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Characteristics of Metabolic Syndrome in a Rural High-Altitude Population of Peru

Características del síndrome metabólico en una población rural de altura del Perú

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ABSTRACT

Introduction: Metabolic syndrome is a major global public health problem, and its prevalence and risk factors can vary significantly in high-altitude populations due to unique physiological adaptations and sociocultural contexts. Evidence on this condition in isolated rural Andean communities remains limited.

Objectives: To determine the risk factors associated with the presence of metabolic syndrome in adults attending outpatient consultation in Acobamba, a high-altitude region in Peru.

Materials and methods: A cross-sectional analytical study was conducted on 176 adults (mean age 52.5 ± 13.8 years; 60.2% women) between January and June 2025. Metabolic syndrome was defined according to adapted criteria of the NCEP-ATP III (National Cholesterol Education Program Adult Treatment Panel III). Sociodemographic, anthropometric, clinical, laboratory, and lifestyle data were collected. Descriptive, bivariate, and multiple logistic regression analyses were applied to calculate adjusted Odds Ratios with 95% confidence intervals.

Results: The prevalence of metabolic syndrome was 37.5% (30.3-45.1). Independently associated factors included: age (1.68 per decade; 1.25-2.26), low educational level (2.15; 1.02-4.53), obesity (body mass index ≥ 30 kg/m²; 2.78; 1.35–5.72), and insufficient physical activity (1.99; 1.01–3.93).

Conclusions: Significant modifiable and non-modifiable risk factors associated with metabolic syndrome were identified in this Andean high-altitude population, underscoring the need for culturally adapted preventive and clinical management interventions focused on these determinants.

Key words: metabolic syndrome; risk factors; altitude; cross-sectional study; epidemiology; Peru

RESUMEN

Introducción: El síndrome metabólico representa un importante problema de salud pública global, y su prevalencia y factores de riesgo pueden variar significativamente en poblaciones de gran altitud debido a adaptaciones fisiológicas y contextos socioculturales únicos. Existe una escasez de datos específicos sobre esta condición en comunidades rurales andinas aisladas.

Objetivos: Determinar los factores de riesgo asociados a la presencia de síndrome metabólico en adultos atendidos en consulta ambulatoria en Acobamba, una región de gran altitud en Perú.

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Materiales y métodos: Se realizó un estudio transversal analítico en 176 adultos (edad media 52.5 ± 13.8 años; 60.2% mujeres) entre enero y junio de 2025. El síndrome metabólico se definió según criterios NCEP-ATP III adaptados. Se recolectaron datos sociodemográficos, antropométricos, clínicos, de laboratorio y de estilos de vida. Se aplicaron análisis descriptivos, bivariados y de regresión logística múltiple para calcular Odds Ratios ajustados con intervalos de confianza del 95%.

Resultados: La prevalencia del síndrome metabólico fue del 37.5 % (30.3-45.1). Los factores asociados de forma independiente fueron la edad (1.68 por década; 1.25-2.26), bajo nivel educativo (2.15; 1.02-4.53), obesidad (índice de masa corporal igual o mayor a 30 kg/m²; 2.78; 1.35-5.72) y baja actividad física (1.99; 1.01-3.93).

Conclusiones: Se identificaron factores de riesgo modificables y no modificables significativos asociados al SM en esta población andina de gran altitud, subrayando la necesidad de intervenciones preventivas y de manejo clínico culturalmente adaptadas y focalizadas en estos determinantes.

Palabras Clave: síndrome metabólico; factores de riesgo; altitud; estudio transversal; epidemiología; Perú

INTRODUCTION

Metabolic syndrome (MS) has emerged as a major public health challenge in the 21st century driven by its impact on morbidity and mortality associated with cardiovascular diseases and type 2 diabetes mellitus. Its prevalence varies according to the geographic and cultural context, and recent studies suggest that altitude may modulate the expression of its components. Chronic exposure to hypobaric hypoxia in Andean populations leads to physiological adaptations that could influence adipose tissue distribution, blood pressure, and lipid profiles; however, its interaction with conventional risk factors such as diet, physical inactivity, and genetic predisposition has not yet been fully elucidated.

At the international level, the evidence supports this variability. The meta-analysis by Zila-Velasque et al[1] reported a MS prevalence of 30.9% (95% CI: 20.0–43.0%) in populations residing at more than 3,500 meters above sea level, highlighting the influence of altitude on the phenotypic expression of the syndrome. Similarly, Huang et al[2] documented in communities of Derong, China (2,060-3,820 meters above sea level) a prevalence of only 3.6%, associated with a lower risk of obesity and dyslipidemia, but a higher risk of hypertension. These findings suggest that altitude may act as a modulating factor, but with heterogeneous effects, depending on cultural and genetic context. In addition, socioeconomic factors also play a relevant role. Su et al[3] (Korea) found a high prevalence of MS (≈47%) among individuals with extremely low income, associated with lower educational level and limited access to health care.

In Peru, several national studies have reported variable prevalences of MS depending on the diagnostic criteria used. Pajuelo and Sánchez[4] estimated a national prevalence of 16.8%, with lower figures in the rural highlands (11.1%), suggesting a protective profile in high-Andean communities. Subsequently, Pajuelo et al. confirmed this trend by finding a significantly lower prevalence in populations living in over 3,000 meters above sea level (10.2%) compared with those below 1,000 meters (19.7%). However, more recent studies show a different picture: Guzmán-Vilca and Carrillo-Larco[6] reported a national prevalence of 46%, with a higher frequency in urban (49%) rather than rural (38%) populations, while Vera-Ponce et al. found an overall prevalence of 40.6%, also highlighting variability according to the diagnostic criteria applied. Taken together, these figures reflect both the country's epidemiological transition and the need to contextualize findings in high-altitude rural populations.

Despite this growing research, important knowledge gaps remain, particularly with regard to rural high-Andean communities with specific socioeconomic conditions. Most studies have focused on capital cities or urban areas, leaving limited information on isolated localities such as Acobamba. In these communities, socioeconomic profiles, limited access to health-care services, traditional dietary patterns (high consumption of carbohydrates and fats, use of coca leaves), and levels of physical activity shape a unique risk profile. Moreover, the diagnostic cut-off points used have rarely been validated for Andean populations, which could lead to underestimation or overestimation of prevalence.

Within this framework, the present study aims to identify risk factors associated with the presence of MS in adults receiving outpatient care at the Hospital Provincial de Acobamba, a high-altitude region of Peru. The objectives are to determine the prevalence of MS and its individual components, and to quantify the association between sociodemographic, anthropometric, lifestyle, and clinical history variables and the likelihood of having MS in this population. Understanding these patterns will improve the epidemiological characterization of the syndrome in the region and lay the groundwork for culturally appropriate preventive and therapeutic interventions.

MATERIALS AND METHODS

An observational, analytical, cross-sectional study was conducted between January and June 2025 in the outpatient clinic of the Hospital Provincial de Acobamba, Huancavelica, Peru. This locality is situated at more than 3,000 meters above sea level, and its population is predominantly rural, making it ideal for this analysis.

The study population included adults aged 18 years and older who attended outpatient consultations. The sample size was 176 individuals, calculated using the single-proportion formula for finite populations, based on the expected prevalence of MS reported in studies of populations with similar geographic and socioeconomic characteristics,[8] a 95% confidence level, a 5% margin of error, and 80% statistical power. Inclusion criteria were limited to legal adulthood and provision of informed consent. Pregnant women, patients with severe acute illnesses, conditions that precluded proper evaluation, or a prior diagnosis of MS under intensive treatment were excluded. Systematic random sampling was implemented, selecting patients from appointment records; a participation rate of 85% was recorded.

The dependent variable was MS, defined according to NCEP-ATP III criteria, considering the presence of three or more of the following components: abdominal obesity (≥ 90 cm in men, ≥ 80 cm in women, adapted for the Andean population), triglycerides ≥ 150 mg/dL, low HDL cholesterol (< 40 mg/dL in men, < 50 mg/dL in women), blood pressure ≥ 130/85 mmHg or antihypertensive treatment, and fasting glucose ≥ 100 mg/dL or a prior diagnosis of type 2 diabetes. Independent variables included sociodemographic, anthropometric, clinical, laboratory, lifestyle, and medical history factors (Table 1). Anthropometric measurements were performed using calibrated instruments and following standardized protocols. Clinical and laboratory data were obtained after an 8-12 hour fast, using standardized enzymatic methods in the hospital laboratory. Physical activity was assessed using the IPAQ-SF (International Physical Activity Questionnaire – Short Form), whose validity has been established in populations with comorbidities.[9]

Data collection was carried out by trained personnel using a structured questionnaire previously pilot-tested in a small sample to verify clarity and comprehension, along with a form for the collection of clinical and laboratory data. All information was coded to ensure confidentiality.

Statistical analysis was performed using SPSS v27.0. Categorical variables were described using frequencies and percentages, while continuous variables were calculated using means and standard deviations or medians and interquartile ranges, depending on their distribution as assessed by the Shapiro-Wilk test. Comparisons between groups with and without MS were conducted using the Chi-square or Fisher's exact test for categorical variables, and Student's t-test or the Mann-Whitney U test for continuous variables. Risk factors were identified through binary logistic regression, calculating crude and adjusted odds ratios (ORs) with 95% confidence intervals (95% CI). Variables with $p < 0.20$ in the bivariate analysis, or those considered clinically relevant, were included in the multivariate model using a backward stepwise selection method. Collinearity was assessed using the variance inflation factor (VIF); and model goodness of fit was evaluated with the Hosmer–Lemeshow test.[10] A p value < 0.05 was considered statistically significant.

The study protocol was approved by the Research Ethics Committee of the Hospital Provincial de Acobamba (HPA-CEI-005-2024). All participants provided written informed consent, and we ensured confidentiality and anonymity in handling data.

RESULTS

Characteristics of the participants

The sample included 176 adults (85% participation rate), with a mean age of 52.5 ± 13.8 years, and 60.2% were women. Table 2 shows significant differences between participants with and without MS, highlighting older age, lower educational level, higher BMI and waist circumference, as well as a higher prevalence of general and abdominal obesity in the group with MS.

Prevalence of metabolic syndrome and its components

The overall prevalence of MS was 37.5% (95% CI: 30.3-45.1). The most frequent component was abdominal obesity, followed by hypertriglyceridemia and low HDL cholesterol (Table 3). Figure 1 shows a significant increase in the prevalence of MS with age.

Comparison of clinical and biochemical parameters

Table 4 shows that patients with metabolic syndrome (MS) had significantly higher values of

TABLE 1. Study variables, operational definitions, and measurement scales

Main variable	Operational definition	Type of variable	Measurement scale	Role in the study
Metabolic syndrome (MS)	Presence of ≥ 3 NCEP-ATP III criteria (with adapted waist circumference cut-offs)	Categorical	Dichotomous (yes/no)	Dependent
Age	Age in years at the time of the interview	Continuous	Ratio (years)	Independent
Sex	Self-report	Categorical	Nominal (man/woman)	Independent
Educational level	Highest level of education attained	Categorical	Ordinal (categories)*	Independent
Body Mass Index (BMI)	Weight (kg) / height (m)²	Continuous	Ratio (kg/m²)	Independent
Waist circumference (WC)	Measurement in centimeters at the midpoint between the last rib and the iliac crest	Continuous	Ratio (cm)	Independent
Systolic blood pressure (SBP)	Mean of two measurements in mmHg	Continuous	Ratio (mmHg)	Independent
Diastolic blood pressure (DBP)	Mean of two measurements in mmHg	Continuous	Ratio (mmHg)	Independent
Fasting blood glucose	Level after ≥ 8 hours of fasting (mg/dL)	Continuous	Ratio (mg/dL)	Independent
Triglycerides (TG)	Level after ≥ 8 hours of fasting (mg/dL)	Continuous	Ratio (mg/dL)	Independent
HDL Cholesterol (HDL-C)	Level after ≥ 8 hours of fasting (mg/dL)	Continuous	Ratio (mg/dL)	Independent
Physical activity	Level according to IPAQ-SF	Categorical	Ordinal (low/mid/high)	Independent
Tobacco consumption	Current smoking status	Categorical	Nominal (is a smoker/is not a smoker/former smoker)	Independent
Alcohol consumption	Frequency and amount (standard units per week)	Categorical/continuous	Ordinal/ratio	Independent
Family history of diabetes	Reported diabetes in first-degree relatives	Categorical	Dichotomous (yes/no)	Independent
Coca leaf consumption	Reported habitual consumption	Categorical	Dichotomous (yes/no)	Independent

blood pressure, fasting blood glucose, triglycerides, uric acid, and ALT (alanine aminotransferase), along with a higher prevalence of hypertension, altered glucose, and hypertriglyceridemia. In contrast, HDL cholesterol levels were lower in both sexes, with a higher prevalence of reduced HDL-C. Figure 2 illustrates the differences in glucose and triglyceride levels between the groups.

Risk factor analysis

The bivariate analysis identified several factors significantly associated with the presence of MS (Table 5). Among these, notable factors include age (per every 10-year increase), low educational level, general obesity (BMI ≥ 30 kg/m²), abdominal obesity, low physical activity, and a family history of diabetes.

Subsequently, in the multiple logistic regression analysis adjusted for sex, the factors that maintained an independent and significant association with the MS were: age, low educational level, obesity (BMI ≥ 30 kg/m²), and low physical activity (Table 6). The adjusted Odds Ratios for these factors are visually presented in Figure 3.

DISCUSSION

This study found a 37.5% prevalence of metabolic syndrome among adults in Acobamba, a high-altitude Andean region. This figure is higher than

TABLE 2. Sociodemographic and anthropometric characteristics of participants (N = 176) with/without metabolic syndrome (MS)

Characteristics	Total (n = 176)	Without MS (n = 110)	With MS (n = 66)	p-value
Age (years), Mean ± SD	52.5 ± 13.8	48.7 ± 12.5	58.6 ± 13.1	< 0.001[1]
Sex, n (%)				0.178[2]
Man	70 (39.8)	48 (43.6)	22 (33.3)	
Woman	106 (60.2)	62 (56.4)	44 (66.7)	
Educational level, n (%)				0.035[2]
No formal education/Primary education	65 (36.9)	35 (31.8)	30 (45.5)	
Secondary education	78 (44.3)	52 (47.3)	26 (39.4)	
Higher education	33 (18.8)	23 (20.9)	10 (15.1)	
BMI (kg/m²), Mean ± SD	28.9 ± 4.5	27.1 ± 3.8	31.8 ± 4.1	< 0.001[1]
Obesity (BMI ≥ 30 kg/m²), n (%)	58 (33.0)	25 (22.7)	33 (50.0)	< 0.001[2]
WC (cm), Mean ± SD				
Men	93.5 ± 10.2	89.8 ± 8.5	99.7 ± 9.3	< 0.001[1]
Women	90.1 ± 11.5	85.5 ± 9.7	97.2 ± 10.8	< 0.001[1]
Abdominal obesity*, n (%)	102 (58.0)	50 (45.5)	52 (78.8)	< 0.001[2]

[1] Student's t-test for independent samples.
[2] Chi-square test.
* WC ≥ 90 cm in men ≥ 80 cm in women. SD= standard deviation

TABLE 3. Prevalence of metabolic syndrome and its individual components in the study population (N = 176)

Component	n	% (95% CI)
Metabolic syndrome (≥ 3 components)	66	37.5 (30.3-45.1)
Abdominal obesity[1]	102	58.0 (50.3-65.4)
Hypertriglyceridemia (≥ 150 mg/dL)	97	55.1 (47.4-62.6)
Low HDL-C[2]	88	50.0 (42.4-57.6)
High arterial pressure[3]	83	47.2 (39.7-54.8)
Altered fasting glucose (≥ 100 mg/dL)	73	41.5 (34.1-49.2)

[1] WC ≥ 90 cm men ≥ 80 cm women
[2] HDL-C < 40 mg/dL men, < 50 mg/dL women
[3] SBP ≥ 130 or DBP ≥ 85 mmHg or on treatment

historical estimates in high-Andean communities, where prevalences of 11.1% and 10.2% were reported in populations living above 3,000 meters above sea level.[4,5] In contrast, it is lower than recent national studies reporting prevalences of 46% and 40.6%,[6,7] although other analyses have described even higher figures, such as 73% in a cross-sectional study based on the VIANEV survey (Food and Nutrition Surveillance by Life Stages).[11] Additionally, Vera-Ponce et al[12] reported that more than 87% of the Peruvian population presents at least one metabolic alteration, more common in women, underscoring the need to reassess diagnostic criteria and design differentiated prevention strategies. This trend reflects the epidemiological transition of MS in Peru, where figures have increased steadily over the past two decades, challenging the previous notion that altitude confers a protective profile against the syndrome.

At the international level, the prevalence observed exceeds that reported in Tibetan communities (3.6%);[2] approaches that observed in low-income populations in Korea (≈47%),[3] and is close to the global average described in the meta-analysis

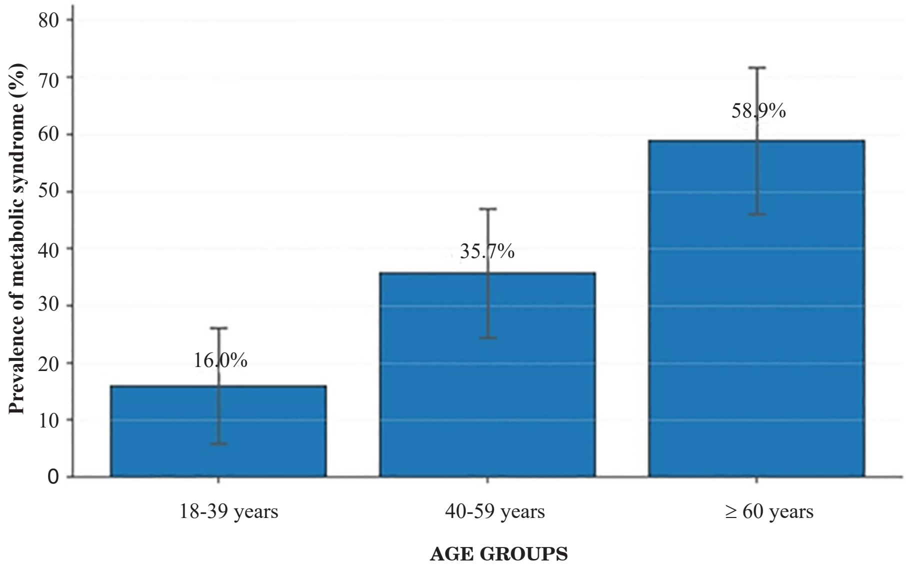

Figure 1. Prevalence of metabolic syndrome (with 95% confidence intervals) by age group in the study population (N = 176), Acobamba 2025. p for trend < 0.001 (Chi-square test for trend).

TABLE 4. Components of metabolic syndrome and clinical/biochemical parameters (N = 176) with/without metabolic syndrome (MS)

Parameter	Without MS (n=110)	With MS (n=66)	p-value
SBP (mmHg), Mean ± SD	122.5 ± 13.8	141.3 ± 15.2	< 0.001[1]
DBP (mmHg), Mean ± SD	78.9 ± 9.2	89.5 ± 10.1	< 0.001[1]
Arterial hypertension*, n (%)	35 (31.8)	48 (72.7)	< 0.001[2]
Fasting glucose (mg/dL), Mean ± SD	95.8 ± 10.5	115.6 ± 22.3	< 0.001[1]
Altered fasting glucose (≥ 100 mg/dL)*, n (%)	28 (25.5)	45 (68.2)	< 0.001[2]
Triglycerides (mg/dL), Median (IQR)	130 (105-160)	195 (165-250)	< 0.001[3]
Hypertriglyceridemia (≥ 150 mg/dL)*, n (%)	42 (38.2)	55 (83.3)	< 0.001[2]
HDL Cholesterol (mg/dL), Mean ± SD			
Men	45.2 ± 8.8	38.5 ± 7.5	< 0.001[1]
Women	50.1 ± 9.5	42.3 ± 8.1	< 0.001[1]
Low HDL-C*, n (%)	38 (34.5)	50 (75.8)	< 0.001[2]
Uric acid (mg/dL), Mean ± SD	5.5 ± 1.5	6.8 ± 1.8	< 0.001[1]
ALT (U/L), Median (IQR)	22 (18-28)	30 (24-40)	< 0.001[3]
Abdominal obesity*, n (%)	102 (58.0)	50 (45.5)	52 (78.8)

[1] Student's t-test. [2] Chi-square test. [3] Mann-Whitney U test.
* Defined according to NCEP-ATP III criteria.

by Zila-Velasque (30.9%).[1] These differences indicate that, in addition to altitude, socioeconomic and cultural factors modulate the expression of the MS. Therefore, comparisons should be interpreted with caution, taking into account diagnostic criteria, sample characteristics, and the modulating effect of altitude, which according to Wang et al[13] may reduce central obesity while increasing hypertension. In this regard, the systematic review by Villegas-Abrill et al[14] confirmed that the most commonly used parameters in high-altitude studies are BMI, waist circumference, blood pressure, triglycerides, HDL cholesterol, and serum glucose, consistent with the criteria applied in this study. This methodological concordance reinforces the validity of the findings and highlights the importance

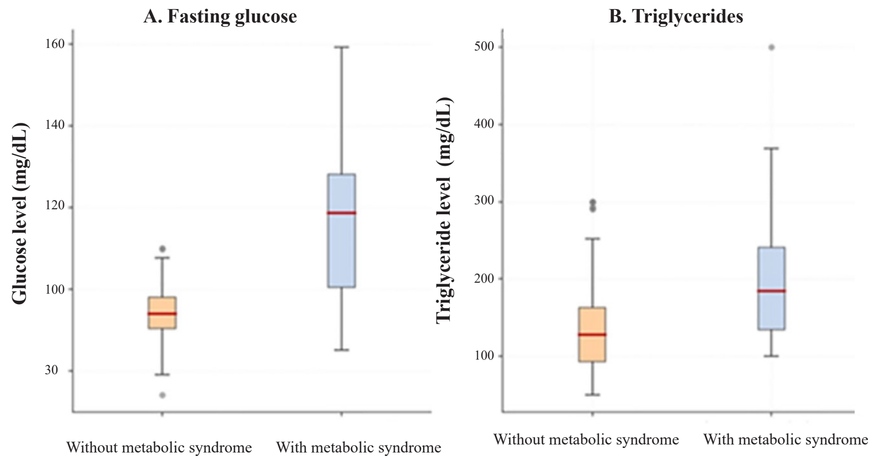

Figure 2. Distribution of fasting glucose (A) and triglyceride (B) levels according to the presence or absence of metabolic syndrome. The boxes represent the interquartile range (IQR), the middle line indicates the median, and the whiskers extend to 1.5 times the IQR. Dots represent outliers. *** $p < 0.001$ (Mann–Whitney U test).

TABLE 5. Bivariate analysis of risk factors associated with metabolic syndrome (N = 176)

Risk factor	Crude OR	95% CI	p-value
Age (per every 10-year increase)	1.85	1.40-2.45	< 0,001
Sex (woman vs. man)	1.52	0.80-2.89	0.198
Educational level (low* vs. high**)	2.80	1.35-5.80	0.005
Obesity (BMI ≥ 30 vs. < 30)	3.45	1.78-6.69	< 0,001
Abdominal obesity (yes or no)	4.21	2.15-8.23	< 0,001
Physical activity (low vs. mod/high)	2.50	1.30-4.80	0.006
Tobacco consumption (current smoker/ non-smoker/former smoker)	1.95	0.95-4.01	0.068
Alcohol consumption (at risk/ no risk)	1.70	0.88-3.29	0.112
Family history of diabetes (yes/ no)	2.10	1.08-4.09	0.029
Family history of AHT (yes/ no)	1.88	0.99-3.56	0.053
Coca leaf consumption (yes/ no)	1.65	0.82-3.31	0.159
Uric acid (mg/dL), Mean ± SD	5.5 ± 1.5	6.8 ± 1.8	< 0.001[1]
ALT (U/L), Median (IQR)	22 (18-28)	30 (24-40)	< 0.001[3]
Abdominal obesity*, n (%)	102 (58.0)	50 (45.5)	52 (78.8)

* Low: No formal education/Primary education. ** High: Secondary/Higher education. Risk consumption defined as >7 U/week (women), >14 U/week (men).

TABLE 6. Multiple logistic regression analysis of risk factors associated with metabolic syndrome (N = 176)

Risk factor	Adjusted OR (aOR)	95% CI	p-value
Age (per every 10-year increase)	1.68	1.25-2.26	0.001
Educational level (low* vs. high**)	2.15	1.02-4.53	0.044
Obesity (BMI ≥ 30 vs. < 30)	2.78	1.35-5.72	0.005
Physical activity (low vs. mod/high)	1.99	1.01-3.93	0.047
Family history of diabetes (yes/ no)	1.85	0.92-3.71	0.083

*Model adjusted for sex. Hosmer–Lemeshow test: p = 0.458. Maximum VIF (Variance Inflation Factor) < 2.5.
* Low: No formal education/Primary education. ** High: Secondary/Higher education

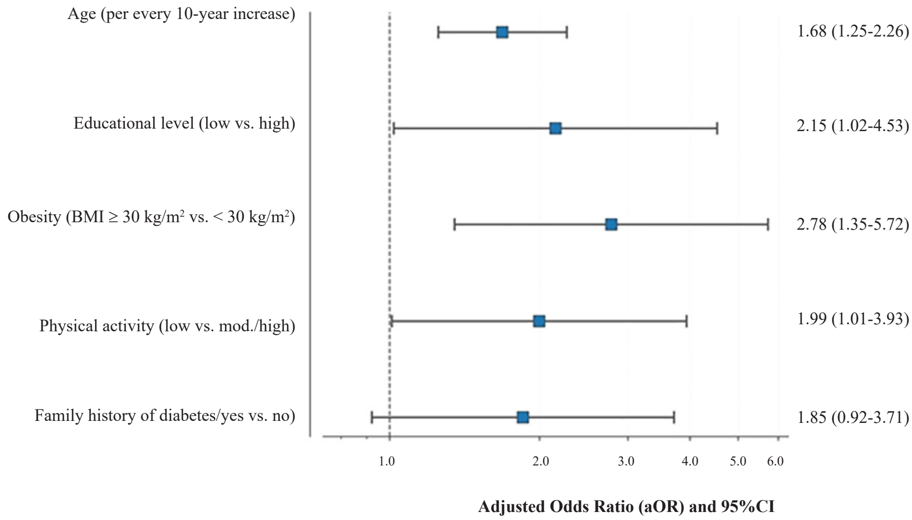

Figure 3. Adjusted Odds Ratios (aOR) and 95% Confidence Intervals for risk factors associated with metabolic syndrome derived from the multiple logistic regression model. The model was adjusted for sex. The vertical line at OR = 1 indicates no association.

of considering multiple diagnostic components in high-altitude populations.

Regarding sociodemographic factors, the positive association between age and the risk of MS is well documented in the literature, and our study is no exception, showing an adjusted OR of 1.68 for each 10-year increase. In a sample of more than 17,000 adults in the United States, Hirode and Wong,[15] reported a significant increase in prevalence from 19.5% among young adults (20-39 years) to 48.6% among people older than 60 years, confirming the strong influence of age on the expression of MS. In addition, Pigeot and Ahrens[16] emphasize that obesity and metabolic disorders develop during childhood and tend to persist into adulthood, reinforcing the importance of considering age as a transversal determinant in the evolution of the syndrome.

Even more revealing is the association with low educational level (aOR = 2.15), a factor that has also been identified among adults in Brazil[17] and among low-income Korean women.[18] This cross-cultural consistency suggests that education could act as a proxy for limited access to health information, reduced capacity to adopt healthy lifestyles, and barriers to prevention-all factors that could be exacerbated in isolated rural communities such as Acobamba. Interestingly, and in line with Gouveia et al[17] but contrary to general expectations, sex did not emerge as an independent predictor in our model. However, in a Swiss cohort, Alipour et al[19] found that low educational level predicts MS in women but not in men, and that women with MS present a higher cardiovascular risk. This discrepancy should be further explored in future studies, to consider gender roles and differential exposure to risk factors in the Andean context.

General obesity, measured by BMI, emerged as a strong independent predictor of MS (aOR = 2.78). In Brazil, Gouveia et al[17] also identified BMI as a key predictor (OR = 1.18), while Kim et al,[20] using machine learning models in a Korean population, identified it as the most important individual factor, even surpassing the waist-to-hip ratio. Although abdominal obesity is a central criterion of the syndrome, the strong association with BMI underscores its value as a simple screening tool in primary care, especially in resource-limited settings.

Regarding lifestyle factors, low physical activity was significantly associated with a higher risk of MS (aOR = 1.99). In Korea, Seo et al[21] demonstrated a dose-dependent protective effect of recreational physical activity, while Gemeda et al[22] in Ethiopia found a strong association between physical inactivity and MS in diabetic patients (aOR = 6.938). In rural Andean populations, occupational activity (agriculture, herding) can be considerable, but it does not always meet the intensity or type of effort that confers metabolic benefits. For this reason, it tends to be underestimated in questionnaires such as the IPAQ-SF, which prioritize structured or leisure-time physical activity. Although this could be perceived as a limitation, it actually highlights the fact that what is relevant for metabolic risk is not only the amount of activity performed, but also its type and intensity.

The implications of these findings are multiple. This study provides evidence on MS in a high-altitude ecosystem, showing that universal factors such as age and obesity remain relevant, while socioeconomic variables such as education acquire particular importance in rural Andean areas. From a public health perspective, the results call for culturally adapted prevention and control strategies, with an emphasis on promoting physical activity, improving health education, and addressing obesity from early ages, leveraging existing community structures.

Among the limitations, the cross-sectional design precludes the establishment of causality, the sampling restricted to users of a health center may introduce selection bias, and the assessment of lifestyle factors through self-reports is susceptible to recall bias. In addition, the possibility of residual confounding persists, and generalization to other high-altitude populations should be undertaken with caution.

Future research should include longitudinal studies to confirm associations and explore cultural barriers to healthy lifestyles, as well as validate biomarkers and cut-off points specific to high-altitude populations. The use of advanced analytical techniques, such as machine learning models, could help identify more complex risk profiles.

This study provides evidence on the prevalence and determinants of metabolic syndrome in a high-altitude Andean community, highlighting the need for culturally adapted strategies for its prevention and control.

Conflict of interest

The authors have no conflict of interest to declare.

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