants aligns closely with existing evidence. Normal-weight obesity (NWO), wherein individuals present normal body weight but elevated body fat, has been identified as a high cardiometabolic risk phenotype associated with dyslipidemia, hypertension, and insulin resistance [22,25–31]. The current findings support this: body fat percentage was more strongly correlated with SBP and triglycerides than was BMI, reinforcing the limitations of BMI and echoing guidelines recommending waist circumference as a routine measure [26,32]. These relationships were evident even within BMI-normal individuals, reinforcing the clinical relevance of identifying “hidden adiposity” phenotypes.

The role of dietary fiber and physical activity emerged as a consistent protective pattern. Fiber intake demonstrated inverse associations with SBP, adiposity, and inflammatory markers—mirroring meta-analyses that reported reductions in blood pressure and coronary risk per 7 g/day increase in fiber [14,26,30,31,33]. Physical activity frequency and duration also correlated inversely with body fat and blood pressure, a well-established pattern in lifestyle intervention literature [8,29]. Interestingly, individuals with higher adiposity reported lower total energy and macronutrient intake, particularly carbohydrates and fats, suggesting possible under-reporting or dietary changes motivated by weight concerns, as previously described in nutritional epidemiology studies.

In contrast, the lack of strong associations between fasting glucose and lifestyle variables diverges somewhat from findings in high-risk or diabetic cohorts, where glucose markers often reflect lifestyle variation. This discrepancy likely reflects the relatively healthy baseline of participants in this cohort, who were predominately normoglycemic. Additionally, the group with altered HbA1c unexpectedly showed lower adiposity and higher levels of physical activity and fiber intake, potentially reflecting compensatory lifestyle changes or pharmacological treatment in individuals already aware of their metabolic risk.

This paradoxical pattern has been described previously in population-based studies, where individuals with early dysglycemia or increased HbA1c adopt healthier behaviors after medical advice or self-perception of risk, leading to apparently inverse associations in cross-sectional analyses [34–36]. It should also be acknowledged that this subgroup represented less than 20% of the sample (n = 63), which may have limited statistical power and contributed to atypical patterns. Nevertheless, the differences in fiber intake and physical activity between HbA1c categories remained robust after adjustment for age and sex, supporting the validity of these associations despite the unequal group sizes.

A particularly unexpected finding was the negative correlation between fasting glucose and blood pressure, which contrasts with the positive associations typically reported in hypertensive or diabetic cohorts. This inverse relationship persisted after adjustment for age and sex, suggesting it was not solely attributable to demographic differences. One plausible explanation is that our sample consisted predominantly of normoglycemic, non-hypertensive individuals, in whom early blood pressure elevations may not yet be accompanied by impaired glucose regulation. Additionally, life-style changes or pharmacological treatment among participants with elevated glucose levels could have attenuated their blood pressure values. Finally, the unequal group sizes and the cross-sectional nature of the study may have contributed to this pattern. These results highlight the complexity of interpreting glycemic and hemodynamic markers in general population settings and the need for longitudinal research to clarify their temporal relationship.

It is also important to emphasize that, because of the cross-sectional design, the observed associations—particularly the paradoxical patterns for HbA1c and blood pressure—should not be interpreted as predictive of future cardiovascular risk. Similar compensatory or treatment-related effects have been reported in other population-based studies, where individuals with early metabolic alterations adopt healthier behaviors or receive pharmacological interventions, leading to attenuated or reversed cross-sectional associations [37–40]. Longitudinal studies are needed to clarify the temporal direction of these relationships and their true impact on cardiovascular outcomes.

These observations reinforce growing consensus regarding the need to refine cardiovascular risk stratification tools. Although BMI remains widely used, it fails to distinguish between lean and fat mass or reflect fat distribution. Studies consistently indicate that excess body fat—even in individuals with normal BMI—contributes independently to adverse cardiometabolic profiles, including elevated blood pressure and dyslipidemia. In the present study, body fat percentage demonstrated stronger associations with systolic blood pressure and triglycerides than BMI or hip circumference, supporting recent calls to prioritize body composition and central adiposity metrics such as waist circumference and waist-to-hip ratio in routine clinical assessment [3,26].

The limited discriminative value of HbA1c and fasting glucose in this general population sample—particularly among non-diabetic individuals—is consistent with previous literature suggesting these markers may fail to capture early metabolic dysregulation in low-risk cohorts. Unlike blood pressure or triglycerides, which showed a progressive gradient across lifestyle and adiposity profiles, glycemic markers remained within narrow ranges and lacked consistent associations with diet or physical activity. This finding supports prior work indicating that HbA1c and fasting glucose reflect late-stage glycometabolic alterations and may underestimate cardiometabolic risk in asymptomatic populations [2,32]. Moreover, HbA1c can be affected by factors unrelated to glycaemia, including hemoglobin variants, erythrocyte turnover, and iron status—introducing potential measurement bias in epidemiological settings. Taken together, these results underscore the greater utility of lipid and blood pressure metrics as early screening tools when interpreted in conjunction with anthropometric and behavioral data.

Additionally, the inverse associations between fiber intake, physical activity, and clinical risk markers support their inclusion in preventive frameworks such as the Life's Essential 8. Higher fiber intake and frequent physical activity were consistently associated with lower adiposity, blood pressure, and triglyceride levels, in line with robust evidence demonstrating the cardioprotective effects of dietary fiber and exercise [8,14,30,31]. These findings underscore the value of promoting lifestyle interventions—even among individuals without overt metabolic disease—as a cornerstone of cardiovascular risk reduction. Moreover, stratified analyses by sex and by adiposity levels revealed that these associations were broadly consistent in both

men and women, though differences in dietary patterns and stress levels suggest tailored preventive strategies may be warranted.

The present findings underscore the relevance of integrating anthropometric, dietary, and lifestyle factors into cardiovascular risk screening, particularly in general population settings. The consistent associations between body fat percentage and key risk markers—such as systolic blood pressure and triglycerides—even among individuals with normal BMI, emphasize the need to go beyond traditional indices like BMI in clinical assessments. Incorporating body composition metrics, such as bioimpedance-derived fat percentage or waist-based measures, may improve the early identification of at-risk individuals who are otherwise classified as low-risk by conventional standards.

Comparisons with international data further contextualize these findings. Large multi-country studies such as the PURE (Prospective Urban Rural Epidemiology) cohort, which included over 135,000 individuals from 27 countries across high-, middle-, and low-income settings, demonstrated consistent associations between adiposity, poor diet quality, and elevated cardiometabolic risk, reinforcing the universality of these risk factors irrespective of socioeconomic context [23,41]. Similarly, studies in North American and Asian populations have reported that excess adiposity—even in individuals with normal BMI—confers an adverse cardiometabolic profile, highlighting the limitations of BMI as a sole risk indicator [25,42]. European cohorts have emphasized the clinical relevance of waist circumference and waist-to-hip ratio for early cardiovascular risk detection [22], while research from Latin America and Sub-Saharan Africa underscores the role of lifestyle behaviors, particularly diet and physical activity, in modulating risk despite contextual differences[8,43]. Taken together, these cross-continental comparisons suggest that the associations observed in our general-population sample are consistent with global patterns, underscoring the universality of body fat percentage, lipid markers, and blood pressure as key early indicators of cardiovascular health.

From a preventive medicine perspective, the results highlight the value of routine assessments in asymptomatic populations, even in the absence of overt metabolic disease. Identifying subtle elevations in blood pressure or triglycerides, and their behavioral correlates, may allow for targeted early interventions and contribute to reducing long-term cardiovascular burden. In particular, evaluating dietary fiber intake and physical activity frequency—through simple questionnaires—can provide actionable insights for risk stratification and personalized counselling.

4.1. Strengths and Limitations

This study has several strengths. It includes a general population sample without exclusion criteria, enhancing the generalizability of findings and offering a more accurate reflection of cardiovascular risk distribution across diverse individuals. The comprehensive assessment of clinical, anthropometric, dietary, and lifestyle variables enables an integrative understanding of cardiometabolic health beyond conventional biomarkers. The inclusion of body fat percentage, rather than relying solely on BMI, permitted the identification of individuals with excess adiposity despite normal weight—a phenotype increasingly recognized for its clinical relevance. Stratified analyses by blood pressure, HbA1c, and adiposity levels further facilitated clinically meaningful comparisons. An additional strength is the explicit adjustment for sex and analysis of sex-stratified patterns, which may inform more personalized public health recommendations.

However, certain limitations must be acknowledged. Firstly, the cross-sectional design precludes causal inference; therefore, all reported associations should be interpreted as correlational rather than causal. Furthermore, the absence of a formal sample size calculation means that some subgroup analyses may have been underpowered, and replication in larger cohorts is required. Secondly, the absence of exclusion criteria, coupled with open recruitment based on community advertisements, may have introduced self-selection bias towards individuals who are more motivated or concerned about health. This could potentially skew the sample towards a healthier or more health-conscious population. We recognize that including individuals with and without established cardiovascular disease (CVD) could affect the interpretation of certain associations. While we present data on participants with a history of CVD, we recognise that these conditions, along with medication use, could impact several of the biological and clinical parameters examined.

The lack of a protocol-based clinical assessment may have resulted in inconsistent data collection. Some variables, such as physical activity, diet, sleep and stress, were self-reported and were therefore subject to recall bias or bias relating to social desirability. Although objective measures were used for anthropometry and blood markers, no imaging or gold-standard methods were available to measure body composition. Additionally, despite including both sexes and a broad age range, residual confounding by unmeasured socioeconomic, genetic or psychosocial factors cannot be ruled out. Finally, it should be noted that lifestyle behaviours such as diet, physical activity, sleep and stress are dynamic and may vary over time. As our study relied on cross-sectional data, we could only capture these factors at one point in time, which may not fully reflect long-term behavioural patterns relevant to cardiovascular risk.

Future studies with stratified designs or longitudinal follow-up may help to disentangle these effects further. Despite these limitations, we believe that the inclusiveness of the cohort enhances the generalisability of the findings, providing a more realistic picture of cardiovascular risk factors in the general population.

5. Conclusions

In this population-based study with no exclusion criteria, body fat percentage emerged as a stronger predictor of cardiovascular risk markers than BMI, highlighting the limitations of weight-based indices for risk assessment. Waist circumference and other adiposity-related measures showed consistent associations with elevated blood pressure and lipid disturbances, even in individuals with normal weight. In contrast, fasting glucose and HbA1c provided limited additional value in this non-diabetic sample. Protective behaviors—particularly higher dietary fiber intake and regular physical activity—were linked to more favorable cardiometabolic profiles, supporting current recommendations for multidimensional prevention strategies. These findings underscore the importance of incorporating comprehensive body composition and lifestyle assessments into cardiovascular risk evaluation and of implementing early preventive measures, even in ostensibly healthy populations.

Abbreviations

The following abbreviations are used in this manuscript:

AHA American Heart Association

BMI Body Mass Index

CVD Cardiovascular Disease

DBP Diastolic Blood Pressure

HbA1c Glycated Hemoglobin

HDL High-Density Lipoprotein

LDL Low-Density Lipoprotein

NWO Normal Weight Obesity

PA Physical Activity

SBP Systolic Blood Pressure

DBP Diastolic Blood Pressure

WC Waist Circumference

WHR Waist-to-Hip Ratio

cm centimeters

mg milligrams

dL deciliters

min minutes

g grams

kg kilograms

Declarations

Author Contributions:

Conceptualization, Belén Leyva-Vela, Piotr Matłosz and Alejandro Martínez-Rodríguez; Data curation, Belén Leyva-Vela, Piotr Matłosz, Maria Martínez-Olcina and Natalia Martínez-Amorós; Formal analysis, Belén Leyva-Vela, Piotr Matłosz, Maria Martínez-Olcina and Natalia Martínez-Amorós; Funding acquisition, Alejandro Martínez-Rodríguez; Investigation, Belén Leyva-Vela, Piotr Matłosz, Maria Martínez-Olcina, Natalia Martínez-Amorós, Manuel Vicente-Martínez, Lucía Gonzalvez-Alvarado, Bernardo Cuestas-Calero, Yolanda Nadal-Nicolás, Marcelo Peñaranda-Moraga, Diego Girona-Macia and Alejandro Martínez-Rodríguez; Methodology, Belén Leyva-Vela, Piotr Matłosz and Alejandro Martínez-Rodríguez; Project administration, Belén Leyva-Vela and Alejandro Martínez-Rodríguez; Resources, Piotr Matłosz and Alejandro Martínez-Rodríguez; Software, Belén Leyva-Vela, Piotr Matłosz, Maria Martínez-Olcina and Natalia Martínez-Amorós; Supervision, Piotr Matłosz and Alejandro Martínez-Rodríguez; Validation, Piotr Matłosz and Alejandro Martínez-Rodríguez; Visualization, Belén Leyva-Vela and Alejandro Martínez-Rodríguez; Writing – original draft, Belén Leyva-Vela, Piotr Matłosz and Maria Martínez-Olcina; Writing – review & editing, Natalia Martínez-Amorós, Manuel Vicente-Martínez, Lucía Gonzalvez-Alvarado, Bernardo Cuestas-Calero, Yolanda Nadal-Nicolás, Marcelo Peñaranda-Moraga, Diego Girona-Macia and Alejandro Martínez-Rodríguez. All authors have read and agreed to the published version of the manu-script.

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Data presented in this study are available on request from the corresponding author. The data are not publicly available due to is personal health information.

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The authors declare no conflicts of interest.

References

1. López-bueno, R.; Núñez-cortés, R.; Calatayud, J.; Salazar-méndez, J.; Petermann-rocha, F.; López-gil, J.F.; Cruz, P. Global Prevalence of Cardiovascular Risk Factors Based on the Life ' s Essential 8 Score : An Overview of Systematic Reviews and Meta-Analysis. *Cardiovasc. Res.* **2024**, *120*, 13–33, doi:10.1093/cvr/cvad176.
2. Ndumele, C.E.; Neeland, I.J.; Tuttle, K.R. A Synopsis of the Evidence for the Science and Clinical Management of Cardiovascular-. **2023**, 1636–1664, doi:10.1161/CIR.0000000000001186.
3. Lloyd-Jones, D.M.; Allen, N.B.; Anderson, C.A.M.; Black, T.; Brewer, L.C.; Foraker, R.E.; Grandner, M.A.; Lavretsky, H.; Perak, A.M.; Sharma, G.; et al. Life's Essential 8: Updating and Enhancing the American Heart Association's Construct of Cardiovascular Health: A Presidential Advisory from the American Heart Association. *Circulation* **2022**, *146*, E18–E43, doi:10.1161/CIR.0000000000001078,.
4. Goldsborough, E. 3rd; Osuji, N.; Blaha, M.J. Assessment of Cardiovascular Disease Risk: A 2022 Update. *Endocrinol. Metab. Clin. North Am.* **2022**, *51*, 483–509, doi:10.1016/j.ecl.2022.02.005.
5. Rikhi, R.; Shapiro, M.D. Assessment of Atherosclerotic Cardiovascular Disease Risk in Primary Prevention. *J. Cardiopulm. Rehabil. Prev.* **2022**, *42*, 397–403, doi:10.1097/HCR.0000000000000746.
6. Asztalos, B.F.; Russo, G.; He, L.; Diffenderfer, M.R. Body Mass Index and Cardiovascular Risk Markers: A Large Population Analysis. *Nutrients* **2025**, *17*, doi:10.3390/NU17050740,.
7. Leyva-Vela, B.; Martínez-Olcina, M.; Asencio-Mas, N.; Vicente-Martínez, M.; Cuestas-Calero, B.J.; Matłosz, P.; Martínez-Rodríguez, A. Integrated Multivariate Predictive Model of Body Composition and Lipid Profile for Cardiovascular Risk Assessment. *J. Clin. Med.* **2025**, *14*, doi:10.3390/JCM14030781,.
8. Powell-Wiley, T.M.; Poirier, P.; Burke, L.E.; Després, J.-P.; Gordon-Larsen, P.; Lavie, C.J.; Lear, S.A.; Ndumele, C.E.; Neeland, I.J.; Sanders, P.; et al. Obesity and Cardiovascular Disease: A Scientific Statement From the American Heart Association. *Circulation* **2021**, *143*, e984–e1010, doi:10.1161/CIR.0000000000000973.
9. Carter, J.L.; Abdullah, N.; Bragg, F.; Murad, N.A.A.; Taylor, H.; Fong, C.S.; Lacey, B.; Sherliker, P.; Karpe, F.; Mustafa, N.; et al. Body Composition and Risk Factors for Cardiovascular Disease in Global Multi-Ethnic Populations. *Int. J. Obes.* **2023**, *47*, 855–864, doi:10.1038/s41366-023-01339-9.
10. Gebremedhin, S.; Mekonene, M.; Hagos, S.; Baye, K.; Shikur, B.; Berhane, A.; Bekele, T. Association between Normal-Weight Obesity and Cardiometabolic Risk Factors among Adults in Addis Ababa, Ethiopia. *Sci. Rep.* **2023**, *13*, doi:10.1038/S41598-023-49039-8,.
11. Khonsari, N.M.; Khashayar, P.; Shahrestanaki, E.; Kelishadi, R.; Nami, S.M.; Heidari-Beni, M.; Abdar, Z.E.; Tabatabaei-Malazy, O.; Qorbani, M. Normal Weight Obesity and Cardiometabolic Risk Factors: A Systematic Review and Meta-Analysis. *Front. Endocrinol. (Lausanne).* **2022**, *13*, doi:10.3389/FENDO.2022.857930/PDF.
12. Wijayatunga, N.N.; Dhurandhar, E.J. Normal Weight Obesity and Unaddressed Cardiometabolic Health Risk—a Narrative Review. *Int. J. Obes.* **2021**, *45*, 2141–2155, doi:10.1038/S41366-021-00858-7,.
13. Wang, X.; Ma, H.; Li, X.; Heianza, Y.; Manson, J.E.; Franco, O.H.; Qi, L. Association of Cardiovascular Health With Life Expectancy Free of Cardiovascular Disease, Diabetes, Cancer, and Dementia in UK Adults. *JAMA Intern. Med.* **2023**, *183*, 340–349, doi:10.1001/JAMAINTERNMED.2023.0015.
14. Wang, M.; Xu, K.; Yang, J.; Bennett, D.A.; Du, H.; Liu, X. Normal-Weight Obesity Subtypes and 10-Year Risks of Major Vascular Diseases in 0.3 Million Adults. *Clin. Nutr.* **2025**, *45*, 36–42, doi:10.1016/j.clnu.2024.12.027.
15. Aggarwal, R.; Yeh, R.W.; Maddox, K.E.J.; Wadhera, R.K. Cardiovascular Risk Factor Prevalence, Treatment, and Control in US Adults Aged 20 to 44 Years, 2009 to March 2020. *JAMA* **2023**, *329*, 899–909, doi:10.1001/JAMA.2023.2307.

16. Ortega, Rosa M.; Pérez-Rodrigo, Carmen; López-Sobaler, Ana M. Métodos de evaluación de la ingesta actual: Registro o diario dietético. Rev esp nutr comunitaria, 2015, vol. 21, no Supl 1, P. Registro de Consumo de Alimentos y Bebidas de Tres Días. **2015**.
17. Mancia, G.; Kreutz, R.; Brunström, M.; Burnier, M.; Grassi, G.; Januszewicz, A.; Muiesan, M.L.; Tsioufis, K.; Agabiti-Rosei, E.; Algharably, E.A.E.; et al. 2023 ESH Guidelines for the Management of Arterial Hypertension the Task Force for the Management of Arterial Hypertension of the European Society of Hypertension: Endorsed by the International Society of Hypertension (ISH) and the European Renal Associat. *J. Hypertens.* **2023**, *41*, 1874–2071, doi:10.1097/HJH.0000000000003480,.
18. American Diabetes Association. Diabetes Diagnosis \& Tests | ADA 2023.
19. Rosenzweig, J.L.; Bakris, G.L.; Berglund, L.F.; Hivert, M.F.; Horton, E.S.; Kalyani, R.R.; Murad, M.H.; Verges, B.L. Primary Prevention of ASCVD and T2DM in Patients at Metabolic Risk: An Endocrine Society Clinical Practice Guideline. *J. Clin. Endocrinol. \& Metab.* **2019**, *104*, 3939–3985, doi:10.1210/JC.2019-01338.
20. Labarthe, D.R.; Kubzansky, L.D.; Boehm, J.K.; Lloyd-Jones, D.M.; Berry, J.D.; Seligman, M.E.P. Positive Cardiovascular Health: A Timely Convergence. *J. Am. Coll. Cardiol.* **2016**, *68*, 860–867, doi:10.1016/j.jacc.2016.03.608.
21. Macek, P.; Biskup, M.; Terek-Derszniak, M.; Krol, H.; Smok-Kalwat, J.; Gozdz, S.; Zak, M. Optimal Cut-off Values for Anthropometric Measures of Obesity in Screening for Cardiometabolic Disorders in Adults. *Sci. Rep.* **2020**, *10*, doi:10.1038/S41598-020-68265-Y,.
22. Ross, R.; Neeland, I.J.; Yamashita, S.; Shai, I.; Seidell, J.; Magni, P.; Santos, R.D.; Arsenault, B.; Cuevas, A.; Hu, F.B.; et al. Waist Circumference as a Vital Sign in Clinical Practice: A Consensus Statement from the IAS and ICCR Working Group on Visceral Obesity. *Nat. Rev. Endocrinol.* **2020**, *16*, 177–189, doi:10.1038/s41574-019-0310-7.
23. Yusuf, S.; Rangarajan, S.; Teo, K.; Islam, S.; Li, W.; Liu, L.; Bo, J.; Lou, Q.; Lu, F.; Liu, T.; et al. Cardiovascular Risk and Events in 17 Low-, Middle-, and High-Income Countries. *N. Engl. J. Med.* **2014**, *371*, 818–827, doi:10.1056/NEJMOA1311890.
24. Selvin, E.; Steffes, M.W.; Zhu, H.; Matsushita, K.; Wagenknecht, L.; Pankow, J.; Coresh, J.; Brancati, F.L. Glycated Hemoglobin, Diabetes, and Cardiovascular Risk in Nondiabetic Adults. *N. Engl. J. Med.* **2010**, *362*, 800–811, doi:10.1056/NEJMOA0908359.
25. Romero-Corral, A.; Somers, V.K.; Sierra-Johnson, J.; Korenfeld, Y.; Boarin, S.; Korinek, J.; Jensen, M.D.; Parati, G.; Lopez-Jimenez, F. Normal Weight Obesity: A Risk Factor for Cardiometabolic Dysregulation and Cardiovascular Mortality. *Eur. Heart J.* **2009**, *31*, 737, doi:10.1093/EURHEARTJ/EHP487.
26. Fu, L.; Zhang, G.; Qian, S.; Zhang, Q.; Tan, M. Associations between Dietary Fiber Intake and Cardiovascular Risk Factors: An Umbrella Review of Meta-Analyses of Randomized Controlled Trials. *Front. Nutr.* **2022**, *9*, 972399, doi:10.3389/FNUT.2022.972399/FULL.
27. Suwała, S.; Junik, R. Body Mass Index and Waist Circumference as Predictors of Above-Average Increased Cardiovascular Risk Assessed by the SCORE2 and SCORE2-OP Calculators and the Proposition of New Optimal Cut-Off Values: Cross-Sectional Single-Center Study. *J. Clin. Med.* **2024**, *13*, 1931, doi:10.3390/JCM13071931.
28. Marques-Vidal, P.; Pécoud, A.; Hayoz, D.; Paccaud, F.; Mooser, V.; Waeber, G.; Vollenweider, P. Normal Weight Obesity: Relationship with Lipids, Glycaemic Status, Liver Enzymes and Inflammation. *Nutr. Metab. Cardiovasc. Dis.* **2010**, *20*, 669–675, doi:10.1016/J.NUMECD.2009.06.001.
29. Gröber-Grätz, D.; Widhalm, K.; Zwaan, M. De; Reinehr, T.; Blüher, S.; Schwab, K.O.; Wiegand, S.; Holl, R.W. Body Mass Index or Waist Circumference: Which Is the Better Predictor for Hypertension and Dyslipidemia in Overweight/Obese Children and Adolescents? Association of Cardiovascular Risk Related to Body Mass Index or Waist Circumference. *Horm. Res. Paediatr.* **2013**, *80*, 170–178, doi:10.1159/000354224.
30. Bazzano, L.A.; He, J.; Ogden, L.G.; Loria, C.M.; Whelton, P.K. Dietary Fiber Intake and Reduced Risk of Coronary Heart Disease in US Men and Women: The National Health and Nutrition Examination Survey I Epidemiologic Follow-up Study. *Arch. Intern. Med.* **2003**, *163*, 1897–1904, doi:10.1001/ARCHINTE.163.16.1897.

31. Threapleton, D.E.; Greenwood, D.C.; Evans, C.E.L.; Cleghorn, C.L.; Nykjaer, C.; Woodhead, C.; Cade, J.E.; Gale, C.P.; Burley, V.J. Dietary Fibre Intake and Risk of Cardiovascular Disease: Systematic Review and Meta-Analysis. *BMJ* **2013**, *347*, f6879, doi:10.1136/BMJ.F6879.
32. Liu, S.; Buring, J.E.; Sesso, H.D.; Rimm, E.B.; Willett, W.C.; Manson, J.E. A Prospective Study of Dietary Fiber Intake and Risk of Cardiovascular Disease among Women. *J. Am. Coll. Cardiol.* **2002**, *39*, 49–56, doi:10.1016/S0735-1097(01)01695-3.
33. Seyedhoseinpour, A.; Barzin, M.; Mahdavi, M.; Valizadeh, M.; Azizi, F.; Ghareh, S.; Hosseinpanah, F. BMI Category-Specific Waist Circumference Thresholds Based on Cardiovascular Disease Outcomes and All-Cause Mortality: Tehran Lipid and Glucose Study (TLGS). *BMC Public Health* **2023**, *23*, 1–10, doi:10.1186/S12889-023-16190-W/FIGURES/1.
34. Gaggero, A.; Gil, J.; Jiménez-Rubio, D.; Zucchelli, E. Does Health Information Affect Lifestyle Behaviours? The Impact of a Diabetes Diagnosis. *Soc. Sci. Med.* **2022**, *314*, doi:10.1016/j.socscimed.2022.115420.
35. Yin, J.; Huang, Y.; Liu, G.; Wang, L.; Shan, Z.; Liu, L. Trends in Dietary Macronutrient Composition and Diet Quality among US Adults with Diagnosed and Undiagnosed Elevated Glycemic Status: A Serial Cross-Sectional Study. *Am. J. Clin. Nutr.* **2022**, *115*, 1602–1611, doi:10.1093/ajcn/nqac061.
36. Wisgerhof, W.; Ruijgrok, C.; Braver, N.R. Den; Berg, K.J.B. Den; Heijden, A.A.W.A. Van Der; Elders, P.J.M.; Beulens, J.W.J.; Alssema, M. Phenotypic and Lifestyle Determinants of HbA1c in the General Population-The Hoorn Study. *PLoS One* **2020**, *15*, doi:10.1371/JOURNAL.PONE.0233769.
37. Wang, Y.; Wan, E.Y.F.; Mak, I.L.; Ho, M.K.; Chin, W.Y.; Yu, E.Y.T.; Lam, C.L.K. The Association between Trajectories of Risk Factors and Risk of Cardiovascular Disease or Mortality among Patients with Diabetes or Hypertension: A Systematic Review. *PLoS One* **2022**, *17*, doi:10.1371/JOURNAL.PONE.0262885.
38. Nuotio, J.; Suvila, K.; Cheng, S.; Langén, V.; Niiranen, T. Longitudinal Blood Pressure Patterns and Cardiovascular Disease Risk. *Ann. Med.* **2020**, *52*, 43–54, doi:10.1080/07853890.2020.1733648.
39. Hulsegge, G.; Spijkerman, A.M.W.; Schouw, Y.T. Van Der; Bakker, S.J.L.; Gansevoort, R.T.; Smit, H.A.; Verschuren, W.M.M. Trajectories of Metabolic Risk Factors and Biochemical Markers Prior to the Onset of Cardiovascular Disease - The Doetinchem Cohort Study. *PLoS One* **2016**, *11*, doi:10.1371/JOURNAL.PONE.0155978.
40. Niedermayer, F.; Schauberger, G.; Rathmann, W.; Klug, S.J.; Thorand, B.; Peters, A.; Rospleszcz, S. Clusters of Longitudinal Risk Profile Trajectories Are Associated with Cardiometabolic Diseases: Results from the Population-Based KORA Cohort. *PLoS One* **2024**, *19*, doi:10.1371/JOURNAL.PONE.0300966.
41. Dehghan, M.; Mente, A.; Zhang, X.; Swaminathan, S.; Li, W.; Mohan, V.; Iqbal, R.; Kumar, R.; Wentzel-Viljoen, E.; Rosengren, A.; et al. Associations of Fats and Carbohydrate Intake with Cardiovascular Disease and Mortality in 18 Countries from Five Continents (PURE): A Prospective Cohort Study. *Lancet* **2017**, *390*, 2050–2062, doi:10.1016/S0140-6736(17)32252-3.
42. Du, S.M.; Ma, G.S.; Li, Y.P.; Fang, H.Y.; Hu, X.Q.; Yang, X.G.; Hu, Y.H. Relationship of Body Mass Index, Waist Circumference and Cardiovascular Risk Factors in Chinese Adult. *Biomed. Environ. Sci.* **2010**, *23*, 92–101, doi:10.1016/S0895-3988(10)60037-2.
43. Organización Mundial de la Salud. Acciones cotidianas para una mejor salud: recomendaciones de La OMS Available online: https://www.who.int/europe/news-room/fact-sheets/item/everyday-actions-for-better-health-who-recommendations (accessed on 25 March 2026).
44. United States Department of Health and Human Services; NCEP. High Blood Cholesterol ATP III Guidelines At-A-Glance Quick Desk Reference. 2021.

Figures

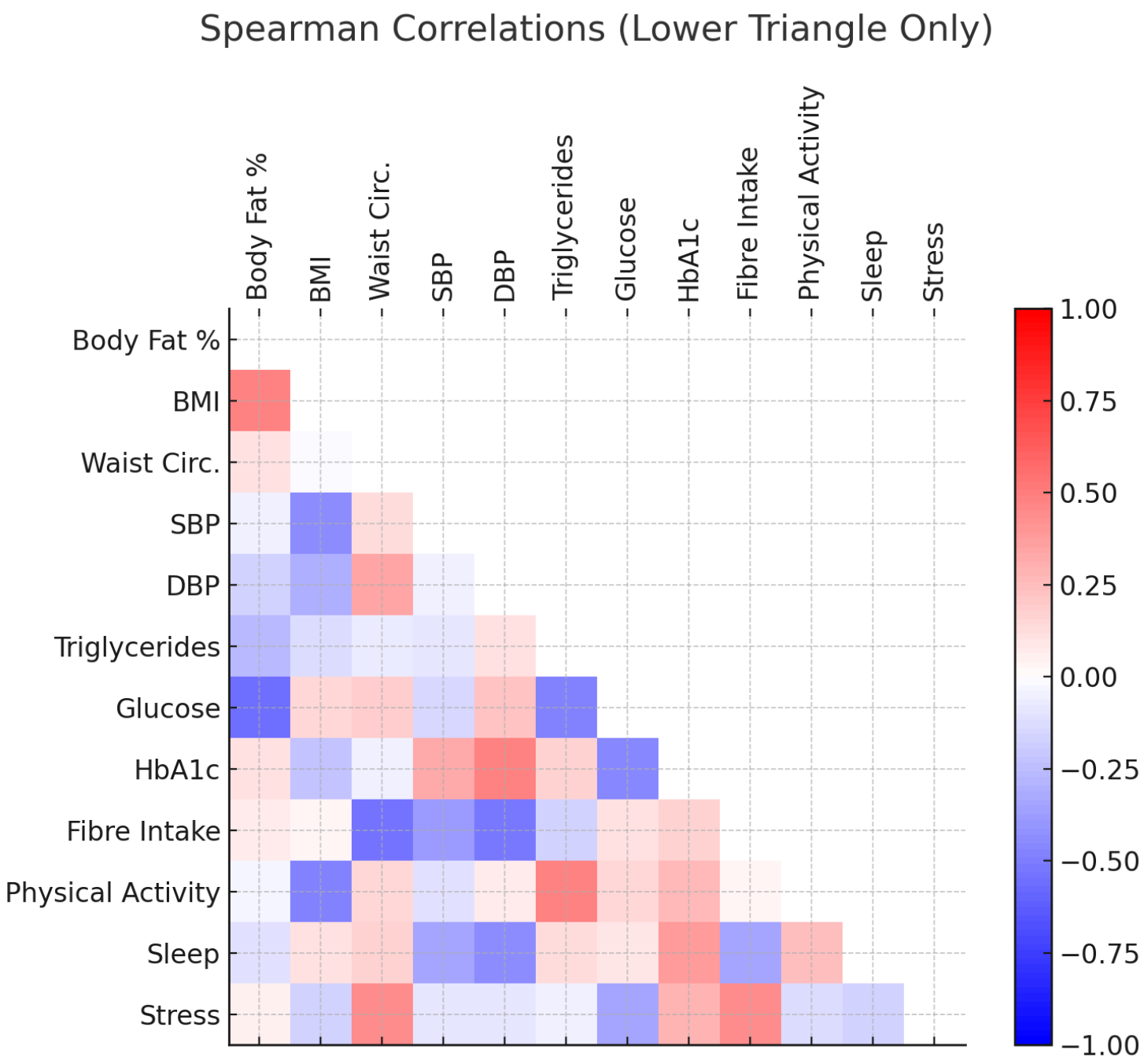


Figure 1

Spearman correlation heatmap of anthropometric, clinical, dietary, and lifestyle variables. Positive correlations are shown in red and negative correlations in blue, with color intensity proportional to the strength of the association (ρ). Only the lower triangle of the correlation matrix is displayed to avoid duplication. Significant correlations are indicated at $p < 0.05$.

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