

Cardiometabolic Risk Patterns Among Adults: A Latent Class Analysis from the Hoveyzeh Cohort Study

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Abstract

Cardiometabolic risk factors may cluster into heterogeneous patterns that are not fully captured by conventional approaches. This study aimed to identify latent cardiometabolic profiles and examine their association with incident dyslipidemia among adults participating in the Hoveyze Cohort Study. This prospective cohort study included 1,660 adults free of dyslipidemia at baseline who were reassessed approximately five years later. Latent class analysis was conducted using five binary indicators: hypertension, diabetes, low physical activity, high saturated-fat intake, and metabolic waist. Two-, three-, and four-class models were evaluated based on fit, convergence, interpretability, and classification quality. Incident dyslipidemia was defined as newly developed dyslipidemia at reassessment. Risk ratios (RRs) and 95% confidence intervals (CIs) were estimated using robust Poisson regression. A two-class model was selected. Class 1 included 1,197 participants (72.1%) and had lower probabilities of the indicators, whereas Class 2 included 463 (27.9%) and showed higher probabilities of hypertension, diabetes, and metabolic waist. During follow-up, 876 participants (52.8%) developed dyslipidemia. No association was observed between Class 2 and incident dyslipidemia in crude ($RR = 0.97$, 95% CI: 0.88–1.08) or adjusted analyses ($RR = 1.03$, 95% CI: 0.92–1.14). Two distinct cardiometabolic profiles were identified, but latent class membership was not associated with incident dyslipidemia.

1. Introduction

Metabolic disorders in adults, including obesity, type 2 diabetes, hypertension, and dyslipidemia, represent a major and growing global public health challenge, contributing substantially to cardiovascular morbidity and mortality [1, 2]. Recent evidence from cluster analyses indicates that cardiometabolic conditions such as hypertension, hyperglycemia, dyslipidemia, and obesity rarely isolation; instead form overlapping clusters reflecting shared pathophysiology [3]. These patterns are driven by common biological pathways, including insulin resistance and chronic inflammation, as well as behavioral and environmental factors such as physical inactivity and dietary habits [4].

Previous studies emphasize that cardiometabolic disorders are not homogeneous entities but rather represent heterogeneous phenotypes with distinct risk profiles and disease trajectories. Population-based studies have demonstrated that combinations of metabolic abnormalities and lifestyle behaviors form identifiable risk patterns that are differentially associated with cardiovascular outcomes, including subclinical atherosclerosis and incident chronic disease [5]. These findings support a shift from traditional single-risk-factor approaches toward more integrated, person-centered frameworks of disease classification.

Conventional epidemiological approaches are typically variable-centered and assume independence or simple additive relationships between risk factors. However, such methods may fail to capture the underlying heterogeneity and latent structure of cardiometabolic risk. In contrast, person-centered techniques such as Latent Class Analysis (LCA) provide a powerful alternative by identifying unobserved subgroups within populations based on shared patterns of risk factor clustering [6, 7]. Recent

applications of LCA in cardiometabolic research have identified distinct metabolic phenotypes characterized by varying combinations of obesity, glucose dysregulation, and lifestyle-related factors, which are associated with different levels of disease risk and prognosis [8]. Furthermore, LCA-derived cardiometabolic phenotypes have demonstrated improved prediction of cardiovascular outcomes and subclinical atherosclerosis compared with traditional risk stratification methods [9]. These findings support the concept that metabolic and behavioral risk factors cluster into heterogeneous and clinically meaningful subgroups across diverse populations [10].

Despite the high burden of obesity [11], diabetes [11], hypertension [12], and dyslipidemia [13] in this region, the patterns of co-occurrence of cardiometabolic risk factors remain insufficiently understood. Moreover, most previous studies conducted in Iran have relied on conventional variable-centered approaches, which may not adequately capture heterogeneity in cardiometabolic risk patterns across individuals. Therefore, this study aimed to identify and characterize distinct latent cardiometabolic profiles among adults participating in the Hoveyzeh Cohort Study and to examine their association with the subsequent development of dyslipidemia over approximately five years of follow-up.

2. Results

A total of 1,660 participants who were free of dyslipidemia at baseline and completed the approximately 5-year follow-up were included in the analysis. During follow-up, 876 participants (52.8%) developed dyslipidemia. The mean age of the study population was 48.4 ± 8.6 years, and women accounted for 63.7% of the participants. Latent class analysis identified two distinct cardiometabolic profiles, with 1,197 participants (72.1%) classified into Class 1 and 463 (27.9%) into Class 2.

Baseline characteristics according to latent class membership are presented in Table 1. Of the 1,660 participants, 1,197 (72.1%) were assigned to Class 1 and 463 (27.9%) to Class 2 based on their highest posterior probability. Class 2 included a higher proportion of women than Class 1 (73.2% vs. 60.1%, $P < 0.001$) and had a greater proportion of participants aged ≥ 55 years (39.5% vs. 19.4%, $P < 0.001$). Participants in Class 2 were also more likely to be widowed and less likely to have higher educational attainment. Urban residence was more common in Class 2 than in Class 1 (70.2% vs. 61.7%, $P = 0.001$). No significant difference was observed in wealth status or smoking status between the two classes.

Table 1
Baseline characteristics of participants according to latent class membership

Characteristic	Overall, n (%)	Class 1, n (%)	Class 2, n (%)	P-value
Age group, years				< 0.001
35–44	638 (38.4)	541 (45.2)	97 (21.0)	
45–54	607 (36.6)	424 (35.4)	183 (39.5)	
55–64	336 (20.2)	189 (15.8)	147 (31.8)	
≥ 65	79 (4.8)	43 (3.6)	36 (7.8)	
Sex				< 0.001
Male	602 (36.3)	478 (39.9)	124 (26.8)	
Female	1,058 (63.7)	719 (60.1)	339 (73.2)	
Wealth status				0.533
Poorest	323 (19.5)	225 (18.8)	98 (21.2)	
Poor	355 (21.4)	264 (22.1)	91 (19.7)	
Moderate	314 (18.9)	219 (18.3)	95 (20.5)	
Rich	309 (18.6)	227 (19.0)	82 (17.7)	
Richest	359 (21.6)	262 (21.9)	97 (21.0)	
Marital status				< 0.001
Single	47 (2.8)	41 (3.4)	6 (1.3)	
Married	1,493 (89.9)	1,093 (91.3)	400 (86.4)	
Widowed	88 (5.3)	42 (3.5)	46 (9.9)	
Divorced	32 (1.9)	21 (1.8)	11 (2.4)	
Education				< 0.001
Illiterate	1,078 (64.9)	732 (61.2)	346 (74.7)	
Primary school	255 (15.4)	195 (16.3)	60 (13.0)	
Secondary school	100 (6.0)	77 (6.4)	23 (5.0)	
High school diploma	107 (6.4)	93 (7.8)	14 (3.0)	
University	120 (7.2)	100 (8.4)	20 (4.3)	
Residence				0.001
Urban	1,063 (64.0)	738 (61.7)	325 (70.2)	

Characteristic	Overall, n (%)	Class 1, n (%)	Class 2, n (%)	P-value
Rural	597 (36.0)	459 (38.4)	138 (29.8)	0.327
Smoking				
No	1,374 (82.8)	984 (82.2)	390 (84.2)	P-value
Yes	286 (17.2)	213 (17.8)	73 (15.8)	

P values were derived from Pearson's chi-square test.

The two latent classes differed markedly in their cardiometabolic profiles (Table 2). Class 1 showed a relatively favorable profile, with low probabilities of hypertension (9.0%) and diabetes (6.0%). In contrast, Class 2 was characterized by substantially higher probabilities of hypertension (50.0%) and diabetes (35.5%), together with a greater prevalence of metabolic waist (82.4% vs. 56.3%). Low physical activity and high saturated-fat intake were also more common in Class 2 than in Class 1 (53.9% vs. 24.4% and 30.2% vs. 19.7%, respectively). Taken together, these findings characterize Class 2 as a higher-risk cardiometabolic profile compared with Class 1.

Table 2
Latent class-specific probabilities of cardiometabolic indicators

Indicator	Class 1	Class 2
Hypertension	9.0% (5.1–15.4)	50.0% (39.7–60.2)
Diabetes	6.0% (3.4–10.4)	35.5% (27.6–44.3)
Low physical activity	24.4% (17.9–32.3)	53.9% (48.7–59.0)
High saturated-fat intake	19.7% (15.1–25.3)	30.2% (26.7–33.9)
Metabolic waist	56.3% (51.3–61.2)	82.4% (75.4–87.7)

Although the three-class model had a marginally lower AIC than the two-class model (9518.538 vs. 9518.789), the two-class model had a substantially lower BIC (9578.349 vs. 9610.586) and provided a more parsimonious and clinically interpretable solution. The four-class model failed to converge and was therefore excluded from further consideration. Accordingly, the two-class model was selected as the final model.

Table 3. Model fit statistics for latent class models

Number of classes	Log Likelihood	AIC	BIC	Convergence
2-class	-4748.394	9518.789	9578.349	Yes
3-class	-4742.269	9518.538	9610.586	Yes
4-class	-4741.080*	NR	NR	No

Abbreviations: AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion.

NR: Not reported because the model did not converge

*The four-class model did not achieve convergence and therefore its AIC and BIC were not considered valid for model selection.

Latent class membership was not significantly associated with incident dyslipidemia. Compared with participants in Class 1, those in Class 2 had a comparable risk of developing dyslipidemia in both the crude model (RR=0.97, 95% CI: 0.88–1.08; P=0.562) and the fully adjusted model (adjusted RR=1.03, 95% CI: 0.92–1.14; P=0.626). Among the covariates, female sex was consistently associated with a lower risk of incident dyslipidemia (adjusted RR=0.77, 95% CI: 0.69–0.85; P<0.001), while participants in the rich wealth category had a lower risk compared with those in the poorest category (adjusted RR=0.82, 95% CI: 0.70–0.95; P=0.009). The crude associations observed for smoking and rural residence were attenuated after adjustment.

Table 4
Crude and adjusted risk ratios (RRs) for incident dyslipidemia according to latent class
and baseline characteristics

Variable	Crude RR (95% CI)	P-value	Adjusted RR (95% CI)	P-value
Latent class				
Class 1	Reference	—	Reference	—
Class 2	0.97 (0.88–1.08)	0.562	1.03 (0.92–1.14)	0.626
Sex				
Male	Reference	—	Reference	—
Female	0.78 (0.71–0.85)	< 0.001	0.77 (0.69–0.85)	< 0.001
Age group (years)				
35–44	Reference	—	Reference	—
45–54	1.05 (0.95–1.17)	0.351	1.02 (0.91–1.13)	0.783
55–64	1.02 (0.90–1.16)	0.776	0.95 (0.83–1.09)	0.448
≥ 65	0.95 (0.75–1.21)	0.698	0.86 (0.68–1.10)	0.236
Wealth index				
Poorest	Reference	—	Reference	—
Poor	0.96 (0.84–1.10)	0.549	0.95 (0.83–1.09)	0.460
Moderate	0.92 (0.80–1.06)	0.263	0.92 (0.79–1.07)	0.264
Rich	0.82 (0.71–0.96)	0.012	0.82 (0.70–0.95)	0.009
Richest	0.94 (0.82–1.08)	0.405	0.93 (0.80–1.08)	0.318
Education				
Illiterate	Reference	—	Reference	—
Primary school	0.97 (0.85–1.11)	0.623	0.94 (0.82–1.08)	0.386
Secondary school	0.97 (0.80–1.19)	0.803	0.93 (0.75–1.15)	0.491
High school diploma	1.13 (0.95–1.33)	0.169	1.05 (0.87–1.27)	0.607
University	1.10 (0.93–1.30)	0.259	1.03 (0.85–1.24)	0.780
Smoking				
No	Reference	—	Reference	—

Variable	Crude RR (95% CI)	P-value	Adjusted RR (95% CI)	P-value
Latent class				
Yes	1.12 (1.01–1.26)	0.040	1.01 (0.90–1.14)	0.872
Residence				
Urban	Reference	—	Reference	—
Rural	1.12 (1.02–1.23)	0.017	1.11 (1.00–1.22)	0.052

Adjusted model: latent class, sex, age group, wealth index, education, smoking, and residence

Outcome: incident dyslipidemia during approximately 5 years of follow-up among 1,660 participants free of dyslipidemia at baseline.

Note: RR = risk ratio; CI = confidence interval. Robust standard errors were used.

3. Discussion

In this prospective cohort study, two distinct latent cardiometabolic profiles were identified among adults who were free of dyslipidemia at baseline. Most participants belonged to Class 1 (72.1%), whereas Class 2 comprised 27.9% of the study population and was characterized by a substantially greater burden of cardiometabolic and lifestyle-related risk factors, particularly hypertension, diabetes, metabolic waist, low physical activity, and high saturated-fat intake. The probabilities of hypertension, diabetes, and metabolic waist were markedly higher in Class 2 than in Class 1, indicating a distinct higher-risk cardiometabolic profile. Despite these differences, latent class membership was not significantly associated with incident dyslipidemia during approximately five years of follow-up; the adjusted relative risk was 1.03 (95% CI: 0.92–1.14; P=0.626). Nevertheless, 52.8% of participants developed dyslipidemia during follow-up, highlighting the substantial burden of newly occurring dyslipidemia in this population. These findings suggest that although cardiometabolic risk factors clustered into distinct latent profiles, the identified profiles did not differentiate individuals according to their subsequent risk of developing dyslipidemia.

The identification of distinct cardiometabolic profiles is consistent with previous latent class analyses showing that metabolic and lifestyle-related risk factors can cluster within distinct population subgroups. Park et al. [14] identified distinct dietary behavior patterns associated with metabolic syndrome, while Kim et al. [15] demonstrated heterogeneous profiles combining lifestyle, metabolic status, and obesity among hypertensive Korean adults. Similarly, Ahanchi et al. reported sex-specific clustering of metabolic syndrome components in a population-based cohort, further supporting the presence of heterogeneous patterns of cardiometabolic risk across individuals [16]. Together, these findings support the utility of a person-centered approach for identifying heterogeneous patterns of

cardiometabolic risk that may not be adequately captured by examining individual risk factors separately.

Sociodemographic characteristics also differed across the latent classes, particularly by sex. Women represented a greater proportion of participants in Class 2 than in Class 1 (73.2% vs. 60.1%, $P < 0.001$), indicating a different sex distribution across the latent profiles. This difference may partly reflect sex-related variation in the distribution of cardiometabolic and lifestyle-related risk factors. Previous latent class studies have similarly reported sex-specific patterns of cardiometabolic risk clustering, although the nature and magnitude of these patterns have varied across populations and settings [15,16]. Age also differed across the latent classes, with older participants being more highly represented in Class 2 than in Class 1. This finding is consistent with the accumulation of cardiometabolic risk factors with advancing age and may indicate that the higher-risk profile reflects a greater clustering of metabolic abnormalities in older adults. Previous studies have similarly reported age-related heterogeneity in the clustering of metabolic and lifestyle-related risk factors [16,17]. Together with the observed sex difference, these findings suggest that the distribution of latent cardiometabolic profiles may vary across key demographic characteristics. Educational attainment also differed between the latent classes, with Class 2 comprising a higher proportion of participants with no formal education and lower proportions with secondary or higher education compared with Class 1. This pattern may be compatible with differences in educational and social circumstances associated with cardiometabolic risk, although the underlying mechanisms cannot be established from the present data. Previous epidemiological studies have similarly reported an association between lower educational attainment and poorer cardiometabolic health [14,17].

Lifestyle and contextual factors also differed across the latent classes. Class 2 included a higher proportion of urban residents than Class 1 (70.2% vs. 61.7%), whereas the distribution of smoking status did not differ significantly between the two classes. The observed difference in residential distribution may reflect variation in socioeconomic conditions, access to healthcare services, and health-related behaviors across urban and rural settings. In contrast, the lack of a significant difference in smoking status suggests that smoking did not substantially distinguish the two latent cardiometabolic profiles in this population [15,17].

Lifestyle-related characteristics also contributed to the differentiation between the latent classes. Class 2 had a higher probability of low physical activity than Class 1, indicating that reduced physical activity formed part of the broader higher-risk cardiometabolic profile. Similarly, high saturated-fat intake was more prevalent in Class 2, suggesting that dietary behavior may have contributed to the clustering of cardiometabolic risk factors in this group. These findings are broadly consistent with previous evidence linking dietary behaviors and lifestyle characteristics with metabolic risk and with latent class studies identifying heterogeneous combinations of lifestyle and metabolic characteristics [14,15]. However, because saturated-fat intake represented only one dietary indicator in the latent class model, these findings should not be interpreted as evidence of an overall unfavorable dietary pattern.

An important finding of this study was that the higher-risk cardiometabolic profile was not associated with a higher risk of incident dyslipidemia. Although Class 2 had substantially higher probabilities of hypertension, diabetes, metabolic waist, low physical activity, and high saturated-fat intake, its risk of developing dyslipidemia was similar to that of Class 1. This finding may be explained by the way the latent classes were constructed. The classes were based on general cardiometabolic and lifestyle characteristics and did not specifically include lipid-related measures. Therefore, Class 2 may represent a broader high-risk metabolic profile rather than a profile specifically associated with the future development of dyslipidemia. Because 52.8% of participants developed dyslipidemia during follow-up, restricting prevention to Class 2 would miss many cases arising in the larger Class 1 group. Thus, latent classes may help characterize patterns of co-occurring risk factors and guide broader preventive strategies, but they should not replace direct lipid measurement or conventional risk assessment for predicting individual dyslipidemia risk [9].

This study has several strengths. First, the use of latent class analysis enabled the identification of distinct cardiometabolic profiles based on the co-occurrence of multiple metabolic and lifestyle-related indicators. Second, the inclusion of both metabolic and behavioral indicators allowed a more comprehensive characterization of cardiometabolic risk patterns. Third, the use of data from the Hoveyze Cohort Study and the approximately five-year reassessment provided an opportunity to examine the relationship between baseline cardiometabolic profiles and incident dyslipidemia during follow-up. However, several limitations should be considered. Some behavioral variables, particularly dietary intake and physical activity, were self-reported and may therefore be subject to recall or measurement error. In addition, the latent classes were derived from a specific set of indicators and may not fully capture the broader spectrum of cardiometabolic risk. Finally, although the analysis was based on prospective follow-up data, residual confounding cannot be excluded. While the identified patterns are consistent with previous studies in other populations, generalizing these findings to different ethnic and geographic groups requires replication in independent cohorts with diverse demographic characteristics.

4. Conclusions

Two distinct cardiometabolic profiles were identified among adults participating in the Hoveyze Cohort Study. Class 2 was characterized by higher probabilities of hypertension, diabetes, low physical activity, high saturated-fat intake, and metabolic waist compared with Class 1. However, latent class membership was not significantly associated with incident dyslipidemia during approximately five years of follow-up. These findings highlight the heterogeneity of cardiometabolic risk profiles in this population while suggesting that class membership alone may not be sufficient to predict subsequent dyslipidemia. Further longitudinal studies are warranted to determine whether these cardiometabolic profiles are associated with other metabolic and cardiovascular outcomes.

5. Methods

5.1. Study Design and Population

This study was conducted within the framework of the Hoveyzeh Cohort Study [11], a population-based cohort study that is part of the Prospective Epidemiological Research Studies in Iran (PERSIAN) cohort [18]. The present analysis used data collected during the reassessment phase, conducted approximately five years after baseline enrollment. Approximately 30% of the original cohort participants were selected using systematic random sampling and invited to participate in the reassessment. Participants who completed the reassessment phase and had complete information on the variables required for latent class analysis were eligible for the present study. Latent classes were derived using cardiometabolic and lifestyle indicators measured at baseline, whereas incident dyslipidemia was assessed using data collected during the reassessment phase approximately five years later. A total of 1,660 participants who were free of dyslipidemia at baseline and had complete information for the primary analysis were included in the final study population. Participants with missing information on any variables required for the primary analysis were excluded, and no imputation was performed.

5.2. Cardiometabolic Indicators and Definition of Dyslipidemia

Five binary cardiometabolic indicators measured during the reassessment phase were included in the latent class analysis: hypertension, diabetes mellitus, low physical activity, high saturated-fat intake, and metabolic waist.

Hypertension was defined as systolic blood pressure ≥ 140 mmHg, diastolic blood pressure ≥ 90 mmHg, current use of antihypertensive medication, or a self-reported physician diagnosis of hypertension. Diabetes mellitus was defined as fasting blood glucose ≥ 126 mg/dL, current use of antidiabetic medication, or a self-reported history of diabetes. Physical activity was assessed using the International Physical Activity Questionnaire (IPAQ) and expressed as metabolic equivalents of task (METs) [19]; low physical activity was classified as the unhealthy exposure category. High saturated-fat intake was defined according to the prespecified categorization of saturated fatty acid intake, with the highest consumption category representing the unhealthy exposure. Metabolic waist was defined according to the prespecified study criteria based on waist circumference and metabolic risk characteristics.

Dyslipidemia was defined according to the Adult Treatment Panel III (ATP III) criteria as having at least one abnormal lipid component, including elevated triglycerides (TG), elevated LDL-C, low HDL-C, or elevated total cholesterol (TC) [20]. Lipid measurements were obtained from fasting blood samples (10–12 hours) using standardized biochemical assays and a BT 1500 autoanalyzer. Quality control was performed using standard control sera and Westgard–Levey–Jennings procedures [13]. Dyslipidemia was assessed using the same diagnostic criteria at baseline and reassessment to ensure comparability over time. Incident dyslipidemia was defined as newly developed dyslipidemia at reassessment among participants who were free of dyslipidemia at baseline. Accordingly, all 1,660 participants in the analytic cohort were free of dyslipidemia at baseline and were followed for approximately five years to assess the occurrence of incident dyslipidemia.

5.3. Demographic, Socioeconomic, and Lifestyle Variables

Demographic, socioeconomic, and lifestyle characteristics were considered potential covariates based on prior epidemiological knowledge and their potential relevance to both latent class membership and incident dyslipidemia. Age was categorized as 35–44, 45–54, 55–64, and ≥ 65 years, and sex was categorized as male or female. Marital status was classified as single, married, widowed, or divorced. Socioeconomic status was assessed using a household wealth index derived from household assets and living conditions and categorized into quintiles ranging from poorest to richest [21,22]. Place of residence was classified as urban or rural, and educational attainment was categorized as illiterate, primary school, secondary school, high school diploma, or university level.

Smoking status was defined according to lifetime cigarette consumption, with participants who had smoked at least 100 cigarettes during their lifetime classified as ever smokers [11,23]. Dietary intake was assessed using a quantitative 130-item food-frequency questionnaire (FFQ), and nutrient intakes, including energy, were estimated using N4 nutrition analysis software [24]. Saturated fatty acid intake was categorized into quartiles according to its distribution in the study population.

5.4. Latent Class Analysis

Latent class analysis (LCA) was conducted using generalized structural equation modeling (GSEM) with a logit link to identify unobserved subgroups of participants with similar cardiometabolic profiles. Five binary cardiometabolic indicators, including hypertension, diabetes mellitus, low physical activity, high saturated-fat intake, and metabolic waist, were included in the latent class model.

Two, three, and four-class models were estimated and compared based on model fit, convergence, class interpretability, and posterior class-membership probabilities. Akaike information criterion (AIC) and Bayesian information criterion (BIC) were used for model comparison when models successfully converged. Participants were assigned to the class for which they had the highest posterior membership probability. Conditional probabilities of the five indicators within each class were used to characterize and label the latent cardiometabolic profiles.

5.5. Statistical Analysis

Descriptive statistics were used to summarize the characteristics of the study population and the distribution of baseline characteristics across latent classes. Differences in categorical variables between latent classes were assessed using the chi-square test. Latent class analysis (LCA) was used to identify distinct cardiometabolic profiles based on five predefined cardiometabolic indicators. The optimal number of latent classes was determined by considering model convergence, Akaike information criterion (AIC), Bayesian information criterion (BIC), class interpretability, and posterior class-membership probabilities.

Incident dyslipidemia was defined as the development of dyslipidemia during the approximately 5-year follow-up among participants who were free of dyslipidemia at baseline. The cumulative incidence of dyslipidemia was compared across latent classes. Relative risks (RRs) and corresponding 95% confidence intervals (CIs) were estimated using generalized linear models with a Poisson distribution and log link, with robust variance estimation to account for the binary outcome.

Crude associations between latent class membership and incident dyslipidemia were initially assessed. Multivariable models were then adjusted for potential confounding variables selected a priori, including sex, age group, socioeconomic status (wealth index and educational level), smoking status, and place of residence. Class 1 was considered the reference category for latent class membership. Because the cardiometabolic indicators used to derive the latent classes were components of the exposure definition, these variables were not additionally included as covariates in the outcome models to avoid overadjustment and potential adjustment for components of the exposure. All statistical analyses were performed using Stata version 14.0. A two-sided P-value <0.05 was considered statistically significant.

Declarations

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Author contributions

ZR and BCh: Conceptualization, Supervision, Writing- Reviewing and Editing. SS: Data Curation, Writing- Reviewing and Editing and Formal analysis. RKh: Methodology, Formal analysis NS and SAH: Investigation, Writing- Reviewing and Editing.

Availability of data and materials

Upon request, we can offer onsite access to external researchers to the data analyzed at Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran. To do so, Dr. Rahimi should be contacted.

Competing interests

The authors declare no conflict of interest.

Ethics approval and consent to participate

The Ethics Research Committee approved this study of Iran University of Medical Sciences with a code of ethics IR.AJUMS.REC.1401.316. This study was conducted based on the Helsinki Declaration. Participants signed a written informed consent form for the interview.

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References

1. Saklayen, M. G. The global epidemic of the metabolic syndrome. *Curr. Hypertens. Rep.* **20**, 12 (2018).
2. Grundy, S. M. Metabolic syndrome update. *Trends Cardiovasc. Med.* **26**, 364–373 (2016).
3. Sookoian, S. & Pirola, C. J. Review article: shared disease mechanisms between non-alcoholic fatty liver disease and metabolic syndrome - translating knowledge from systems biology to the bedside. *Aliment. Pharmacol. Ther.* **49**, 516–527. <https://doi.org/10.1111/apt.15163> (2019).
4. Tsai, T. Y. et al. Factor analysis for the clustering of cardiometabolic risk factors and sedentary behavior, a cross-sectional study. *PloS one.* **15**, e0242365 (2020).
5. de Faria, F. R. et al. in *Healthcare* **925** (MDPI).
6. Berlin, K. S., Parra, G. R. & Williams, N. A. An introduction to latent variable mixture modeling (part 2): longitudinal latent class growth analysis and growth mixture models. *J. Pediatr. Psychol.* **39**, 188–203 (2014).
7. Nylund-Gibson, K. & Choi, A. Y. Ten frequently asked questions about latent class analysis. *Translational issues Psychol. Sci.* **4**, 440 (2018).
8. Nuskabayeva, G. et al. Identifying cardio-metabolic subtypes of prediabetes using latent class analysis. *Med. Sci.* **13**, 243 (2025).
9. Anindya, K. et al. A latent class analysis of cardiometabolic risk factors and the predicted prevalence of subclinical atherosclerosis in middle-aged Swedish adults. *Scientific Reports* (2026).
10. Zeng, Z. & Xiao, Z. Cardiometabolic risk phenotypes and chronic kidney disease incidence in older adults: a nationwide longitudinal cohort study. *BMC Public. Health.* **25**, 2581 (2025).
11. Cheraghian, B. et al. Cohort profile: The Hoveyzeh Cohort Study (HCS): A prospective population-based study on non-communicable diseases in an Arab community of Southwest Iran. *Med. J. Islamic Repub. Iran.* **34**, 141 (2020).
12. Raeisi Zadeh, M. et al. Awareness, Treatment, Control, and Determinants of Hypertension: A Population-Based Cross-Sectional Study in Southwest Iran. *Med. J. Islam Repub. Iran.* **40** <https://doi.org/https://doi.org/10.47176/mjiri.40.11> (2026).
13. Cheraghian, B. et al. Evaluation of dyslipidemia based on ATP III guideline in adults in Southwest Iran: a population-based study. *Sci. Rep.* **15**, 9463 (2025).
14. Park, J. H. et al. A latent class analysis of dietary behaviours associated with metabolic syndrome: a retrospective observational cross-sectional study. *Nutr. J.* **19**, 116. <https://doi.org/10.1186/s12937-020-00636-7> (2020).

15. Kim, S., Cho, S. & Nah, E. H. The patterns of lifestyle, metabolic status, and obesity among hypertensive Korean patients: a latent class analysis. *Epidemiol. Health.* **42**, e2020061. <https://doi.org/10.4178/epih.e2020061> (2020).
16. Ahanchi, N. S., Hadaegh, F., Azizi, F. & Khalili, D. Sex- specific clustering of metabolic syndrome components and incidence of cardiovascular disease: A latent class analysis in a population-based cohort study. *J. Diabetes Complicat.* **35**, 107942. <https://doi.org/https://doi.org/10.1016/j.jdiacomp.2021.107942> (2021).
17. Ghanbari, J. et al. Subgroups of lifestyle patterns among hypertension patients: a latent-class analysis. *BMC Med. Res. Methodol.* **18**, 127. <https://doi.org/10.1186/s12874-018-0607-6> (2018).
18. Poustchi, H. et al. Prospective epidemiological research studies in Iran (the PERSIAN Cohort Study): rationale, objectives, and design. *Am. J. Epidemiol.* **187**, 647–655 (2018).
19. Ainsworth, B. E. et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med. Sci. Sports Exerc.* **32**, S498–S516 (2000).
20. Iii, A. & Reference, D. ATP III guidelines at-A-glance quick desk reference. *Natl Cholest Educ Progr ATP* 1–33 (2001). (2001).
21. Smits, J. & Steendijk, R. The international wealth index (IWI). *Soc. Indic. Res.* **122**, 65–85 (2015).
22. Rahimi, Z., Saki, N., Cheraghian, B., Amini, P. & Solaymani Dodaran, M. Association between individual, household, and area-level socioeconomic status indicators and sensorineural hearing loss in adults in southwest Iran: a population-based study. *Front. Public. Health.* **11**, 1140500. <https://doi.org/10.3389/fpubh.2023.1140500> (2023).
23. Cheraghian, B., Rahimi, Z., Hashemi, S. J. & Torabipour, A. Association Between Smoking and Amnesia in Southwest Iran: A Population-Based Cross-sectional Study. *J. Res. Health Sci.* **25**, e00647. <https://doi.org/10.34172/jrhs.2025.182> (2025).
24. Rahimi, Z., Hosseini, S. A., Alemohammad, S. Y., Sarvandian, S. & Cheraghian, B. Association between individual, household, and area-level socioeconomic status indicators with anthropometric indexes. *Prev. Med. Rep.* **53**, 103036 (2025).