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# Holistic approaches to understanding obesity and metabolic diseases in urban environments

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# Holistic approaches to understanding obesity and metabolic diseases in urban environments

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# Editorial: Holistic approaches to understanding obesity and metabolic diseases in urban environments

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Editorial on the Research Topic
Holistic approaches to understanding obesity and metabolic diseases in urban environments

Although obesity has a complex multi-factorial etiology, requiring interdisciplinary expertise to discern the potential patterns of drivers involved in its increasing prevalence worldwide, most studies use a uni-disciplinary approach: psychological, sociocultural, physiological or genetics, a scientific strategy probably responsible for the current failure to prevent obesity, whose prevalence has tripled since 1975 according to WHO (1). Hence, the biocultural background of populations is insufficiently considered to assess their particular adaptive capacity for evolving in new urban environments, in order to minimize their exposure to the risks of obesity related cardiometabolic diseases (ORCDs). Although the generic determinants of obesity are well-understood, their respective effect as well as systemic interactions on BW regulation remain poorly understood. Moreover, the pathways predicting ORCDs between sociodemographic indirect determinants (age, sex, education, migration, etc.) and socio-ecological direct determinants (body weight norms, dietary intake and physical activity) are also rarely explored to study the etiology of ORCDs (2). Yet, both respective and cumulative contributions of these drivers, as well as the multiple driver pathways leading to ORCDs, must be explored to explain the difference in the prevalence and incidence of ORCDs between countries, and better identify at-risk subgroups toward this rising burden. The aim of this Research Topic consists in refocusing the study of obesity at an anthropological scale, by considering holistically populations' characteristics (sociodemographic and socio-ecological) that influence their degree of adaptation to obesogenic urban environments, to provide new insights to develop anthropologically relevant targeted programs to prevent and treat obesity and ORCDs.

Based on 13 relevant contributions, from an articulation between 11 original researches conducted worldwide, including 7 quantitative, 1 real-world, 1 mixed-methods and 2 longitudinal studies, and 2 reviews, this Research Topic, covering all age ranges, provided relevant findings as well as critical analyses and interpretations to deeply explore the synergetic effects of ORCDs' determinants in a globalized obesogenic urban environment. Through contributions at both national and regional scales, focusing on the complex etiology of obesity, ORCDs, as well as body composition and body fat distribution, covering all continents, the Research Topic: "*Holistic Approaches to Understanding Obesity and Metabolic Diseases in Urban Environments*" allows an original overview of factors leading to cardiometabolic diseases in countries situated at contrasted stages of the nutrition transition (1). This Research Topic has a focus on Low- and Middle-income Countries (LMICs) where the urbanization rates are the highest (3), as the incidence ORCDs (4). Consequently, this collective work will provide original insights to support innovative intervention strategies and programs aiming to reduce at mid- or long-term the ORCDs pandemic, with a variety of tools and skills to adapt them to local and population specificities (5).

Hence, two first contributions, from Jiao et al. and Zhang et al., explored, respectively, in Northwest and Southwestern China the determinants of ORCDs in adults. These quantitative cross-sectional studies showed that the urban transition occurring in both regions overexposed at-risk subgroups, i.e., women and middle-aged people, to ORCDs. This seems particularly true in non- or ex-smokers as well as in rural people experiencing a rapid shift in their lifestyle (e.g., increasing sedentary behaviors and energy-dense food), attesting that China presents an advanced stage of nutrition transition. The next contribution carried out by Szemik et al. focused longitudinally on the determinants overweight/obesity in another at-risk subgroups: the students. Indeed, this study implemented in an urban Polish area showed that the exposure to overweight/obesity increased across the years through specific risk factors as male sex, social insecurity and abundant meat consumption. Then, a real-world cross-sectional study conducted by Liu et al. in American Adults from the National Health and Nutrition Examination Survey demonstrated a negative association between the dietary intake of live microbes and obesity, mediated partially by the serum vitamin D. This suggests that foods with higher microbial concentrations could be beneficial for cardiometabolic health and vice versa. Another quantitative cross-sectional study, also carried out in the same population by Li et al., showed significant associations between three abdominal fat distribution indices—lipid accumulation product (LAP), body roundness index (BRI), and waist triglyceride index (WTI)—and osteoarthritis. In addition, stronger associations appeared in participants with lower education, hypertension (for WTI), without hyperlipidemia (for LAP) and non-smokers (for BRI). A literature review, conducted by Ard et al. in the United States, highlighted the evidence that a holistic integrated approach to obesity management, including campaigns fighting stigma, messaging encouraging the public to consider all levels of intervention, policy advocacy for anti-obesity medication coverage, and environmental change, results in better outcomes for people with obesity as it is a chronic, complex, and often relapsing disease.

Other contributions focused on the determinants of ORCDs in disadvantaged populations overexposed to obesity and/or barriers for health facilities access. A first contribution conducted in Hispanic American children by Vazquez et al. explored longitudinally how neighborhood opportunities, via a Childhood Opportunity Index (COI) illustrating the cumulative positive and negative environmental aspects (e.g., parent BMI and education, family income) involved in child health, are related to childhood weight status. Globally, all the higher COI levels were linked to healthier weight status compared to the lowest COI level. Then, a systematic review conducted by Jalilzadeh and Goharinezhad found worldwide 82 factors influencing overweight and obesity, categorized into five major groups: sociocultural, economic, technological, environmental, and political. Consequently, multi-sectoral interventions are required by the authors to address the obesity pandemic, especially in vulnerable population groups mainly concentrated in LMICs where studies on public health nutrition remain scarce. Another contribution conducted by Chagas et al. focused quantitatively, through a cross-sectional study, on the determinants of body composition among adult outpatients of a public university hospital specializing in cardiology in Northeastern Brazil. Distinct factors were found to influence visceral and subcutaneous obesity (VAT and SAT): sedentary behavior emerged as an independent predictor of visceral obesity while alcohol consumption was associated with a subcutaneous obesity pattern. In addition, diabetes and sociodemographic factors (older age, non-White race, and lower education) were predictive of an elevated VAT/SAT ratio.

Kawalkar et al. found in their mixed-methods study conducted among adult patients with type 2 diabetes mellitus (T2DM) of the tertiary care hospital in Vidarbha region of India that male participants exhibited higher awareness levels across various aspects of dietary recommendations. Because female participants presented lower knowledge in health related nutrition including recommended fruit and vegetable intake, milk product consumption, and types of fruits suitable for diabetics, the conclusions consequently emphasize gender-sensitive educational interventions to enhance diabetes-related nutrition knowledge and self-management practices among T2DM patients. Then, another cross-sectional quantitative study conducted by Ebrahimi et al. among adult Iranian women with overweight and obesity, who were referred to health centers of the Tehran University of Medical Sciences, observed that participants with higher lifestyle risk score, including SES, education levels, sleep quality, waist-to-height ratio, dietary behavior (vegetables, grains and legumes intake) and physical activity, had higher body mass index associated with metabolically morbidities. The authors recommended further prospective studies to advance understanding of the relationship between lifestyle and obesity in the country.

Yimer et al. carried out a cross-sectional quantitative study among urban bank employees from Ethiopia (Dessie) to explore the determinants of abdominal obesity. As expected, the mean waist circumference among this group was high, with more than half having central obesity. Being older and married, consuming discretionary calorie, and presenting lower metabolic equivalence task hours (as a proxy of physical activity) were the significant factors of waist circumference. From these interesting findings, the authors suggested a promotion of healthy activities such as leisure-time physical activity and lower discretionary calorie intake in this at-risk subgroup. The last contribution in the Democratic Republic of Congo (DRC), conducted by Wakilongo et al., was a rural-urban cross-sectional study among adult women focusing quantitatively on the determinants of overweight and obesity. A binomial logistic regressions highlighted that overweight-obesity has a significant positive correlation with: duration of urban residence, socio-economic status (SES) and valorisation of stoutness. In addition, a pathway analysis based on a structural equation model, showed that urban residence and SES were associated with an increase in overweight-obesity, with a positive correlation with processed food consumption and a negative correlation with physical activity. Age was associated with an increase in overweight-obesity through a negative association with physical activity, whereas stoutness valorisation directly increased overweight-obesity. The conclusions advised that the DRC public authorities should consider how socio-demographic and socio-ecological factors contribute jointly to the rising prevalence of overweight-obesity in the country.

These fruitful, diverse and complementary contributions made this Research Topic: "*Holistic Approaches to Understanding Obesity and Metabolic Diseases in Urban Environments*" innovative and relevant to explore worldwide, through various indicators, overweight, obesity, ORCDs and its determinants. Health nutrition related behaviors (e.g., sedentary behaviors and energy dense food) were pointed out as major factors of the obesity pandemic within the globalized urban transition. Several at-risk subgroups were also identified to be overexposed to this public health issue, especially elders, women and ethnic minorities. The Research Topic also highlighted the necessity to concentrate the efforts on LMICs where the incidence rates of obesity are the highest while public health infrastructures to deal with this phenomenon are often insufficient. The critical aspect to be considered in LMICs is the promotion and the development of nutritional education programs to prevent and/or reduce the rising obesity pandemic, while the social exclusion of minorities in high income countries must be addressed to fight against this persisting burden in this region of the world. In all socio-ecological contexts, the intervention programs shall adopt a holistic approach of the determinants of obesity and ORCDs to obtain better results for their prevention and reduction.

## Author contributions

EC: Writing – original draft, Writing – review & editing. MD: Writing – original draft, Writing – review & editing.

## Conflict of interest

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# Prevalence and determinants of overweight or obesity among medical students over a 2-year observation

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**Introduction:** University students are a special population group characterized by changes in BMI values over the subsequent years of education, with an upward tendency to BMI. The presented study aims to evaluate the prevalence of overweight and obesity and their determinants in medical students during the 2-year follow-up observation.

**Materials and methods:** We analyzed data collected from the first follow-up of the cohort study named "POLLEK" conducted among medical students at the Medical University of Silesia in Katowice. Students were followed at two points of time: in their inaugural year of studies (the academic year 2021/2022, T1, $N = 427$), and subsequently in their second year (the academic year 2022/2023, T2, $N = 335$).

**Results:** In the initial year of evaluation, 371 individuals (86.9%) exhibited normal body weight, 47 (11.0%) were overweight, and 9 (2.1%) were classified as obese. Subsequent assessments during the second year revealed the following distribution: 277 students (84.2%) with normal body weight, 40 (12.2%) classified as overweight, and 12 (3.6%) identified as obese. In summary, regardless of the academic year, an increased risk of being overweight or obese was significantly associated with dissatisfaction with personal health, financial strain, and a diet abundant in animal products.

**Conclusion:** The results of our study confirmed an increase in the prevalence of overweight or obesity among medical students during the 2-year follow-up observation. Significant determinants of overweight or obesity among medical students were: dissatisfaction with individual health status, male sex, financial deficiencies, and a diet abundant in meat consumption.

KEYWORDS
overweight, obesity, public health policy, medical students, prospective study

## 1 Introduction

According to the World Health Organization (WHO) reports, more than 20% of people in the European region are obese. Obesity, diagnosed with a Body Mass Index (BMI) value above 29.9 kg/m$^2$, is recognized as the most dangerous chronic disease, which—untreated—could lead to hormonal disorders, type 2 diabetes, metabolic syndrome, development of cardiovascular diseases, and finally, increases the risk of cancers (1, 2). Numerous scientific studies show that university students are a special population group characterized by changes in BMI values over the subsequent years of education, with an upward tendency to BMI. There are many determinants in the academic life of freshman university students that can influence BMI changes in subsequent years of study, including eating habits, physical activity, alcohol consumption, and stress levels (3, 4). Changes in BMI observed among students over time may predispose to changes in the quality of life (QoL) of these students, both in the present and later years of their lives. Quality of life (QoL) is "an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards, and concerns" (5–7).

Medical students are a social group that should be characterized as sustaining possibly the highest quality of life to maintain motivation to learn. QoL assessment among medical students is used to identify the range of problems this group struggles with, which may affect their later professional life. QoL can be influenced by many factors, including stress level, eating habits, stimulant use, sleep, and weight disorders. Scientific researchers have found that chronic stress associated with medical studies promotes eating disorders and alcohol or drug abuse (8). Incorrect eating habits predispose to poor nutritional status. Researchers have observed a correlation between a high level of stress and nutritional status, assessed by anthropometric indicators such as Body Mass Index (BMI). BMI is a useful screening tool to evaluate nutritional status, which is an easy, non-invasive, cheap method of assessing body weight (9). Both overweight and undernutrition among university students can have a significant impact on their academic quality of life, including concentration, sleep, memory, and physical and intellectual condition. Medical students' life patterns are somewhat different from university students of other facilities in the same age group. Following Carl Rogers' humanistic theory, people throughout their lives undergo a process of change correlated with self-development. Medical students' ability to learn and adapt to changes plays a key role in the process of creating their QoL (10, 11).

Overweight and obesity are increasing worldwide—in children, adolescents, and adults. World Health Organization's statistics predict that global obesity prevalence is going to reach 21% in women and about 18% in men by 2025. Excessive body weight is perceived as one of the most serious public health problems in Poland. University years have had a high influence on shaping adult habits, concerning everyday diet, physical activity, tobacco smoking, and alcohol drinking. Acquiring unhealthy lifestyle behaviors at an early stage of life may also result in a distorted body view. Therefore, it is very important to investigate body weight changes in students during their university education (12–15).

Early detection of weight disorders among students, especially medical students can be used to plan strategies to improve their future quality of life and prevent the occurrence of obesity-related chronic diseases in the future.

Considering the above, the presented study aims to evaluate the prevalence of overweight and obesity and their determinants in medical students during the 2-year follow-up observation.

Abbreviations: QoL, Quality of Life; POLLEK, Polski Lekarz; ID, Anonymous identifier; BMI, Body mass index; WHO, World Health Organization; AUDIT, Alcohol Use Disorder Identification Test.

# 2 Materials and methods

## 2.1 Study design

The data presented in this paper was collected in a follow-up cohort study called POLLEK (POLski LEKarz), undertaken among medical students at the Medical University of Silesia in Katowice. Our earlier primary papers have delved into analyses concerning their quality of life, general health levels, and patterns of alcohol consumption, encompassing even the period of the COVID-19 pandemic (13, 16, 17). We have included all students in the study who entered the medical school in the academic year 2021/2022. The questionnaire surveys were conducted at two distinct time points, initially during their inaugural year of studies (the academic year 2021/2022), and subsequently during their second year (the academic year 2022/2023). The total number of participants during the initial period was 427, reflecting an 83.7% response rate. In contrast, during the subsequent period, the participant count was slightly lower at 335, maintaining a consistent response rate of 83.8%. During the observation period, the dropout rate was determined at 21.5%, primarily attributed to students withdrawing from studies ($n = 87$) or failing to attend on the measurement day ($n = 5$). Data collection was facilitated through paper-form questionnaires, with written informed consent obtained from all participants. Each participant was assigned a unique, anonymous identifier (ID), which was also included on the distributed paper forms. This implementation of IDs aimed to facilitate follow-up procedures in subsequent phases of the study while ensuring complete anonymity. The study received approval from the Bioethics Committee of the Medical University of Silesia in Katowice (approval number KNW/0022/KB/217/19; dated 8 November 2019).

## 2.2 Measures

The POLLEK questionnaire encompassed a set of questions, including assessments related to Quality of Life (QoL), the incidence of hazardous alcohol consumption, sociodemographic factors (such as sex, age, current financial status, and residence during medical studies), lifestyle indicators (including current usage of traditional or electronic cigarettes, and frequency of physical activity), as well as health-related variables (self-reported health status, presence of chronic illnesses, measurements of body weight and height for BMI calculation, and systolic and diastolic blood pressure indices). Measurements of systolic (SBP) and diastolic (DBP) blood pressure were conducted after a min. of 5-min rest in the sitting position. The cuffs of the blood pressure monitors were adapted to the dimensions of the arm. Body weight and height measurements were carried out during the whole study period using the same validated device (Body Composition Analyzer Model: ioi 353 manufactured zby Jawon Medical Co., Ltd.), and under the supervision of a research team member.

To identify the overweight and obesity among study participants, the criteria of the World Health Organization (WHO) have been used, which are as follows:

- overweight as a BMI greater than or equal to 25; and
- obesity as a BMI greater than or equal to 30 (18).

Then, for statistical analysis, two categories of blood pressure were established:

- normal: systolic less than 120 mm Hg; diastolic less than 80 mm Hg (19); and
- high: systolic greater than or equal to 120 mm Hg; diastolic systolic greater than or equal to 80 mm Hg.

Quality of Life (QoL) was assessed across four domains (physical health, psychological, social relationships, and environmental domain) using the WHOQOL-BREF questionnaire (20), validated in Polish. Respondents rated aspects of their QoL as satisfactory or not, transformed into a 0–100 scale per WHO guidelines. Approval for using the questionnaire in the POLLEK study was obtained from WHO.

The prevalence of hazardous alcohol consumption among medical students was evaluated using a Polish version of the AUDIT questionnaire, developed by WHO in 1989. This 10-item tool screens for excessive alcohol consumption, covering recent use, dependence symptoms, and related issues. Each item scores from 0 to 4, with a maximum of 40 points. Hazardous drinking was identified with a score of ≥8 points (13).

## 2.3 Dietary assessment

Students' dietary habits were evaluated by using a qualitative assessment method developed by Starzyńska. The questionnaire contains six items identifying the number of meals per during the day planned in the menu (4–5, 3, less than 3), and frequency of consumption of individual nutrients such as Nowicki et al. (21) and Mazurek-Kusiak et al. (22):

- the number of meals with animal protein (in all meals vs. 75% of meals vs. fewer meals),
- frequency of milk or cheese consumption (daily in at least two meals, as opposed to daily in at least one meal and 50% of days in two meals vs. less often);
- frequency of vegetables or fruits (daily in at least three meals, as opposed to daily in at least two meals vs. less often);
- frequency of raw vegetables or fruits (daily vs. 75% of meals vs. less often); and
- frequency of wholemeal bread, groats, and dry leguminous vegetable consumption (daily at least in one meal, in 75% of meals, or at least one of the products mentioned, less often).

In each question, the respondents could receive 5 points, 3 points, or 0 points resulting in a possible score range between 0 and 30 points. The total points represent the dietary assessment within the categories such as a good diet with 30 points when eating well; adequate diet with 21–28 points when eating adequately; almost adequate diet with 12–20 points but without 0 scores; 11 points and below was characterized as poor diet (21).

## 2.4 Statistical analysis

The qualitative variables were presented by the number of observations and frequency. The quantitative variables were described as mean values and standard deviations. Due to the Shapiro–Wilk test results, all statistical procedures have been performed using nonparametric analyses. Consequently, a Spearman correlation has been used to assess the relationship between quantitative variables. Moreover, the Wilcoxon signed-rank test for paired quantitative variables was adopted to assess differences between both years of observation. Additionally, McNemar's test has been used to assess the same differences in paired nominal data. Differences between groups specified in T1 and T2 were tested by the U-Mann Whitney test for the continuous variables and the chi-squared test for categorical variables. Finally, odds ratio values have been calculated to estimate the relationship between categorial dependent and explanatory variables. The level of statistical significance in all analyses was considered at $p$ values below 0.05. All statistical analyses were undertaken using the Statistica 13.3 package (TIBCO Software Inc., Palo Alto, CA, United States).

# 3 Results

The presented study involved 289 female and 138 male first-year students (67.7 and 32.2% of the study group respectively). In the second year, the study was continued among 226 female (67.5%) and 109 male students (37.5%). The comparison of medical students in their first and second years of observation regarding selected quantitative variables is presented in Table 1. In terms of BMI calculation, a significant increase in score has been identified during the second year of observation. Additionally, it should be noted that values indicating systolic and diastolic pressure have also increased during the same period. Simultaneously, the QoL scores of students decreased in their second year of studies in the somatic and psychological domains.

**TABLE 1** The comparison of medical students in their first and second years of observation concerning selected quantitative variables.

| Variable | The first year of observation ($N$ = 427) | | The second year of observation ($N$ = 335) | | $p$ -value |
|---|---|---|---|---|---|
| | M | SD | M | SD | |
| Age | 19.96 | 1.76 | 20.80 | 1.57 | <0.001 |
| Weight | 64.16 | 13.53 | 65.32 | 14.35 | <0.001 |
| Height | 172 | 10.0 | 171 | 10.0 | <0.001 |
| BMI | 21.64 | 3.26 | 22.11 | 4.12 | <0.001 |
| Systolic blood pressure | 114.44 | 12.32 | 117.59 | 11.79 | <0.001 |
| Diastolic blood pressure | 72.41 | 8.47 | 76.11 | 11.17 | <0.001 |
| QoL somatic domain | 62.82 | 15.15 | 44.96 | 12.25 | <0.001 |
| QoL psychological domain | 62.23 | 16.80 | 49.9 | 12.0 | <0.001 |
| QoL social relationship domain | 69.51 | 18.57 | 69.34 | 19.15 | 0.379 |
| QoL environmental domain | 64.35 | 12.57 | 66.18 | 13.59 | 0.001 |
| AUDIT score | 6.06 | 4.49 | 6.03 | 4.11 | 0.621 |

M, Mean; SD, Standard deviation; QoL, Quality of life; $p$, Statistical significance.

Table 2 shows results of dietary habits assessment in medical students, in both years of observation. It has been observed that the proportion of students who declared a poor dietary assessment was relatively higher during the second year of an investigation (37.2 vs. 32.9% in the first year). Conversely, the percentages of students categorized as having almost adequate or adequate/good dietary assessments were slightly lower in the second year compared to the first.

In the next stage, descriptive statistics have been provided for the selected qualitative variables across both observation periods, with differences being verified through statistical significance tests (Table 3). Notably, students examined during the second year of observation exhibited a significantly higher frequency of living outside the family home compared to the first year ($p = 0.016$). Moreover, they declared significantly lower rates of current tobacco smoking (<0.001). Concurrently, a higher incidence of chronic disease diagnosis was observed ($p = 0.014$), alongside a decreased consumption of wholemeal bread, groats, and dry leguminous vegetables in their daily diet ($p = 0.008$).

Then, the differences between BMI, and blood pressure values in the groups of students were defined by selected qualitative variables identifying elements of lifestyle, dietary behaviors, or financial situation across both years of observation (Table 4). In the initial year of medical university, significantly higher BMI values concerned students declaring a worse financial situation ($p = 0.034$) and those indicating a worse health status ($p = 0.042$). However, these discrepancies dissipated by the second year. On the other hand, during the second year, significantly higher BMI values were linked to students who did not or rarely engaged in physical activity ($p = 0.046$) and consumed more fruit and vegetables in their daily diet ($p = 0.048$). Furthermore, it is noteworthy that consistently higher BMI values were evident among students consuming animal protein daily, compared to those who consumed it less frequently, and this observation persisted throughout both years of the study.

Regarding systolic blood pressure values, it was consistently noted that the average value was higher among students who consumed animal protein in the majority of their meals daily, with statistical significance observed in both years ($p < 0.001$ and $p = 0.086$, respectively). Additionally, there was a trend toward elevated systolic blood pressure among students reporting lower quality of life and decreased satisfaction with their health during the initial year of study, as well as those exhibiting higher alcohol consumption and reduced physical activity levels in the second year of studies.

Conversely, significantly elevated diastolic blood pressure values were observed among students who frequently consumed meals rich in animal protein during the first year of the study ($p = 0.048$). Furthermore, during the following year of observation, higher diastolic blood pressure was associated with students reporting satisfaction with their health ($p = 0.024$) and engaging in regular physical activity ($p = 0.051$).

Ultimately, higher BMI values were significantly correlated with increased systolic blood pressure values across the entire observation period, with $R = 0.37$ ($p < 0.001$) in the first year and $R = 0.33$ ($p < 0.001$) in the second year of the study. A similar relationship was documented for diastolic blood pressure, although obtained values of Spearman correlation coefficient were lower, $R = 0.19$ ($p < 0.001$) and $R = 0.27$ ($p < 0.001$), respectively in the first and second year of observation.

Table 5 presents the prevalence of overweight and obesity in both years of observation including selected explanatory variables. In the initial year of evaluation, 371 individuals (86.9%) exhibited

**TABLE 2** Percentage and number of medical students in particular dietary habits assessment group in the first and second years of observation according to obtained scoring in Starzyńska questionnaire.

| Year of observation | Dietary assessment | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Poor diet | | Almost adequate diet | | Adequate/Good diet | | Missing data | |
| | *N* | % | *N* | % | *N* | % | *N* | % |
| First ($N = 427$) | 139 | 32.6 | 212 | 49.6 | 71 | 16.6 | 5 | 1.2 |
| Second ($N = 335$) | 124 | 37.0 | 159 | 47.5 | 50 | 14.9 | 2 | 0.6 |

**TABLE 3** Differences in the number and the percentage across categories defined by selected explanatory variables—data for both observational years.

| Variable | | T1 | | T2 | | *p*-value |
|---|---|---|---|---|---|---|
| | | *N* | % | *N* | % | |
| Current place of residence during studies at university | Family home | 124 | 29.0 | 87 | 26.0 | 0.016 |
| | Dormitory/rented flat or room | 303 | 71.0 | 247 | 74.0 | |
| Current cigarette smoking (traditional or electronic) | Never or in the past, not now | 358 | 84.1 | 296 | 88.6 | <0.001 |
| | Yes, still | 68 | 15.9 | 38 | 11.4 | |
| Ever diagnosed with chronic disease | Yes | 101 | 23.8 | 95 | 28.4 | 0.014 |
| | No | 324 | 76.2 | 240 | 71.6 | |
| Frequency of wholemeal bread, groats, and dry leguminous vegetables consumption | Daily at least in one meal, at least 75% of meals | 273 | 64.1 | 187 | 55.8 | 0.008 |
| | Less often | 153 | 35.9 | 148 | 44.2 | |

N, Number; *p*, statistical significance; T1, The first year of study; T2, The second year of study.

TABLE 4 Differences in BMI and blood pressure values in the groups were defined by selected qualitative variables identifying elements of lifestyle, dietary behaviors, or financial situation in both years of observation.

| Explanatory variable | | BMI | | | | | |
|---|---|---|---|---|---|---|---|
| | | T1 | | *p*-value | T2 | | *p*-value |
| | | M | SD | | M | SD | |
| Current financial situation | Average or poor | 22.3 | 3.7 | 0.034 | 22.4 | 4.3 | 0.230 |
| | Good or very good | 21.4 | 4.0 | | 22.0 | 3.7 | |
| Frequency of physical activity | Yes, regularly or less often | 21.5 | 3.1 | 0.374 | 21.6 | 5.3 | 0.046 |
| | Not at all | 22.1 | 3.9 | | 22.2 | 3.7 | |
| Current health status | Average or poor | 22.1 | 2.9 | 0.042 | 22.2 | 4.0 | 0.679 |
| | Good or very good | 21.3 | 3.6 | | 20.0 | 4.2 | |
| Number of meals containing animal protein | In all meals, at least 75% of meals | 22.1 | 3.4 | <0.001 | 22.8 | 4.5 | <0.001 |
| | Fewer meals | 20.9 | 2.8 | | 21.1 | 3.2 | |
| Frequency of vegetable or fruit consumption | Daily in at least twice a day | 21.5 | 3.1 | 0.264 | 22.3 | 3.7 | 0.048 |
| | Less often | 21.9 | 3.6 | | 21.8 | 4.8 | |
| **Explanatory variable** | | **Systolic blood pressure** | | | | | |
| | | **T1** | | ***p*-value** | **T2** | | ***p*-value** |
| | | **M** | **SD** | | **M** | **SD** | |
| Declared quality of life | Average or poor | 112.5 | 11.3 | 0.068 | 116.6 | 13.6 | 0.552 |
| | Good or very good | 115.1 | 12.6 | | 117.7 | 11.0 | |
| Satisfaction of health status | Yes, satisfied | 112.1 | 11.7 | 0.099 | 116.0 | 12.8 | 0.444 |
| | Average or dissatisfied | 115.2 | 12.6 | | 118.2 | 11.1 | |
| Frequency of alcohol consumption | Never or rarely | 114.4 | 12.3 | 0.961 | 116.9 | 12.1 | 0.085 |
| | More often than 2–4 times a week | 114.5 | 12.4 | | 122.8 | 7.5 | |
| Frequency of physical activity | Yes, regularly or less often | 113.7 | 13.6 | 0.641 | 116.5 | 12.5 | 0.062 |
| | Not at all | 114.6 | 12.0 | | 121.2 | 8.2 | |
| Current health status | Average or poor | 113.8 | 12.1 | 0.353 | 115.1 | 13.1 | 0.056 |
| | Good or very good | 114.9 | 12.5 | | 119.1 | 10.7 | |
| Number of meals containing animal protein | In all meals, at least 75% of meals | 116.9 | 12.8 | <0.001 | 119.3 | 10.7 | 0.086 |
| | Fewer meals | 111.2 | 10.9 | | 115.5 | 12.8 | |
| Frequency of wholemeal bread, groats, and dry leguminous vegetables consumption | Daily at least in 1 meal, at least 75% of meals | 113.6 | 12.1 | 0.097 | 117.2 | 12.8 | 0.907 |
| | Less often | 115.9 | 12.7 | | 118.1 | 10.3 | |
| **Explanatory variable** | | **Diastolic blood pressure** | | | | | |
| | | **T1** | | ***p*-value** | **T2** | | ***p*-value** |
| | | **M** | **SD** | | **M** | **SD** | |
| Satisfaction of health status | Yes, satisfied | 72.7 | 8.3 | 0.117 | 77.7 | 12.9 | 0.024 |
| | Average or dissatisfied | 71.8 | 8.8 | | 72.6 | 9.7 | |
| Frequency of physical activity | Yes, regularly or less often | 72.3 | 8.4 | 0.845 | 75.4 | 12.2 | 0.051 |
| | Not at all | 73.0 | 9.0 | | 78.2 | 6.4 | |
| Number of meals containing animal protein | In all meals, at least 75% of meals | 73.0 | 8.7 | 0.048 | 76.6 | 12.3 | 0.497 |
| | Fewer meals | 71.6 | 8.0 | | 75.5 | 9.7 | |
| Frequency of vegetable or fruit consumption | Daily in at least twice a day | 72.9 | 8.1 | 0.057 | 76.8 | 9.7 | 0.391 |
| | Less often | 72.1 | 8.5 | | 74.7 | 13.7 | |

M, Mean; SD, Standard deviation; *p*, Statistical significance; T1, The first year of study; T2, The second year of study.

TABLE 5 The number and percentage of overweight or obese students in both observation years.

| Explanatory variable | | T1 (*N* = 427) | | T2 (*N* = 329) | |
|---|---|---|---|---|---|
| | | Overweight or obesity *N* = 56 (13.1%) | *p*-value | Overweight or obesity *N* = 52 (15.8%) | *p*-value |
| Sex | Male (*N*1 = 138; *N*2 = 108) | 30 (21.7%) | <0.001 | 30 (27.8%) | <0.001 |
| | Female (*N*1 = 289; *N*2 = 221) | 26 (9.0%) | | 22 (9.9%) | |
| Declared quality of life | Average or poor (*N*1 = 117; *N*2 = 89) | 18 (15.4%) | 0.393 | 17 (19.1%) | 0.318 |
| | Good or very good (*N*1 = 310; *N*2 = 240) | 38 (12.3%) | | 35 (14.5%) | |
| Satisfaction of health status | Yes, satisfied (*N*1 = 146; *N*2 = 118) | 28 (9.9%) | 0.007 | 17 (14.4%) | 0.566 |
| | Average or dissatisfied (*N*1 = 281; *N*2 = 208) | 28 (19.2%) | | 35 (16.8%) | |
| Frequency of alcohol consumption | Never or rarely (*N*1 = 175; *N*2 = 298) | 25 (14.3%) | 0.560 | 48 (16.1%) | 0.641 |
| | More often than 2–4 times a week (*N*1 = 251; *N*2 = 31) | 31 (12.3%) | | 4 (12.9%) | |
| Current financial situation | Average or poor (*N*1 = 115; *N*2 = 87) | 24 (20.9%) | 0.003 | 20 (23.0%) | 0.033 |
| | Good or very good (*N*1 = 312; *N*2 = 241) | 32 (10.3%) | | 32 (13.3%) | |
| Current place of residence during studies at university | Family home (*N*1 = 124; *N*2 = 85) | 17 (13.7%) | 0.815 | 13 (15.3%) | 0.869 |
| | Dormitory/rented flat or room (*N*1 = 303; *N*2 = 243) | 39 (12.9%) | | 39 (16.0%) | |
| Current cigarette smoking (traditional or electronic) | Never or in the past, not now (*N*1 = 358; *N*2 = 37) | 45 (12.6%) | 0.419 | 10 (27.0%) | 0.048 |
| | Yes, still (*N*1 = 68; *N*2 = 291) | 11 (16.2%) | | 42 (14.4%) | |
| Frequency of physical activity | Yes, regularly or less often (*N*1 = 347; *N*2 = 260) | 41 (11.8%) | 0.088 | 42 (16.1%) | 0.554 |
| | Not at all (*N*1 = 79; *N*2 = 68) | 15 (18.9%) | | 9 (13.2%) | |
| Current health status | Average or poor (*N*1 = 175; *N*2 = 129) | 35 (20%) | <0.001 | 25 (19.4%) | 0.153 |
| | Good or very good (*N*1 = 251; *N*2 = 200) | 21 (8.4%) | | 27 (13.5%) | |
| Ever diagnosed with chronic disease | Yes (*N*1 = 101; *N*2 = 93) | 19 (18.8%) | 0.044 | 17 (18.3%) | 0.439 |
| | No (*N*1 = 324; *N*2 = 236) | 36 (11.1%) | | 35 (14.8%) | |
| Number of meals per day | At least 3 a day (*N*1 = 378; *N*2 = 285) | 47 (12.4%) | 0.247 | 44 (15.4%) | 0.596 |
| | Less than 3 (*N*1 = 49; *N*2 = 43) | 9 (18.4%) | | 8 (18.6%) | |
| Number of meals containing animal protein | In all meals, at least 75% of meals (*N*1 = 244; *N*2 = 191) | 42 (17.2%) | 0.003 | 40 (20.9%) | 0.002 |
| | Fewer meals (*N*1 = 183; *N*2 = 138) | 14 (7.6%) | | 12 (8.7%) | |
| Frequency of milk or cheese consumption | Daily in at least once a day (*N*1 = 271; *N*2 = 215) | 36 (13.3%) | 0.930 | 38 (17.7%) | 0.201 |
| | Less often (*N*1 = 154; *N*2 = 114) | 20 (13.0%) | | 14 (12.3%) | |
| Frequency of vegetables or fruit consumption | Daily in at least twice a day (*N*1 = 283; *N*2 = 220) | 32 (11.3%) | 0.107 | 35 (15.9%) | 0.941 |
| | Less often (*N*1 = 142; *N*2 = 109) | 24 (16.9%) | | 17 (15.6%) | |
| Frequency of raw vegetables or fruit consumption | Daily, at least 75% of meals (*N*1 = 193; *N*2 = 137) | 24 (12.4%) | 0.705 | 22 (16.1%) | 0.931 |
| | Less often (*N*1 = 234; *N*2 = 191) | 32 (13.7%) | | 30 (15.7%) | |
| Frequency of wholemeal bread, groats, and dry leguminous vegetables consumption | Daily at least in one meal, at least 75% of meals (*N*1 = 273; *N*2 = 185) | 32 (11.7%) | 0.245 | 26 (14.0%) | 0.323 |
| | Less often (*N*1 = 153; *N*2 = 144) | 24 (15.7%) | | 26 (18.1%) | |

*N*, Number; *N*1, Number in the first year of study; *N*2, Number in the second year of study; *p*, Statistical significance; T1, The first year of study; T2, The second year of study.

normal body weight, 47 (11.0%) were overweight, and 9 (2.1%) were classified as obese. Subsequent assessments during the second year revealed the following distribution: 277 students (84.2%) with normal body weight, 40 (12.2%) classified as overweight, and 12 (3.6%) identified as obese. For 6 individuals at T2, missing data made it impossible to assess overweight and obesity. The calculated odds ratios highlight a significantly heightened incidence of overweight or obesity among first-year students who reported: male sex (OR = 2.809; 95% CI: 1.587–4.973); dissatisfaction with their health (OR = 2.145; 95% CI: 1.215–3.787); worse financial situation (OR = 2.307; 95% CI: 1.292–4.120); deteriorating health condition (OR = 2.738; 95% CI: 1.532–4.892); diagnosis of a chronic illness by a physician (OR = 1.855; 95% CI: 1.010–3.412); and consumption of animal protein-rich foods in at least 75% of daily meals (OR = 2.512; 95% CI: 1.326–4.761). Within the same cohort during their second year of study, a significantly elevated occurrence of overweight or obesity was associated with male sex (OR = 3.479; 95% CI: 1.891–6.398); dissatisfaction with health status (OR = 2.057; 95% CI: 1.128–3.759); worse financial situation (OR = 1.949; 95% CI: 1.045–3.634); and current cigarette smoking (OR = 2.197; 95% CI: 0.908–4.878), although this result lacks statistical significance; regular consumption of animal protein-rich foods (OR = 2.785; 95% CI: 1.400–5.555). In summary, regardless of the academic year, variables significantly associated with an increased risk of being overweight or obese include dissatisfaction with personal health, financial strain, and a diet abundant in animal products.

## 4 Discussion

The main objective of our study was to evaluate the prevalence of overweight and obesity among medical students taking into account changes during a 2-year observation period and their selected determinants. Data for the general population demonstrated nearly 60% of adults in the WHO European Region are burdened with overweight or obesity, while almost one in three children contend with the same issue. Obesity represents a complex health problem, manifested in various determinants and consequences (23). The obtained results of our study revealed that 56 students (13.10%) in the first year of medical university were overweight or obese, and 52 (15.8%) in the second. Regardless of the academic year, the increased risk of being overweight or obese was significantly associated with dissatisfaction with individual health status, male sex, financial deficiencies, and a diet abundant in meat consumption. Studies conducted among student populations highlight geographic and cultural variations in the prevalence of obesity and overweight. For instance, research conducted among medical and healthcare faculties in Saudi Arabia and the United Arab Emirates revealed that 34.7–41.5% of participants were classified as overweight or obese (24–26), with 22.1% falling into the same category in Syria's population of medical students (27). Furthermore, a study conducted among the extensive population of Western Balkans medical students indicated the prevalence of overweight was 12% and obesity was 2.3% (28). The findings obtained in the cited study are in line with our observations. Additionally, the results from the referenced studies confirmed that the male sex was a positive predictor of overweight and obesity, with current smoking status emerging as an additional significant factor.

In most cases, the reports regarding the prevalence of overweight and obesity among medical students are elaborated on a cross-sectional research approach. In contrast, our study allows us to identify the changes in these health concerns over time. The education phase of university students is considered a time when a young person has an opportunity to test himself in an independent life, and thus make his own choices and bear their consequences, which directly impact the quality of life. Medical studies, due to the high level and amount of knowledge to be acquired in a short time, often require students to focus mainly on education at the expense of chronic stress, lack of activity, reaching for stimulants such as alcohol or cigarettes, and incorrect eating habits. Co-occurrence of these factors may influence the prevalence of weight disorders leading to overweight or obesity during studies and adult life. BMI is a useful anthropometric indicator for screening assessment of body composition as well as nutritional status. In terms of BMI calculation, in our study, a significant increase in score has been identified during the second year of observation. In a prospective observational Deliens et al. study, concerning changes in body weight and body composition across 5 years at university, an increase in both BMI and body fat was found in approximately 70% of students, with a statistically significantly higher increase in men than in women, in contrary to the results of own study. What is more, the highest increase in BMI and fat occurred during the first semester and in the last year of studies (29). Similar results were obtained in a 3-year study of health faculty students, which showed an average weight gain of 1.6 kg in men. The reason for these results could be found in a statistically significant increase in diet energy intake and a decrease in physical activity in students after the first year of their studies (3). In our study, higher BMI was observed in medical students who consumed animal protein in their everyday diet, which can be explained by the higher content of high-calorie saturated fats in their meals. Moreover, throughout the entire observation period, a relationship has been observed between higher BMI levels and increased consumption of a diet abundant in meat products. Interestingly, the assessment of dietary patterns as poor and the percentage of daily meat consumption was slightly higher in the second year of the study compared to the first. Additionally, in the second year of observation, a significant proportion of male participants and students reporting a poor financial situation were identified among those who were overweight or obese, contrasting with the previous year. We hypothesize that the heightened prevalence of these factors in the second year of observation may have contributed to an increased prevalence of overweight and obesity over the 2 years. Available published data also describes the relationship between overweight and obesity, and emotional eating. For instance, factors such as prolonged psychological distress, anxiety, or depression may provoke unhealthy dietary patterns and are matched with an increase in body weight (30). While not directly addressed in our study, it is plausible that emotional eating contributes to the increased frequency of overweight and obesity observed in the second year of our study.

However, underweight and obesity are considered age-related issues as well. Scientific research indicates that progressive mitochondrial dysfunction plays a key role in the development of overweight and obesity. The reasons for the dynamic impairment of mitochondrial function in young people can be found in an unhealthy diet, rich in processed products that are a source of saturated fatty acids and salt. Medical students in the second year of the study more often than in the first year declared that their diet was insufficient ("poor diet assessment"). They also admitted that they less often consumed wholemeal bread, groats, and dry leguminous vegetables in their daily diet, unlike alcohol consumption. The aging of the body is associated with a physiological slowdown of metabolism and, consequently, an increase in abdominal obesity. Both, early mitochondrial dysfunction and adipocyte hyperplasia, which also leads to metabolic dysregulation and may be caused by an incorrect lifestyle in students, support the physiological process of slowing down the metabolism. It may clarify higher BMI values in students in the second year of our study in comparison to the first year (31–33).

Traditional or electronic cigarette smoking is a high-powered addiction. People start to experiment with smoking in late childhood or adolescence and they continue smoking while studying. Some research showed that cigarette smoking could decrease blood pressure

(BP), as a result of a temporary reduction in the smoker's stress level. Medical students are the future authorities in the field of health care and for this reason, society expects, they should lead a healthy lifestyle. The presented study reported that 16% of examined students used to smoke during the first year of observation and the number of smokers decreased to 11% in the second year of observation. Students who smoked cigarettes represented lower systolic blood pressure values than non-smokers in both, the first and second years of observation. On the other hand, the study demonstrated a statistically significant positive correlation between BMI and both, systolic and diastolic blood pressure values in the examined group of students. Some studies indicate cardiometabolic disorders in supposedly healthy nonobese young people, which could be caused by chronic cigarette smoking, alcohol consumption, and poor dietary habits (34–36).

In conclusion, the determinants of overweight and obesity are complex and difficult to explain unequivocally. The factors contributing to overweight and obesity among medical students may be similar to those affecting the general population but can also include issues specific to this group. On the one hand, a study conducted among a large group of fourth-year medical students identified the primary causes of overweight and obesity as physical inactivity, overeating, marketing of unhealthy food, poor nutritional knowledge, psychological problems, genetic factors, and metabolic defects such as endocrine disorders (37). Additionally, students' irregular schedules and daily lifestyles can make it challenging to maintain a healthy diet. Notably, the consumption of sweet beverages is relatively high among students, which is associated with an increased risk of obesity (38). A common factor among students is certain overall unhealthy lifestyle behaviors that coexist and interact, thereby increasing the risk of overweight and obesity in this population (39).

### 4.1 Strengths and limitations

According to the Supreme Audit Office's recent report, 24% of adults in Poland are obese and most of the people with excessive body weight were recorded in the Silesian Voivodeship—69.2% of the population (40). Our findings indicate that the prevalence of overweight or obesity among medical students aligns more closely with data from the European Balkan region than with that of Arab countries, in terms of both geographical and cultural Background. The study we conducted addresses a timely and enduring topic of universal relevance. By adhering to strict inclusion criteria, we achieved a participation rate of over 80% among first- and second-year medical students, effectively encompassing nearly the entire available population and ensuring a representative sample. It is also one of the few studies that show the change or maintenance of determinants influencing the lifestyle, body weight, and nutritional status of young people over time because, in our study, medical students were surveyed twice in the 2-year interval. Our findings underscore the significance of early-life quality of life on the development of body weight disorders and associated health implications later in life. Specifically, we identify a relationship between unsatisfactory quality of life among students and the potential for future overweight or obesity-related health issues. The attention of local and university government authorities should be drawn to help students shape healthy attitudes also through systemic activities, such as nutritional education, access to nutritious food in campus canteens, and cooperation with dieticians. Moreover, among the solutions aimed at enhancing students' well-being, Mindfulness-Based Interventions (MBIs) have proven to be particularly effective (41). Programs that include meditation classes, dietary guidance, and brief yoga sessions have been shown to reduce overall distress significantly. Additionally, these interventions improve attention maintenance, resilience, mental well-being, and emotional regulation (42). In a broader context, early interventions that help medical students manage stress and develop healthy nutrition habits can include the continuous promotion of physical activity and sleep hygiene (43). An intriguing solution for medical students, as part of the younger population, could be the development and promotion of mobile apps and online platforms. These tools could offer resources on healthy eating, exercise routines, and mental health support.

The primary limitations of the study revolve around its relatively small sample size, which consists solely of students from the Medical University of Silesia in Katowice. However, it is worth noting the high participation rates observed during both data collection periods. Furthermore, the prospective nature of the study lends credibility to the significance of the findings presented. Furthermore, our ongoing prospective study of medical students includes plans for a third observation point (T3), which is scheduled to take place during their fourth year of studies.

## 5 Conclusion

1. The results of our study confirmed an increase in the prevalence of overweight or obesity among medical students during the 2-year follow-up observation.
2. Dissatisfaction with individual health status, male sex, financial deficiencies, and a diet abundant in meat consumption were significant determinants of overweight or obesity among medical students.
3. Our findings indicate the necessity for medical schools to actively encourage a healthy lifestyle within their curriculum and incorporate programs aimed at fostering positive behaviors among medical students.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The approval to use the WHOQOL-BREF questionnaire in the POLLEK study has been obtained from the World Health Organization (WHO). Written informed consent was obtained from all subjects involved in the study. The study was conducted with the approval of the Bioethics Committee of the Medical University of Silesia in Katowice (number KNW/0022/KB/217/19; date: 8 November 2019).

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## Author contributions

SS: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. IZ-Z: Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Conceptualization. ES: Writing – review & editing, Writing – original draft, Resources, Data curation. MK: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Biocultural determinants of overweight-obesity among adult women experiencing the nutritional transition in the Democratic Republic of Congo

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**Introduction:** The African Great Lakes region is experiencing rapid urbanization, which is leading to a nutritional transition and its related chronic diseases. Similar to other Great Lakes countries, the nutritional transition in the Democratic Republic of Congo (DRC) is reflected by increased non-communicable diseases, including morbid obesity. The 2014 Demographic Health Survey (DHS) revealed a rising incidence of overweight among women, ranging from 10% in 2001 to 16% in 2014. Furthermore, over 20% of individuals in several provinces of the DRC are classified as overweight-obese. This study aimed to investigate the prevalence as well as the main biocultural determinants of overweight-obesity among adult women in the DRC.

**Methods:** In a cross-sectional survey, including a representative sample of adult Congolese women living in the South Kivu province, participants were randomly recruited using a two-stage cluster sampling technique after an initial urban–rural stratification. The estimation of the was based on previous results from DHS. Thus, a total of 495 individuals were selected, including 325 urban and 170 rural subjects. Data were collected from households by dietitians who were specifically trained for this survey.

**Results:** In this study population, the prevalence of overweight-obesity was 33.6%, with 7.1% classified as obese. The prevalence of obesity was significantly higher among urban people, while all subjects with obesity were from the older age group (>35 years). Using binomial logistic regressions, it was observed that overweight-obesity had a significant positive correlation with the duration of urban residence, namely, **Migrants' status:** "New residents" 4.6 [1.9–11.7] $p < 0.003$, "Long term residents" 8.7 [3.5–21.5] $p < 0.001$; **Socio-economic status (SES):** "High" 2.4 [1.1–5.3] $p < 0.03$, and **Stoutness valorization:** "Yes" 6.1 [3.4–10.9] $p < 0.001$. In a pathway analysis conducted based on a structural equation model (SEM), we discovered that urban residence and SES were associated with an increase in overweight-obesity, with a positive correlation with processed food consumption and a negative correlation with physical activity. Age was associated with an increase in overweight-obesity through a negative association with physical activity, whereas stoutness valorization directly increased overweight-obesity.

**Discussion:** In order to properly guide public health policies, public authorities in the DRC should consider the main findings of this original study, which identify how socio-demographic and socio-ecological factors contribute jointly to the rising prevalence of overweight-obesity in the country.

KEYWORDS

**overweight-obesity, determinants, nutritional transition, women, Democratic Republic of Congo**

## 1 Introduction

Obesity is a risk factor for serious health problems (1), especially chronic diseases, which can highly impair the quality of life. However, the persistent rise in overweight-obesity rates is alarming worldwide. Adults' who are overweight or obese are defined by their body weight (kg) and height (m) squared ratio (body mass index, BMI), from which they are derived. In 1990, it was estimated that around 12% of the world's population was obese, with the rate reaching 20% in 2015, with a higher increase among women (2). In 2017, the World Health Organization (WHO) estimated that 1.9 billion adults worldwide were classified as overweight-obese, with 650 million of them being obese (2). By 2030, 1 billion people will be classified as obese, representing one in five women and one in seven men (3). Previously considered diseases of rich countries, overweight-obesity is now increasing in low-income countries. Indeed, they are currently undergoing a rapid urbanization process, characterized by increased access to energy-dense processed foods and motorized transports. This is favoring both overnutrition and sedentary behaviors that lead to an obesogenic nutritional transition (4, 5). During the last decades, the prevalence of obesity has increased significantly in Africa, from 5%—10% globally during the 1990s to a maximum of 30%—50% actually in some regions. The highest prevalence is in urban areas (6).

Few studies have been conducted on the rising obesogenic environment in the Democratic Republic of Congo (DRC) (7–9) in the context of nutritional transition. Some studies have reported an increasing incidence of cardiometabolic diseases (10, 11). Hence, the latest Demographic Health Survey (DHS) revealed that the proportion of women who have overweight, or women with overweight has increased from 10% in 2001 to 11% in 2007, and 16% in 2014, with over 20% of individuals in several provinces (Kinshasa, North Kivu, and South Kivu) exhibiting overweight-obesity (7, 12). A recent study conducted among adult women in Kinshasa in 2023 confirmed this trend, with an overweight-obesity prevalence of 32.7% (9). Musung et al. have also demonstrated a significantly higher mean BMI in adolescent girls from Lubumbashi compared to their male counterparts, with potential poor cardiometabolic consequences (8).

The rapid urbanization dynamic experienced by African countries leads to an obesogenic lifestyle, including jointly a higher energy-dense food accessibility (13, 14), increasing sedentary behaviors (5, 15), and a persisting sociocultural valorization of stoutness (6, 16). These biocultural risk factors are primarily responsible for an imbalance between energy intake and expenditure, leading to overweight-obesity and related chronic diseases. In the context of increasing urbanization, African cities attract rural populations looking for a potential better life, abundance, and comfort with more work opportunities and easier access to basic services (17). Therefore, urbanization, which represents the major environmental dimension of the nutritional transition, is shaped by multiple socio-demographic and socio-ecological factors (5), leading together to obesity and related diseases in Africa (18), especially among women (17, 19).

Bukavu, the capital city of the South Kivu province in the east of the DRC (20), is an illustrative example of the rapidly growing African cities due to the recent rural exodus and the massive displacement of populations (21). Furthermore, the rapid transformation of Bukavu is exacerbated by the social, political, and economic instability and the recurrent local wars taking place in the surrounding region (20, 21). Despite this rapid urban transition in South Kivu, little is known about the health impact of the intrinsic nutritional transition within this environmental dynamic urban transition (8, 9). In addition, a thorough investigation of the risk factors for overweight-obesity has never been conducted in this transitional country. Since previous research indicated that women are more susceptible to overweight-obesity than men, particularly during the initial nutritional transition stages (17, 19), this original rural–urban study conducted in South Kivu province aimed to focus on the biocultural determinants that contribute to overweight-obesity among adult women, who are in the first at-risk group to develop morbid obesity (14).

From March to June 2017, we conducted an innovative survey among adult women from Bukavu and its surrounding rural area (Katana area at the northeast of South Kivu province) in order to assess the prevalence of overweight-obesity and explore its main biocultural determinants (body image, physical activity, and dietary intake) in the context of the ongoing nutritional transition in the DRC.

## 2 Materials and methods

### 2.1. Study design and sampling

A sample size was established by considering 26.5% of the expected prevalence of overweight-obesity, 95 % of the confidence level, 3% of desired precision, and 5% of risk α. These statistical criteria were defined from the previous DHS conducted in the DRC in 2007 and 2014 (7, 12). This cross-sectional study was conducted using a multi-stage clustering sample (22), which was also used in the DHS of the DRC. To avoid potential dropout during the study, the sample size has been increased by 10%. To obtain a

TABLE 1 Socio-demographic characteristics of the study population according to living area.

| Characteristics | Overall $N = 495$ | Rural $N = 241$ | Urban $N = 254$ | p |
|---|---|---|---|---|
| **Age class** | | | | **0.048** |
| 18–25 years | 36.0% | 42.8% | 29.5% | |
| 26–35 years | 35.5% | 47.7% | 24.1% | |
| >35 years | 28.5% | 9.5% | 46.4% | |
| **Age (means)** | 30 ± 9 | 27 ± 7 | 33 ± 10 | 0.1 |
| **Migrant status** | | | | **<0.001** |
| Rural | 48.6% | 100.0% | _ | |
| New residents (<15 years) | 27.1% | _ | 52.6% | |
| Former residents (≥15 years) | 24.4% | _ | 47.4% | |
| **SES** | | | | **0.003** |
| Low | 23.8% | 21.6% | 25.9% | |
| Medium | 54.9% | 71.6% | 39.1% | |
| High | 21.3% | 6.8% | 35 % | |
| **SES score (means)** | −0.08 ± 0.87 | −0.34 ± 0.35 | 0.17 ± 1.1 | 0.2 |
| **Marital status** | | | | 0.5 |
| Not married | 24% | 22.2% | 25.7% | |
| Married | 76% | 77.8% | 74.3% | |
| **Ethnicity** | | | | 0.7 |
| Lega | 19.6% | 18.4% | 20.8% | |
| Shi | 80.4% | 81.6% | 79.2% | |

$p < 0.05$ in bold.

representative sample that encompasses the diversity of the study population in South Kivu province, the subjects' recruitment was based on the identification of the strata (i.e., rural–urban residence) and a two-stage random sampling of clusters within this strata. During stage 1, 30 representative neighborhoods in the urban and 20 representative villages in the rural areas were selected. In stage 2, the primary responsible mother in each household selected was recruited (<5% of all households). Finally, 495 participants (325 in urban and 170 in rural areas) with complete and reliable data were selected (Supplementary Figure S1). The rural–urban proportion of the sample and selected rural–urban areas were determined from provincial population registers in order to be representative of the target populations. These registers, which are used in population surveys such as DHS (7, 12), are based on regional censuses commissioned by the DRC government and constructed through rigorous and regionally representative sampling (7). Subjects were included in the study if they were: (i) female, (ii) at least 18 years old, (iii) not reportedly pregnant, (iv) and did not have a disability or any other chronic or infectious pathologies likely to affect corpulence. These last two exclusion criteria are particularly important for the anthropometric results.

## 2.2 Data collection

From March to June 2017, we conducted a quantitative survey using a global questionnaire comprising eight headings: identification of the study subjects, socio-demographic characteristics, socio-economic status (SES), migratory history, dietary intake, physical activity, body perception, and anthropometric measurements. WE used specific survey tools, from previously validated instruments (23–26), to administer questionnaires assessing SES, 24-h qualitative dietary intake, food frequency, physical activity, body weight perceptions, and an anthropometric measurement protocol. The survey was based on face-to-face interviews conducted within the household in a separate space, for confidentiality, by Congolese dieticians (in French or Swahili vernacular language when necessary) trained to administer the study protocol.

### 2.2.1 Socio-demographic characteristics

***Age*** was determined from an identity document or as reported by the participant and was classified into 3 categories: 18–25 years old; 26–35 years old; and >35 years old, based on the terciles of its distribution in the study population. ***Marital status*** was categorized into "married" and "unmarried (with divorce, single, widow, and mistress)." Parity was not collected because it is strongly correlated with age and is associated with marital status, particularly in the DRC, where motherhood is expected with age and marital life. ***Place of residence*** was categorized as "urban" for an urban residence for more than 1 year and "rural" for a shorter duration. This categorization allowed to balance the rural–urban stratification since our sample included urban dwellers for less than

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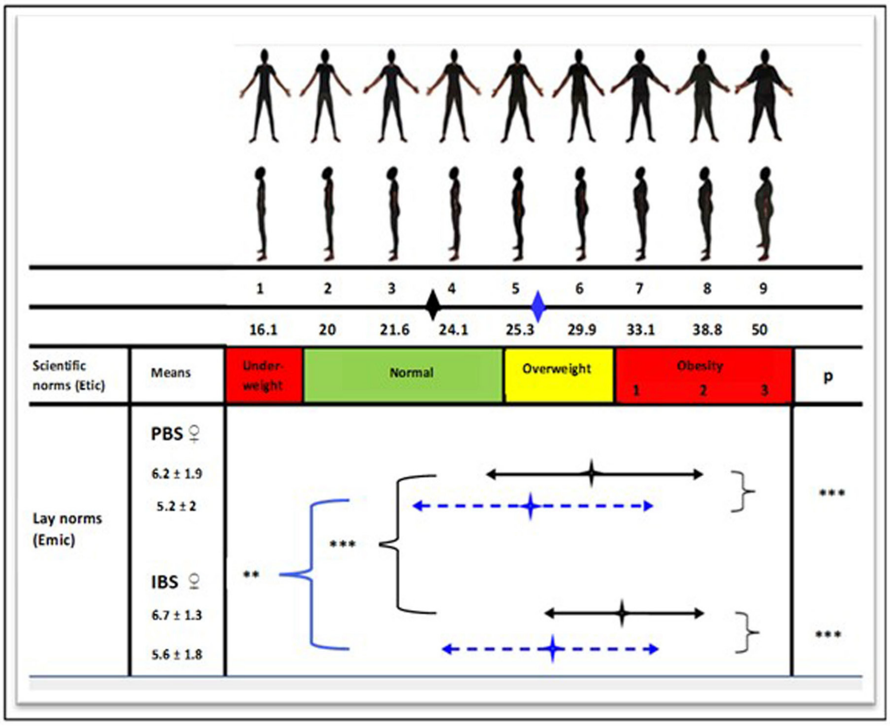


FIGURE 1
Perception of body image in women by area of residence. The marks in the middle of the two-way arrows correspond to the mean BMIs as perceived by women. The two-way arrows correspond to the standard deviation. The black and blue diamonds just below the body silhouettes indicate BMI averages for rural and urban populations, respectively. A *t*-test was performed between the two samples: ** $p < 0.01$; *** $p < 0.001$. , Rural area; , Urban area. PBS, Perceived body size; IBS, Ideal body size.

a year. The ***ethnicity*** of the participants primarily comprised two major ethnic groups in the DRC, namely *Shi* and *Lega* (27). ***Urban duration*** was calculated from the length of residence in an urban area and was classified as short duration if the duration was <15 years and long duration if the duration was ≥15 years. The ***SES*** was constructed from the goods owned by families, considered as a proxy of wealth through the first axis of a principal component analysis (PCA) summarizing the variability of household assets (44.5% of total inertia, Supplementary Figure S2), as described by Kombiané (23), and updated by Escofier and Pagès (28). Scores of SES status were categorized into terciles in order to define low, medium, and high SES levels. A Kaiser–Mayer–Olkin (KMO) index of 0.727 and a highly significant Bartlett test of sphericity ($p < 0.0001$) indicated both strong sampling adequacy and a correlation matrix.

## 2.2.2 Socio-ecological characteristics

### 2.2.2.1 Stoutness valorization

In order to accurately assess body weight perceptions and identify the social valorization of overweight-obesity, the Body Size Scale (BSS) was used. This validated tool presents real human photos of body size for both sexes, coded from 1 to 9, and covers the total BMI gradient from underweight to obesity (25). A body image assessment guide (BIAG) was created to compare body weight local norms with scientific norms measured with the BSS. The BIAG is composed of two questions on Perceived Body Size (PBS) and Ideal Body Size (IBS) for the participant and one's partner. The degree of stoutness valorization was determined by comparing the IBS score with a threshold established according to the silhouettes' BMI on the scale, as follows: no valorization of stoutness below the 5$^{th}$ silhouette (beginning of overweight on the BSS), and a valorization of stoutness above the 5$^{th}$ silhouette (15).

### 2.2.2.2 Physical activity

The International Physical Activity Questionnaire (IPA) was used to assess the level of physical activity (26). It calculates the equivalent metabolic task (MET/minutes) of each physical activity (intense, moderate, walking, and sedentary behaviors) according to its respective duration and number of practiced days per week. A score of physical activity, expressed in MET/minute/week, was calculated after considering all the activities declared by the participant during the last 7 days preceding the interview. This physical activity score was also categorized into three terciles: [0–0.8]; [0.9–2.2]; and [2.3–4.9] for low, medium, and high physical activity levels, respectively.

### 2.2.2.3 Dietary intake

#### 2.2.2.3.1 Dietary diversity score (DDS)

A qualitative 24-h dietary recall, developed by the Food and Agriculture Organization (FAO) (29), was used to assess the diversity of food groups consumed by participants. It captures the intake of 16 main food groups, including cereal, white roots

TABLE 2 Socio-ecological characteristics according to living area.

| Characteristics | Overall $N = 495$ | Rural $N = 241$ | Urban $N = 254$ | *p* |
|---|---|---|---|---|
| **Physical activity level** | | | | **<0.001** |
| Low | 69.4% | 45.5% | 92.1% | |
| High | 30.6% | 54.5% | 7.9% | |
| **Physical activity score (means)** | $1.2 \pm 1.1$ | $1.7 \pm 1.3$ | $0.7 \pm 0.6$ | **<0.001** |
| **Stoutness valorization** | | | | **<0.001** |
| No (≤4) | 27.7% | 18.2% | 36.7% | |
| Yes (>4) | 72.3% | 81.8% | 63.3% | |
| **Dietary Diversity Score (DDS)** | | | | 0.8 |
| Low (<7) | 38.7% | 39.9% | 37.5% | |
| High (≥7) | 61.3% | 60.1% | 62.5% | |
| **DDS (means)** | $6.9 \pm 1.7$ | $6.7 \pm 1.4$ | $7 \pm 1.8$ | 0.5 |
| **Processed food consumption** | | | | **<0.001** |
| Low | 83% | 97.8% | 69.1% | |
| High | 17% | 2.2% | 30.9% | |
| **Processed food score (means)** | $-0.2 \pm 0.9$ | $-0.9 \pm 0.7$ | $0.4 \pm 0.8$ | **<0.001** |
| **Traditional food consumption** | | | | **<0.001** |
| Low | 81% | 69% | 92.3% | |
| High | 19% | 31% | 7.7% | |
| **Traditional food score (means)** | $0.1 \pm 1$ | $0.4 \pm 1$ | $-0.3 \pm 0.9$ | **<0.001** |

$p < 0.05$ in bold.

and tubers, vitamin A-rich vegetables and tubers, dark green leafy vegetables, other vegetables, vitamin A-rich fruits, other fruits, organs, flesh meats, eggs, fish, legumes and nuts, milk and dairy products, oils and fats, sweets, and spices and beverages. Based on the median, dietary diversity was categorized as high diversity if the participant's dietary diversity score was at least 7, and low diversity if the score was lower than 7.

#### 2.2.2.3.2 Food consumption frequency

Using a culturally relevant food frequency questionnaire (FFQ) of 80 food items (including soft and alcoholic drinks) divided into 28 food groups (30), we collected information about the consumption frequency of each food item during the previous 7 days. The results from the seven-day FFQ were then analyzed using a PCA. Food intake was classified as "processed" vs. "traditional" from a specific anthropological literature of the DRC, which characterizes foods from historical culinary practices and processed foods from industrialization (31). Our PCA results, based on the foods having the highest contribution on the two first factors, revealed that the foods significantly associated (>0.3) with the first factor correspond to the "processed" food category, and the foods significantly associated (>0.3) with the second factor correspond to the "traditional" food category (32–34). Therefore, the two first factors were kept, representing, respectively, "processed foods" and "traditional foods" (Supplementary Figure S3, Supplementary Table S1). We used the KMO index (0.7) and the Bartlett's sphericity test ($p <$ 0.001) to confirm both the strength of sampling adequacy and the correlation matrix of the PCA. The food consumption frequency scores were then aggregated into deciles, with "High" coded by (+) and "Low" coded by (–) to carry out a multiple correspondence analysis (MCA) aiming to determine a dietary consumption pattern according to urban duration. Both D1 and D2 (32.1% total inertia) of the MCA synthesized the maximum amount of information to describe the food consumption and depict it graphically.

It is noteworthy that tobacco consumption was not collected in this study because tobacco is rarely used in the DRC, particularly among women (7).

### 2.2.3 Anthropometric measurements

The participant's weight in kilograms was measured standing with minimal clothing using an electronic scale (UNICEF SCALE) with a capacity of 150 kg and a precision of 100 g. The height was measured standing without shoes, using a portable stadiometer (Sieber Hegner, Zurich, Switzerland), with an accuracy of 1 mm. The BMI was used to assess the nutritional status of participants, expressed in Kg/m$^2$. The BMI ranges were defined according to the WHO thresholds applicable to adults (35): underweight: <18.5 Kg/m$^2$; normal weight: (18.5–24.9) Kg/m$^2$; overweight: (25.0–29.9) Kg/m$^2$; and obesity: ≥0.0 Kg/m$^2$. Study subjects were classified based on whether they had overweight-obesity (BMI ≥ 25 kg/m$^2$) or not (BMI < 25 Kg/m$^2$).

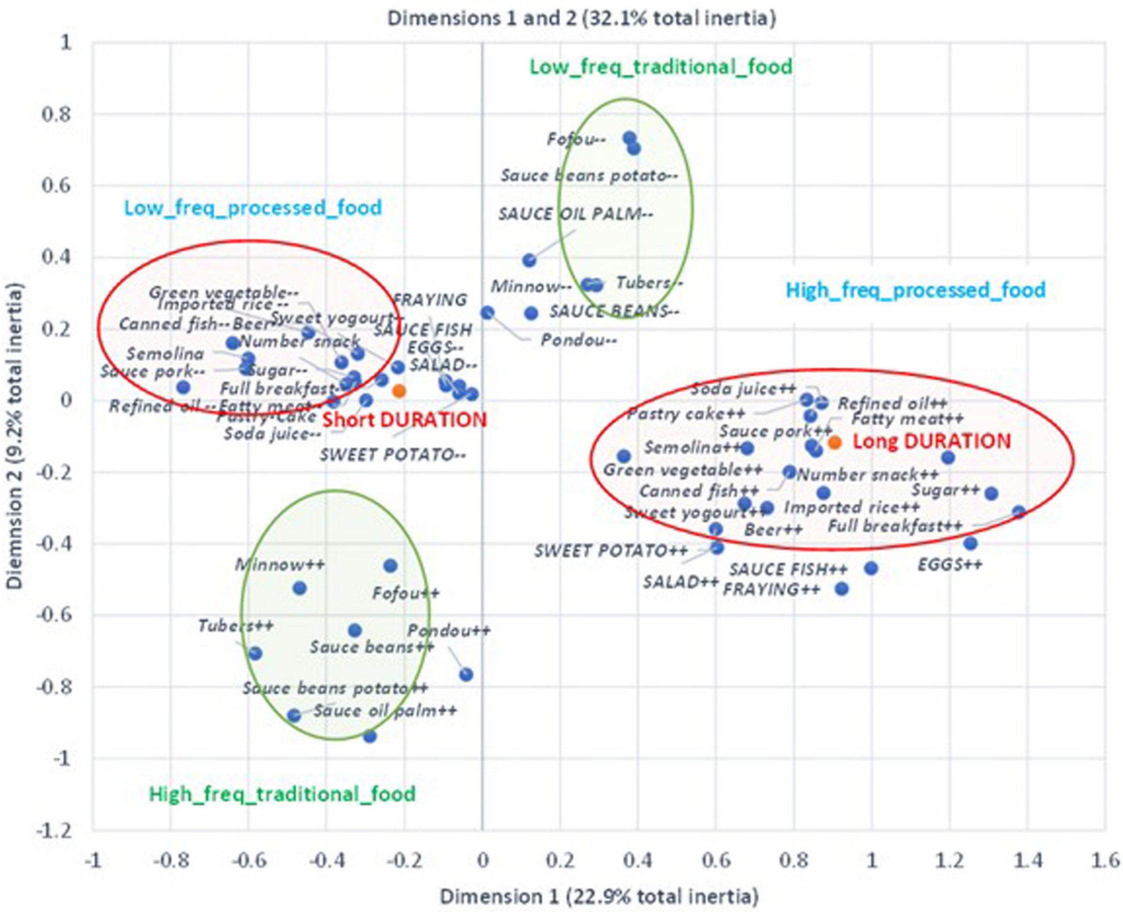


FIGURE 2
Consumption food pattern with urban duration. Distribution of very regularly consumed food according to urban duration: the additional modalities in red color represent the variable "Urban duration," whose modalities "Short duration" indicate residence in a rural environment or urban duration <15 years, and "Long duration" indicates urban duration more than 15 years. The variables in red circles (followed by + and − signs) indicate, respectively, the very frequent vs. not frequent consumption of ultra-processed food. The variables in green circles (followed by + and − signs) indicate, respectively, the very frequent vs. not frequent consumption of traditional foods. The ellipses were plotted according to factor loadings >0.3 for both Dimensions 1 and 2. All variables were significantly correlated with either Dimension 1 or 2.

## 2.3 Data analysis

Additional tables and figures regarding score construction are provided in the Supplementary material. Simple linear regressions were employed to evaluate distinct associations between physical activity, frequency of processed food consumption (PFC), BMI, and urban duration. The comparison of variables and statistical tests necessitated a weighted coefficient based on the differential rural–urban clustering of the study (with a coefficient of 1.4 and 0.2 for the rural and urban areas, respectively) and an adjustment for age. Chi-squared/exact Fisher tests were used for categorical variables, and the Wilcoxon rank test was used for continuous variables.

The MCA was carried out to assess the relationships between food consumption frequency and urban duration. The MCA graph was used to display consumption food patterns according to urban duration. To investigate the biocultural factors associated with overweight-obesity, we performed an adjusted binomial logistic regression. The adjusted odds ratios (OR), their 95% Confidence Intervals (95% CI), as well as the degree of significance ($p < 0.05$) were analyzed to identify the factors that are independently associated with overweight-obesity. Finally, a structural equation model (SEM) was used to determine the casual pathways between socio-demographic factors (age, ethnicity, marital status, urban duration, and SES), socio-ecological factors (dietary intake, physical activity, and stoutness valorization), and overweight-obesity. The software R (v.4.2.1) and R Studio (v.2022.07.1) were used for data analysis, whereas XLSTAT software (from Excel) was used to conduct factorial analyses (MCA and PCA) and reduce the substantial variance into proxies.

## 2.4 Ethics

The study was conducted in accordance with the South Kivu provincial ethics committee (UCB/CIES/NC/015/2024). After being informed about the objective of the study, oral approval and

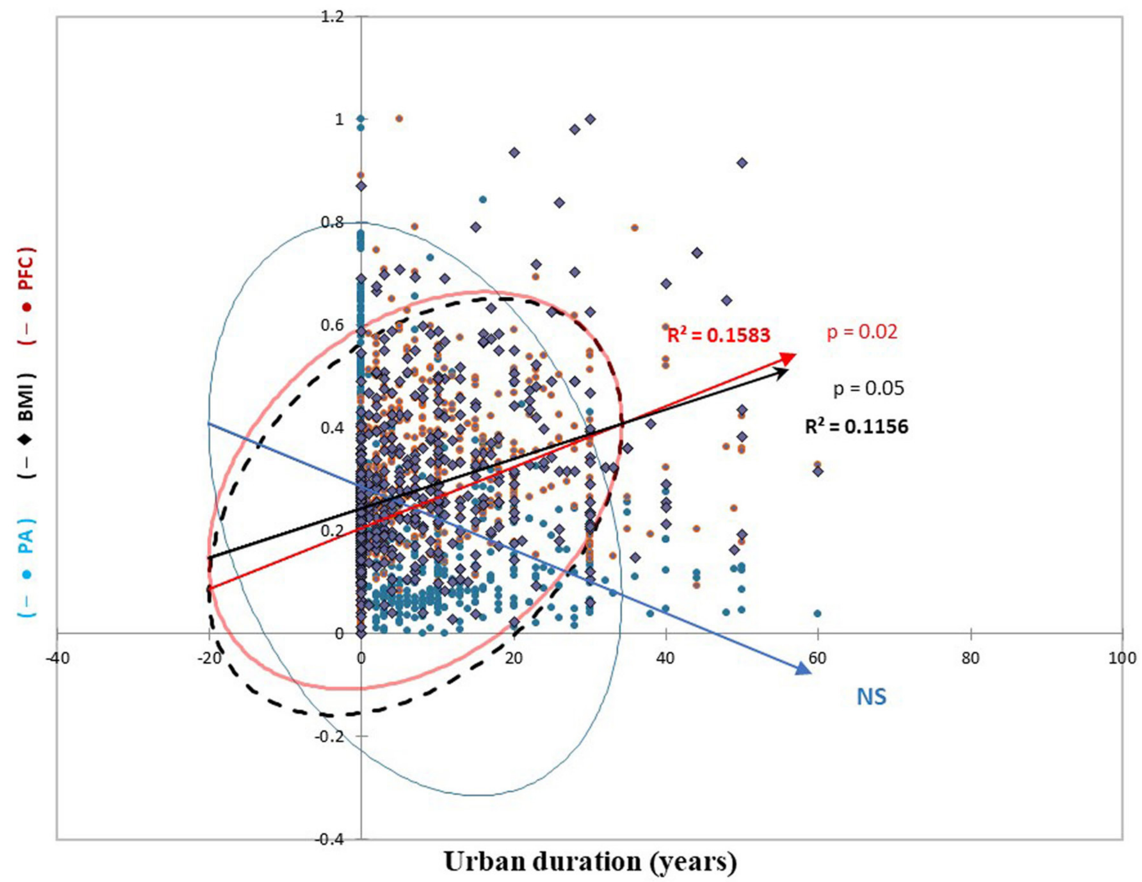


FIGURE 3
Physical activity (PA), body mass index (BMI), and processed food consumption (PFC) according to urban duration. The y-axis data has been standardized for comparability. The circles synthesize the point clouds to calculate the different regression lines. NS, Non-Significant.

written consent were obtained from each participant before the start of the study.

# 3 Results

## 3.1 Socio-demographic characteristics

Our findings (Table 1) indicate that the mean age of urban dwellers was not significantly different from that of rural dwellers. However, nearly half of urban subjects were over 35 years old, compared to only 10% of rural dwellers. Among urban dwellers, over half have lived in the urban area for <15 years. A third of urban dwellers were in the highest SES category, compared to <10% of their rural counterparts. Majority of the participants were from the Shi ethnicity.

## 3.2 Prevalence of overweight-obesity

The prevalence of overweight-obesity in the study sample was 33.6%, including 7.1% of participants who were obese. The overweight prevalence was significantly higher among urban dwellers, with 49.1%, compared to rural dwellers with a prevalence of 17.2%. Similarly, obesity prevalence was significantly higher among urban dwellers (11.5%) as compared to a prevalence of 2.5% among rural dwellers ($p < 0.001$). Overweight-obesity prevalence did not exhibit significant a correlation with age. The prevalence was 34.5% among the age group 18–25 years, 28.9% among the age group 26–35 years, and 36.6% among the age group older than 35 years. All subjects (100%) with obesity were within the oldest group.

## 3.3 Socio-ecological characteristics

### 3.3.1 Stoutness valorization

Our results indicate that rural dwellers have a larger perceived body size (PBS) than urban dwellers (Figure 1). Many rural dwellers underestimated their own weight. The diamonds in the middle of the bidirectional arrows, representing respectively means and standard deviations (SD), indicate that rural dwellers' PBS was situated in the overweight category, while their real BMI mean was situated in the normal weight category. Both rural and urban dwellers had IBS means that were situated in the overweight category. However, the SD for rural dwellers covered the overweight and obesity categories, while some urban participants had an IBS within the normal weight category.

TABLE 3 Odds ratio (OR) and 95% confidence intervals (CI) between subjects classified and non-classified as overweight-obese, non-adjusted and adjusted by binomial logistic regression.

| Characteristics | OR-non-adjusted for overweight-obesity | | OR- adjusted for overweight-obesity | |
|---|---|---|---|---|
| | OR 95% CI | *p* | OR 95% CI | *p* |
| **(Intercept)** | | | 0.03 [0.01–0.19] | **<0.001** |
| **Age (means)** | 1.01 [0.98–1.05] | 0.36 | 1.00 [0.97–1.03] | 0.9 |
| Marital status | | | | |
| Non-married | 1— | | 1— | |
| Married | 1.16 [0.69–1.92] | 0.57 | 1.27 [0.70–2.33] | 0.4 |
| Ethnicity | | | | |
| Lega | 1 — | | 1— | |
| Shi | 0.90 [0.45–1.79] | 0.75 | 1.02 [0.49–2.1] | >0.9 |
| Urban duration | | | | |
| Rural | 1 — | | 1 — | |
| New residents | 3.45 [1.76–6.78] | **<0.001** | 4.64 [1.85–11.7] | **0.003** |
| Long term residents | 6.65 [3.47–12.7] | **<0.001** | 8.72 [3.54–21.5] | **<0.001** |
| SES | | | | |
| Low | 1 — | | 1 — | |
| Medium | 1.06 [0.57–1.98] | 0.85 | 1.51 [0.71–3.19] | 0.3 |
| High | 3.45 [1.60–7.44] | **0.003** | 2.39 [1.08–5.30] | **0.034** |
| **Physical activity (means)** | 0.64 [0.50–0.80] | **<0.001** | 0.84 [0.63–1.13] | 0.2 |
| Stoutness valorization | | | | |
| No | 1 — | | 1 — | |
| Yes | 3.36 [2.03–5.58] | **<0.001** | 6.10 [3.43–10.9] | **<0.001** |
| Dietary diversity score | | | | |
| Low | 1 — | | 1 — | |
| High | 0.94 [0.56–1.59] | 0.82 | 0.85 [0.51–1.41] | 0.5 |
| Processed food consumption | | | | |
| Low | 1 — | | 1 — | |
| High | 1.38 [0.86–2.21] | 0.18 | 0.73 [0.45–1.20] | 0.2 |

The lines (-) indicate the modalities taken as reference, $p < 0.05$ in bold.

Furthermore, we noted that IBS scores were higher than PBS scores in both groups, with a more accentuated tendency in rural areas.

### 3.3.2 Dietary intake

Our results presented in Table 2 showed a high dietary diversity score (DDS). Almost two-thirds of participants consumed at least seven food groups during the previous 24 h. In addition, there was no significant difference in DDS between both areas of residence. Moreover, our results showed that processed foods were more consumed by urban dwellers compared to rural dwellers, while traditional foods were more consumed in rural areas compared to urban areas.

Figure 2 shows that, in an urban setting, processed foods were more frequently consumed by individuals with an urban duration of ≥15 years, while traditional foods were more regularly consumed by individuals with a shorter urban duration.

### 3.3.3 Physical activity

Physical activity was generally low in the study population, with two-thirds of the study sample reporting low physical activity (Table 2). Physical activity was found to be significantly higher among rural dwellers as compared to their urban counterparts.

### 3.3.4 Relationships between BMI, PFC, physical activity, and urban duration

Figure 3 shows that PFC frequency and BMI were positively associated with urban duration, whereas physical activity was negatively associated with urban duration.

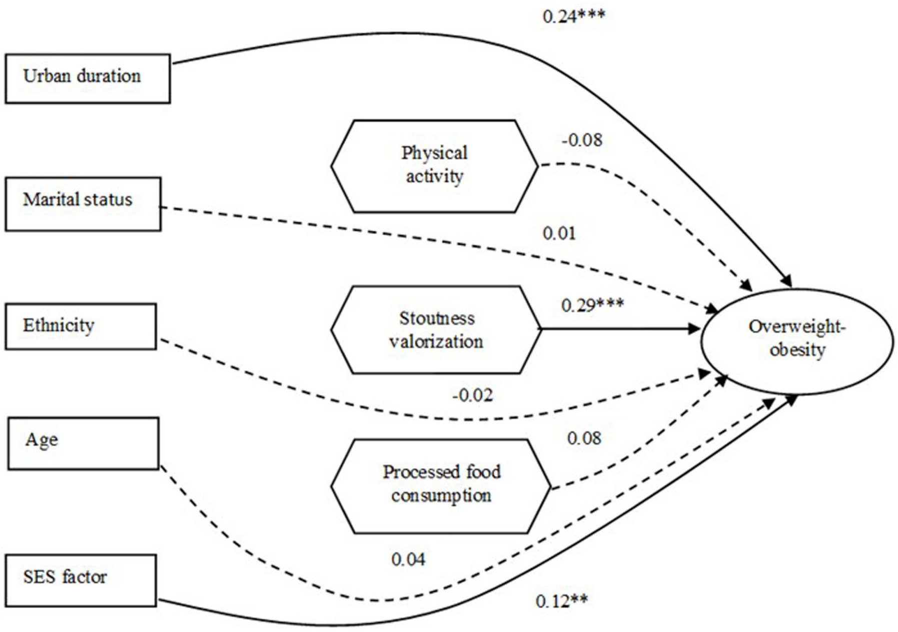


FIGURE 4
Results of structural equation modeling (SEM) show direct associations between socio-demographic/socio-ecological factors and overweight-obesity status. Bold, solid lines show significant associations, and dotted lines show non-significant associations. Their coefficients and their degrees of significance are indicated by numbers and stars: **$p < 0.01$; ***$p < 0.001$.

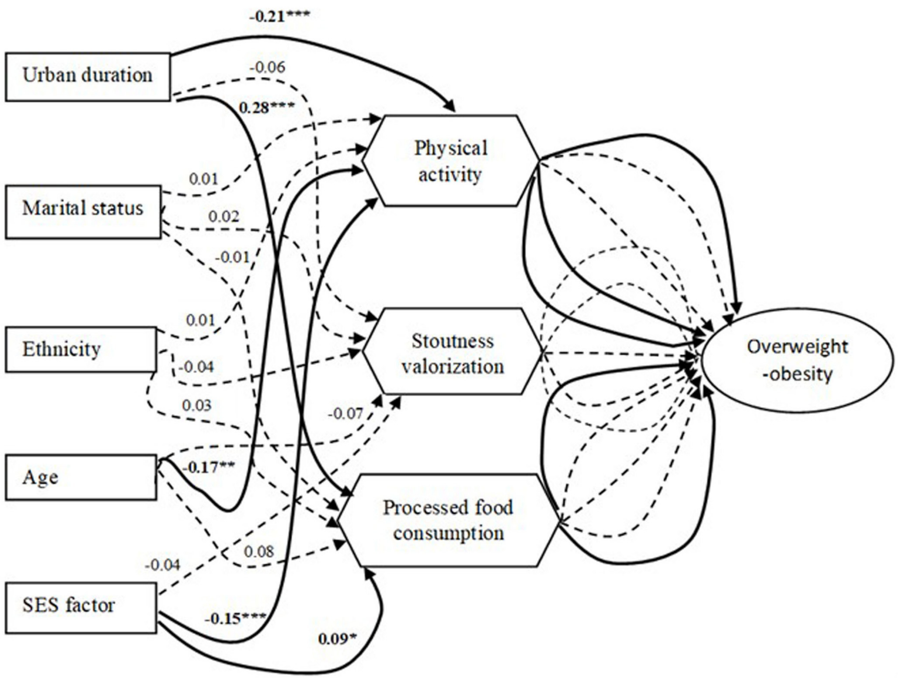


FIGURE 5
Results of structural equation modeling (SEM) show indirect associations between socio-demographic/socio-ecological factors and overweight-obesity status. Bold, solid lines show significant associations, and dotted lines show non-significant associations. Their coefficients and their degrees of significance are indicated by numbers and stars: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

## 3.4 Predictors of overweight-obesity

### 3.4.1 Overweight-obesity-adjusted and unadjusted factors

The results from the logistic regression as presented in Table 3 show that urban duration, SES, and stoutness valorization were independently and positively associated with overweight-obesity. Urban dwellers, independently of urban duration, were more at risk of having overweight-obesity compared to rural dwellers. Similarly, participants with the highest SES were more at risk of having overweight-obesity than those within the lowest SES tercile. Finally, participants who valorized stoutness were more at risk of having overweight-obesity than those who did not valorize stoutness.

### 3.4.2 Driver pathway analysis

The results of the SEM presented in Figures 4, 5 on the relationships between socio-demographic and socio-ecological factors and overweight/obesity show direct and indirect driver pathways.

#### 3.4.2.1 Direct pathway association

Urban duration, SES, and stoutness valorization were positively associated with overweight-obesity.

#### 3.4.2.2 Indirect pathway association

Some socio-demographic factors influenced overweight-obesity through intermediate socio-ecological factors. Urban duration and SES were positively associated with overweight-obesity, mediated positively by PFC and negatively by physical activity. Age was also found to be positively associated with overweight-obesity through a negative mediation with physical activity.

## 4 Discussion

The prevalence of overweight-obesity was high in this study sample of Congolese women. The socio-ecological factors analyzed showed that physical activity was significantly higher in rural areas than in urban areas and that PFC was significantly higher in urban areas than in rural areas, with a reversed trend for traditional food consumption frequency. In addition, the stoutness valorization was significantly higher in the rural area. It was demonstrated that urban duration, SES, and stoutness valorization were directly associated with overweight-obesity, while physical activity and PFC mediated the associations between overweight-obesity and urban duration, SES, and age (only physical activity for the last one).

Our results indicate that overweight-obesity is a public health issue in this region of the DRC, especially in urban area of South Kivu. The elevated prevalence of 33.6% observed could be attributed to the increasing urbanization of Bukavu, resulting from the ongoing and actual rural exodus experienced by this expanding city. The increasing urban environment is shaped by the globalization of the market economy which creates an obesogenic socio-ecological environment that exposes the population to overweight-obesity, as observed in Cameroon and Burkina Faso (16, 24). These results are in line with the DHS reporting in 2014 a prevalence of overweight-obesity of 26.5% and 27.8% in South and North Kivu, respectively, and a prevalence of 32.2% in Kinshasa, the capital city of the country (7). A similar prevalence was reported in Uganda (36), while the prevalence of overweight-obesity was higher in Cameroon, Tanzania, Nigeria, and South Africa, probably due to their advanced nutritional transition stages (16, 36).

In this study population, several socio-demographic factors interacted with socio-ecological factors leading to overweight-obesity, as observed in Cameroon by Cohen et al. (16). Our study findings indicate that urban duration and higher SES are significant risk factors for overweight-obesity, mediated by a decrease in physical activity and an increase in PFC. Similar trends are discussed in other studies conducted by Cohen et al. (15) in Senegal; Popkin et al. (5); and Delisle (17) in low and middle-income countries, especially in Benin and Burkina Faso. The improving SES has also been identified as a risk factor for overweight-obesity in other studies conducted in France and Cameroon (16, 37). Similarly, Correia et al. showed in two surveys carried out in seven African countries (10 years apart) that the prevalence of overweight-obesity was, over time, positively correlated with the socio-economic level of households (6).

Despite the overall poor economy in South Kivu, particularly in urban areas, a part of the population has found informal means to improve their income (7, 21). This new relatively high purchasing power has changed living standards and lifestyles, leading concomitantly to an increasing PFC and a decrease in physical activity. Such reversed tendencies in PFC and physical activity found in this study are observed along the nutritional transition in other African countries (30). Delisle (17) showed that rich households in poor countries, according to their relatively high purchasing power, are exposed to imported processed foods that are rich in added sugar, fat, and, salt, which increase the risk of developing non-communicable diseases and obesity.

The escalating risk of overweight-obesity associated with the enhancement of socio-economic conditions, mediated by a higher PFC, indicates that South Kivu is experiencing an early nutritional transition stage, similar to other sub-Saharan African countries. Our results support the findings of Abrahams et al. (38) showing that African Great Lakes countries neighboring the DRC, particularly the South Kivu region (Rwanda, Burundi, Uganda, Tanzania, and Kenya), are situated at an early phase of the nutritional transition.

In this study, there was no association between overweight-obesity and age, but all individuals with obesity were over 35 years old. This is in line with other African studies demonstrating that age is a risk factor for overweight-obesity (9, 39). As mentioned by Talimula et al. (40) in Benin, physical activity decreases with age and exposes individuals to a sedentary lifestyle, which constitutes a major risk factor for overweight-obesity. Hence, we observed in our study a relationship between age and overweight-obesity mediated negatively by physical activity.

The sociocultural aspects, particularly the valorization of corpulence, also mediate several factors of overweight-obesity during the nutritional transition (15, 16). Indeed, corpulence can be perceived as a sign of peacefulness, wellbeing, good health and social success, as observed in multiple historical social representations. Hence, our study found, both in rural and urban areas, emic (lay) norms of corpulence to be far superior to etic (biomedical) norms. This was also confirmed with dissatisfaction one's body image and the intention to gain weight (41). Although this intention to gain weight could manifest differently, the urban environment can exacerbate this behavior; the weight gain is perceived by less modernized people as a symbol of accession to the urban Eldorado. Therefore, such a sociocultural trend can be a risk factor for overweight-obesity in societies experiencing a rapid nutritional transition, as observed in this study and other African studies (30).

Since women are more at risk of developing overweight and obesity during the early nutritional transition stages (13, 19), studying overweight-obesity in this group from a biocultural perspective helps to better understand this transitional phenomenon in order to propose appropriate public health policies. In addition, our study has benefited from the use of recommended factorial analyses in nutritional epidemiology to assess the relationship between dietary patterns and overweight-obesity (42). Moreover, even with a limited sample, the SEM used in this study enables the identification of the driver pathways between socio-demographic and socio-ecological factors leading to overweight-obesity, a relevant data analysis strategy in line with our previous study conducted in Cameroon (16). However, our study presents some limits, which, after all, do not exclude the value of its results. First, we sampled more elderly subjects in urban areas than in rural areas. This can be explained by the fact that older dwellers choose to migrate to urban areas for finding safety, amidst the continuous insecurity in the region. Contrarily, young rural dwellers might be forced to stay, and for their subsistence, they pursue agricultural work and other activities around natural resource exploitation, such as mining. Then, the cross-sectional design of this study did not allow a longitudinal observation of overweight-obesity and its biocultural determinants. Also, a qualitative approach interpreting deeply their relationships would have been relevant. Future studies should develop such approaches to provide a causal dimension to the relationships observed in this study (30, 43), with a possible gender comparison as well as a national-level survey to obtain an overview of the obesogenic effects of the nutritional transition in the DRC. We also believe that a culturally relevant tool to quantitatively estimate food intake, as developed in Cameroon and Mozambique (44, 45), would provide more arguments to objectively identify the contribution of food consumption in terms of energy intake, and therefore accurately assess its impact on obesity in this region. Finally, in this study, only the BMI was used to assess overweight-obesity. Because this index is a very convenient and appropriate tool to assess the risk factor for morbid obesity at a population level, but not a clinical marker of cardiometabolic diseases at an individual level, our results must be interpreted with caution (46).

In spite of this, this study demonstrated innovatively the relationships between socio-demographic and socio-ecological factors as driver pathways leading to overweight-obesity in the Great Lakes region of the DRC.

## 5 Conclusions

The issue of overweight-obesity among adult women from Bukavu city and its surrounding rural area is a matter of public health concern. We have observed that urban duration, SES, and stoutness valorization are positively associated with overweight-obesity, primarily due to decreased physical activity and elevated frequency of processed food consumption. Understanding the drivers of excess weight, especially in at-risk subgroups, could provide the basis for interventions and public strategies on biocultural trajectories determining overweight-obesity, to prevent its rising prevalence in the Democratic Republic of Congo.

## Data availability statement

The main data collected for the study are presented in this article/Supplementary material. Further inquiries can be directed to the corresponding authors.

## Ethics statement

The study involving humans was approved by the Institutional Committe of Health Ethics with the approval number: UCB/CIES/NC/015/2024. The study was conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

WW: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Project administration, Resources, Software, Writing – review & editing. SA: Formal analysis, Writing – review & editing. LV: Formal analysis, Writing – review & editing. NA: Writing – review & editing. MM: Writing – review & editing. CE: Formal analysis, Writing – review & editing. PP: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing. EC: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

## Publisher's note



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2024.1341710/full#supplementary-material

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# Factors influencing waist circumference among urban bank employees in Northeast Ethiopia: a cross-sectional study

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**Introduction:** A widely recognized public health issue affecting people worldwide is central obesity. Numerous chronic conditions, such as type 2 diabetes mellitus, cardiovascular disease, and malignancies are linked to this syndrome. There is limited information about waist circumference (WC) and its related variables among urban bank workers in Ethiopia. Therefore, the purpose of this study was to evaluate waist circumference and the factors associated with it among bank workers in Northeast Ethiopia.

**Methods:** An institution-based cross-sectional study was carried out in Dessie, Northeast Ethiopia, between 2 October 2023 and 24 October 2023. A random selection method was employed to select 363 bank workers. STATA version 17 was used for analysis after the data were imported into EpiData version 4.4.2.0. Univariate and multivariate linear regression analyzes were performed to identify factors related to waist circumference. Normality, homoscedasticity, significant outliers, and multicollinearity were assessed, and a $p$-value of less than 0.05, along with a 95% confidence interval, was considered statistically significant.

**Results:** A total of 345 participants were included in the final analysis, with a 95% response rate. The overall mean $\pm$ standard deviation (SD) of the waist circumference of the employees was 81.7 $\pm$ 6.8 cm, with 82.4 $\pm$ 6.5 cm for men and 80.7 $\pm$ 7.2 cm for women. The overall prevalence of central obesity was 57.7%, with 48.2% for the men and 70.3% for the women. The overall mean $\pm$ SD of the waist-to-hip ratio (WHR) was 0.90 $\pm$ 0.05, with 0.91 $\pm$ 0.04 for men and 0.89 $\pm$ 0.05 for women. The average waist circumference was significantly associated with the participants' age (0.2 cm per year (SE: 0.1)) and MET hours (0.2 cm (SE: 0.1)). The mean waist circumference was 2.7 cm (SE:0.8) higher in the married women, 4.6 cm (SE:1.9) higher in the participants with non-communicable diseases (NCDs), and 1.7 cm (SE:0.8) higher in the participants who consumed discretionary calories for 4 days/week.

**Conclusion:** The mean waist circumference among bank employees was higher, with more than half of the participants having central obesity. Age, marital status, discretionary calorie intake, non-communicable diseases, and metabolic equivalence task hours were the significant factors of waist circumference. Therefore, promoting activities aimed at preventing non-communicable diseases, such as leisure-time physical activity, and reducing discretionary calorie intake are essential for reducing high waist circumference measurements.

KEYWORDS

**waist circumference, central obesity, factors, non-communicable disease, Eastern Ethiopia**

# 1 Introduction

Obesity, defined by waist circumference (WC) and measured midway between the lowest rib cage at the mid-clavicular line and the anterior superior iliac spine, is the most practical indicator of fat distribution and central obesity (1). It is the most common condition that causes disability, disease, and premature death and is measured using body mass index (2). The National Cholesterol Education Program Third Adult Treatment Panel (NCEP-ATP III) defines central obesity as a waist circumference of ≥102 cm for men and ≥88 cm for women, while the International Diabetes Federation (IDF) establishes cut-off points of ≥94 cm for men and ≥80 cm for women (3, 4). Additionally, specific cut-off points for Ethiopians are 83.7 cm for men and 78 cm for women (5).

A complex combination of behavioral, environmental, social, and hereditary factors contribute to obesity (3, 6). Being overweight or obese has been estimated to cause 35.8 million (2.3%) disability-adjusted life years and 2.8 million deaths worldwide each year (7). Sub-Saharan Africa has been facing the double burden of communicable and non-communicable diseases in recent years (8). Compared to BMI, central obesity is more strongly correlated with diabetes mellitus (DM) and cerebrovascular disease (CVD) (9). According to a linear dose–response analysis, the incidence of CVD increased by 3.4% for women and 4.0% for men with every 10 cm rise in waist circumference (WC) (10). The World Health Organization lists obesity as the fifth and seventeenth major risk factor contributing to the overall burden of disease in emerging nations with low and high death rates, respectively (11). Obesity has been linked to approximately 44% of diabetes cases, 23% of ischemic heart disease cases, and 7–41% of certain cancer cases (12).

Chronic health issues such as type 2 diabetes and cardiovascular diseases have been on the rise in many developing and underdeveloped nations, including Ethiopia, as a result of obesity and overweight. In Ethiopia, central obesity and overweight have become serious public health concerns, particularly among urban residents (13, 14). Ethiopia is currently facing the fallout from epidemiologic, demographic, economic, and nutritional shifts that continue to drive the spread of chronic non-communicable disease (NCD) epidemics (15). The burden of chronic disease morbidity and mortality is still rising despite government efforts to reduce risk factors for chronic diseases, such as central obesity (16).

There have been very few studies conducted on the prevalence of obesity based on body mass index in our country (17). Work environments that require limited physical activity (18), such as banks, are major employers. Thus, the purpose of this study was to evaluate obesity among urban bank employees in the study area. The results of this study can serve as a guide, especially for individuals who are at high risk.

# 2 Methods

## 2.1 Study design and setting

An institution-based cross-sectional study was conducted from 2 October to 24 October 2023 among urban bank employees in Dessie. Dessie is a city located 400 km to the north of the capital, Addis Ababa. It has a population of more than 230,733 people across five sub-cities (19). The city has 23 banks, with a total of 1,870 permanent employees, of whom 1,174 are men and the remaining 696 are women.

## 2.2 Study participants

The study population consisted of individuals aged ≥18 years, randomly selected from among the bank employees during the data collection period.

## 2.3 Inclusion and exclusion criteria

All permanent bank employees were included in the study, whereas pregnant women, mothers with <6 months postpartum, individuals with deformities on their backs, individuals unable to stand in an erect position, those with chronic edema, and non-permanent employees (employees with less than 6 months of work experience and outsourced security workers) were excluded from the study.

## 2.4 Sample size and sampling procedure

The sample size was calculated using the mean waist circumference formula, as the single population proportion formula and the double population proportion formula had lower sample sizes compared to using the mean. Therefore, with a standard deviation (SD) of 13.9 cm, a maximum accepted margin of error of 1.5 cm [taken from a previous study (20)], and a 95% CI, the final sample size, allowing for a 10% non-response rate, was 363.

There are 23 banks in Dessie city. Of these, five banks (Hibret, CBE, Amhara, Oromia, and Abay banks) were randomly selected. Then, an exhaustive list of permanent employees from the selected banks was prepared, and the number of the included participants from each bank was allocated proportionally. Finally, the participants were selected through systematic random sampling with a $k$-value of 2 ($N/n = 761/363 \approx 2$). The first participant was selected using simple

Abbreviations: BMI, Body mass index; CAD, Cerebrovascular disease; DM, Diabetes mellitus; METs, Metabolic equivalent of tasks; NCD, Non-communicable diseases; WC, Waist circumference; WHR, Waist to hip ratio.

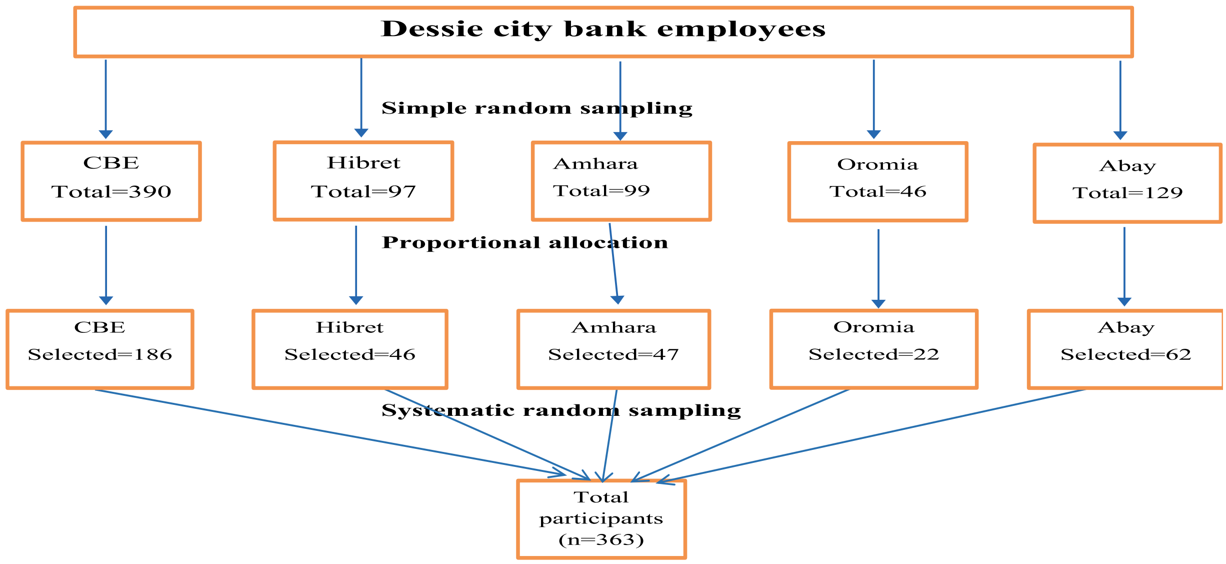


FIGURE 1
Schematic representation of the sampling procedure for waist circumference and the associated factors among the bank employees in Northeast Ethiopia, 2023.

random sampling (lottery method), and the subsequent participants were selected at every second interval (Figure 1).

## 2.5 Measurement of variables

### 2.5.1 Central obesity

For Ethiopian adults, it was defined as a waist circumference of 83.7 cm for men and 78 cm for women (21). Another cut-off point for Ethiopian adults was a waist-to-hip ratio (WHR) of 0.88 for men and 0.82 for women (5).

### 2.5.2 Dietary diversity score

The dietary intake of the study participants was evaluated using a 24-h dietary recall. From the morning of the previous day to the morning of the current day, the participants were asked to list everything they had eaten, including snacks and food consumed outside their houses. The FAO's nine food groups were used to classify these foods. Based on the number of food groups consumed, the participants were scored as being in the low, medium, or high range, with low being equal to or less than 3, medium being equal to or less than 4–5, and high being equal to or more than 6 (20).

### 2.5.3 Servings of fruit and vegetables

After calculating the average daily consumption of fruits and vegetables, two groups were created, with the cut-off point being the mean consumption value of 0.95 servings/day (22).

### 2.5.4 Alcohol consumption

The frequency of alcohol consumption was recorded, ranging from daily to less than once per month, based on the subjects' consumption over the previous 12 months (23).

### 2.5.5 Discretionary calorie intake

Discretionary foods include items such as soft drinks, cakes, Chocolate, and other high-sugar, low-nutrient food items that are also high in saturated fat, added sugars, and added salt (24).

## 2.6 Data collection procedure and tools

The data collection tool was designed according to the WHO STEP-wise approach to non-communicable disease surveillance and the Food and Agriculture Organization assessment guidelines (25). The questionnaires regarding demographic data, behavioral assessments, and physical assessments in the survey were completed. Four trained clinical nurses, two men and two women, collected the data under the direction of a healthcare professional holding a Master of Public Health degree. Using a constant tension tape, the waist circumference was measured to the nearest 0.1 cm at the midpoint between the top of the iliac crest and the lower edge of the last perceptible rib. Similarly, the hip circumference was measured at the level of the greater trochanter, or the widest part of the gluteal muscle, recorded to the nearest 0.1 cm.

## 2.7 Data quality assurance

Before the data were collected, the questionnaire was written in English, translated into Amharic, and then back into English using a different translator to maintain the questionnaire's consistency. Training for supervisors and data collectors lasted 2 days. Before the actual data collection, 5% (19) of the final sample size had the questionnaire pretested on bank workers.

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## 2.8 Data processing and analysis

EpiData version 4.4.2.0 was used to enter the obtained data, and the data were exported to STATA version 17 for analysis. Tables and figures were used to present the results of the computation of descriptive statistics. For each explanatory variable, univariate linear regression analysis was performed first, and multivariate linear regression analysis was then performed for variables with *p*-values less than 0.20. Multicollinearity in the multivariate linear regression model was assessed using the variance inflation factor (VIF) (values <10 for individual variables and <5 for the global value). The level of significance was set at a *p*-value of < 0.05.

# 3 Results

## 3.1 Sociodemographic characteristics

A total of 345 participants were included in the analysis, with a 95.0% response rate. The mean age of the study participants was 34.4 ± 6.7 years. The majority of respondents (216) were in the age category of 30–44 years. Only 27 (7.8%) participants had a tertiary education, and 42 (12.2%) held managerial positions (Table 1).

## 3.2 Behavioral and personal health-related factors

Nearly all (99.4%) participants were non-smokers, and 204 (59.1%) had never consumed alcohol. The mean metabolic equivalent of task (MET)-min ± standard deviation (SD) was 203 ± 211, with only 18 (5.2%) participants meeting the target of 600 MET-min/week. Nearly all (99%) participants were non-smokers and 92.7%of the participants slept for 8 h/day. Only 13 (3.8%) of the participants had been diagnosed with non-communicable diseases (NCDs) (Table 2).

**TABLE 1** Sociodemographic characteristics of the study participants among the bank employees in Northeast Ethiopia, 2023 (*n* = 345).

| Variables | Categories | Frequency (%) |
|---|---|---|
| Sex | Men | 197 (57.1) |
| | Women | 148 (42.9) |
| Age | 18–29 | 98 (28.4) |
| | 30–39 | 216 (62.6) |
| | 40–49 | 31 (9.0) |
| Current position | Officer | 225 (65.2) |
| | Coordinator | 78 (22.6) |
| | Manager | 42 (12.2) |
| Marital status | Married | 210 (60.87) |
| | Unmarried | 135(39.13) |
| Level of education | Below degree | 4 (1.2) |
| | Degree | 314 (91.0) |
| | Above degree | 27 (7.8) |
| Family size | 1 | 110 (31.9) |
| | 2–4 | 139 (40.3) |
| | ≥5 | 96 (27.8) |
| Monthly income | <19,000 | 86 (24.9) |
| | 19,000–25,999 | 78 (22.6) |
| | 26,000–35,999 | 94 (27.3) |
| | ≥36,000 | 87 (25.2) |

Degree = Those who have completed grade 12.

## 3.3 Nutritional factors

The mean ± SD of the servings of fruit and vegetables consumed per day was 0.95 ± 0.69, with 57.1% of the participants exceeding the mean value. The majority, 286 (91.0%), of participants had a medium DDS value, and 94 (27.3%) reported being currently fasting (Table 3).

## 3.4 Waist-to-hip ratio and hip circumference

The overall mean ± SD of the waist circumference of the bank employees was 81.7 ± 6.8 cm. The mean WC was higher among men (82.4 ± 6.5 cm) than women (80.7 ± 7.2 cm). Accordingly, the overall mean ± SD of the WHR was 0.90 ± 0.05, with men having a value of 0.91 ± 0.04 and women having a value of 0.89 ± 0.05. The prevalence of central obesity was 57.7% (95% CI, 52.4–62.8%) (Figure 2).

Similarly, the prevalence of central obesity based on the WHR was 62.0% (95% CI, 56.8–67.0%) (Figure 3).

## 3.5 Factors associated with waist circumference

In the univariate linear regression analysis, age, sex, position, marital status, family income, khat chewing, discretionary calorie intake, time spent sleeping, having NCDs, number of meals eaten outside the home/week, meal-skipping habits, and MET-hours were considered. The variables with *p*-values less than 0.2 were then included in the multivariate linear regression analysis (Table 4).

Thus, a one-year increase in age was associated with Intermediate increase of 0.2 cm (Standard error (SE): 0.1) in WC. In addition, the mean WC was 2.7 cm (SE:0.8) higher in married women compared to unmarried women. Similarly, the participants who consumed discretionary calories for 4 days/week had Intermediate WC increase of 1.7 cm (SE:0.8) compared to those who consumed discretionary calories for 3 days/week. Moreover, participants with NCDs had Intermediate WC value of 4.6 cm (SE:1.9) higher than their counterparts. A one-unit increase in MET-hours was associated with Intermediate decrease of 0.2 cm in the WC (SE:0.1).

Regarding the standardized beta coefficient, marital status and age had a greater effect on the waist circumference compared to the other significant variables. Accordingly, a change of one standard deviation in age resulted in a 0.18 standard deviation increase in the waist circumference. Similarly, on average, the married participants had a 0.19 standard deviation increase in the waist circumference compared to the unmarried participants.

TABLE 2 Behavioral and personal health-related characteristics of the bank employees in Northeast Ethiopia, 2023 ($n$ = 345).

| Variable | Category | Frequency (%) |
|---|---|---|
| Ever smoked a cigarette | No | 340 (98.55) |
| | Yes | 5 (1.45) |
| Ever chewed chat | No | 322 (93.3) |
| | Yes | 23 (6.7) |
| Currently chewing chat ($n$ = 23) | No | 17 (73.91) |
| | Yes | 6 (26.06) |
| Duration of chewing chat ($n$ = 23) | <12 months | 11 (47.8) |
| | ≥12 months | 12 (52.2) |
| Average grams of chat chewed ($n$ = 23) | <100 gram | 5 (21.7) |
| | ≥100 gram | 18 (78.3) |
| Ever consumed alcohol | No | 141 (40.9) |
| | Yes | 204 (59.1) |
| MET-min/week | | 203 ± 211 |
| | Not meeting (<600 MET) | 327 (94.8) |
| | Meeting (≥600 METs) | 18 (5.2) |
| Time spent sitting (hours) | | 8.2 ± 1.2 |
| | ≤8 | 264 (76.5) |
| | >8 | 81 (23.5) |
| Time spent watching TV or using the computer (hours) | | 2.7 ± 0.7 |
| | ≤2 | 144 (41.7) |
| | >2 | 201 (58.3) |
| Time spent sleeping (hours) | | 8.5 ± 0.9 |
| | ≤7 | 25 (7.3) |
| | ≥8 | 320 (92.7) |
| Having NCDs | No | 332 (96.2) |
| | Yes | 13 (3.8) |
| Type of NCD ($n$ = 13) | HTN | 8 (61.5) |
| | DM | 4 (30.8) |
| | Kidney disease | 1 (7.7) |
| Ever used contraception ($n$ = 148) | No | 51 (34.5) |
| | Yes | 97 (65.5) |
| Length (years) of contraception use ($n$ = 97) | | 2.9 ± 3.1 |
| | ≤2 | 53 (54.6) |
| | >2 | 44 (45.4) |

Values are numbers (percentages) or means ± SD as appropriate; HTN, Hypertension; DM, Diabetes mellitus.

# 4 Discussion

The mean ± SD values of the WHR and WC were found to be 0.90 ± 0.05 cm and 82.4 ± 6.5 cm, respectively, based on the results. The prevalence of central obesity was 57.7% based on WC and 62.0% based on the WHR. The average waist circumference was 81.7 ± 6.8 cm (95% CI: 81.0–82.4 cm). Compared to women [80.7 ± 7.2 cm (95%CI, 79.5–81.9)], men reported higher WC values [82.4 ± 6.5 cm (95%CI, 81.5–83.3 cm)]. In comparison to studies conducted in Australia, Costa Rica, and Indonesia, the mean waist circumference (WC) in this study was lower. In Australia, the mean WC was 97.5 cm for men and 87.5 cm for women (26); in Costa Rica, it was 86.4 cm for women and 88.1 cm for men (27); and in Indonesia, it was 92.4 ± 1.3 cm for men and 89.5 ± 3.2 cm for women (28). This discrepancy may be attributed to the higher intake of processed foods, sugar-sweetened beverages, and sedentary lifestyle in developed countries (29, 30). However, a lower mean WC was reported in Mozambique, with values of 75.2 cm for women and 76.1 cm for men (31). This disparity could be explained by differences in the study time, study environment (urban vs. both urban and rural), and study design (community-based vs. institution-based). Furthermore, the main causes for the various WC reports are national

TABLE 3 Nutrition-related characteristics of bank employees in Northeast Ethiopia, 2023 (*n* = 345).

| Variable | Category | Frequency (%) |
|---|---|---|
| Servings of fruit and vegetables consumed/day | | 0.95 ± 0.69 |
| | <0.95 | 197 (57.1) |
| | ≥0.95 | 148 (42.9) |
| Protein source from animals/week or days | <4 | 293 (84.9) |
| | ≥4 | 52 (15.1) |
| Protein source from plants /week or days | 4 | 55 (15.9) |
| | ≥4 | 290 (84.1) |
| Starchy staples/week or days | <4 | 49 (14.2) |
| | ≥4 | 296 (85.8) |
| Milk and dairy products/week or days | <4 | 320 (92.8) |
| | ≥4 | 25 (7.3) |
| Fats and oil products/week or days | <4 | 5 (1.5) |
| | ≥4 | 340 (98.5) |
| Discretionary calories/ days | <4 | 245 (71.0) |
| | ≥4 | 100 (29.0) |
| Fried foods/week or days | <4 | 338 (98.0) |
| | ≥4 | 7 (2.0) |
| Types of oil commonly used | Liquid vegetable oil | 266 (77.1) |
| | Others | 79 (22.9) |
| Meals not prepared at home/week | <3 meals | 268 (77.7) |
| | ≥3 meals | 77 (22.3) |
| Usually skips meal | Yes | 93 (27.0) |
| | No | 252 (73.0) |
| Currently fasting | Yes | 94 (27.3) |
| | No | 251 (72.7) |
| DDS | High | 28 (8.1) |
| | Medium | 286 (91.0) |
| | Low | 31 (9.0) |

Other*: Solidified vegetable oil, butter, margarine/peanut butter, shenolega, or none.

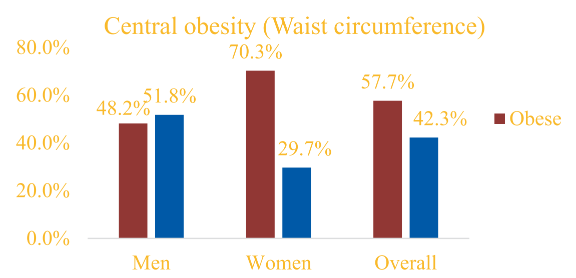


FIGURE 2
Prevalence of central obesity among bank employees in Northeast Ethiopia based on WC, 2023 (*n* = 345).

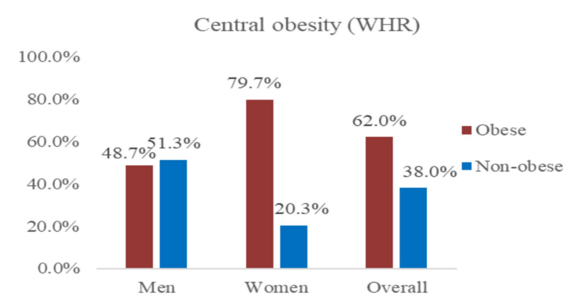


FIGURE 3
Prevalence of central obesity among bank employees in Northeast Ethiopia based on the WHR, 2023 (*n* = 345).

variations in sociocultural, economic, and behavioral norms. Conversely, similar results were found in a survey conducted in Addis Ababa, Ethiopia (81.8 cm for men and 80.7 for women) (20). This could be a result of the research's comparable metropolitan settings and similar study periods. Based on the study's findings, each additional year of age was linked to an average increase of 0.2 cm. Scientific data indicate that aging is linked to an increase in abdominal obesity, with a mean rise of 2.43–2.68 cm in visceral adipose tissue (32). In addition, metabolic rate, muscle mass, and bone mass decrease as age increases (33, 34). These findings are

TABLE 4 **Univariate and multivariate linear regression of factors associated with waist circumference among bank employees in Northeast Ethiopia, 2023 (*n* = 345).**

| | | Waist circumference (cm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Univariate linear regression | | | | | Multivariate linear regression | | | |
| | | Slope | | | | | Slope | | | |
| | *n* | $r^2$ | *b* | ± | SE | *p*-value | *b* | ± | SE | *p*-value |
| Total | 345 | | | | | | | | | |
| Sex | | 1.5% | | | | | | | | |
| Men | 197 | | 1.7 | ± | 0.7 | 0.02 | 1.3 | ± | 0.7 | 0.08 |
| Women | 148 | | (80.7) | | | | ref | | | |
| Age | 345 | 9.5% | 0.3 | ± | 0.1 | <0.001 | 0.2 | ± | 0.1 | 0.01* |
| Position | | 4.9% | | | | | | | | |
| Manager | 42 | | 3.5 | ± | 1.1 | 0.002 | 1.1 | ± | 1.4 | 0.43 |
| Coordinator | 78 | | 3.0 | ± | 0.9 | 0.001 | 1.2 | ± | 1.0 | 0.26 |
| Officer | 225 | | (80.6) | | | | ref | | | |
| Marital status | | 7.0% | | | | | | | | |
| Married | 210 | | 3.7 | ± | 0.7 | <0.001 | 2.7 | ± | 0.8 | 0.001* |
| Unmarried | 135 | | (79.4) | | | | ref | | | |
| Monthly family income | | 5.3% | | | | | | | | |
| <19,000 | 86 | | (80.1) | | | | ref | | | |
| 19,000–25,999 | 78 | | 0.1 | ± | 1.0 | 0.96 | −1.5 | ± | 1.0 | 0.13 |
| 26,000–35,999 | 94 | | 2.4 | ± | 1.0 | 0.02 | −1.6 | ± | 1.2 | 0.18 |
| ≥360,000 | 87 | | 3.7 | ± | 1.0 | <0.001 | −2.6 | ± | 1.5 | 0.09 |
| Chat chewing | | 0.8% | | | | 0.11 | | | | |
| No | 322 | | (81.5) | | | | ref | | | |
| Yes | 23 | | 2.4 | ± | 1.5 | | 2.1 | ± | 1.4 | 0.14 |
| Discretionary calorie intake/week | | 2.1% | | | | | | | | |
| ≤3 days/week | 245 | | (80.9) | | | | ref | | | |
| ≥4 days/week | 100 | | 2.5 | ± | 0.8 | 0.002 | 1.7 | ± | 0.8 | 0.03* |
| Time spent sleeping (hours) | 345 | 0.6% | 0.5 | ± | 0.4 | 0.20 | 0.7 | ± | 0.4 | 0.05 |
| Having NCDs | | 2.7% | | | | | | | | |
| No (%) | 332 | | (81.5) | | | | ref | | | |
| Yes (%) | 13 | | 5.9 | ± | 1.9 | 0.002 | 4.6 | ± | 1.9 | 0.01* |
| Number of meals/weeks | 345 | 1% | 0.5 | ± | 0.3 | 0.07 | 0.4 | ± | 0.3 | 0.19 |
| Usually skips meal | | 1.2% | | | | | | | | |
| Yes (%) | 93 | | (80.4) | | | | ref | | | |
| No (%) | 252 | | 1.7 | ± | 0.8 | 0.04 | 0.8 | ± | 0.8 | 0.31 |
| Physical activity (MET-hours) | 345 | | −0.2 | ± | 0.1 | 0.02 | −0.2 | ± | 0.1 | 0.03* |
| Constant | | | | | | | 66.5 | ± | 3.7 | |

**p*-value < 0.05; SE, Standard Error.

supported by related similar studies from South Africa (35), Korea (36), Iran (37), Benin (38), Southwest Ethiopia (39), Western Ethiopia (40), Eastern Ethiopia (41), and Adama town, Ethiopia (42), which reported a positive association between age and central obesity.

Married participants had a significantly higher average waist circumference value than the unmarried participants. This result is in line with studies conducted in China among twins (43), Greece (44), Western Ethiopia (31), Eastern Ethiopia (20), and Adama town, Ethiopia (45). This may be due to changes in behavior and lifestyle that occur after marriage, which affect energy consumption and expenditure. Moreover, married individuals may engage in less daily activities and exercises as parents often have less time for such activities (46, 47). The level of physical activity, computed as MET-hours, had a significant association with WC. This finding is supported by studies conducted in Ethiopia (14), Sri Lanka (48), Benin (49), Iran (50), Southwest Ethiopia (39), and Eastern Ethiopia (41). This may be because physical activity helps in reducing belly fat and increases total energy expenditure. The most changeable aspect of energy expenditure is leisure-time physical activity, and workplace physical activity may lower the risk of obesity in adults (51).

The study found a strong correlation between waist circumference and discretionary calorie intake each week. This result is consistent with other research findings, which reported that adults who consumed fewer discretionary calories had noticeably smaller waist circumference compared to adults who consumed more calories (52). This may be because discretionary foods are high in calories, low in nutrients, and high in saturated fat, added sugars, added salt, and cholesterol (48, 53). In addition, compared to their counterparts, individuals with NCDs had a noticeably higher average WC value (54, 55).

### 4.1 Strengths and limitations of the study

The study addresses an important gap by investigating central obesity in a specific occupational group (bank employees) in Ethiopia, a setting with limited prior research. The inclusion of diverse variables (e.g., dietary diversity, physical activity, and discretionary calorie intake) allowed for a robust multivariate analysis of central obesity determinants. The lack of detailed hip circumference analysis may have diminished the validity of the WHR findings. In addition, establishing causal inference was not possible due to the cross-sectional nature of the study. Furthermore, causal inferences could not be established due to the cross-sectional design of the study. Furthermore, height and weight data were not collected for the study group, allowing us to assess the limits of their influence on our findings.

## 5 Conclusion

Because bank personnel had a high mean waist circumference value, almost half of the participants were classified as centrally obese. Significant variables that influenced the waist circumference included age, marital status, discretionary calorie intake, the presence of NCDs, and MET-hours. These results highlight the necessity of implementing initiatives specifically designed to prevent non-communicable diseases by encouraging physical activity, promoting exercise during leisure time, building physical fitness facilities, and raising awareness of the importance of a healthy diet. All of these efforts can contribute to reducing the burden of obesity in the general population.

## Data availability statement

The original contributions presented in the study are included in the article and further inquiries can be directed to the corresponding author.

## Ethics statement

The studies involving humans were approved by Ethical clearance and approval were obtained from Wollo University College of Medicine and Health Sciences ethical review committee. Official letters were written to each selected bank and permission was obtained from the responsible managers. Oral informed consent was obtained from study participant and confidentiality and anonymity was secured. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

WY: Methodology, Writing – review & editing, Investigation, Supervision, Writing – original draft. LA: Data curation, Methodology, Writing – review & editing. FG: Methodology, Writing – original draft. TA: Methodology, Writing – review & editing. AM: Investigation, Methodology, Writing – original draft. FY: Formal analysis, Methodology, Writing – original draft.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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# Prevalence and associated factors of adult overweight and obesity in Southwestern China

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**Background:** Data on the prevalence of overweight and obesity in Southwestern China were limited. The aims of this study were to estimate the prevalence of overweight/obesity and their associated factors in this area.

**Methods:** A cross-sectional study was conducted from 2013 to 2014 in Chengdu and Chongqing, two megacities in Southwestern China. Data were obtained from questionnaires, physical examinations and lab tests. A total of 11,096 residents aged 35–79 years were included in the final analysis of this study.

**Results:** The prevalence of overweight and obesity among adults aged 35–79 years in Southwestern China were 29.7 and 4.4%, respectively. Multivariable logistic regression analysis suggested that women, non-smokers, ex-smokers, being hypertensive and diabetic were related to higher obesity prevalence, and that physically active adults and those aged 65–79 years were less likely to have obesity.

**Conclusion:** Obesity and overweight were prevalent in Southwestern China, especially among women, those with diabetes and/or hypertension, and those who have quitted smoking for more than 3 years.

KEYWORDS

**overweight, obesity, prevalence, risk factors, China**

## 1 Introduction

Overweight and obesity have increased in pandemic dimensions (1–5). To make the situation more complexing, regional differences exist in both obesity prevalence and trends between countries and within countries (1–4). Data (2) show that higher-than-optimal BMI caused an estimated 5 million deaths from noncommunicable diseases such as cardiovascular diseases, diabetes, cancers, neurological disorders, chronic respiratory diseases, and digestive disorders in 2019. To address the rising pandemic of obesity, there are widespread calls for regular monitoring of the trends in adult overweight and obesity prevalence in all populations (3–5). The prevalence of overweight and obesity in China have been on the rise in recent decades (6–8) and are projected to increase further (9), primarily driven by an increasing adoption of a western lifestyle and decreased physical activity (10, 11). Literature consistently shows that the prevalence of overweight and obesity varied considerably among provinces and regions in China (6–8). More than 14% of China's population live in Southwestern China (12), where about 53 million living in two megacities - Chengdu and Chongqing (13, 14). Southwestern China has economically developed fast over the past few decades, resulting in dramatic changes of lifestyle and probably growing prevalence of overweight and obesity.

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However, data on the prevalence and related factors of adult overweight and obesity in this area were lacking. In the current article, we estimate the prevalence of adult overweight and obesity and explore their potential influencing factors in Southwestern China.

# 2 Methods

## 2.1 Study oversight

Data used in our study were obtained from the survey of cardiovascular risk factors in Chengdu and Chongqing performed from 2013 to 2014. The survey was conducted in accordance with the basic principles of the Declaration of Helsinki. The protocol of this survey was approved by Ethics Committee of the Chengdu Second People's Hospital (No 2013015). All participants provided written informed consent before the enrollment.

## 2.2 Study population

This was a population-based cross-sectional survey conducted in urban areas of Chengdu and Chongqing, Southwestern China from September 2013 to March 2014. A multi-stage sampling method was used to select the study sample. In the first stage, we randomly selected three districts of Jinjiang, Longquanyi and Chenghua from Chengdu City, and two districts of Yubei and Jiangbei from Chongqing City. In the second stage, a subdistrict was selected randomly from each of these five districts. The third stage involved a random selection of one community from each subdistrict. Residents aged 35–79 years old were eligible if they had lived in these communities for 5 years or longer. According to the protocol, residents were ruled out if they had mental illness, malignancy, secondary hypertension, or if they were on dialysis or refused to participate.

## 2.3 Data collection

The current survey included face-to-face interviews, physiological examinations, both administered by trained medical personnel, and as well as laboratory tests. The health interview involved questions on demographic characteristics, lifestyle habits and other health-related questions. Examination components included body measurements (height and weight) and blood pressure. Height was measured without shoes and hat. Weight was measured after removal of shoes, hat and heavier trousers. The blood pressure was measured twice and the mean value was recorded. Laboratory components included fasting plasma glucose (FPG) and 2-h plasma glucose (2-h PG) after a 75 g oral glucose.

BMI was calculated as weight in kilograms divided by the square of the height in meters. Overweight and obesity were, respectively, defined as $25 \leq \text{BMI} < 30\ \text{kg/m}^2$ and $\text{BMI} \geq 30\ \text{kg/m}^2$ according to the WHO classification (15); the BMI cut-off points of the Working Group on Obesity in China ($\text{BMI} \geq 24.0\ \text{kg/m}^2$, $\text{BMI} \geq 28.0\ \text{kg/m}^2$) for overweight and obesity were also used (16). Smokers were defined as having smoked at least one cigarette per day and for more than a year, currently or having no smoking for less than 3 years prior to the survey. Ex-smokers were defined as those quitted smoking 3 years ago or earlier and once having at least one cigarette per day and for more than a year. Non-smokers were defined as having never smoked or having an average of less than one cigarette daily for less than a year. Alcohol drinkers were defined as having consumed at least once a week and for more than a year, currently or having no drinking for less than 3 years. Ex-drinkers were defined as those quitted drinking alcohol 3 years ago or earlier and once consumed alcohol at least once a week and for more than a year. Non-drinkers were defined as having never consumed alcohol or having consumed an average of less than once a week for less than a year. Participants were considered as being physically active if they reported having physical activity at least once a week. Patients were considered to have diabetes if they had a FPG level of at least 7.0 mmol/L and/or a 2-h PG level of at least 11.1 mmol/L, or if they had a medical history of diabetes. Patients were considered to have hypertension if they had a systolic blood pressure value of at least 140 mmHg and/or a diastolic blood pressure of at least 90 mmHg, or if they had a medical history of hypertension.

## 2.4 Statistical analysis

All statistical analyses were conducted with SPSS 23.0 software. A $p$ value of <0.05 was considered to be statistically significant. Continuous variables were presented as the mean ± standard derivation (SD), and the differences between different groups were compared by t-test or analysis of variance. Categorical variables were presented as percentage (%), and chi-square test was used to compare the differences between different groups. Trend analysis was done by Chi-Square trend test. The univariable and multivariable analyses of obesity were conducted by using the non-conditional Logistic regression model, and variable selecting was conducted by using the forward stepwise selection method. The likelihood ratio (LR) and odds ratio (OR) value and its 95% confidence interval were calculated.

# 3 Results

We excluded 638 participants from the 14,016 eligible residents according to the protocol and then 2,282 participants due to incomplete information, resulting in a total of 11,096 participants included in the final analysis. The mean age of the participants was 55.09 ± 10.96 years, 91.0% were married, 64.5% were women, 23.7% were self-reported having high school education or higher, 58.9% were physically active; 22.3% were smokers, 75.1% were non-smokers and 2.6% were ex-smokers; 17.2% were alcohol drinkers, 81.3% were non-drinkers and 1.5% were ex-drinkers. The mean values of systolic and diastolic blood pressure were 130.92 ± 21.53 mmHg and 78.50 ± 11.38 mmHg, respectively. The mean FPG and 2-h PG levels were 5.67 ± 2.05 mmol/L and 7.92 ± 3.83 mmol/L, respectively.

Compared with men (Table 1), women appeared to have higher rates of non-smokers (95.3% vs. 38.4%, $p < 0.001$), alcoholic non-drinkers (95.5% vs. 55.4%, $p < 0.001$) and being physically active (60.0% vs. 57.0%, $p = 0.002$), and have a lower rate of being married (88.8% vs. 95.0%, $p < 0.001$), having lower education (19.0% vs. 32.2%, $p < 0.001$). Women had significantly lower mean systolic and mean diastolic blood pressure values (129.90 ± 21.96 mmHg vs. 132.77 ± 20.08 mmHg, $p < 0.001$ and 77.45 ± 11.37 mmHg vs. 80.40 ± 11.14 mmHg, $p < 0.001$, respectively) and a significantly

TABLE 1 Characteristics of the participants stratified by sex*.

| Variable | Overall ($n$ = 11,096) | Men ($n$ = 3,935) | Women ($n$ = 7,161) | $p$ values |
|---|---|---|---|---|
| Age (y) | 55.09 ± 10.96 | 56.36 ± 11.21 | 54.39 ± 10.75 | < 0.001 |
| Married (%) | 10,097 (91.0) | 3,738 (95.0) | 6,359 (88.8) | < 0.001 |
| Higher education† (%) | 2,629 (23.7) | 1,269 (32.2) | 1,360 (19.0) | < 0.001 |
| Smoking status (%) | | | | < 0.001 |
| Smoker | 2,472 (22.3) | 2,175 (55.3) | 297 (4.1) | |
| Non-smoker | 8,338 (75.1) | 1,510 (38.4) | 6,828 (95.3) | |
| Ex-smoker | 286 (2.6) | 250 (6.4) | 36 (0.5) | |
| Alcohol drinking status (%) | | | | < 0.001 |
| Drinker | 1911 (17.2) | 1,631 (41.4) | 280 (3.9) | |
| Non-drinker | 9,021 (81.3) | 2,181 (55.4) | 6,840 (95.5) | |
| Ex-drinker | 164 (1.5) | 123 (3.1) | 41 (0.6) | |
| Physically active (%) | 6,505 (58.9) | 2,231 (57.0) | 4,274 (60.0) | 0.002 |
| SBP (mmHg) | 130.92 ± 21.35 | 132.77 ± 20.08 | 129.90 ± 21.96 | < 0.001 |
| DBP (mmHg) | 78.50 ± 11.38 | 80.40 ± 11.14 | 77.45 ± 11.37 | < 0.001 |
| FPG (mmol/L) | 5.67 ± 2.05 | 5.69 ± 1.89 | 5.66 ± 2.14 | 0.513 |
| 2-h PG (mmol/L) | 7.92 ± 3.83 | 7.75 ± 3.82 | 8.01 ± 3.83 | 0.001 |

*SBP denotes systolic blood pressure, DBP denotes diastolic blood pressure, FPG denotes fasting plasma glucose, 2-h PG denotes 2-h plasma glucose.
†Participants reported having high school education or higher.

higher mean 2-h PG level (8.01 ± 3.83 mmol/L vs. 7.75 ± 3.82 mmol/L, $p$ = 0.001). No significant difference for the FPG level was observed between male and female (5.66 ± 2.14 mmol/L vs. 5.69 ± 1.89 mmol/L, $p$ = 0.513).

In the overall participants, the mean BMI was 23.90 ± 3.53 kg/m$^2$ (Table 2). One-way ANOVA analysis showed a significant difference across the age groups ($p$ < 0.05). Additionally, women (24.04 ± 3.60 kg/m$^2$) had a higher BMI than men (23.64 ± 3.39 kg/m$^2$) ($p$ < 0.05). As for overweight and obesity (Table 3), the prevalence were 29.7 and 4.4%, respectively. The prevalence of overweight increased significantly with advancing age ($P$ for trend <0.05). Comparing with men, women have a significantly higher prevalence of overweight (30.5% for women and 28.1% for men, $p$ < 0.05) and obesity (5.1% for women and 3.2% for men, $p$ < 0.05). Similar results were observed based on the BMI cutoffs recommended by the Working Group on Obesity in China (Table 4).

Univariable logistic regression analysis suggested that women, non-smokers, ex-smokers, non-drinkers, being hypertensive and diabetic were associated with a higher prevalence of obesity and that being physically active was associated with a lower obesity prevalence (Table 5). Multivariable logistic regression analysis further supported that women, non-smokers, ex-smokers, being hypertensive and diabetic were related to higher obesity prevalence, and that physically active adults and those aged 65–79 years were less likely to have obesity.

TABLE 2 Age-sex-specific distributions of BMI*.

| Age | Overall ($n$ = 11,096) | Men ($n$ = 3,935) | Women ($n$ = 7,161) |
|---|---|---|---|
| 35–44 | 23.70 ± 3.56 | 23.67 ± 3.34 | 23.71 ± 3.66 |
| 45–54 | 23.78 ± 3.57 | 23.66 ± 3.30 | 23.83 ± 3.68 |
| 55–64 | 24.16 ± 3.49 | 23.74 ± 3.44 | 24.41 ± 3.50 |
| 65–79 | 23.85 ± 3.47† | 23.49 ± 3.42 | 24.13 ± 3.48 |
| Total | 23.90 ± 3.53 | 23.64 ± 3.39‡ | 24.04 ± 3.60 |

*BMI denotes body-mass index.
†One-way analysis of variance (ANOVA) $p$ < 0.05.
‡Compared with women, $p$ < 0.05.

## 4 Discussion

To our knowledge, this is the first large population-based face to face survey to investigate the prevalence of overweight and obesity in Chengdu and Chongqing in Southwestern China. The current study shows that 34.1% of the adults in this area had overweight or obesity. However, the obesity prevalence among the Southwestern China adults in our study (4.4%) is lower than the national prevalence of obesity in China (5.2%) (7), much lower than the adult obesity prevalence in the United States (41.9%) (17), that in Asian Americans (16.1%) (17), and that in the European Region (23%) (18), there are estimated to be several million adults with a BMI of ≥30 kg/m$^2$ due to the large population in this area. Furthermore, a recent research (9) suggests that the prevalence of overweight and obesity in Chinese adults are projected to increase further. Unsurprisingly, obesity and overweight represent major health challenges for local health-care system.

The prevalence of overweight and obesity in Southwestern China in our study were comparable to those in regions of South China (19) but much lower than those in North China (20–23). The striking North–South difference of the obesity prevalence in China has been documente with a BMI of ≥30 kg/m$^2$ d before (6–8). The regional disparities of obesity prevalence within countries have also been reported in Germany (24) and in the United States (25). The regional

TABLE 3 Age-sex-specific prevalence of overweight and obesity defined by WHO.

| Age | Overall ($n$ = 11,096) | | Men ($n$ = 3,935) | | Women ($n$ = 7,161) | |
|---|---|---|---|---|---|---|
| | Overweight | Obesity | Overweight | Obesity | Overweight | Obesity |
| 35–44 | 668 (27.0) | 106 (4.3) | 231 (28.5) | 27 (3.3) | 437 (26.3) | 79 (4.8) |
| 45–54 | 803 (29.1) | 117 (4.2) | 233 (29.2) | 16 (2.0) | 570 (29.0) | 101 (5.1) |
| 55–64 | 1,071 (30.1) | 177 (5.0) | 359 (27.2) | 46 (3.5) | 712 (31.7) | 131 (5.8) |
| 65–79 | 748 (32.6)† | 88 (3.8) | 282 (28.0) | 35 (3.5) | 466 (36.1) | 53 (4.1) |
| Total | 3,290 (29.7) | 488 (4.4) | 1,105 (28.1)* | 124 (3.2)‡ | 2,185 (30.5) | 364 (5.1) |

†$p$-trend for age < 0.05.
*Compared with women, $p < 0.05$.
‡Compared with women, $p < 0.05$.

TABLE 4 Age-sex-specific prevalence of overweight and obesity defined by the Working Group on Obesity in China.

| Age | Overall ($n$ = 11,096) | | Men ($n$ = 3,935) | | Women ($n$ = 7,161) | |
|---|---|---|---|---|---|---|
| | Overweight | Obesity | Overweight | Obesity | Overweight | Obesity |
| 35–44 | 752 (30.4) | 274 (11.1) | 288 (35.5) | 69 (8.5) | 464 (28.0) | 205 (12.4) |
| 45–54 | 925 (33.5) | 295 (10.7) | 279 (35.0) | 68 (8.5) | 646 (32.9) | 227 (11.5) |
| 55–64 | 1,328 (37.3) | 413 (11.6) | 462 (35.0) | 115 (8.7) | 866 (38.6) | 298 (13.3) |
| 65- | 850 (37.0)† | 239 (10.4) | 343 (34.1) | 79 (7.8) | 507 (39.3) | 160 (12.4) |
| Total | 3,855 (34.7) | 1,221 (11.0) | 1,372 (34.9) | 331 (8.4)‡ | 2,483 (34.7) | 890 (12.4) |

†$p$-trend for age < 0.05.
‡Compared with women, $p < 0.05$.

TABLE 5 Univariable and multivariable logistic regression analysis of obesity and the associated factors.

| | Univariable model | Multivariable model |
|---|---|---|
| Sex | | |
| Men | 1.000 (reference) | 1.000 (reference) |
| Women | 1.646 (1.337–2.026)† | 1.352 (1.035–1.765)† |
| Age (years) | | |
| 35–44 | 1.000 (reference) | 1.000 (reference) |
| 45–54 | 0.986 (0.754–1.290) | 0.941 (0.718–1.233) |
| 55–64 | 1.165 (0.911–1.491) | 0.989 (0.768–1.274) |
| 65–79 | 0.888 (0.665–1.185) | 0.658 (0.487–0.889)† |
| Married | 0.948 (0.695–1.294) | |
| Higher education* | 1.179 (0.773–1.796) | |
| Smoking history | | |
| Smoker | 1.000 (reference) | 1.000 (reference) |
| Non-smoker | 1.871 (1.437–2.436)† | 1.485 (1.074–2.055)† |
| Ex-smoker | 2.018 (1.136–3.584)† | 1.958 (1.096–3.497)† |
| Alcohol drinking history | | |
| Drinker | 1.000 (reference) | |
| Non-drinker | 1.572 (1.189–2.078)† | |
| Ex-drinker | 1.424 (0.639–3.173) | |
| Physically active | 0.698 (0.552–0.884)† | 0.752 (0.589–0.960)† |
| Hypertension | 1.981 (1.651–2.377)† | 1.987 (1.641–2.406)† |
| Diabetes mellitus | 1.593 (1.299–1.952)† | 1.401 (1.135–1.731)† |

†$p < 0.05$.
*Participants reported having high school education or higher.

differences between North and South China are at least partly related to or resulted from differences in climate, diet and living habits between the two areas (26, 27).

Obesity is a complex condition with many causal contributors including genetic ones and many environmental factors (28). Unsurprisingly not only the prevalence but also the associated risk factors of obesity vary across different regions of China. Our study shows that BMI, overweight prevalence and obesity prevalence in women were significantly higher than in men, in line with the findings of some researches in China (21). Multivariate logistic regression analysis suggested that women were related to a higher obesity prevalence. However, large heterogeneity in obesity prevalence in women and men existed in the published literature. A higher obesity prevalence in women than in men was also found at the global level (1). However, a lower obesity prevalence among women than among men was reported in some provinces of China (22, 23). In a research conducted in the overall China (8), men had a lower prevalence of obesity than did women in 2004, but this pattern had reversed by 2018. In the United States, there was no significant differences of adult obesity prevalence between men and women although the prevalence of severe obesity in adults was higher in women than men (17). The disparities suggest women may not be an independent risk factor of obesity, and understanding the drivers of these disparities might help to provide guidance for the most promising intervention strategies.

The current study shows the prevalence of obesity increased progressively with increasing age until 65 years, then dropped after 65 years, similar to previous studies (6), while the prevalence of overweight grew with increasing age across all age groups. The definite cause of the obesity prevalence drop in the older adult seems elusive. An assumption in a previous study (6) was that it was due to a decrease in total energy intake, muscle loss with age, chronic disease consumption in the older adult (29, 30). However, this assumption failed to explain the increased prevalence of overweight in the adults aged of 65–79 years. Another theory is that it could be due to survival disadvantage associated with obesity in the older population (28), which could explain the paradoxical changes of prevalence of overweight and obesity in the age group 65–79 since in older adults, as a meta-analysis showed (31), being overweight was not found to be associated with an increased mortality risk while having a BMI >33 kg/m$^2$ was.

Our study shows ex-smokers as well as non-smokers were more likely to have obesity, consistent with prior study (19). Smoking cessation at every age was associated with longer survival (32) and undoubtedly should be encouraged for all smokers even in the presence of a potential risk of weight gain. However, professional advice for weight control is reasonable for a greater health benefit even after 3 years of smoking cessation.

There are several limitations in this study. Firstly, the participants in our study were enrolled from Chengdu and Chongqing which made it inappropriate to extrapolate its conclusion to other regions of China. Secondly, the survey was conducted in urban areas of Southwestern China. As a result, it should be cautious to extrapolate the results to rural areas although recent evidence showed narrowing urban–rural difference among men and even higher mean BMI and obesity prevalence in women in rural settings compared with women in urban settings (8). Thirdly, the causal relationships between overweight/obesity and their associated factors cannot be established due to the cross-sectional design of the current study.

## 5 Conclusion

In summary, our study provides important information on the prevalence of overweight and obesity among adults in Southwestern China and important reference significant for preventing, screening, and controlling overweight and obesity in this vast population.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving humans were approved by Ethics Committee of the Chengdu Second People's Hospital. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

X-QZ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. H-AD: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. CH: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. J-XL: Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. Y-MH: Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. YL: Conceptualization, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. X-BH: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

## Publisher's note

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# The association between the lifestyle risk score and metabolically healthy and unhealthy obesity phenotype in Iranian women with overweight and obesity: a cross-sectional study

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**Background:** The evidence shows that all women with obesity do not develop metabolic complications thus, they may be metabolically healthy. The lifestyle factors in combination may influence obesity phenotypes including metabolically healthy and unhealthy obesity. While previous studies examined associations between single lifestyle factors and obesity phenotype, no previous study has examined associations between lifestyle risk score (LRS) and obesity phenotypes. This study for the first time created the LRS which is a combination of lifestyle factors and investigated the LRS in relation to various obesity phenotypes among women with overweight and obesity.

**Methods:** This cross-sectional study analyzed 278 women referred to health centers of the Tehran University of Medical Sciences. A multistage sampling method was used to recruit the participants. The LRS was created based on diet, physical activity (PA), sleep, obesity, and sociodemographic characteristics. A binary logistic regression analysis was used to evaluate the association between obesity phenotypes and LRS.

**Results:** Women with higher LRS had higher body mass index (BMI) and high-sensitivity C-reactive protein (hs-CRP) while had lower high-density lipoprotein cholesterol (HDL-C), PA, education levels, sleep quality, vegetables, grains and legumes intake. Furthermore, women with higher LRS were more likely to experience metabolically unhealthy obesity (MUO).

**Conclusion:** This study found significant associations between higher LRS and an increased likelihood of MUO. Further prospective studies are needed to advance our understanding of the relationship between lifestyle and obesity.

KEYWORDS

**lifestyle risk score, obesity phenotypes, metabolically healthy obesity, metabolically unhealthy obesity, healthy lifestyle**

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# Introduction

The global prevalence of overweight and obesity has risen steadily since 1975, affecting all regions (1). In particular, the Eastern Mediterranean Region (EMR) has undergone a significant nutrition transition in recent decades. Obesity stands out as a major health concern in EMR countries, including Iran (2). A systematic review and meta-analysis 2021, reported that the prevalence of overweight and obesity in Iranian adults was 35 and 21%, respectively (3). Notably, obesity rates are higher among Iranian women compared to men (4). Obesity is associated with metabolic disorders and non-communicable diseases (NCDs) such as diabetes, cardiovascular diseases, non-alcoholic fatty liver disease, and cancer (5). NCDs prevalence is increasing in the EMR countries, with NCDs being the major cause of 82% of deaths in Iran in 2020 (6). However, not all people with obesity develop metabolic complications (7). Some people with obesity are not experiencing dyslipidemia, hyperglycemia, and hypertension (8). This obesity phenotype is called metabolically healthy obesity (MHO). On the other hand, the metabolically unhealthy obesity (MUO) phenotype is the state of having at least two or more metabolic disorders (9). Based on the Karelis criteria, triglyceride (TG), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), hs-CRP, and homeostatic model assessment for insulin resistance (HOMA-IR) are involved in determining MHO (10, 11).

There is limited evidence on the determinant factors of MHO and MUO. The evidence shows that higher compliance with a healthier diet and higher physical activity (PA) levels are associated with a healthier metabolic state (12, 13). Furthermore, shorter sleepers are at a higher risk of developing metabolic complications (14).

The existing evidence shows that lifestyle-related factor including adiposity is associated with a higher risk of chronic diseases (15). Central body fat distribution and impaired adipose tissue function have been shown to be the predictors of obesity-related metabolic abnormalities (16). Also, a study reported that adults with lower levels of education and income are more likely to experience MUO (17).

Obesity is related to various lifestyle factors such as diet, PA, and sleep. As a result, several factors may simultaneously affect obesity. Lifestyle factors are often interconnected, with individuals typically adopting related lifestyle patterns (18, 19). As a result, lifestyle factors should be examined together to more effectively assess their impact on health (18, 19). *A priori* approach provides Information on a variety of lifestyle factors that can be described by a single score. This score could be used for assessing associations between healthy and unhealthy lifestyles and health outcomes (19, 20). While previous studies have explored the relationship between individual lifestyle factors and MHO and MUO, understanding how a combination of various lifestyle factors collectively influences obesity phenotypes remains limited. Holistic approaches such as *a priori* and posteriori methodologies offer a comprehensive perspective by examining lifestyle factors concurrently (21). Despite the importance of exploring the combined impact of different factors on MHO and MUO, there is a paucity of evidence in this area. A study on Lebanese adults with overweight and obesity in 2020 applied the factor analysis approach for the first time and assessed the association between lifestyle patterns and MHO and MUO and found a positive link between a healthy lifestyle pattern and MHO (22). Nevertheless, no prior study has employed an *a priori* approach to investigate the correlations between lifestyle scores and MHO and MUO. Consequently, this study is designed to explore the associations between lifestyle risk scores (LRS) and various obesity phenotypes among Iranian women with overweight and obesity. While Middle Eastern populations including Iranians have a particular type of obesity which is characterized by abdominal fat accumulation and greater waist circumference, the evidence on the lifestyle factors in relation to obesity phenotype is scant in this population. As a result, it is of significance to advance knowledge about this region (23).

# Methods

## Study design and population

This cross-sectional study was conducted on 278 Iranian women with overweight and obesity who were referred to health centers of the Tehran University of Medical Sciences (TUMS). A multistage random sampling method was used to recruit participants from the health centers in Tehran which were affiliated with TUMS. The inclusion criteria included adult women with a BMI of ≥25 kg/m$^2$. Individuals with a history of cardiovascular diseases, stroke, kidney disorders, liver diseases, thyroid disease, inflammatory illnesses, cancer, pregnancy, lactation, and menopause were excluded. Menopause could significantly change body composition, metabolic and hormonal changes (24, 25). Furthermore, based on the previous studies, under and over reporters of energy intakes below 800 or exceeding 4,200 kcal/day along with those with ongoing weight loss programs or taking weight loss supplements, were excluded (26–28). Women who did not respond to more than 70 questions on the food frequency questionnaire (FFQ) were excluded from participating in this study (29). A trained nutritionist conducted all the face to face interviews on one visit. This study was approved by the Ethical Committee of the Tehran University of Medical Sciences (ethics number: IR.TUMS.VCR.REC.1398.142) (30, 31). All methods were performed in accordance with the relevant guidelines and regulations. This article is prepared based on the Strengthening the Reporting of Observational Studies in Epidemiology—Nutritional Epidemiology (STROBE-Nut) reporting checklist (32).

## Sociodemographic characteristics

A trained nutritionist collected the data on sociodemographic characteristics including age, education level, marital status, occupation, and income, using a questionnaire in an interview. Participants were grouped based on their education levels and employment status: high education level (bachelor degree and higher), low education level (diploma and lower), employed and non-employed. Participants were categorized into high-income (above the poverty line) and low-income (below the poverty line) based on the poverty line in Iran which was determined as 11 million and 500 thousand rials for each person in 2018. The variables including occupation, education and income, were used to measure the socioeconomic status (SES) (33). Based on the SES median score, participants were categorized into two groups: high SES (≥2) and low SES (<2). The Pittsburgh Sleep Quality Index (PSQI) was used to assess participants' sleep quality including subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medications, and daytime dysfunction. The

PSQI score ranges between 0 and 21, and a total score over five indicates poor sleep quality (34). The International Physical Activity Questionnaire (IPAQ) was used to collect participants' PA (35). PA >20 the metabolic equivalent of task (MET-h/week) and PA $\leq$ 20 MET-h/week, were considered high and low levels of PA, respectively.

## Anthropometric indices

A Seca digital scale (Germany) was used to measure participants' body weight while the height was measured using a Seca 206 stadiometer (Germany) with a precision of 0.2 cm. Waist circumference (WC) and hip circumference (HC) were measured to the nearest 0.2 cm. The waist-to-height ratio (WHtR) was calculated as WC (cm) divided by height (cm). Given that WHtR is an indicator of early health risk linked to central obesity, two obesity categories were created; WHtR≤0.5 cm (non-obesity) and WHtR>0.5 (obesity), respectively (36, 37). Body composition was measured using a bioelectrical impedance analyzer (BIA; Inbody 770 Co., Seoul, Korea). Fat mass was measured using Dual Energy X-ray Absorptiometry (DXA) and bioelectrical Impedance Analysis.

## Dietary intake assessment

The frequency of each food consumed over the past year was collected using a 147-item semi-quantitative FFQ by a trained nutritionist. Participants reported the frequency of consumption for a given serving of each food item over the last year on a daily, weekly, monthly, or yearly basis. Portion size for the consumed food was converted to grams per day using household measurements (38). The NUTRITIONIST-IV (version 7.0; N Squared Computing, Salem, OR, United States) was used to measure the nutrients and energy intake. Considering the strong link between obesity and cardiovascular diseases, the American Heart Association (AHA) diet score was calculated for each participant (39, 40). The AHA components include fruits and vegetables, fish and shellfish, sodium, sugar-sweetened beverages, whole grains, nuts, seeds and legumes, processed meats, and saturated fats. Scores for each component ranged from 0 to 10, with a total score ranging from 0 to 80. Participants were categorized into two groups: those with lower adherence to dietary recommendations (< 40) and those with higher adherence to dietary recommendations (≥40) (41, 42) (Supplementary Table 1).

## Biochemical parameters

The blood test was taken after 10–12 h of fasting in the nutrition laboratory of the Tehran University of Medical Sciences. Fasting blood glucose (FBS), triglycerides (TG), and total cholesterol (TC) were measured using the glucose oxidase-phenol 4-amino antipyrine peroxidase (GOD-PAP) and glycerol-3-phosphate oxidase–phenol 4-amino antipyrine peroxidase (GPO-PAP) methods. Low-density lipoprotein (LDL) and high-density lipoprotein (HDL) cholesterol levels were determined through direct enzymatic clearance. The evaluation was based on the ratio of triglycerides (TG) to high-density lipoprotein cholesterol (HDL-C). Aspartate transaminase (AST) and Alanine transaminase (ALT) levels were measured based on the International Federation of Clinical Chemistry and Laboratory procedures. An immunoturbidimetric test with the Pars Azmoon kit (Pars Azmoon Inc. Tehran) was used to measure hs-CRP levels. Fasting blood sugar (FBS) was evaluated using the glucose Oxidase Phenol 4-Aminoantipyrine Peroxidase method. Insulin resistance (IR) was assessed based on the Homeostatic Model Assessment-Insulin Resistance (HOMA-IR) formula: fasting serum insulin (mIU/L) * FBS (mmol/L) / 22.5. The insulin levels were measured using a radio-immune assay method (28).

## LRS assessment

Based on the previous studies, lifestyle-related factors relevant to Iranians were selected (23, 43). The variables including sleep quality, SES, WHtR, dietary behavior and PA were used to create the LRS based on the previous studies (23, 43). Participants were scored 1 if the AHA diet score was <40, PA $\leq$ 20 MET-h/week, PSQI>5, WHtR>0.5, SES < 2, otherwise, there were scored 0.Participants were categorized as the high LRS group if the total LRS was higher than the median (score > 2). However, participants were classified as the low LRS group if the total LRS was lower than the median (score $\leq$ 2) (Supplementary Table 2).

## Metabolic health and its components

The metabolic healthy and unhealthy obesity were described based on the Karelis criteria which were used in the previous Iranian studies (28, 44, 45). The Karelis criteria have been utilized as they incorporate both insulin resistance and inflammation as practical indicators for assessing health in individuals with obesity (46). The participants were considered metabolically healthy subjects if they had four or more of the following components: triglycerides ≤1.7 mmol/L or use of lipid-lowering drugs, HDL ≥ 1.3 mmol/L, LDL ≤2.6 mmol/L, HOMA ≤2.7, and hs-CRP ≤3.0 mg/L. Otherwise, they were classified as metabolically unhealthy subjects (10, 11).

# Data analysis

The sample size was measured using the formula below: With $\alpha = 0.05$, $\beta = 0.95$, and r = 0.25, $n = [(Z\,1-\alpha + Z\,1-\beta) \times \sqrt{1} - r2]/r\,2 + 2)$. SPSS software version 26 was used to perform the data analysis. The Kolmogorov–Smirnov test was utilized to confirm the normal distribution of dependent variables. Continuous variables were presented as mean and standard deviation while categorical variables were presented as the number and percentage. The continuous variables between the two groups were compared using a one-way analysis of variance (ANOVA), while categorical variables were compared using the chi-square test. Analysis of covariance (ANCOVA) was used to adjust the analysis for potential confounders including age, energy intake, and BMI. A binary logistic regression analysis was used to evaluate the association between obesity phenotype categories (binary dependent variable) and LRS (continuous independent variable). The analysis was adjusted for age and energy intake. The 0.05 level of significance was considered as minimal statistical significance. A *p*-value <0.05 was considered statistically significant.

# Results

## The characteristics of participants

The mean age of participants was 36.2 years (± 8.4), with an average weight of 79.4 kg (± 10.8), a BMI of 30.5 kg/m$^2$ (± 3.6), and a WC of 94.9 cm (± 15.6). The majority of participants were married (72%), had supplementation intake (58%), had moderate SES (46%), had high LRS (65%), and were MUO (73%).

## The characteristics of participants over the median of LRS

The association between the characteristics of participants over the median of LRS is presented in Table 1. After adjusting for age, energy intake, BMI, women with higher LRS had lower PA ($p$ = 0.035), lower HDL ($p$ = 0.041) and higher hs-CRP ($p$ = 0.040) than women with lower LRS. The majority of women with higher LRS had lower education levels ($p$ < 0.001) and poor sleep quality ($p$ < 0.001).

## Dietary intakes over the median of LRS

Participants' dietary intake over the median of LRS is presented in Table 2. Women with higher LRS had a lower intake of vegetables ($p$ = 0.038), whole grains ($p$ = 0.007), and legumes ($p$ = 0.006) than women with lower LRS.

## The association between LRS and obesity phenotype

The association between LRS and obesity phenotype is found in Table 3. Women with higher LRS were more likely to be MUO (OR = 2.5, 95% CI = 1.3, 4.9, $p$ = 0.01). After controlling for age and energy intake, there was a significant positive association between higher LRS and MUO (OR = 2.4, 95% CI = 1.2, 4.7, $p$ = 0.01).

# Discussion

To the best of our knowledge, this study, for the first time, applied *a priori* approach to examine the LRS in relation to obesity phenotype. For developing the LRS, dietary intake, PA, sleep quality, WHtR, and SES were involved. The primary finding indicates that women with higher LRS are more likely to experience MUO.

This study demonstrated that women with higher LRS were at a greater risk of developing MUO. Our findings underscore the impact of lifestyle factors on obesity, particularly the role of PA. Women with higher LRS, indicative of unhealthier lifestyles, demonstrated lower levels of PA. The evidence consistently supports the positive influence of PA on metabolic health, with benefits including improved lipid profiles, insulin sensitivity, glucose uptake, and reduced blood pressure and inflammation (13, 47, 48). Furthermore, PA levels are found to be inversely associated with CRP levels (49). While no previous study assessed the LRS in relation to obesity phenotype, only one study employed an empirical approach and examined a combination of lifestyle factors in relation to obesity phenotype. (22) In accordance with our findings, a cross-sectional study by Naja et al. investigated 350 Lebanese adults and found a positive association between a healthier lifestyle pattern and MHO. This healthier lifestyle pattern was characterized by increased levels of PA (22). However, findings from studies examining the relationship between PA and obesity phenotype are inconsistent. While Farabi et al. and Lopez-Garcia et al. on 99 and 11,520 adults from America and Spain found that the MHO group had higher levels of PA than the MUO group (50, 51). A study on 3,807 adults from Irland did not find any difference in the levels of PA between MUO and MHO groups (52).

The positive association between higher LRS or unhealthier lifestyle and MUO might be due to dietary intake. Participants with lower LRS had a higher intake of whole grains, legumes and vegetables. Vegetables, whole grains and legumes have a high content of fibers, vitamin C, vitamin A, carotenoids, and phytochemicals, which are protective compounds against inflammation and oxidative stress (53). Consistent with our findings, Naja et al.2020 showed that a healthier lifestyle pattern characterized by a higher intake of fruits, vegetables, and legumes was positively linked to MHO (22). Furthermore, a study on 203 Iranian adolescents with overweight and obesity found that higher vegetable intake was negatively associated with MUO risk (54). Also a study on 137 adults with obesity from Brazil found that participants with MHO had a higher diet quality index (55).

A direct link between higher LRS and MUO may be explained by the sociodemgraphic characteristics of study participants. The majority of women with higher LRS had lower levels of education. There is limited evidence on the association between education levels and MHO and MUO. In line with our findings, two studies on 20,430 US adults and 11,520 Spanish adults found that participants with obesity and MUO had lower levels of education (17, 51). A study on 1,073 students from a Mexican university reported that higher education levels were associated with better metabolic health (56). There is abundant evidence indicating that a higher level of education is associated with improved health results and people with higher levels of education are more likely to follow the healthier behavior (56–59). Furthermore, the majority of participants with higher LRS had poor sleep quality. A study on 1,777 US adults reported that participants with sleep complications were less likely to be MHO. While the relationship between sleep and obesity phenotype is still unclear, the evidence shows that chronic lack of sleep results in weight gain through endocrine pathways including leptin and ghrelin which regulate appetite. Poor sleep quality is also associated with higher inflammation, increased sympathetic nervous system activity, insulin resistance, cardiometabolic dysfunction and obesity (60–62).

This study has several limitations that need to be taken into consideration. Firstly, the study design is cross-sectional which is susceptible to reverse causality when examining associations between the LRS and obesity phenotypes. Secondly, dietary intake was assessed through the FFQ, which introduces the potential for memory bias. Thirdly, it is important to note that the study participants were exclusively women from Tehran, making the sample non-representative of the entire Iranian population. Fourthly, this study used the Karelis criteria which does not account for blood pressure. This limitation should be taken into account while comparing the findings of this study with the studies that considered

TABLE 1 Characteristics of participants over the median of LRS ($n$ = 278).

| Variables | LRS | | p-value | p-value* |
|---|---|---|---|---|
| | Low risk ($n$ = 106) Median ≤ 2 | High risk ($n$ = 172) Median > 2 | | |
| | Mean ± SD | | | |
| Continuous variables, mean ± SD | | | | |
| Age (year) | 34.6 ± 8.1 | 36.4 ± 8.9 | 0.161 | 0.183 |
| Weight (Kg) | 77.8 ± 12.8 | 79.7 ± 8.9 | 0.260 | 0.369 |
| Height (cm) | 161.8 ± 5.2 | 160.7 ± 5.9 | 0.209 | 0.345 |
| PA (MET min/ week) | 1274.9 ± 1242.3 | 833.3 ± 1044.4 | **0.018** | **0.035** |
| BMI (Kg/m$^2$) | 29.6 ± 4.2 | 30.8 ± 2.9 | **0.021** | 0.064 |
| WC (cm) | 92.6 ± 22.3 | 95.7 ± 8.5 | 0.293 | 0.298 |
| Body fat mass (Kg) | 31.4 ± 8.4 | 33.3 ± 6.1 | 0.082 | 0.220 |
| FBS (mg/l) | 85.9 ± 8.5 | 87.4 ± 9.8 | 0.333 | 0.499 |
| TG (mg/l) | 113.9 ± 61.8 | 124.3 ± 58.4 | 0.265 | 0.524 |
| Chol (mg/l) | 177.7 ± 32.0 | 180.7 ± 32.6 | 0.545 | 0.839 |
| HDL (mg/l) | 49.3 ± 10.5 | 46.3 ± 9.5 | 0.055 | **0.041** |
| LDL (mg/l) | 93.7 ± 21.3 | 99.4 ± 21.9 | 0.093 | 0.263 |
| hs-CRP (mg/l) | 3.2 ± 3.7 | 5.2 ± 5.3 | **0.008** | **0.040** |
| Categorical variables, n (%) | | | | |
| Supplementation intake, N (%) | | | | |
| Yes % | 35 (36.1) | 62 (63.9) | 0.872 | 0.710 |
| No % | 25 (37.3) | 42 (62.7) | | |
| Educational status, N (%) | | | | |
| Diploma and under Diploma | 16 (18.0) | 73 (82.0) | **< 0.001** | **< 0.001** |
| Bachelor and higher | 50 (56.8) | 38 (43.2) | | |
| Marital status, N (%) | | | | |
| Single | 19 (37.3) | 32 (62.7) | 0.984 | 0.933 |
| Married | 46 (37.1) | 78 (62.9) | | |
| Economic status, N (%) | | | | |
| Poor | 17 (36.2) | 30 (63.8) | 0.429 | 0.546 |
| Moderate | 27 (34.6) | 51 (65.4) | | |
| Good | 22 (45.8) | 26 (54.2) | | |
| Sleep quality, N (%) | | | **<0.001** | **<0.001** |
| Poor | 22 (20.4) | 86 (79.6%) | | |
| Good | 42 (50%) | 42 (50%) | | |

BMI, body mass index; chol, Cholesterol; FBS, fasting blood sugar; HDL, High-density lipoprotein cholesterol; HOMA-IR index: Homeostatic Model Assessment of Insulin Resistance index; LDL, Low-density lipoprotein cholesterol; LRS, lifestyle risk score; MET, metabolic equivalent of task; PA, physical activity; WC, waist circumstance; WHR: waist to hip ratio, TG, Triglycerides. Values are represented as means and SD and number (%) for continuous and categorical variables, respectively. *$p$-value obtained from ANCOVA. The analysis was adjusted for age, energy intake, BMI. $p < 0.05$ were considered as significant. BMI was considered the collinear variable for body composition, and anthropometric measurements. The bold values are statistically significant $p < 0.05$.

blood pressure to define obesity phenotype. Fifthly, this study used *a priori* approach to create LRS which has limitations. The indices are created based on the current knowledge and the evidence. As a result, this approach is limited by the existing evidence (20). Lastly, the majority of participants were MUO which could influence the findings of this study. This study has a number of strengths. To the best of our knowledge, for the first time, this study applied an *a priori* approach, created the LRS and examined associations between the LRS and obesity phenotypes. The analysis of this study was controlled for several confounding factors. Given the obesity is more prevalent in the women from the EMR than men, this study included Iranian women with overweight and obesity.

## Conclusion

This study, used a novel *a priori* approach through the creation of LRS, showed significant associations between an unhealthier

TABLE 2 Dietary intake over the median of LRS ($n$ = 278).

| Variables | LRS | | $p$-value | $p$-value* |
|---|---|---|---|---|
| | Low risk ($n$ = 106) Median ≤ 2 | High risk ($n$ = 172) Median > 2 | | |
| | Mean ± SD | | | |
| Macronutrients and energy | | | | |
| Energy intake (kcal/d) | 2653.2 ± 781.3 | 2584.1 ± 741.4 | 0.558 | – |
| Cho (% TEI) | 56.8 ± 6.2 | 56.9 ± 6.8 | 0.859 | 0.945 |
| Fat (% TEI) | 31.9 ± 6.1 | 32.2 ± 6.2 | 0.750 | 0.674 |
| Protein (% TEI) | 14.3 ± 2.4 | 13.7 ± 2.3 | 0.245 | 0.249 |
| SFA (mg/d) | 27.8 ± 10.4 | 28.9 ± 12.4 | 0.560 | 0.248 |
| PUFA (mg/d) | 19.6 ± 9.3 | 20.4 ± 7.9 | 0.547 | 0.422 |
| MUFA (mg/d) | 30.6 ± 11.5 | 31.4 ± 11.0 | 0.859 | 0.211 |
| Trans fat (g/d) | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.325 | 0.355 |
| Total fiber (g/d) | 45.2 ± 18.8 | 44.5 ± 18.9 | 0.812 | 0.686 |
| Linoleic acid (g/d) | 16.7 ± 8.9 | 17.8 ± 7.6 | 0.390 | 0.324 |
| Linolenic acid (g/d) | 1.3 ± 0.7 | 1.2 ± 0.6 | 0.324 | 0.304 |
| EPA (g/d) | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.435 | 0.621 |
| DHA (g/d) | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.476 | 0.666 |
| Micronutrients | | | | |
| Vit A (mg/d) | 813.9 ± 431.6 | 751.4 ± 380.4 | 0.316 | 0.395 |
| Vit C (mg/d) | 188.3 ± 116.1 | 197.2 ± 148.5 | 0.676 | 0.436 |
| Vit E (mg/l) | 15.9 ± 8.0 | 17.9 ± 9.0 | 0.123 | 0.111 |
| Ca (mg/d) | 1184.9 ± 472.5 | 1155.6 ± 406.2 | 0.663 | 0.976 |
| Iron (mg/d) | 19.6 ± 6.5 | 18.3 ± 5.8 | 0.171 | 0.185 |
| Thiamin (mg/d) | 2.1 ± 0.7 | 2.1 ± 0.6 | 0.602 | 0.942 |
| Niacin (mg/d) | 26.0 ± 9.4 | 24.5 ± 8.9 | 0.300 | 0.603 |
| Riboflavin (mg/d) | 2.2 ± 0.8 | 2.2 ± 0.9 | 0.977 | 0.465 |
| Vit B5 (mg/d) | 6.8 ± 2.4 | 6.4 ± 2.8 | 0.308 | 0.470 |
| Vit B6 (mg/d) | 2.3 ± 0.8 | 2.1 ± 0.7 | 0.087 | 0.068 |
| Biotin (mg/d) | 40.3 ± 2.9 | 4.3 ± 1.9 | 0.235 | 0.460 |
| Folate (mcg/d) | 629.7 ± 193.7 | 589.3 ± 169.3 | 0.147 | 0.240 |
| Vit B12 (mcg/d) | 4.6 ± 2.9 | 4.3 ± 1.9 | 0.371 | 0.433 |
| Zinc (mg/d) | 13.7 ± 4.4 | 12.6 ± 4.3 | 0.105 | 0.060 |
| Copper (mg/d) | 2.1 ± 0.7 | 1.9 ± 0.8 | 0.224 | 0.353 |
| Selenium (mg/d) | 122.4 ± 42.3 | 117.6 ± 39.9 | 0.459 | 0.821 |
| Chromium (mg/d) | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.300 | 0.477 |
| Caffeine (mg/d) | 127.7 ± 83.9 | 147.3 ± 105.9 | 0.201 | 0.142 |
| Food groups | | | | |
| Fruits (g/d) | 545.9 ± 341.3 | 502.4 ± 329.8 | 0.669 | 0.908 |
| Vegetables (g/d) | 501.6 ± 289.5 | 403.5 ± 234.5 | **0.031** | **0.038** |
| Whole grains (g/d) | 9.8 ± 11.9 | 5.3 ± 7.6 | **0.005** | **0.007** |
| Nuts (g/d) | 17.0 ± 16.9 | 12.7 ± 14.7 | 0.111 | 0.138 |
| Legumes (g/d) | 67.3 ± 51.6 | 45.9 ± 33.6 | **0.004** | **0.006** |
| Eggs | 23.6 ± 13.2 | 19.8 ± 14.3 | 0.033 | 0.041 |
| Refined grains (g/d) | 443.4 ± 245.4 | 429.3 ± 192.6 | 0.243 | 0.309 |
| Dairy (g/d) | 418.3 ± 273.9 | 382.4 ± 226.7 | 0.667 | 0.820 |
| Red meat (g/d) | 443.4 ± 245.4 | 429.3 ± 192.6 | 0.080 | 0.099 |

*(Continued)*

TABLE 2 (Continued)

| Variables | LRS | | $p$-value | $p$-value* |
|---|---|---|---|---|
| | Low risk ($n$ = 106) Median ≤ 2 | High risk ($n$ = 172) Median > 2 | | |
| | Mean ± SD | | | |
| White meat (g/d) | 51.7 ± 45.2 | 45.4 ± 49.9 | 0.233 | 0.256 |
| Sea foods (g/d) | 12.5 ± 13.5 | 10.6 ± 11.4 | 0.779 | 0.720 |

Cho, Carbohydrate; DHA, Docosahexaenoic acid; EPA, eicosapentaenoic acid; LRS, lifestyle risk score; MUFA, monounsaturated fatty acid; SFA, saturated fatty acid; Pro, protein; PUFA, polyunsaturated fatty acid; TEI, Total energy index. Values are represented as means (SD). $p$-value obtained from ANVOVA test. The analysis was adjusted for macronutrients and micronutrients and energy intake. $p < 0.05$ were considered as significant. The bold values are statistically significant $p < 0.05$.

TABLE 3 Associations between obesity phenotypes and LRS ($n$ = 278).

| Obesity phenotype MUO | High LRS | | | | | |
|---|---|---|---|---|---|---|
| | Crude model | | | Model 1 | | |
| | OR | 95% CI | $p$ value | OR | 95% CI | $p$ value |
| | 2.5 | 1.3, 4.9 | **0.01** | 2.4 | 1.2, 4.7 | **0.01** |

CI, confidence interval; LRS, lifestyle risk score; MUO, metabolic unhealthy obesity. $p$-value was obtained using binary logistic regression. The odds ratio (OR) has been reported. Model 1: The analysis was adjusted for age, and energy intake. Metabolic healthy phenotype was considered a reference group. Low LRS was considered a reference group. $p < 0.05$ were considered significant. The bold values are statistically significant $p < 0.05$.

lifestyle, as indicated by a higher LRS, and an increased likelihood of MUO in Iranian women with overweight and obesity. The study highlights the intricate interplay between lifestyle elements and obesity phenotypes, emphasizing the need for comprehensive interventions addressing multiple factors to promote metabolic health. However, the study's cross-sectional nature introduces limitations, and further research, ideally incorporating longitudinal designs and diverse populations, is warranted to validate these associations and enhance our understanding of the complex relationship between lifestyle and obesity.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving humans were approved by the Human Ethics Committee of Tehran University of Medical Sciences (Ethics Number: IR.TUMS.VCR.REC.1398.142). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

SE: Writing – original draft, Writing – review & editing. FS: Writing – review & editing. ML: Writing – review & editing. AI: Writing – review & editing. NN: Writing – review & editing. KM: Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2025.1490937/full#supplementary-material

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# Evaluating diabetes-related nutrition knowledge and dietary beliefs among type 2 diabetes patients in Vidarbha region, Maharashtra: a mixed method approach for insightful analysis

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**Introduction:** The purpose of this study is to evaluate diabetes-related nutrition knowledge and dietary beliefs among Type 2 Diabetes Mellitus (T2DM) patients in the Vidarbha region, Maharashtra, utilizing a mixed method approach. The study aims to assess the existing gaps in nutritional education and dietary practices among T2DM patients, with a specific focus on understanding gender-based differences in knowledge levels.

**Methods:** A convergent parallel mixed method approach was employed at tertiary care hospital in Vidarbha region, over 18 months. Participants aged 30 years and above, diagnosed with T2DM for at least 6 months, were included. Quantitative data collection utilized structured questionnaires during interviews to assess socio-demographic characteristics and diabetes-related nutrition knowledge. Qualitative data collection involved in-depth interviews to explore participants' perspectives on dietary beliefs and practices, ensuring ethical approval and informed consent.

**Results:** Total 384 T2DM patients participated, revealing significant gender disparities in diabetes-related nutrition knowledge. Male participants exhibited higher awareness levels across various aspects of dietary recommendations. Quantitative analysis highlighted gender differences in knowledge regarding recommended fruit and vegetable intake, milk product consumption, types of fruits suitable for diabetics, inclusion of rice in diabetic diets, alcohol consumption, and recommended salt intake. Qualitative analysis identified key themes related to food choices, meal timing, portion control, dietary restrictions, and cultural influences.

**Conclusion:** The study emphasizes gender-sensitive educational interventions to enhance diabetes-related nutrition knowledge and self-management practices among T2DM patients. Tailored interventions addressing gender-based knowledge gaps are crucial for improving diabetes management outcomes and overall health among T2DM patients in Vidarbha, Maharashtra.

KEYWORDS
diabetes mellitus, diabetes nutrition, diabetes nutrition knowledge, Vidarbha region, dietary beliefs

## Introduction

Diabetes is a chronic, metabolic disease characterized by elevated levels of blood glucose (or blood sugar), which leads over time to serious damage to the heart, blood vessels, eyes, kidneys and nerves. The most common is type 2 diabetes, usually in adults, which occurs when the body becomes resistant to insulin or does not make enough insulin (1). Globally, the number of people with diabetes has increased from 382 million in 2013 to 592 million in 2023 and number is projected to more than doubled to 1.3 billion people by 2050, with most of those affected being in developing nations (2). With type 2 diabetes accounting for over 90% of cases, this sharp increase is closely linked to changing dietary and lifestyle choices characterized by higher energy intake and decreased physical activity—a trend that is parallel to the rising obesity epidemic of recent decades (3). India, widely known as the global centre for diabetes, reflects this alarming pattern, which is marked by a high percentage of undiagnosed cases that are frequently discovered only after complications arise (4, 5). In Maharashtra state prevalence of diabetes is 14.6% in urban and 10.7% in rural area among women, while 15.3% in urban area and 12.4% in rural area among men (6).

Despite advances in medical interventions, particularly the development of new antidiabetic drugs, combating diabetes remains difficult (7). The main source of the problem is the poor nutritional education and largely disregarded eating patterns of people with diabetes (8). It is essential to acknowledge the critical role that nutritional education plays, particularly in patients with Type 2 diabetes mellitus (T2DM) (9). This entails empowering people with diabetes-related nutrition knowledge encouraging healthy eating habits, such as sensible portion control and respect for suggested alcohol intake limits (10). In order to guarantee that nutrition education is effectively provided to people with type 2 diabetes, it becomes necessary to conduct a thorough evaluation of the gaps in the general public's knowledge regarding diabetes-related nutrition (11).

Existing literature reveals a weakly positive relationship between nutrition knowledge and dietary intake, with a consistent association between higher knowledge levels and increased consumption of fruits and vegetables (12). However, the extent of this relationship in the context of T2DM remains relatively unexplored. Against this backdrop, the present study seeks to address this gap by examining diabetes-related nutrition knowledge using a validated instrument. Our focus is on a sample of T2DM adults managed in usual care settings, aiming to contribute valuable insights into the intricate interplay between nutrition knowledge and dietary behaviors within this specific population. In the Vidarbha region of India, where diabetes prevalence is significant, understanding the dietary beliefs and practices among type 2 diabetes mellitus (T2DM) patients is crucial for effective management. We quantitatively estimate diabetes related nutrition knowledge of T2DM adults managed in usual care using validated instrument with respect to gender. Our study also wants to gain deeper insights into the factors influencing dietary behaviors and identify potential areas for intervention and education. This study not only contributes to the existing body of knowledge on T2DM management but also provides context-specific insights that can inform tailored interventions to improve dietary practices and ultimately enhance the quality of life for T2DM patients in the Vidarbha region. So, with this background this study plans to evaluate the diabetes related nutrition knowledge and the dietary beliefs among the population of Vidarbha region with Type2 diabetes.

## Materials and methods

Convergent parallel mixed method approach study design was adopted to investigate diabetes-related nutrition knowledge among Type 2 Diabetes Mellitus (T2DM) individuals at a tertiary care hospital from Vidarbha region, Maharashtra, India. This hospital, provides treatment to patients referred from the four districts of Vidarbha region which includes Buldhana, Washim, Akola and Amarvati district. The study spanned 18 months and focused on individuals aged 30 years and above, diagnosed with T2DM for at least 6 months, and willing to participate. Exclusions comprised pregnant or lactating women, with other co-morbidities and those with intensive care unit admissions. Ethical Approval was taken from Institutional Ethics Committee of Government Medical College, Akola, and informed consent was obtained from each participant before data collection. The study adhered to the guidelines outlined in the Declaration of Helsinki, with approval from the Ethics and Medical Research Committee.

### Quantitative component

A sample size of 384 was calculated using a 95% confidence interval and a 10% allowable error, assuming a 50% prevalence of diabetes-related nutrition knowledge (13). Data collection involved a structured questionnaire administered through interviews, conducted in the local Marathi language. The questionnaire comprised socio-demographic like socioeconomic status was categorized on the basis of having Below Poverty Line (BPL) card issued by the competent government authority and personal characteristics, including age, sex, duration of diabetes, family history etc. Next section focused on diabetes-related nutrition knowledge, utilizing a pretested and predesigned questionnaire derived from a general nutrition knowledge questionnaire as per the National Institute of Nutrition (ICMR-NIN) dietary guidelines for Indian (14). The questionnaire was peer-reviewed by the experts such as public health experts, nutritional counselor, diabetic specialist and physician and piloted beforehand. It encompassed topics such as dietary recommendations, food groups, healthy food choices, and diet-disease and weight management. Random blood sugar (RBS) was also measured at time of data collection with glucometer manufactured by Morepen Laboratories Limited, with its validity ensured through regular quality control checks, calibration against certified reference materials, for accuracy and precision. Blood drop was drawn from the finger cleaned with alcohol swab and priced with the help of sterile lancet for RBS measurement.

### Qualitative component

The qualitative approach for this study involved conducting in-depth interviews with 22 diabetic patients with their consent to explore their perspectives on various themes related to dietary management. Participants were selected purposefully to ensure diversity in age, gender, and cultural backgrounds. Each interview focused on exploring the participants' food choices, meal timing habits, portion control strategies, adherence to dietary restrictions, and the influence of cultural factors on their dietary practices. The data saturation meets after the 22 interviews as no new information or themes were emerged. Three trained interviewers which were post graduate students from Masters in Public Health (Nutrition) students were involved in data collection. All interviewers underwent a standardization process before conducting the interviews, which included familiarization with the questionnaire and regular monitoring to ensure consistency in how questions were asked. UK supervise and observed for the data accuracy and quality. Interviews were semi-structured and about 20–30 min. Participants were allowed to have the freedom to express their experiences and perspectives. Selected Participant group, ultimately help to provide rich insights into the lived experiences of diabetic patients in managing their diet.

## Data analysis

### Quantitative component

Analysis of data incorporated a standardized proforma for consistency and inter-observer agreement. Collected data was cross-checked and supervised. MS- excel is used for data entry, Epi info and Open Epi software were employed for analysis, along with duplicate entry to ensure data consistency. Simple proportions were calculated for each outcome indicator, and Chi-square test were applied to compare qualitative variables.

### Qualitative component

In data analysis was done manually, AM oversaw the thematic analysis process, ensuring consistency and accuracy across all stages: familiarization, coding, theme identification, theme review, theme definition, and reporting. SF conducted initial data coding, identifying key themes related to food choices, meal timing, portion control, dietary restrictions, and cultural influences. UK provided expertise in qualitative research methods, contributing to the refinement of themes, their review and definition, and the interpretation of findings, ensuring a comprehensive and robust analysis.

## Results

The study was conducted at the tertiary care hospital, aiming to explore the diabetes-related nutrition knowledge of T2DM adults managed in usual care. A total of 384 patients actively participated in the study.

TABLE 1 Baseline characteristics of study participants.

| Socio-demographic factors | *n*: 384 (%) |
|---|---|
| **Age (years)** | |
| 31–40 | 28 (7.31%) |
| 41–50 | 47 (12.2%) |
| 51–60 | 159 (41.47%) |
| >60 | 150 (39.02%) |
| **Sex** | |
| Male | 234 (60.9%) |
| Female | 150 (39.1%) |
| **Residence** | |
| Urban | 281 (73.2%) |
| Rural | 103 (26.8%) |
| **Marital status** | |
| Married | 365 (95.1%) |
| Single (Widow/Divorced/Single) | 19 (4.9%) |
| **Religion** | |
| Hindu | 262 (68.3%) |
| Muslim | 93 (24.4%) |
| Other | 29 (7.3%) |
| **Socio-economic status** | |
| Above poverty line (APL) | 150 (39.1%) |
| Below poverty line (BPL) | 234 (60.9%) |
| **Duration of diabetes (years)** | |
| <3 | 94 (24.4%) |
| 3–6 | 122 (31.7%) |
| 6–10 | 66 (17.1%) |
| >10 | 102 (26.8%) |
| **Fasting blood sugar (mg/dl)** | |
| Controlled (≤130) | 88 (22.8%) |
| Uncontrolled (>130) | 240 (62.6%) |
| Not knowing | 56 (14.6%) |
| **Management** | |
| Oral medication only | 253 (65.9%) |
| Insulin only | 19 (4.9%) |
| Combination (oral+ Insulin) | 112 (29.2%) |

The socio-demographic characteristics of the study participants revealed interesting trends from Table 1. The majority belonged to the age group of 51–60 years, constituting 159 (41.47%). The gender distribution favored males, comprising 234 (60.9%) of the participants. Urban residents constituted a substantial portion, accounting for 281 (73.2%) of the sample, while the majority were married 262 (95.1%). Hinduism was the predominant religion among the participants, with 262 (68.3%), and a significant proportion belonged to lower socio-economic classes, i.e., Below Poverty Line (BPL) 234 (60.9%).

TABLE 2 Diabetes related nutrition knowledge among study participant.

| Diabetes related nutrition knowledge | Correct answer (*n*: 384) (%) | Male (*n*: 234) (%) | Female (*n*:150) (%) | *p* value* |
|---|---|---|---|---|
| 1. How many times in one week a diabetic patient should eat fruits and vegetables? | 131 (34%) | 94 (40%) | 37 (25%) | 0.03 |
| 2. How many times in a week diabetic patient should consume milk and milk products? | 113 (29%) | 94 (40%) | 19 (13%) | 0.02 |
| 3. Which type of fruits the diabetic patient should eat? | 75 (20%) | 56 (24%) | 19 (13%) | 0.0001 |
| 4. Whether diabetic patients should include rice in their meals? | 225 (58.5%) | 150 (64%) | 75 (50%) | 0.0001 |
| 5. Should a diabetic patient drink alcohol? | 338 (88%) | 225 (96%) | 113 (75%) | 0.0001 |
| 6. In how much quantity salt should be eaten by patients suffering from diabetes? | 290 (75%) | 215 (92%) | 75 (50%) | 0.0001 |

*Chi-square test.

Examining the characteristics related to diabetes, it was observed that a considerable number of participants had been living with diabetes for 3–6 years 122 (31.7%). Fasting blood sugar levels were predominantly uncontrolled (>130 mg/dL) in 240 (62.6%) of cases. The majority managed their diabetes through oral medication 253 (65.9%), with a smaller percentage on insulin therapy or a combination of oral and insulin treatment.

The evaluation of knowledge related to diabetes and nutrition revealed notable differences among participants, particularly in terms of gender as mentioned in Table 2. Male participants demonstrated significantly higher awareness levels compared to their female counterparts in various aspects. For example, males showed better understanding of recommended fruit and vegetable intake (40% compared to 25% in females, $p = 0.03$), as well as milk product consumption (40% compared to 13% in females, $p = 0.02$). Similarly, males exhibited greater knowledge regarding the types of fruits suitable for diabetic individuals (24% compared to 13% in females, $p = 0.0001$) and the inclusion of rice in diabetic diets (64% compared to 50% in females, $p = 0.0001$). However, both genders showed similar levels of understanding regarding alcohol consumption (88% overall) and the recommended salt intake for diabetic patients (75% overall).

The thematic analysis (Table 3) of qualitative interviews conducted among study participants revealed several key findings regarding their dietary beliefs. Participants emphasized a strong inclination toward traditional food preferences, such as jowar (*Sorghum*), bajri (*pearl millet*), and tur (*red gram*), alongside a preference for locally sourced ingredients, attributing them with freshness and superior taste. As one participant remarked, *"I prefer locally grown vegetables and grains because they are fresh and healthier."* Additionally, participants expressed a consensus regarding the importance of early dinner consumption for controlling blood sugar levels, reflecting a belief in the direct impact of meal timing on glycemic control. A participant highlighted this, saying, *"I eat dinner early, around 7 pm, to manage our sugar levels better."* Portion control emerged as a prominent strategy, with participants employing visual cues and individualized approaches to manage portion sizes effectively. One participant stated, *"I use smaller plates to control portions and prevent overeating."* However, adherence to dietary restrictions posed significant challenges, particularly concerning sugar and carbohydrate intake, exacerbated during social gatherings where maintaining dietary discipline proved arduous. *"It's hard to resist sweets and snacks during festivals and parties,"* lamented a participant, reflecting on the challenges they faced. Cultural influences were cited as pervasive, shaping food choices and consumption patterns profoundly. "*I adhere to the practice of having dates during Ramadan as they provide a quick source of energy, but cautious about the portion sizes due to diabetes,*" emphasized a Muslim participant, highlighting the intersection of cultural traditions with dietary considerations among diabetic patients in the Vidarbha region. Another participant remarked, "Our culture emphasizes rich, flavorful food, which can be difficult to avoid, even with diabetes." Furthermore, participants predominantly relied on healthcare providers, particularly doctors and dietitians, for guidance on dietary management, highlighting the pivotal role of medical professionals in shaping dietary beliefs and practices among T2DM patients.

## Discussion

The results of the research we conducted reveal notable variations, in diabetes-related nutrition knowledge between male and female participants, highlighting the need for gender-specific educational interventions in managing Type 2 Diabetes Mellitus (T2DM). Our results are consistent with previous research, supporting earlier studies conducted in different regions that also identified gender-based disparities in diabetes knowledge and self-management practices. Our study did not prescribe or evaluate a single definition of an optimal diabetes diet. Instead, we adhered to the ICMR-NIN dietary guidelines for Indians, which provide evidence-based recommendations tailored to the Indian context. These guidelines emphasize culturally appropriate, region-specific, and balanced dietary choices for individuals with diabetes.

Our study revealed significant gender differences in DRNK, with male participants demonstrating higher knowledge across multiple domains, including recommended fruit and vegetable intake, milk product consumption, and types of fruits suitable for diabetics. This aligns with findings from Han et al. (11) who emphasized the importance of culturally tailored and gender-specific nutrition education programs to address these gaps. Similarly, Mankar et al. (15) highlighted that gender-specific factors, such as access to education and healthcare, significantly influence glycemic control in Indian populations. Similar to prior research in Bangladesh, our study reveals a widespread lack of knowledge among T2DM patients concerning the causes, management, and risk factors of diabetes,

TABLE 3 Qualitative findings on dietary beliefs among study participants.

| Theme | Sub-theme | Description | Representative quote | Interpretation |
|---|---|---|---|---|
| Food choices | Traditional food preferences | Most of the study participants said that they prefer traditional foods such as roti, dal, and vegetables, reflecting cultural dietary habits. | *I eat roti, dal and vegetable as it feels like complete meal.* | Cultural and familial influenced majorly contribute to diet preferences and practices in daily food consumptions. |
| | Preference for locally sourced ingredients | Locally sourced ingredients like fresh vegetables and fruits were favored due to their perceived health benefits and availability in the region by study participants | *I eat locally grown vegetables and grains like spinach, brinjal, jowar, wheat because they are fresh and healthier.* | It highlights the trust in local faming practices and belief of high-quality produces. |
| Meal timing | Early dinner preference | Many individuals exhibited a preference for early dinners, believing it helps in better blood sugar control and digestion. | *I eat dinner early, around 7 pm, to manage sugar levels better* | This reflects the belief of meal timing is deeply rooted in the society as the measure to control the glycemic levels. |
| | Belief in controlling blood sugar levels | There was a prevalent belief among many study participants that timing meals according to blood sugar levels can help manage diabetes effectively, influencing meal timing choices. | *I consume some food every two-three hourly. It help to keep my sugar levels under control* | Awareness of meal timing in glycemic control indicates knowledge about medical perspectives among population. |
| Portion control | Individualized portion management | Portion sizes were often adjusted based on individual preferences and perceived hunger levels, indicating a personalized approach to portion control. | *I use smaller plates to control portions. I am avoiding to eat some heavy foods like samosa; kachori; ghee etc.* | The individuals prefer different methods or approaches for the portion control in order to maintain ideal diet and glycemic levels. |
| Dietary restrictions | Struggle with sugar and carb intake | Majority of study participants talked about facing challenges in limiting sugar and carbohydrate intake, especially with traditional sweets and carb-rich foods deeply ingrained in local festivals. | *It's hard to resist sweets and snacks during festivals and parties.* | Emotional or behavioral psychological factors influenced the dietary restrictions among the individuals |
| | Challenges during social gatherings | Social gatherings present challenges as patients may encounter pressure to consume foods not aligned with their dietary restrictions, leading to dilemma told by study participants. | *In family functions like marriage; birthday parties or festivals like Diwali; Hoi it is difficult to say no to sweets and fried foods* | Social and peer pressure leading to poor adherences to the dietary practices especially at gatherings. |
| Cultural influences | Influence of cultural practices on diet | Cultural practices heavily influence dietary choices, with traditional beliefs shaping food preferences and meal habits among diabetic patients. | *I adhere to the practice of having dates during Ramadan as they provide a quick source of energy, but I am cautious about the portion sizes due to diabetes* | There strong cultural significance in dietary practices among the people with different cultural follows different diets and practices irrespective of its glycemic index |
| | Integration of modern dietary advice | While traditional practices dominate, there's an increasing integration of modern dietary advice, reflecting a shift toward incorporating medical recommendations. | *I follow my doctor's advice but still eats traditional sweets like puran-poli during festive seasons* | The integration of modern dietary advice alongside traditional practices highlights a gradual adaptation of medical recommendations by individuals but with selective adherence influenced by cultural preferences |

despite receiving professional health education (16). Likewise, studies in Thailand and Saudi Arabia have shown poor adherence to dietary recommendations among T2DM patients, indicating difficulties in translating knowledge into action (17). These results highlight the critical need for better educational initiatives catered to the unique requirements of individuals with type 2 diabetes, particularly in addressing gender-based differences. Cultural preferences and beliefs emerged as prominent themes influencing dietary practices among T2DM patients. Traditional foods, such as jowar and bajri, were favored, reflecting a reliance on locally sourced ingredients. This finding echoes the work of Leblanc et al. (18), who noted that cultural dietary patterns significantly shape adherence to dietary interventions. However, challenges, including adherence during social gatherings and cultural events, were evident. Blanks et al. observed similar challenges in their study of African American women, where social and cultural contexts shaped dietary behaviors and intervention outcomes.

In contrast, studies in China and Singapore have demonstrated the effectiveness of targeted educational interventions in improving diabetes-related nutrition knowledge and self-management behaviors among T2DM patients (19). Educational programs in China led to significant enhancements in nutrition knowledge and practice accuracy, resulting in better glycaemic control (19). Similarly, although no direct link was found between knowledge and diet quality in Singapore, barriers and facilitators to dietary guideline adherence were identified, emphasizing the importance of comprehensive educational interventions (11). Nutrition education plays a pivotal role in bridging knowledge gaps and improving self-management among T2DM patients. The systematic review by Karkhah et al. (20) found that higher education levels and family history of diabetes were positively correlated with better DRNK. Our findings, where urban male participants demonstrated higher knowledge, further emphasize the need for education tailored to rural and female populations. Furthermore, Ramadas et al. (21) and Ahmed et al. emphasized the role of structured educational interventions in bridging these gaps, demonstrating improvements in dietary practices and glycemic control post-intervention.

Additionally, studies conducted in Trinidad and Tobago demonstrated the critical impact that dietary guidance has in improving diabetes knowledge, attitudes, and practices among patients (22). Patients who received counseling demonstrated better knowledge and adherence to dietary recommendations compared to those who did not receive counseling. Barriers, such as lack of time, stress, and conflicts between personal values and medical advice, were consistent with global studies. Han et al. (11) identified similar barriers in Singapore, emphasizing the need for personalized and context-specific interventions to improve dietary adherence. Furthermore, Auryan and Itamar (23), stressed the importance of addressing gender-specific challenges, particularly among women who face unique physiological and socio-economic barriers. This emphasises how important personalized education and counseling are in improving diabetes-related outcomes.

In comparison to these studies, our research makes a contribution by identifying the precise domains of diabetes-related nutrition knowledge where gender differences are present. Male participants showed higher awareness levels compared to females in various aspects of dietary recommendations for diabetes management but reasons for this is not studied in our research. It might be due to the cultural or other factors like education that need to be explored in further future research. These variations highlight the requirement for customized educational interventions that address gender-specific knowledge gaps and empower all T2DM patients to make informed dietary choices for better disease management.

The study conducted by Colles et al. (24) among a group of older, well-educated Asian Indians residing in urbanized regions of New Delhi shed light on various dietary patterns and beliefs prevalent among individuals with Type 2 diabetes mellitus (T2DM). Despite recommendations for higher consumption of fruits and vegetables, the average daily intake among respondents remained low, with a preference for processed meals and snacks being observed. Interestingly, those who reported eating according to what they were served displayed lower consumption of fruits and vegetables, indicating a potential lack of personal food choice responsibility. Additionally, erroneous beliefs regarding the health value of certain foods, particularly processed snack foods, were associated with higher consumption frequency. The study emphasized the importance of personalized dietary education and active participation in diabetes self-management, highlighting the need for interventions targeting cultural influences and promoting healthier food choices. These findings echo those of other studies, such as the one conducted in Southern India, which also reported poor knowledge about diabetes management, especially among females and those less educated (25). Furthermore, the study revealed the common use of high-fat ingredients like butter and desi ghee, suggesting a need for public health interventions aimed at reducing saturated fat intake and increasing awareness about healthier dietary practices. Despite its limitations, including the reliance on memory for dietary reporting and the small sample size, this study provides valuable insights into the dietary beliefs and behaviors of T2DM patients in urban North India, underscoring the necessity for tailored dietary interventions to improve metabolic health outcomes in this population. The exclusion of LGBTQ+ individuals, whose unique dietary beliefs and access to healthcare may differ from the general population. Additionally, individuals with other comorbid conditions were not included, which may limit the generalizability of the findings to those with complex health profiles that require specialized dietary and medical interventions.

In conclusion, our study highlights the importance of gender-sensitive educational interventions in improving diabetes-related nutrition knowledge and self-management practices among T2DM patients. By addressing the knowledge gaps between genders and offering specialized education and counseling, healthcare providers can effectively enhance diabetes management outcomes and promote better overall health and well-being among T2DM patients.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving humans were approved by the Institutional Ethics Committee Government Medical College, Akola vide letter no. ANAT 204/2022. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

UK: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MP: Data curation, Software, Supervision, Writing – review & editing, Investigation, Methodology. AS: Writing – review & editing, Visualization, Software. ST: Data curation, Formal analysis, Writing – review & editing. AG: Writing – review & editing, Supervision. MT: Resources, Validation, Writing – review & editing, Data curation, Investigation, Project administration, Supervision. SF: Project administration, Writing – review & editing, Data curation, Investigation, Validation.

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# Different factors modulate visceral and subcutaneous fat accumulation in adults: a single-center study in Brazil

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**Background:** Abdominal adipose tissue consists of visceral and subcutaneous fat deposits, each with unique metabolic and functional properties. Identifying the characteristics that influence different obesity phenotypes can support targeted prevention and intervention strategies.

**Objective:** To identify predictive factors associated with visceral and subcutaneous adipose tissue accumulation.

**Methods:** This is a cross-sectional study including adults of both sexes aged ≥20 years under outpatient care in a public healthcare service in Northeast Brazil. Visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT) were measured via ultrasound. Anthropometric, clinical, sociodemographic, and behavioral variables were incorporated into the predictive model.

**Results:** A total of 347 individuals were included. They were median age of 47.0 years (interquartile range: 39.0 to 56.0). Visceral obesity was found in 79.3% of the sample. Adjusted analysis demonstrated that physical inactivity (OR 2.3; 95% CI 1.1–4.7; $p$ = 0.023) and elevated waist circumference (WC) (OR 6.4; 95% CI 2.6–15.8 $p$ < 0.001) were associated with VAT accumulation. Alcohol consumption increased the likelihood of SAT accumulation by 2.2 times (95% CI 1.3–3.7; $p$ = 0.005), while elevated WC raised this likelihood by 4.5 times (95% CI 2.1–9.8; $p$ < 0.001). The VAT/SAT ratio was significantly higher in older adults (OR 5.5; 95%CI 2.0–14.8; $p$ = 0.001), among individuals of Mixed Race and Black, those with lower educational levels (OR 2.4; 95%CI 1.1–5.2; $p$ = 0.028), and in diabetics (OR 2.4; 95%CI 1.2–4.9; $p$ = 0.017).

**Conclusion:** Distinct factors influence visceral and subcutaneous obesity. Sedentary behavior emerged as an independent predictor of visceral obesity, while alcohol consumption was associated with a subcutaneous obesity pattern. Diabetes and sociodemographic factors (older age, non-White race, and lower education) were predictive of an elevated VAT/SAT ratio.

KEYWORDS

**abdominal fat, subcutaneous fat, body fat distribution, obesity, body composition**

## 1 Introduction

Obesity is a chronic, complex, and multifactorial condition involving biological, psychosocial, socioeconomic, and environmental factors. Obesity can result from high intake of poor-quality foods combined with low energy expenditure (1). Obesity is a serious public health challenge; in recent decades, its prevalence has tripled worldwide, emerging as a major cause of mortality and disability with significant impact on adult morbidity patterns. According to estimates from the World Health Organization (WHO), 2.5 billion adults were classified as overweight in 2022, and in the previous year, obesity contributed to approximately 2.8 million deaths due to non-communicable diseases (NCDs) (2, 3).

Adipose tissue serves multiple functions, primarily as an energy reservoir (4, 5). However, body fat distribution is an additional crucial predictor of cardiovascular risk (4, 5). Abdominal fat comprises subcutaneous and visceral fat, each of which poses distinct risks for metabolic and hemodynamic changes (6). Roughly 80% of total body fat is located subcutaneously, predominantly in the gluteofemoral region, back, and anterior abdominal wall. Visceral fat, however, constitutes 10–20% of total fat in men and 5–8% in women (7) and is located around the viscera and peritoneum, bordering the dorsal side of the intestine and the ventral surface of the kidney (4).

Subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT) differ in morphology and function. SAT drains venously through the systemic circulation, whereas VAT is perfused by the portal circulation (8, 9), rendering VAT metabolically more active and a greater source of inflammatory cytokines (4, 7, 10). Consequently, the lipolytic activity of abdominal VAT constantly releases free fatty acids, which, drained by the portal vein, accumulate in the liver, leading to alterations in lipid and glucose metabolism (7) and directly contributing to the rise in chronic diseases (6, 11). However, the absolute VAT quantification individually may not fully reflect an individual's risk for visceral obesity. The VAT/SAT ratio is considered as an alternative and appropriate indicator, as it reflects both visceral fat accumulation and an individual's predisposition to preferentially store fat viscerally (12, 13). This ratio has also been described as a proxy for cardiometabolic risk (13).

The deleterious effects of excessive body fat are extensive; however, the tendency to store fat in different locations under conditions of excess energy intake varies greatly between individuals (14). Despite this, there remain significant gaps in understanding the profiles of individuals at higher risk of accumulating abdominal fat in either subcutaneous or visceral deposits. Therefore, the objective of this study was to assess the predictive factors influencing the accumulation of subcutaneous and visceral adipose tissue. This approach potentially contributes to identifying characteristics that define subcutaneous and visceral abdominal obesity phenotypes, guiding targeted intervention strategies.

## 2 Materials and methods

This is a cross-sectional study conducted at a public university hospital specializing in cardiology in Northeastern Brazil. Volunteers of both genders aged ≥20 years, receiving outpatient care at a public university hospital in Northeast Brazil, were included. At this outpatient clinic, the population is predominantly composed of individuals with chronic non-infectious diseases: systemic arterial hypertension, diabetes mellitus, metabolic syndrome, and dyslipidemia.

All patients provided informed consent and the study protocol adhered to ethical standards for research involving human subjects and was approved under protocol number 4.659.262/2021. Exclusion criteria were individuals with hepatomegaly and/or splenomegaly, ascites, recent abdominal surgery, underwent surgical weight loss treatment, pregnancy, or had given birth within 6 months prior to the study screening. Participants with physical limitations precluding anthropometric measurements were also excluded, as these conditions could affect intra-abdominal fat measurement.

Sample size was calculated using the STATCALC module in Epi Info software, version 6.04 [WHO/CDC, Atlanta, GA, United States], based on a visceral obesity prevalence of 68.3%, obtained from a pilot study involving the first 30 patients. A 5.0% standard error and a 95% confidence interval were applied, resulting in a minimum required sample of 333 patients. To account for potential losses, the sample size was increased by 10%, leading to a final sample size of 367 individuals.

VAT and SAT were assessed using ultrasound (US) with a Vivid T8 Pro Color Doppler Ultrasound System (GE, P.O., Asia). All participants were evaluated in the supine position, with the right arm raised and a minimum fasting period of 4 h (15, 16). A 3.5 MHz convex electronic transducer was positioned transversely 1 cm above the umbilical scar. Visceral fat thickness was defined as the greatest distance, in centimeters, between the inner (deep) surface of the rectus abdominis muscle and the anterior wall of the aorta. Subcutaneous fat thickness was measured as the distance, in centimeters, between the skin and the upper surface of the rectus abdominis muscle (16). Measurements were taken with participants exhaling and without abdominal pressure to avoid underestimation. Each measurement was taken twice and repeated if the measurement error exceeded 0.1 cm (16).

Cut-off values for visceral obesity were set at VAT ≥5.39 cm for men and ≥ 4.27 cm for women (17). Subcutaneous obesity was defined by SAT values above the upper tertile for each sex, with thresholds of ≥2.83 cm for men and ≥ 3.68 cm for women (18). The visceral-to-subcutaneous fat ratio (VAT/SAT) was calculated, with values above the highest tertile for each sex (≥3.60 for men and ≥ 2.14 for women) used as indicators of visceral fat accumulation predisposition and as criteria for elevated VAT/SAT ratio. Among anthropometric parameters, body mass index (BMI) was calculated using the equation weight/height$^2$, following WHO classifications (19). Waist circumference (WC) was measured at the narrowest point between the last rib and the iliac crest (20) and classified as WC ≥94 cm for men and ≥ 80 cm for women to indicate higher values (19).

Weight (kg) and height (m) were measured according to techniques recommended by Lohman et al. (20), using an electronic scale (Welmy®, Santa Bárbara d'Oeste, São Paulo, Brazil) with a capacity of 150 kg and an accuracy of 100 g, equipped with an attached stadiometer precise to 1 mm. For WC (cm) measurement, a flexible, non-elastic measuring tape with 0.1 cm accuracy was used. Measurements were collected twice by trained observers, with additional measurements taken if discrepancies greater than 1 cm or 100 g were noted.

Sociodemographic variables included age, sex, self-reported race & ethnicity (categorized as White, Black, and Mixed race), years of education, per capita family income, and socioeconomic status. Clinical variables included hypertension and diabetes mellitus, defined by prior medical diagnosis, use of antihypertensive, oral hypoglycemic, or insulin medications, and recorded in the participant's medical records. To determine socioeconomic status, the "Brazilian Economic Classification Criteria" established by the Brazilian Association of Anthropology and the Brazilian Association of Research Companies (21) was used. This tool scores household possessions and the education level of the family head, classifying individuals into economic classes A1, A2, B1, B2, C1, C2, D, and E, from highest to lowest purchasing power (21). These economic classes were subsequently recategorized into high (A1 and B1), middle (B2 and C1), and low (C2, D, and E) socioeconomic status (22).

Behavioral variables included alcohol consumption, smoking, and physical activity level. Smoking status was categorized as smoker (individual currently smoking), non-smoker (individual who never smoked or quit over 10 years ago), and former smoker (individual who quit between one and 10 years before the study) (23). Alcohol consumption was recorded as a dichotomous variable ("yes" or "no"). To assess physical activity, the International Physical Activity Questionnaire (IPAQ) short version was used, covering four domains of physical activity: leisure, household activities, occupational activities, and transportation-related activities. A physical activity score in minutes per week was calculated by summing the time spent on all activities, with <150 min per week serving as the cutoff for classifying individuals as insufficiently active or sedentary (24, 25).

Data were analyzed using the Statistical Package for Social Sciences – SPSS version 13.0 (IBM® Inc., Chicago, IL, United States). Continuous variables were tested for normality using the Kolmogorov–Smirnov test. Variables with a normal distribution were described using mean and standard deviation, while non-Gaussian variables were presented as medians and interquartile ranges. Proportions were reported with a 95% confidence interval using a binomial approximation to the normal distribution. Intra- and inter-observer reproducibility of the US measurements was evaluated using the intraclass correlation coefficient and 95% limits of agreement, with triplicate measurements for each anatomical site.

A univariate analysis was conducted between the dependent variables (visceral and subcutaneous obesity) and the independent variables, using the Chi-square test and determining prevalence ratios (PR) with their 95% confidence intervals. To examine the independence of associations between dependent and independent variables, a multivariable binary logistic regression model was developed. Independent variables were tested for multicollinearity using Variance Inflation Factor (VIF) and Tolerance statistics (>0.10 and < 3). Logistic regression was performed using the purposeful selection method, where variables associated with the outcome with $p < 0.20$ in univariate analysis were included. Equality of hypotheses was rejected for $p < 0.05$.

## 3 Results

Intra- and inter-observer calibration evaluation for US procedures demonstrated a high inter-observer reproducibility, with Intraclass Correlation Coefficients (ICC) exceeding 0.97 for VAT and greater than 0.98 for SAT. Intra-observer reproducibility was also high, with ICC values above 0.90 for all VAT and SAT assessments.

A total of 367 patients were initially screened. Following exclusions (data inconsistencies or refusal), the final sample included 347 individuals. They were most women (66.3%), with a median age of 47.0 years (interquartile range: 39.0–56.0). A total of 78.8% of the sample presented with more than 9 years of education, and 62.0% classified as middle to low socioeconomic status. Hypertension and diabetes mellitus was found in 47.3 and 25.1%, respectively. Around 75% of the participants were insufficiently active, and 92.0% were overweight by BMI. The prevalence of visceral obesity was 79.3% (Table 1).

Univariate analyses are detailed in Tables 2–4. Visceral obesity was associated with female sex, age ≥ 60 years, lower education level, higher income, lower social class, hypertension, diabetes, physical inactivity, smoking (current or former), overweight, and elevated waist circumference. Higher subcutaneous fat accumulation was associated with age (more common in individuals aged 20–59), higher education, absence of diabetes, alcohol consumption, normal weight, and elevated WC. An elevated VAT/SAT ratio was associated with older age, lower education level, higher income, hypertension, diabetes, current or former smoking, overweight, elevated waist circumference, and abstention from alcohol consumption.

After adjusting for confounders, only physical inactivity and elevated WC remained associated with VAT accumulation, with an odds ratio of 2.3 (95% CI 1.1–4.7; $p = 0.023$) for visceral obesity in sedentary individuals and 6.4 (95% CI 2.6–15.8; $p < 0.001$) for individuals with elevated waist circumference. Regarding subcutaneous obesity, older adults, individuals with malnutrition, and those with BMI >25 kg/m$^2$ were protected against SAT accumulation, while alcohol consumption increased the odds of SAT accumulation by 2.2 times (95% CI 1.3–3.7; $p = 0.005$), and elevated waist circumference increased this likelihood by 4.5 times (95% CI 2.1–9.8; p < 0.001). An elevated VAT/SAT ratio was more common among older adults (OR 5.5; 95% CI 2.0–14.8; $p = 0.001$), individuals of Mixed Race and Black, those with lower education (OR 2.4; 95% CI 1.1–5.2; $p = 0.028$), and diabetics (OR 2.4; 95% CI 1.2–4.9; $p = 0.017$). Alcohol consumption provided protection against an elevated VAT/SAT ratio (OR 0.5; 95% CI 0.2–0.9; $p = 0.015$) (Table 5).

## 4 Discussion

This study aimed to identify predictive factors for visceral and subcutaneous obesity phenotypes and characteristics associated with an elevated VAT/SAT ratio, demonstrating that distinct factors may influence the accumulation of each abdominal adipose tissue (AAT) component. Our main results demonstrate that physical inactivity was predictor of higher VAT, while older age and alcohol consumption were independently associated with greater SAT accumulation. The predisposition to accumulate VAT, represented by the VAT/SAT ratio, was influenced by sociodemographic factors (older age, non-White race, and lower education) and diabetes. WC was an independent predictor of both VAT and SAT, though not of the ratio between these components.

Studies investigating modulating factors of the abdominal fat distribution across visceral and subcutaneous depots remain underexplored. However, it is known that abdominal fat distribution is influenced by complex interactions among multiple factors, including genetics, sex, race, age, dietary habits, physical activity level,

TABLE 1 Characteristics of the sample (*N* = 347).

| Variables | N | % | 95% CI |
|---|---|---|---|
| Sex | | | |
| Male | 117 | 33.7 | 29.0–38.9 |
| Female | 230 | 66.3 | 61.2–71.1 |
| Age in years | | | |
| 20–59 | 298 | 85.9 | 81.8–89.2 |
| ≥60 | 49 | 14.1 | 10.9–18.2 |
| Race and ethnicity | | | |
| White | 113 | 32.6 | 27.9–37.7 |
| Black | 75 | 21.6 | 17.6–26.2 |
| Mixed race | 159 | 45.8 | 40.6–51.1 |
| Years of study | | | |
| ≤9 | 76 | 22.0 | 17.9–26.6 |
| >9 | 270 | 78.8 | 73.2–81.9 |
| Income | | | |
| Lowest tertile | 230 | 66.5 | 61.2–71.1 |
| 2nd and 3rd tertile | 116 | 33.5 | 28.7–38.6 |
| Social status | | | |
| A1 e B1 (High) | 24 | 7.1 | 4.7–10.1 |
| B2 e C1 (Middle) | 183 | 53.8 | 47.5–57.9 |
| C2. D e E (Low) | 133 | 39.1 | 33.4–43.6 |
| SAH | 164 | 47.3 | 42.1–52.5 |
| DM | 87 | 25.1 | 20.8–29.9 |
| Alcohol intake | 153 | 44.1 | 39.0–49.4 |
| Physical activity status | | | |
| Insufficient (<150 min/week) | 251 | 74.9 | 67.4–76.8 |
| Sufficient (≥150 min/week) | 87 | 25.1 | 20.8–29.9 |
| Smoking status | | | |
| Current | 11 | 3.2 | 1.8–5.6 |
| Non-smoker | 271 | 78.1 | 73.4–82.1 |
| Former | 65 | 18.7 | 15.0–23.2 |
| BMI (kg/m$^2$) | | | |
| Underweight | 50 | 14.4 | 11.1–18.5 |
| Normal range | 82 | 23.6 | 19.5–28.4 |
| Excess weight | 215 | 62.0 | 56.8–66.9 |
| Waist circumference | | | |
| Normal | 115 | 33.4 | 28.4–38.2 |
| Elevated | 229 | 66.6 | 60.9–70.8 |
| Visceral obesity | | | |
| No | 72 | 20.7 | 16.8–25.3 |
| Yes | 275 | 79.3 | 74.7–83.2 |

95% CI: 95% confidence interval; BMI: body mass index; DM: Diabetes mellitus; SAH: systemic arterial hypertension.

comorbidities, and hormonal factors (23, 26–29). Given the distinct metabolic and functional behaviors of different abdominal fat compartments (30, 31), there is growing global interest in quantifying abdominal adiposity and identifying factors influencing its accumulation (26, 32).

## 4.1 Behavioral factors

In our study, physical inactivity was a predictor of higher VAT accumulation. This result was also found in previous studies (33, 34). Better physical activity status and reduced sedentary behavior favor a

TABLE 2 Factors associated with visceral adiposity among outpatients from a university cardiology hospital (*N* = 347).

| Variables | Visceral obesity | | | | PR (95 CI%) | *P* |
|---|---|---|---|---|---|---|
| | No | | Yes | | | |
| | n | % | n | % | | |
| Sex | | | | | | 0.031 |
| Male | 32 | 27.4 | 85 | 72.6 | 0.88 (0.78–0.99) | |
| Female | 40 | 17.4 | 190 | 82.6 | 1.0 | |
| Age in years | | | | | | 0.002 |
| 20–59 | 70 | 23.5 | 228 | 76.5 | 1.0 | |
| ≥60 | 2 | 4.1 | 47 | 95.9 | 1.25 (1.15–1.37) | |
| Race and ethnicity | | | | | | 0.862 |
| White | 25 | 22.1 | 88 | 77.9 | 1.0 | |
| Black | 16 | 21.3 | 59 | 78.7 | 1.01 (0.87–1.18) | |
| Mixed race | 31 | 19.5 | 128 | 80.5 | 1.03 (0.91–1.17) | |
| Years of study | | | | | | <0.001 |
| ≤9 | 2 | 2.6 | 74 | 97.4 | 1.30 (1.21–1.42) | |
| >9 | 69 | 25.6 | 201 | 74.4 | 1.0 | |
| Income | | | | | | 0.003 |
| Lowest tertile | 58 | 25.2 | 172 | 74.8 | 0.84 (0.76–0.93) | |
| 2nd and 3rd tertile | 13 | 11.3 | 102 | 88.7 | 1.0 | |
| Social status | | | | | | 0.011 |
| A1 e B1 (High) | 9 | 37.5 | 15 | 62.5 | 1.0 | |
| B2 e C1 (Middle) | 43 | 23.5 | 140 | 76.5 | 1.22 (0.89–1.69) | |
| C2. D e E (Low) | 18 | 13.6 | 114 | 86.4 | 1.38 (1.01–1.90) | |
| SAH | | | | | | <0.001 |
| No | 57 | 31.1 | 126 | 68.9 | 1.0 | |
| Yes | 15 | 9.1 | 149 | 90.9 | 1.32 (1.18–1.47) | |
| DM | | | | | | 0.001 |
| No | 65 | 25.0 | 195 | 75.0 | 1.0 | |
| Yes | 7 | 8.0 | 80 | 92.0 | 1.22 (1.12–1.35) | |
| Alcohol intake | | | | | | 0.738 |
| No | 39 | 20.1 | 155 | 79.9 | 1.0 | |
| Yes | 33 | 21.6 | 120 | 78.4 | 0.98 (0.88–1.09) | |
| Physical activity status | | | | | | 0.002 |
| Insufficient (<150 min/week) | 42 | 16.7 | 209 | 83.3 | 1.24 (1.06–1.44) | |
| Sufficient (≥150 min/week) | 29 | 32.6 | 60 | 67.4 | 1.0 | |
| Smoking | | | | | | 0.019 |
| Current | 1 | 9.1 | 10 | 90.9 | 1.20 (0.98–1.46) | |
| Non-smoker | 65 | 24.0 | 206 | 76.0 | 1.0 | |
| Former | 6 | 9.2 | 59 | 90.8 | 1.19 (1.08–1.32) | |
| BMI (kg/m$^2$) | | | | | | <0.001 |
| Underweight | 14 | 28.0 | 36 | 72.0 | 1.11 (0.88–1.41) | |
| Normal range | 29 | 35.4 | 53 | 64.6 | 1.0 | |
| Excess weight | 29 | 13.5 | 186 | 86.5 | 1.34 (1.13–1.58) | |
| Waist circumference | | | | | | <0.001 |
| Normal | 51 | 44.3 | 64 | 55.7 | 1.0 | |
| Elevated | 20 | 8.7 | 209 | 91.3 | 1.64 (1.39–1.94) | |

95% CI: 95% confidence interval; BMI: body mass index; DM: Diabetes mellitus; PR: prevalence ratio; SAH: systemic arterial hypertension.

TABLE 3 Factors associated with subcutaneous adiposity among outpatients from a university cardiology hospital ($N$ = 347).

| Variables | Subcutaneous obesity | | | | PR (95% CI) | P |
|---|---|---|---|---|---|---|
| | No | | Yes | | | |
| | n | % | n | % | | |
| Sex | | | | | | 0.957 |
| Male | 78 | 66.7 | 39 | 33.3 | 1.0 | |
| Female | 154 | 67.0 | 76 | 33.0 | 1.0 (0.72–1.36) | |
| Age in years | | | | | | <0.001 |
| 20–59 | 186 | 62.4 | 112 | 37.6 | 1.0 | |
| ≥60 | 46 | 93.9 | 3 | 6.1 | 0.16 (0.05–0.47) | |
| Race and ethnicity | | | | | | 0.200 |
| White | 82 | 72.6 | 31 | 27.4 | 1.0 | |
| Black | 51 | 68.0 | 24 | 32.0 | 1.17 (0.75–1.82) | |
| Mixed race | 99 | 62.3 | 60 | 37.7 | | |
| Years of study | | | | | | 0.023 |
| ≤9 | 59 | 77.6 | 17 | 22.4 | 0.62 (0.39–0.96) | |
| >9 | 172 | 63.7 | 98 | 36.3 | 1.0 | |
| Income | | | | | | 0.331 |
| Lowest tertile | 81 | 70.4 | 34 | 29.6 | 0.88 (0.63–1.23) | |
| 2nd and 3rd tertile | 150 | 65.2 | 80 | 34.8 | 1.0 | |
| Social status | | | | | | 0.042 |
| A1 e B1 (High) | 19 | 79.2 | 5 | 20.8 | 1.0 | |
| B2 e C1 (Middle) | 112 | 61.2 | 71 | 38.9 | 1.86 (0.84–4.15) | |
| C2. D e E (Low) | 96 | 72.7 | 36 | 27.3 | 1.31 (0.57–3.0) | |
| SAH | | | | | | 0.222 |
| No | 117 | 63.9 | 66 | 36.1 | 1.0 | |
| Yes | 115 | 70.1 | 49 | 29.9 | 0.83 (0.61–1.22) | |
| DM | | | | | | 0.001 |
| No | 161 | 61.9 | 99 | 38.1 | 1.0 | |
| Yes | 71 | 81.6 | 16 | 18.4 | 0.48 (0.30–0.77) | |
| Alcohol intake | | | | | | <0.001 |
| No | 151 | 77.8 | 43 | 22.2 | 1.0 | |
| Yes | 81 | 52.9 | 72 | 47.1 | 2.12 (1.55–2.90) | |
| Physical activity status | | | | | | 0.074 |
| Insufficient (<150 min/week) | 66 | 74.2 | 23 | 25.8 | 0.71 (0.48–1.05) | |
| Sufficient (≥150 min/week) | 160 | 63.7 | 91 | 36.3 | 1.0 | |
| Smoking | | | | | | 0.881 |
| Current | 7 | 63.6 | 4 | 36.4 | 1.12 (0.50–2.49) | |
| Non-smoker | 183 | 67.5 | 88 | 32.5 | 1.0 | |
| Former | 92 | 80.0 | 23 | 20.0 | 0.62 (0.41–0.92) | |
| BMI (kg/m$^2$) | | | | | | <0.001 |
| Underweight | 44 | 88.0 | 6 | 12.0 | 0.25 (0.11–0.54) | |
| Normal range | 42 | 51.2 | 40 | 48.9 | 1.0 | |
| Excess weight | 146 | 67.9 | 69 | 32.1 | 0.66 (0.49–0.88) | |
| Waist circumference | | | | | | 0.005 |
| Normal | 89 | 77.4 | 26 | 22.6 | 1.0 | |
| Elevated | 143 | 61.6 | 89 | 38.4 | 1.69 (1.17–2.47) | |

95% CI: 95% confidence interval; BMI: body mass index; DM: Diabetes mellitus; PR: prevalence ratio; SAH: systemic arterial hypertension.

TABLE 4 Factors associated with elevated VAT/SAT ratio among outpatients from a university cardiology hospital ($N$ = 347).

| Variables | Elevated VAT/SAT ratio | | | | PR (95% CI) | *P* |
|---|---|---|---|---|---|---|
| | No | | Yes* | | | |
| | n | % | n | % | | |
| Sex | | | | | | 0.957 |
| Male | 78 | 66.7 | 39 | 33.3 | 1.01 (0.73–1.38) | |
| Female | 154 | 67.0 | 76 | 33.0 | 1.0 | |
| Age in years | | | | | | <0.001 |
| 20–59 | 222 | 74.5 | 76 | 25.5 | 1.0 | |
| ≥60 | 10 | 20.4 | 39 | 79.6 | 3.12 (2.45–3.97) | |
| Race and ethnicity | | | | | | 0.069 |
| White | 85 | 75.2 | 28 | 24.8 | 1.0 | |
| Black | 48 | 64.0 | 27 | 36.0 | 1.45 (0.94–2.26) | |
| Mixed race | 99 | 62.3 | 60 | 37.7 | 1.52 (1.04–2.22) | |
| Years of study | | | | | | <0.001 |
| ≤9 | 27 | 35.5 | 49 | 64.5 | 2.68 (2.05–3.51) | |
| >9 | 204 | 75.6 | 66 | 24.4 | 1.0 | |
| Income | | | | | | 0.002 |
| Lowest tertile | 166 | 72.2 | 64 | 27.8 | 0.63 (0.47–0.84) | |
| 2nd and 3rd tertile | 64 | 55.7 | 51 | 44.3 | 1.0 | |
| Social status | | | | | | 0.126 |
| A1 e B1 (High) | 18 | 75.0 | 6 | 25.0 | 1.0 | |
| B2 e C1 (Middle) | 129 | 70.5 | 54 | 29.5 | 1.18 (0.57–2.44) | |
| C2. D e E (Low) | 80 | 60.6 | 52 | 39.4 | 1.58 (0.76–3.25) | |
| SAH | | | | | | <0.001 |
| No | 148 | 80.9 | 35 | 19.1 | 1.0 | |
| Yes | 84 | 51.2 | 80 | 48.8 | 2.55 (1.82–3.57) | |
| DM | | | | | | <0.001 |
| No | 199 | 76.5 | 61 | 23.5 | 1.0 | |
| Yes | 33 | 37.9 | 54 | 62.1 | 2.64 (2.01–3.48) | |
| Alcohol intake | | | | | | <0.001 |
| No | 113 | 58.2 | 81 | 41.8 | 1.0 | |
| Yes | 119 | 77.8 | 34 | 22.2 | 0.53 (0.38–0.75) | |
| Physical activity status | | | | | | 0.729 |
| Insufficient (<150 min/week) | 61 | 68.5 | 28 | 31.5 | 0.94 (0.66–1.34) | |
| Sufficient (≥150 min/week) | 167 | 66.5 | 84 | 33.5 | 1.0 | |
| Smoking | | | | | | 0.010 |
| Current | 5 | 45.5 | 6 | 54.5 | 1.87 (1.06–3.31) | |
| Non-smoker | 192 | 70.8 | 79 | 29.2 | 1.0 | |
| Former | 35 | 53.8 | 30 | 46.2 | 1.58 (1.15–2.18) | |
| BMI (kg/m$^2$) | | | | | | <0.001 |
| Underweight | 40 | 80.0 | 10 | 20.0 | 1.17 (0.56–2.43) | |
| Normal range | 68 | 82.9 | 14 | 17.1 | 1.0 | |
| Excess weight | 124 | 57.7 | 91 | 42.3 | 2.48 (1.50–4.10) | |
| Waist circumference | | | | | | <0.001 |
| Normal | 96 | 83.5 | 19 | 16.5 | 1.0 | |
| Elevated | 133 | 58.1 | 96 | 41.9 | 2.54 (1.64–3.93) | |

*Sex-stratified highest tertile (males ≥ 3.60, females ≥ 2.14). 95% CI confidence interval; BMI: body mass index; DM: Diabetes mellitus; PR: prevalence ratio; SAH: systemic arterial hypertension.

TABLE 5 Logistic binary regression.

| Variables | OR adjusted | 95% CI | P* |
|---|---|---|---|
| Visceral obesity | | | |
| Insufficiently active | 2.3 | 1.1–4.7 | 0.023 |
| WC elevated | 6.4 | 2.6–15.8 | <0.001 |
| Subcutaneous obesity | | | |
| ≥60 years | 0.1 | 0.1–0.5 | 0.003 |
| Alcohol intake | 2.2 | 1.3–3.7 | 0.005 |
| Underweight | 0.3 | 0.1–0.8 | 0.014 |
| Excess weight | 0.4 | 0.2–0.8 | 0.011 |
| WC elevated | 4.5 | 2.1–9.8 | <0.001 |
| VAT/SAT ratio | | | |
| ≥60 years | 5.5 | 2.0–14.8 | 0.001 |
| Black | 2.7 | 1.2–6.0 | 0.017 |
| Mixed race | 2.0 | 1.1–4.1 | 0.048 |
| Lower educational level (≤9 years of study) | 2.4 | 1.1–5.2 | 0.028 |
| DM | 2.4 | 1.2–4.9 | 0.017 |
| Alcohol intake | 0.5 | 0.2–0.9 | 0.015 |

*Wald Test. 95% CI: 95% confidence interval; BMI: body mass index; DM: diabetes mellitus; OR: odds ratio; SAH: systemic arterial hypertension. Factors associated with visceral, subcutaneous obesity and elevated VAT/SAT ratio.

negative energy balance by increasing resting energy expenditure. Although the direct causal relationship between physical activity status and preferential VAT reduction remains unclear, evidence suggests that visceral adipocytes are more sensitive to catecholamine stimulation released during exercise than abdominal subcutaneous adipocytes, resulting in greater lipolytic capacity and attenuation of VAT accumulation (27, 33).

The level of physical activity in our study was assessed using the IPAQ; however, only the total time spent on weekly activities was considered in the analysis, without evaluating exercise intensity or sedentary behavior duration. Future research should delve deeper into the role of physical activity in abdominal adipose composition, incorporating data on the frequency and intensity of physical activity. Understanding how different types of daily activities are linked to different adiposity phenotypes could shed light on the mechanisms by which sedentary time and physical inactivity contribute to multiple adverse health outcomes, including changes in body composition. This knowledge could ultimately inform more targeted guidelines on sedentary behavior and physical activity (34).

Lifestyle factors (i.e., behavioral) evaluated in this study differentially influenced AAT components. While physical inactivity influenced VAT accumulation, alcohol consumption modulated SAT accumulation. The role of alcohol consumption in determining AAT components has not been thoroughly explored, and differing results have been reported (35). Some studies identified alcohol as an independent predictor of VAT accumulation (36, 37). These discrepancies may be related to methodological variations in defining “alcohol consumption” or to synergistic characteristics that could amplify or reduce this association’s effect. It’s relevant noting that we did not assess the frequency and intensity of alcohol consumption, which may limit more definitive interpretations and conclusions.

## 4.2 VAT/SAT ratio

Elevated WC was predictive of higher VAT and SAT concentrations but not of an elevated VAT/SAT ratio. This finding underscores WC as a useful screening tool to estimate excessive intra-abdominal fat but highlights its limited ability to discriminate a greater predisposition for VAT over SAT accumulation. Evidence suggests that the VAT/SAT ratio may offer a better metric for assessing cardiometabolic risk than absolute quantification of each depot (12, 38). This is because the ratio provides an estimate of the relative contribution of visceral adipose tissue to total abdominal fat (38).

The ectopic fat model, represented by the VAT/SAT ratio, suggests that excess energy resulting from an imbalance between dietary intake and caloric expenditure is initially stored in subcutaneous compartments. When these subcutaneous stores reach their maximum capacity, the excess energy may be redirected to visceral compartments. This overload of fat in adipocytes can lead to reduced subcutaneous fat storage capacity, resulting in visceral fat accumulation (12). Given the variability in body shape and size across populations, the absolute values of VAT may not adequately reflect the risk differences associated with visceral obesity. In this context, assessing the VAT-related risk becomes challenging in individuals with diverse body types. Taken together, the VAT/SAT ratio theoretically provides a more accurate indicator for evaluating an individual’s body composition and associated health risks.

The VAT/SAT ratio, as measured by US scans, is associated with abnormal glucose metabolism and an increased risk of developing type 2 diabetes mellitus (39, 40). In a cohort of 473 female patients, the VAT/SAT ratio was independently linked to clusters of cardiometabolic risk factors (41). Furthermore, it holds prognostic significance as a unique predictor of cardiometabolic risk, independent of age and BMI (42). However, an elevated SAT may lower the absolute value of the VAT/SAT ratio without mitigating the associated risk. In this context, it is evident that abdominal fat accumulation, irrespective of its specific compartment, poses a health risk and should be addressed as a significant cardiometabolic risk factor.

## 4.3 Biological factors

Notably, aging is associated with changes in body fat distribution, including increases in intra-abdominal fat. Our findings indicated a higher predisposition for VAT accumulation (elevated VAT/SAT ratio) in older individuals (≥60 years). This trend may be explained by age-related body fat redistribution and decreased basal energy expenditure, leading to a greater concentration of visceral abdominal fat, while subcutaneous fat tends to decline (2, 43).

The observation that an elevated VAT/SAT ratio was more common among non-White individuals (Mixed race and Black) may reflect the influence of socioeconomic, biological, environmental, and cultural factors (44), as well as genetic and epigenetic factors (8, 45). However, contrasting with our study, it is generally recognized that African-American men tend to have lower VAT concentrations than White men, whereas VAT levels are more comparable between White and African-American women (46, 47).

The observed differences can be partially attributed to the unique characteristics of our population, including the mixed genetic background of Brazilian individuals, which stems from the integration of Indigenous, European, and African ancestry (48, 49). This high degree of miscegenation presents a challenge when comparing Brazilian individuals with other racial and ethnic groups. Further studies are necessary to investigate the predictive factors of abdominal adipose composition in such a diverse population.

## 4.4 Clinical factors

Demerath et al. (46) showed that SAT concentration may be higher in Black women compared to White women, a difference not observed among men. The independent association of a higher VAT/SAT ratio with lower educational attainment may reflect risk behaviors associated with limited social conditions. Education is a recognized proxy for socioeconomic status, which is a strong determinant of health behaviors across both sexes and all age groups (28). Furthermore, dietary behaviors are influenced by social and educational status, with low socioeconomic and educational levels being associated with obesity and higher consumption of ultra-processed foods and refined carbohydrates (50, 51). Another study highlighted that higher socioeconomic status was linked to healthier dietary choices, particularly more frequent fruit and vegetable consumption (52), a habit that may support a healthier pattern of intra-abdominal fat distribution (2).

## 4.5 Sociodemographic factors

Moreover, the quality of self-care and the ability to interpret information related to preventive health behaviors, including abdominal fat accumulation, can also be influenced by educational attainment and socioeconomic factors (44). However, the relationship between the predisposition for VAT accumulation and socioeconomic status requires further investigation due to the complexity of understanding how social factors may impact biological processes.

The association between the VAT/SAT ratio and DM may be bidirectional (53). Excess visceral adiposity can precede the development of DM due to the direct supply of free fatty acids and inflammatory adipokines to the liver, which are secreted by visceral adipocytes. Free fatty acids inhibit insulin secretion from pancreatic cells and limit insulin-induced glucose uptake, likely by impairing signaling and transduction mechanisms (6, 8). Conversely, individuals with DM are at increased risk of developing obesity due to insulin resistance, which raises hepatic glucose production and, consequently, insulin levels, further contributing to fat accumulation (53).

## 4.6 Future perspectives

This study is not without limitations. The sampling method did not allow for a randomized sample, and recruiting individuals from a healthcare setting may limit the generalizability of the findings. The observational design and cross-sectional sample restrict the ability to infer causality from the observed associations. Furthermore, some important variables that influence abdominal adipose tissue composition, such as dietary intake, genetic, and hormonal factors, were not analyzed.

We also acknowledge that the use of more precise instruments could provide more relevant insights into the sociodemographic and behavioral profile of the studied sample; however, this was not feasible in our study. Nonetheless, we emphasize that this limitation reflects the real-world challenges faced in clinical routines within public healthcare settings, where time for detailed investigations is often constrained. Additionally, the absence of analyses using raw/continuous data may limit the modeling effects and the detection of small statistical differences, which we propose as a focus for future investigations.

On a positive note, this study included the use of an imaging technique (i.e., US) for the non-invasive assessment and separate quantification of abdominal fat depots. US has been reported as a useful alternative to reference methods for evaluating different body compartments. Furthermore, we incorporated a wide range of explanatory variables in the conceptual model and assessed the predisposition to accumulate VAT relative to SAT (VAT/SAT ratio). In addition, the intra- and inter-observer calibration evaluation confirmed the adequate reproducibility of the imaging method used, reinforcing the methodological standardization of the study.

It is noteworthy that adipose distribution patterns vary across ethnic groups, highlighting the need for future multicenter, multiethnic studies with large sample sizes. Longitudinal studies are also required to explore the effects of social, biological, and behavioral aspects on adipose characteristics over time. Furthermore, in-depth investigations into the VAT/SAT ratio metric and its metabolic implications should be conducted across different ethnic and social populations.

# 5 Conclusion

Patterns of adipose tissue distribution across different abdominal fat compartments is influenced by complex interactions among multiple factors. Physical inactivity emerged as an independent predictor of the visceral obesity phenotype, while alcohol consumption was associated with a subcutaneous abdominal obesity pattern. DM and sociodemographic factors, such as older age, non-White race, and lower education, were predictive factors for an elevated VAT/SAT ratio. Our study adds to the growing body of evidence, aiding in identifying characteristics that determine different obesity phenotypes, provide relevant data that can guide strategies aimed at groups at potential risk for complications related to the accumulation of TAV, in addition to signaling indicators that can serve as tools for monitoring and evaluating specific provisions for this audience. However, further evidence from diverse populations is still needed to clarify how sociodemographic and behavioral factors influence the accumulation of different abdominal adipose tissue components, considering additional aspects such as dietary intake, genetic, and hormonal factors.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Ethics statement

The studies involving humans were approved by Comite de Ética e Pesquisa em Seres Humanos HUOC/PROCAPE. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

CC: Conceptualization, Investigation, Data curation, Writing – original draft. NS: Conceptualization, Data curation, Investigation, Writing – original draft. IR: Data curation, Investigation, Methodology, Validation, Writing – review & editing. GA: Data curation, Investigation, Validation, Writing – original draft. VF: Data curation, Investigation, Writing – review & editing. DS: Investigation, Supervision, Validation, Writing – review & editing. AD: Investigation, Supervision, Validation, Writing – review & editing. CP: Investigation, Writing – review & editing, Conceptualization, Formal Analysis, Supervision. PC: Investigation, Supervision, Validation, Writing – review & editing. IA: Conceptualization, Investigation, Supervision, Validation, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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# Tackling the complexity of obesity in the US through adaptation of public health strategies

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Obesity prevalence continues to rise in the US despite more than two decades of recommendations and guidelines for its prevention and management. The encouragement of individuals to adopt a healthy diet and lifestyle has remained the focus of clinical interventions and recommendations despite these efforts alone proving ineffective for long-term weight management. There are many recognized barriers to obesity prevention and management in community and clinical settings including political factors, social determinants of health, weight bias and stigma, and inequities in access to treatment and insurance coverage. We discuss these barriers in more detail and attempt to identify areas where public health and healthcare approaches can be better aligned, allowing for better advocating by public health officials to enable a more meaningful and population-level change in obesity prevention and management in the US.

KEYWORDS

**equity, healthcare, obesity, policy change, public health, US**

## 1 Introduction

Obesity was first recognized as a chronic disease in a 1997 report published by the World Health Organization (WHO) and the International Obesity Task Force entitled "Obesity: Preventing and Managing the Global Epidemic" (1). The American Medical Association followed in 2013, and adopted policy recognizing obesity as a chronic disease state requiring efforts toward treatment and prevention (2), a viewpoint that has subsequently become more widely accepted (3). The Obesity Society 2018 position statement notes that obesity is covered by the classical definition of diseases as maladaptive changes from "normal" body function and structure as a result of underlying pathophysiological mechanisms, and specifically that adiposity exceeding a predefined threshold may be accompanied by structural abnormalities, functional abnormalities, signs and symptoms, elevated premature mortality risk and increased comorbidity risk (4). Public health, as defined by the Centers for Disease Control and Prevention (CDC), is "the science of protecting and improving the health of people and their communities" (5). Obesity is increasingly recognized as one of the most urgent public health issues in the US (6), affecting >40% of adults (7), with an estimated annual medical cost in the US in 2019 of $173 billion (8). The impact of obesity on public health includes effects on life expectancy, quality of life, comorbidities, employment, direct and indirect economic costs, and military readiness (6, 9). In an observational study, utilizing pooled prospective national health survey data from 114,567 adults in two Finnish cohort studies, obesity was associated with 21 non-overlapping digestive, respiratory, cardiometabolic, infectious, musculoskeletal, and neurological diseases, with a confounder-adjusted hazard ratio for developing complex comorbidity (four or more comorbid diseases) of 12.39 (95% CI 9.26–16.58; population attributable fraction 55.2% [95% CI 50.9–57.5]), compared with healthy weight. The proportion of patients with complex comorbidity was the same at age 55 years in participants with obesity as age 75 years in participants with healthy weight (10). With respect to infections (surgical site, respiratory tract, skin, and urinary tract), obesity has been identified as a risk and recurrence factor, and is often associated with more severe disease and mortality (11), particularly as noted during the COVID-19 pandemic [severe disease odds ratio [OR] 3.13, 95% CI 1.41–6.92, $p = 0.005$; mortality OR 1.36, 95% CI 1.09–1.69, $p = 0.006$; (12)]. In the US, estimates suggest that obesity accounts for more than 350,000 excess deaths per year (13), with other studies noting that an increased risk of death from all causes, and particularly from cancer and cardiovascular disease, is associated with obesity (14, 15).

Evidence suggests that ≥5% weight loss is associated with improvements in various comorbidities and associated factors including type 2 diabetes, healthcare costs, quality of life, and mortality (16). A UK study found that a median weight loss of 13% among individuals with an assumed body mass index (BMI) of 40 kg/m$^2$ before weight loss (i.e., BMI 34.8 kg/m$^2$ after weight loss) was associated with reductions in risk of 41% for developing type 2 diabetes (T2D), 40% for sleep apnea, 22% for hypertension, 19% for dyslipidemia, 18% for asthma, and 13% for chronic kidney disease, relative to an individual with a stable BMI of 30 kg/m$^2$ (17). Guidelines by the American College of Cardiology/American Heart Association/The Obesity Society (AAC/AHA/TOS) and American Association of Clinical Endocrinologists/American College of Endocrinology (AACE/ACE) recommend multidisciplinary lifestyle interventions (e.g., aerobic exercise, resistance training, reduced-calorie diet) for the management of overweight and obesity, followed by the use of pharmacotherapy and/or surgical procedures and devices, based on factors including disease stage and success of lifestyle interventions (18–20). These interventions may include psychologists, psychiatrists, and dietitians, and should be individualized to each patient to improve adherence and outcomes. Despite these guidelines, no US state has been able to reverse the upward trends in obesity prevalence and incidence (21), suggesting that these guidelines alone are not enough to tackle the obesity epidemic, and/or that better implementation of such recommendations may be required. We know from experience gleaned during the COVID-19 pandemic, which was declared a public health emergency, that public health officials have the training and desire to quickly and effectively tackle public health crises, including facilitating primary, secondary and tertiary prevention strategies across multiple levels of influence (22, 23), yet attempts to tackle obesity remain self-evidently unsuccessful. Obesity is complex to tackle, and the state of science and will of system decision-makers differs from traditional public health initiatives such as tackling tobacco use. There are many recognized barriers to obesity prevention and management at both the public health and healthcare levels in the US, including inadequate government funding, inadequate data on effective strategies, racial disparities (24), socioeconomic factors (such as access to treatment), healthy foods (25, 26), insurance coverage (25), weight bias and stigma (27–30), and a lack of training and education of practitioners regarding effective treatment options (31).

A public health focus on prevention and treatment is needed to improve outcomes in people with overweight and obesity, as well as for addressing barriers. Effective public health campaigns in the US, such as tackling tobacco access and use to decrease and mitigate morbidity and mortality (from lung cancer and cardiovascular disease), have leveraged influence at organizational, community, societal, policy, and environmental levels. The Healthy People strategic framework, an initiative by the Office of Disease Prevention and Health Promotion, is a set of data-driven national objectives for improving health and wellbeing, using evidence-based resources to inform development of programs and policies based on what is effective, replicable, scalable, and sustainable (32). With regards to tobacco use, 13 of the 27 objectives are currently classed as "improving" or "target met" or "exceeded" in Healthy People 2030 (33). These have been driven by evidence-based strategies including smoke-free policies (34), price increases (35), health education campaigns (36, 37), counseling, and medication (38). Multi-level public-health approaches, like those implemented for smoking cessation, are key for addressing the complexity of obesity in the US. Many of these approaches are reflected in the obesity recommendations by Trust for America's Health (TFAH) for federal, state, and local policymakers and other stakeholders: (1) advance health equity by strategically dedicating federal resources to efforts that reduce obesity-related disparities and related conditions; (2) decrease food and nutrition insecurity while improving nutritional quality of available foods; (3) change the marketing and pricing strategies that lead to health disparities; (4) make physical activity and the built environment safer and more accessible for all, and; (5) work with the healthcare system to reduce disparities and close gaps in clinical-to-community settings (39).

The aim of this review is to highlight and discuss areas of obesity prevention and management in the US where public health and healthcare initiatives can be better aligned to have a more meaningful and population-level impact on the current state of obesity, and increase access to care.

# 2 Discussion

## 2.1 Diet and lifestyle interventions

Current AAC/AHA/TOS, AACE/ACE and Academy of Nutrition and Dietetics guidelines for the management of overweight and obesity recommend diet and lifestyle interventions as the first line of defense (18–20, 40). However, this achieves little sustained success, with one meta-analysis of long term maintenance of weight loss with non-surgical interventions demonstrating no evidence of effectiveness, including lifestyle changes in dietary intake and physical activity (41), and another meta-analysis of long-term weight loss studies demonstrating that the average individual only maintained a reduced weight of ∼3% of initial body weight 5 years after completing a structured weight-loss program (42). This illustrates the relapsing nature of obesity as a chronic disease and highlights the need for long-term follow-up and support to help patients manage weight recurrence. Although it is clear that diet and lifestyle interventions alone are insufficient to make substantial changes in obesity outcomes broadly, most healthcare professionals (HCPs) in the ACTION study, which explored barriers to medical care and support and perspectives on obesity, agreed that general improvements in eating and physical activity are "completely effective" for long-term weight management (43). This highlights the failure among HCPs in recognizing obesity as a chronic relapsing disease that is more complex than voluntary overeating and inactivity, and further makes the case for a holistic approach to obesity management, supported by a multidisciplinary team (MDT), as well as a need to improve education among HCPs.

Patients' best efforts to incorporate recommended interventions can be counteracted or undermined by the obesogenic environment. Thus, despite decades of advice to adopt healthy eating patterns and reduce intake of added sugars, solid fats, and sodium, the Healthy Eating Index (HEI) score 2020 (an assessment of how well diets of the US population align with dietary patterns and key recommendations published by the Dietary Guidelines for Americans), was only 58/100 for ages 2+ years, demonstrating that the average diet quality does not align with the guidelines (44). This relates to changes in the food environment over the last few decades including increased food availability, which in turn has resulted in "added value" foods with altered appetitive properties that drive consumption, changes in normative eating behaviors e.g., snacking between meals (45), and increased consumption of ultra-processed foods (46). The importance of tackling the obesogenic environment is reflected in recommendations 2–4 of the TFAH obesity 2023 report (39). Various public health strategies and approaches can be undertaken by communities and neighborhoods to improve diet, behaviors, and physical activity in line with these recommendations, including advocating for zoning that limits fast food establishments, increasing the availability of farmers' markets, facilitating the situation of supermarkets in underserved areas, enhancing walking infrastructure, and increasing the number of parks and bike paths (47). Produce prescription projects are also becoming increasingly common, whereby HCPs can "prescribe" fruit and vegetables for patients experiencing food insecurity. With respect to aligning this with public health, suggestions by the CDC include engaging representatives from Medicaid programs in implementing, expanding and evaluating produce prescription programs, and supporting policies that increase participation in prescription initiatives (48).

Addressing the obesogenic environment and instituting effective strategies for tackling obesity is a complex challenge. There is mixed evidence on the effectiveness of traditional public health approaches such as introducing supermarkets in food deserts and improving access to healthier food options on nutritional inequality, dietary habits, or obesity (49–52). Alternative measures for obesity prevention have been instigated or investigated in other countries around the world, albeit again with mixed results. At least one type of sugar-sweetened beverage (SSB) tax is enforced by more than 100 countries worldwide (53) but the impact is varied, with one systematic review finding a positive effect of this tax on decreasing the prevalence of overweight and obesity (54), however another study found no significant change in consumption of taxed beverages (55). Calorie labeling on menus is another measure that has been projected to prevent cases of obesity across all racial and ethnic groups [126–185 cases per 100,000 people; (56)]. However, a review of studies assessing the real-world impact of numeric calorie posting found the evidence to be mixed, and the effect of menu labeling to be dependent on context (57). For example, low-income customers may respond to labeling by choosing higher-calorie options, as they perceive items containing more calories per dollar as being of better value (58).

These measures are also sometimes considered controversial, with issues including resistance lobbying and legal action, such as in the case of the New York SSB portion cap being overturned (59). The prospect of resistance makes it more difficult to build stakeholder support.

Another aspect of SSB taxes that makes them controversial is that they can be considered a "regressive tax." In the US, households in the lowest income quintile spend ∼31% of their income on food, which is nearly 4 times the amount of households in the highest income quintile [∼8%; (60)]. Therefore, SSB taxes have the greatest impact on those with lower incomes, particularly if the tax results in a substantial price pass-through to the consumer, as was observed in Portugal following the introduction of an SSB tax (61). Additionally, when these taxes are applied to diet drinks, the increase in price makes it harder for individuals to make healthy informed choices, as the non-diet versions may be more cost-effective to purchase.

While we understand that evidence for these newer and more controversial approaches is limited and needs further investigation, there is an opportunity for HCPs to move away from the historic ineffective approach of placing the onus on the individual, and instead help to create environments that are supportive of healthy lifestyles in a way that is easy, cost efficient, and which will become the norm. To enable healthcare providers to take a more holistic approach with patients through health education and promotion, they need to be supported by public health practices that improve access to care and tackle the obesogenic environment at its root. With this type of systemic change, we may find more success with obesity prevention and weight maintenance after initiating treatment, particularly when used in combination with medications, as we will discuss next.

## 2.2 Pharmacotherapy and surgery for weight loss in obesity

Due to the limited success in obesity management of lifestyle modification alone, medical treatment guidelines recommend use of adjunctive anti-obesity medication (AOM) for the best outcomes, including greater and more sustained weight loss (18, 19). An improved understanding of obesity pathophysiology and appetite regulation has led to the availability of a number of pharmacological treatments for obesity and overweight (62–64). AACE/ACE guideline-recommendations include orlistat, phentermine-topiramate and naltrexone-bupropion combinations, and the glucagon-like peptide-1 receptor agonist (GLP-1 RA) liraglutide (19). The US Food and Drug Administration (FDA) has also recently approved the GLP-1 RA semaglutide (2.4 mg subcutaneously once-weekly) and the GLP-1/glucose-dependent insuliotropic polypeptide RA tirzepatide (up to 15 mg subcutaneously once-weekly) as adjuncts to a diet and exercise for chronic weight management in adult patients with a BMI $\geq$27 kg/m$^2$ and $\geq$1 weight-related complication, or a BMI $\geq$30 kg/m$^2$ (65). Semaglutide has demonstrated efficacy and safety in patients with overweight or obesity, and is associated with a significant 11.8% body weight reduction compared with placebo (66–71). In patients with obesity, with and without type 2 diabetes, tirzepatide 15 mg was associated with a mean change in body weight of −14.7% and −20.9%, respectively (72, 73). Individuals with obesity may need to try multiple medications to find an optimal intervention, determined through conversations with their HCPs on health goals, comorbidities, responsiveness, side effects, willingness, and adherence challenges. Patient autonomy is a key practice, and patients should be encouraged to engage in a shared-decision making process with their clinician to choose the optimal obesity care for them as an individual (74).

Public health communication campaigns could play a role in public awareness and understanding in terms of what to discuss when considering pharmacotherapy for obesity management, including with providers and employers regarding insurance coverage. Many people have a perception that AOM therapy is for short-term use only (75, 76). However, discontinuation of AOM has been associated with a reduction in the achieved benefits, as demonstrated in the STEP 1 trial, wherein 1 year after withdrawing from semaglutide 2.4 mg and lifestyle intervention, individuals experienced weight recurrence of a mean of two-thirds of the weight lost after 68 weeks of treatment (77). This again highlights the chronic relapsing nature of obesity, and makes a case for life-long monitored adjunctive therapy with AOMs to prevent weight recurrence. Metabolic and bariatric surgery (MBS) is another effective option for patients with obesity across all BMI classes who have not achieved substantial weight loss with non-surgical interventions, with long-term data consistently demonstrating its safety, efficacy and durability, and decreased mortality compared with non-operative treatment methods (78). Additionally, public health campaigns could be used to expand acceptance of the use of AOMs and MBS. Weight bias and stigma can lead to an overvaluation of achievement of weight management success through diet and lifestyle interventions, such that we attribute virtue and assume a high level of self-control and discipline for the few that can achieve success with lifestyle intervention only. By default, this can result in the use of AOMs being rejected as an effective treatment option, as they may be perceived as a "crutch," or "an easy way out," suggesting a possible personal failing to achieve meaningful weight loss. In two studies of adults assigned to read about a woman who had lost 15% of her body weight either through diet and exercise or GLP-1 use, or bariatric surgery in one study, the results suggested greater beliefs that GLP-1 RA use and bariatric surgery were a weight loss "shortcut" (79, 80). Incorporating clinical trial results into public health campaigns may help to further educate people about the nature of obesity as a chronic relapsing disease with a physiological basis, and help to mitigate bias and stigma.

Despite the potential offered by AOMs, and the substantial evidence over the last decade for the efficacy and safety of MBS, both options are underutilized in the US, with most Medicaid programs not offering coverage for FDA-approved weight loss drugs (81) and only ∼1% of individuals meeting guideline criteria actually undergoing MBS every year, despite most major insurance plans covering weight loss surgery (82–84). Out-of-pocket costs for AOMs can also create a health equity issue, with some GLP-1 RAs costing >$1,000 (85). Treatments may also have high copay amounts, which can be prohibitive for prospective patients. In one nationwide poll of 1,479 American adults (86), 54% of insured users noted difficulty with affording costs, and 23% answered that meeting costs was "very difficult." Additionally, 57% of insured adults had to cover part of the cost themselves, and 19% had to pay the full cost themselves.

Improvements in US health insurance for coverage for AOMs and MBS could also positively impact employment and costs. One survey by the Obesity Action Coalition found that 44% of people with obesity would change jobs to gain coverage for treatment, and more than 50% would stay at a job they didn't like to keep coverage (87). Additionally, obesity has been shown to double the annual medical costs of adults relative to those of normal weight (a total of $5,010 per year vs. $2,504 (88)—costs that could potentially be offset by offering increased coverage. This feeds back into the potential for public health campaigns to increase public awareness of pharmacotherapy options, and understanding how and what to discuss with employers in terms of insurance coverage.

## 2.3 Multi-component interventions, including community-based approaches

We have already highlighted the importance of a multifaceted approach to obesity management with both lifestyle modification and adjunctive AOMs. Table 1 (89–95) provides an overview of community-based randomized trials and weight-loss programs in the US that have utilized such an approach, including personalized SMS messaging, counseling, support from community health workers, financial incentives, health technology, and health education (89–95). For all interventions listed, groups of people with access to more resources generally saw greater mean reductions in body weight, ranging from 0.6 to 4.0 kg. In a trial evaluating the effectiveness of behavioral weight loss maintenance, one group of participants who had maintenance sessions (practicing strategies associated with weight maintenance in the context of connecting faith with health) for 12 months following the initial 6-month behavioral treatment for weight loss, experienced a slower rate of weight recurrence compared to participants who did not have maintenance sessions (body weight change at 12 months: 0.90 kg vs. 1.58 kg, respectively; 93). While there are limitations to community-based approaches, including scalability, workforce availability and training, and insurance coverage, the strategies and interventions utilized are a useful starting point for informing policy, systems, and environmental (PSE) changes that need to be made by policy makers and stakeholders.

TABLE 1 Overview of community-based trials of obesity management in the US post-2015.

| Study | Geographic location and population | Design | Groups and obesity management strategy utilized | Weight loss outcomes |
|---|---|---|---|---|
| Griffith et al. (89) | Atlanta, Georgia<br><br>Middle-aged and older African American men | Community-based, cluster-randomized, longitudinal parallel group design; 4 churches | Control ($n = 22$) and weight loss ($n = 21$)<br>Both conditions:<br>• FitBit, Bluetooth-enabled scale, t-shirt, gift cards for participation, and 45-min small group physical activity led by a certified personal trainer<br>Weight loss condition:<br>• 45-min of health education, individually tailored SMS texts | Mean change in body weight:<br>Control: −5.11 lbs (2.3 kg; $p = 0.005$)<br>Weight loss: −7.14 lbs (3.2 kg; $p = 0.005$)<br>Mean change in body fat:<br>Control: −0.18 % points ($p = 0.36$)<br>Weight loss: −2.37 % points ($p = 0.005$) |
| Ard et al. (90) | Deep South (Mississippi and Alabama)<br><br>Rural African American women | Two-group cluster randomized controlled trial | Weight Loss Only (WLO; $n = 154$) and Weight Loss Plus (WLP; $n = 255$)<br>Both groups:<br>• Weight loss intervention sessions with a focus on moderate energy restriction and regular moderate-intensity physical activity, behavioral strategies, tailored reinforcement messages, continued self-monitoring, relapse prevention, social support and problem solving<br>WLP:<br>• Support for implementing strategies to promote healthy eating and/or physical activity in the local community e.g., community garden, enhancement of a walking trail, incentives for the purchase of a fresh produce from the local farmers' market, and a dance class | Mean change in body weight:<br>WLO: −1.9 kg<br>WLP: −2.7 kg |
| McVay et al. (91) | North Carolina<br><br>Men and women with obesity and an obesity-related comorbidity | Randomized controlled trial | Participant-reported counseling ($n = 141$) and provider-documented counseling ($n = 134$); no counseling, general weight counseling or intervention-specific counseling<br>Participant reported counseling:<br>• General weight counseling: asked about their weight, advised them to lose weight, assessed their readiness to lose weight, referred them to a weight loss program, discussed weight loss medication, discussed weight loss surgery, or arranged a future contact to discuss weight<br>• Intervention-specific counseling: talked to them about Track, asked about their progress toward Track goals, encouraged them to talk to their Track coach, encouraged them to take Track phone calls, talked to them about their weight change since starting Track, or provided ideas to help them meet Track goals<br>Provider-documented weight counseling:<br>• General weight counseling: patients' physical activity, patients' diet or eating behavior, specific weight loss goal, external weight loss program<br>• Intervention-specific counseling: track was explicitly documented, track was referred to but not explicitly mentioned, provider reinforced engagement in Track, Track provider update was copied into visit notes | At 6–12 months:<br>Patient-reported provider weight counseling:<br>• Intervention specific counseling was associated with +0.4 kg ($p = 0.68$) compared to general weight counseling, and −0.6 kg ($p = 0.60$) compared to no counseling<br>0–12 months:<br>Provider-documented weight coun-seling:<br>• Intervention specific counseling was associated with −3.1 kg ($p = 0.02$) compared to general weight counseling, and −4.0 kg ($p = 0.04$) compared to no counseling |
| Lee et al. (92) | Southeast Texas<br><br>Employees of the Pasadena Independent School District with overweight or obesity | 6-month worksite-weight-loss program | Vibrant Lives Basic (VLB; $n = 131$), Vibrant Lives Plus (VLP; $n = 87$), and Vibrant Lives Plus + Support (VLP + S; $n = 88$)<br>All groups:<br>• Materials and tailored text messages<br>VLP and VLP + S:<br>• WIFI-enabled activity monitors and scales and participation in health challenges throughout the year<br>VLP + S:<br>• Coaching support | Mean change in body weight:<br>VLB: −2.5 kg<br>VLP: −2.5 kg<br>VLP + S: −3.4 kg<br>$\beta = -2.34$<br>SE = 0.45<br>$p < 0.001$ |
| Yeary et al. (93) | Arkansas Delta<br><br>Rural Blacks of faith | Cluster randomized controlled trial | Weight Loss Only (WLO; $n = 218$) and Weight Loss + Maintenance (WLM; $n = 208$) | |

*(Continued)*

TABLE 1 (Continued)

| Study | Geographic location and population | Design | Groups and obesity management strategy utilized | Weight loss outcomes |
|---|---|---|---|---|
| | | | WLO:<br>• 6 months behavioral treatment for weight loss, followed by 12 months assessment<br>WLM:<br>• 6 months behavioral treatment for weight loss, followed by 12 months weight loss maintenance | Mean change in body weight from baseline to 6 months:<br>WLO: −2.63 kg<br>WLM: −2.45 kg<br>$p = 0.8045$<br>Mean change in body weight from 6 months:<br>12 months:<br>WLO: +1.04 kg ($p = 0.0006$)<br>WLM: +0.48 kg ($p = 0.1164$)<br>18 months:<br>WLO: +1.58 kg ($p = 0.0002$)<br>WLM: +0.90 kg ($p = 0.0408$) |
| Rosas et al. (94) | San Mateo County, California<br><br>Low-income Latinos with obesity and ≥1 heart disease risk factor | Community-based randomized controlled trial | Usual Care Control (UC; $n = 41$), Case Management (CM; $n = 84$), and Case Management + Community Health Worker (CM + CHW; $n = 82$)<br>CM and CM + CHW:<br>• 12-month intensive phase (12 group sessions + 4 individual sessions) followed by 12-month maintenance phase (3 group sessions + 1 individual session)<br>CM + CHW:<br>• 5 home visits in the intensive phase and 2 home visits in the maintenance phase | Mean body weight changes<br>6 months:<br>UC: −0.9 kg<br>CM: −1.6 kg<br>CM + CHW: −2.1 kg<br>CM + CHW vs. UC: $p = 0.05$<br>CM + CHW vs. CM: $p = 0.65$<br>12 months:<br>UC: −0.7 kg<br>CM: −1.4 kg<br>CM + CHW: −1.9 kg<br>CM + CHW vs. UC: $p = 0.21$<br>CM + CHW vs. CM: $p = 0.76$<br>24 months:<br>UC: −0.6 kg<br>CM: −1.0 kg<br>CM + CHW: −1.0 kg<br>CM + CHW vs. UC: $p = 0.76$<br>CM + CHW vs. CM: $p = 0.98$ |
| Newton et al. (95) | Louisiana<br><br>African American adults with obesity | Cluster-randomized trial design; 8 churches | Control ($n = 29$) and Intervention ($n = 68$)<br>Control:<br>• Encouraged to maintain normal eating and exercise habits for 6 months, and received 2–3 automated SMS messages per week on health topics specific to African American adults<br>Intervention:<br>• Community health coach leading 10 group sessions over 6 months, covering obesity management topics, and 5 automated SMS messages per week covering lesson content ($n = 2$), motivation ($n = 1$) and behavioral prompts ($n = 2$) | Mean change in body weight:<br>Control: +0.2 kg<br>Intervention: −1.4 kg<br>$p = 0.03$<br>Effect size: 0.55<br>Mean percent weight loss:<br>Control: +0.3%<br>Intervention: −1.6%<br>$p = 0.04$ |

Authors' review of PubMed searches relevant to obesity and weight loss. CM, case management; CM + CHW, case management + community health worker; SE, standard error; UC, usual care control; VLB, Vibrant Lives basic; VLP, Vibrant Lives plus; VLP + S, Vibrant Lives plus + support; WLM, weight loss + maintenance; WLO, weight loss only; WLP, weight loss plus.

The most effective way to implement a multifaceted approach to obesity management is through the adoption and utilization of an MDT, ideally including a physician with expertise in pharmacotherapy, a nurse and/or nurse practitioner, an exercise physiologist, a dietitian, a health education specialist, psychologist, and potentially a MBS surgeon (40, 96). Figure 1 (97) provides an overview of how a specialized integrated care model might address specific conditions or aspects related to chronic disease, including obesity, through employment of non-physician personnel. Several studies have demonstrated the effectiveness of an MDT in the primary care setting, including nurses, lay educators, dietitians, behavioral therapists, and health coaches (98–100). It would be beneficial to see further studies investigating the use of AOMs in conjunction with the input of an MDT on obesity outcomes, and particularly, weight management and recurrence. As obesity is a chronic relapsing disease, obesity management must also integrate aspects of personalized medicine, ensuring that patient circumstances, availability, costs and comorbidities inform treatment choices.

## 2.4 Existing public health initiatives

Healthy People 2030 is one of the existing public health initiatives for overweight and obesity management in the US. One objective, to reduce the proportion of adults with obesity, is currently not being achieved, with the proportion of adults with obesity continuing to increase (101). The evidence-based strategies backing this initiative are worksite programs (102), interventions including activity monitors (103), and technology-supported multicomponent coaching or counseling interventions to reduce weight (104) and maintain weight loss (105). It should be noted that many of these recommendations are based on outdated reviews of the literature, and while still helpful, it would be beneficial for an updated review to be carried out.

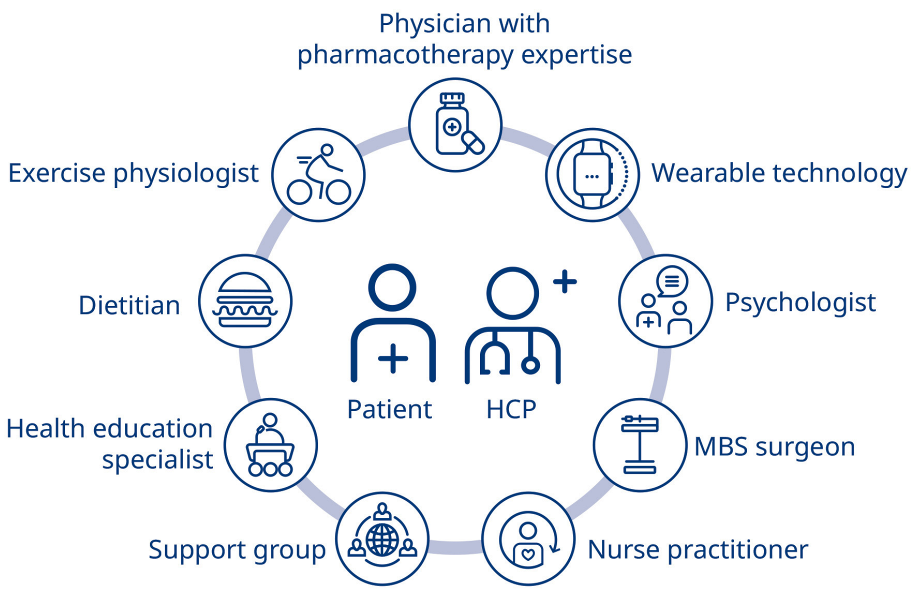


FIGURE 1
Integrated chronic care model (97). HCP, healthcare professional; MBS, metabolic and bariatric surgery.

There are also numerous programs aimed at promoting healthy dietary habits and increasing physical activity to reduce obesity in adults, many of which use intervention approaches recommended by the Community Preventive Services Task Force (CPSTF). Two of these programs had weight change as a primary outcome [Table 2; (104, 106, 107)]. In ENERGY, the Experimental group (group-based behavioral intervention supplemented with telephone counseling and tailored newsletters) experienced significantly greater weight loss than the comparison group (weight management resources and materials and monthly telephone calls and/or emails) at 6, 12, and 18 months (106). Weight Loss for Life demonstrated significant weight loss in the Experimental treatment group (the Coach Approach exercise supported protocol, followed by group nutrition sessions), in both the weight loss phase and over the duration of the study (107). While both programs had significant results at ≥18 months, this is not long-term within weight management, and it is not known if the observed weight loss was maintained following the end of the programs. These programs and recommended intervention approaches reflect the continued focus of health officials on promoting diet and lifestyle changes; however, individuals will likely require a long-term follow-up plan and/or lifelong support to ensure that they continue with the recommended approaches and thus avoid relapsing disease. While the population-based programs reported in this section align with current clinical practice guidelines for lifestyle behavioral counseling in a community setting, it is important to integrate these with healthcare-based interventions for individuals and groups, along with ecological approaches to foster supportive, healthy environments.

To date, there are only 3 CDC-funded state and local programs working to increase healthy eating and active living, and to prevent adult and childhood obesity (108). There is inadequate funding to sufficiently support every state, with respect to effective community prevention programs (39), with only $0.31 per person allocated for CDC obesity-prevention efforts (109). There are large differences in the funding awarded to CDC programs, with the Division of Diabetes Translation having a 2022 budget of $193.4 million (110), compared with the 2021 budget for the Division of Nutrition, Physical Activity, and Obesity of $56.9 million (111). This may highlight inequities at a public health level of how importantly obesity prevention and management is viewed compared with other diseases, and could also reflect that obesity is still not properly recognized as a chronic condition, requiring multiple approaches and lifelong treatment.

This also relates back to the relationship between obesity and the risk of developing complications of obesity, as discussed earlier. Obesity drives the development of many chronic diseases, including T2D. Effective resource allocation to improve multidisciplinary team engagement to address obesity early could mitigate or eliminate the development of these complications, thus being an effective primary prevention strategy for many chronic diseases like T2D that increase morbidity and mortality and disproportionately affect individuals from marginalized and low-resource communities. Addressing obesity as a driver of other diseases may also be another strategy to reduce stigma and increase access to care that addresses disparities and preventable disease. However, other critical problems must be considered in this context, such as perceptions about the relative roles of public health and healthcare in obesity, the relative lack of data on the effectiveness of the strategies historically applied, and a possible lack of political willpower for effective intervention at public health level.

Public health awareness and advocacy campaigns nevertheless play a key part in educating people that obesity is a chronic disease, and addressing historical misinformation and stigma around weight. "Obecity, USA" is a public health advocacy campaign that aims to both raise awareness and shift public perception of obesity as a disease, and provides individuals and communities with evidence-based research and resources essential to leading healthy lives (112). The Obesity Action Coalition has also developed several

TABLE 2 Existing obesity evidence-based programs in the US.

| Program title and year | Geographic location | Purpose | CPSTF recommendation utilized | Intended audience | Design | Key findings |
|---|---|---|---|---|---|---|
| Exercise and Nutrition to Enhance Recovery and Good Health for You (ENERGY), (106) | San Diego, California; Denver, Colorado; St Louis, Missouri; Birmingham, Alabama | Promote healthy dietary habits to reduce obesity | Technology-supported multicomponent coaching or counseling to reduce weight (104) | Female breast cancer survivors aged ≥21 years with overweight or obesity | 4-year randomized clinical trial<br>Control and Intervention groups<br>Control ($n = 348$):<br>• Weight management resources and materials, monthly telephone calls and/or emails<br>Intervention ($n = 344$):<br>• Group based behavioral intervention, supplemented with telephone counseling and tailored newsletters | *Mean weight change vs. baseline at 6 months:*<br>Control: −1.2 kg<br>Intervention: −5.0 kg<br>$p = 0.002$<br>*Mean weight change vs. baseline at 12 months:*<br>Control: −1.2 kg<br>Intervention: −5.3 kg<br>$p = 0.003$<br>*Mean weight change vs. baseline at 18 months:*<br>Control: −1.2 kg<br>Intervention: −4.4 kg<br>$p = 0.02$ |
| Weight Loss for Life, (107) | Eastern US | Promote healthy dietary habits and increase physical activity to reduce obesity | N/A | Women aged ≥21 years with obesity and a self-reported goal of weight loss | Comparison (COM) and Experimental (EXP) treatment<br>COM ($n = 55$):<br>• Print manual plus telephone follow-ups<br>EXP ($n = 55$):<br>• The Coach Approach exercise-support protocol for 2 months, followed by group nutrition sessions with a focus on generalizing self-regulatory skills from an exercise support to a controlled eating context | *Weight loss phase (6 months) mean weight reductions:*<br>COM: −2.09 kg;<br>$p < 0.001$<br>EXP: −5.73 kg;<br>$p < 0.001$<br>*Full study duration (24 months) mean weight reduction:*<br>COM: −1.25 kg;<br>$p = 0.068$<br>EXP: −5.11 kg;<br>$p < 0.001$ |

National Cancer Institute Obesity Evidence-Based Programs Listing. Only trials where weight loss was a primary outcome have been reported. COM, comparison; CPSTF, Community Preventive Services Task Force; EXP, experimental; N/A, not applicable.

public health campaigns regarding obesity management including "Your Weight Matters" (113), "Obesity Care Week" (114), and "Stop Weight Bias" (115). Unlike other public health campaigns, Obesity Care Week provides resources not just for people with obesity, but also for HCPs. As HCPs are generally under-prepared to tackle obesity management, such resources are important for improving relationships between people with obesity and their primary care providers, and enabling more open and productive conversations regarding obesity management.

Current public health initiatives are still largely focused on the actions of the individual and making changes to diet and lifestyle, and supported by the above-mentioned CDC programs targeting obesity prevention and mitigation (108). There is some evidence that a significant proportion of the population have already begun to adopt lifestyle changes. Although not directly comparable due to changes in scoring systems and age categories, HEI scores have generally increased from ∼54 for adults in 2005–2006 (116), to 57 in 2017–2018 (117). While highly personalized approaches such as diet and exercise modification must consider individual lifestyle choices, effective design of public health initiatives must also consider each respective community; the unique needs, resources and risks of varying populations must be addressed going forward. Assessment of the unique social, biological, and behavioral needs and preferences at both the individual and population levels is central to targeting strategies for the given circumstances (i.e., individual and small groups or entire communities); such factors may dictate which public health interventions will be more relevant and successful in different areas and for different populations. However, future public health initiatives need to do more to encompass, advertise, and improve access to personalized lifelong obesity management options, including utilization of AOMs and MBS.

## 2.5 Additional barriers to accessing obesity treatment

Some of the barriers to obesity prevention and management already discussed are an obesogenic environment, insufficient access to AOMs (due to factors such as arbitrary insurance coverage decisions or prohibitively high co-pay requirements) and underutilization of AOMs and MBS, bias and stigma in the context of obesity, and related factors e.g., use of AOMs, underutilization of MDTs, and lack of funding.

In relation to public health campaigns, while they can improve awareness and education among the general public, there is the potential that they can create an inadvertent additional barrier in that obesity-related public health media campaigns could be perceived as stigmatizing rather than motivating. A review of major obesity public health campaigns in the US, UK, and Australia found that messages perceived to be the most motivating and positive did not mention the word "obesity," with the focus instead on making healthy behavioral changes, and no reference to body weight. Conversely, the messages with the lowest intentions to comply and the most negative ratings were those that had been publicly criticized for their stigmatizing content (118). Another study found that the use of stereotypical images in anti-obesity campaigns were rated as the most stigmatizing, and were also associated with more desired social distance from the target, and lower positive and higher negative trait ratings of the target, compared to counter-stereotypical images, neutral images, or no images (119).

Although HCPs are increasingly recognizing obesity as a chronic disease, it is often not treated as such and this may relate to a lack of education among both HCPs and people with obesity. A thematic analysis revealed weight bias and negative views and attitudes among HCPs with regards to patients with obesity, their role in obesity assessment, and inadequate training and equipment for obesity assessments, along with citing a lack of time, lack of incentives in the health system, and increased financial cost implications (120). The lack of comprehensive training could be reflective of a legacy of low priority given to obesity education in US medical schools, with only 10% of students in a survey responding that they were "very prepared" to manage patients with obesity, and 30% of schools reporting little or no education in nutrition and behavioral interventions, appropriate communication with patients with obesity, or pharmacotherapy (121). A cross-sectional study of HCPs established that around one-third did not have sufficient knowledge of how to diagnose or treat obesity (122). If HCPs are unable to diagnose obesity, this limits referral to appropriate treatment resources, such as an MDT. The lack of knowledge of obesity amongst HCPs may contribute to knowledge gaps among patients with respect to obesity as a disease, their weight status and how much it is likely to affect their future health, and available treatment options (43). Improving health education, among both HCPs and patients, is key to overcoming some of the barriers to obesity management, including weight bias and stigma. One study found that HCPs who received a 4-h continuing medical education (CME) intervention containing theory-based elements of changing attributions of responsibility of obesity, increasing empathy, creating self-awareness of weight bias, and creating a bias-free culture, had significantly reduced self-reported negative obesity stereotypes compared to baseline ($p < 0.001$), and significantly increased self-reported empathy ($p = 0.006$) and confidence in caring for patients with obesity ($p < 0.001$) immediately post-intervention, which were maintained at 4- and 12-month follow-up. Additionally, compared to HCPs who did not attend the CME intervention, those who did had significantly increased odds (range 60%−212%) of both diagnosis and obesity-related referrals in the 12 months following the intervention (123). It would also be beneficial for professional training of HCPs to focus on methods for assessing the risks of overweight and obesity and associated comorbidities, individual to the patient, so that appropriate referrals can be made to clinical and public health programs and resources, whereby individual treatment plans can be developed using a combination of lifestyle behavioral assessment, clinical risk assessment data, and personal preference.

With respect to expanding access to obesity care in the primary care setting, this links back to an MDT approach in which team-based care could be utilized for lifestyle-focused treatment. There are challenges to sustainably funding and staffing a primary care-based weight management program, although one potential solution would be to use chronic care management codes for patients with obesity (124). This would require an overhaul of diagnostic coding, medical billing, and reimbursement practices in the US. Research by Avalere, a healthcare consulting firm, identified 5 key diagnostic coding and administrative barriers to care for people with obesity: (1) overall lack of understanding of appropriate coding for obesity contributes to underdiagnosis at all stages of a patient's care journey; (2) treatments for complications associated with obesity are often prioritized over coding for and treating obesity; (3) system challenges deter providers from utilizing obesity-specific diagnosis codes, resulting in underutilization; (4) low utilization of preventative care and chronic care management programs to treat people with obesity exists due to coverage burden or associated hurdles and; (5) provider challenges in diagnosing and coding patients for obesity can create barriers to shared decision making (125). As of October 1, 2024, new ICD-10-CM diagnosis codes have been introduced for adult and childhood obesity, which align with the newest recommendations from professional societies. These will help to improve accuracy of obesity severity, improve coding practice as obesity is currently under-coded, enhance the usefulness of data, and help reduce stigma and bias by using accurate and clinically relevant terms (126). Although more still needs to be done, this is an important first step toward improving diagnosis and diagnostic coding of obesity, and therefore appropriate treatment referrals.

## 2.6 What changes need to be made?

Obesity can be described as a systems problem, whereby it is the result of multiple interconnected components, which interact in complex ways (127). This is evidenced by several factors, including global scope, heterogeneous patterns of prevalence, wide-ranging impacts, lack of a single cause, and the failure of a single solution (127); thereby a systems integrated approach to obesity prevention and management is likely to be required.

The 5-tier health impact pyramid is an alternative conceptual framework to improve health through different types of public health interventions. It proposes that the bottom two tiers, comprised of socioeconomic factors, or social determinants of health (SDOH), and changing the context to make individuals' default decisions healthy, generally improve health for more people at lower unit cost than those levels at the top of the health impact pyramid [long-lasting protective interventions, clinical interventions, and counseling and education; (128); Figure 2]. With respect to unit cost, this refers to the assumed cost per individual. Within the health impact pyramid, factors closer to the base of the pyramid have greater population impact, whereas the factors further from the base are designed to help individuals, and so while broad changes at a population level may be more expensive, the overall cost per individual is lower than changes implemented at the top tiers of the pyramid. PSE change is the key way in which the first two levels of the health impact pyramid can be addressed, bringing about much needed improvements in infrastructure, funding, and resources that are needed by public health officials to have the biggest impact and population reach. As suggested by TFAH, these can include measures such as increasing funding for obesity prevention programs, supporting multisector collaborations to address upstream drivers of chronic disease, instituting economic policies to reduce poverty, and ensuring that health equity in planning and decision-making at federal agencies is prioritized (39).

There are some existing frameworks that aim to inform local and state action for obesity prevention, with respect to PSE approaches. The National Council on Aging identified 10 policy solutions for improving obesity care in older adults, addressing a multitude of challenges, and recognized that action needs to be taken by a variety of people and groups, including researchers, healthcare providers, public health professionals, policymakers, and other stakeholders (129). These policy solutions include personalizing obesity treatment, considering several measures of health (i.e., not just BMI), accounting for all conditions that affect health and weight (e.g., SDOH), and better coordination between health systems and community-based weight management and obesity treatment services (130). These are again similar to the proposed recommendations from the TFAH, and at local and state governance levels include addressing food production and processing, distribution, marketing, retail, restaurants and food service, infrastructure and planning, education, employment, transportation, sports and recreation.

More also needs to be done to foster better partnerships between public health system organizations and healthcare settings, to address the five domains of SDOH [economic stability, education access and quality, health care access and quality, neighborhood and built environment, and social and community context; (131)], and to close disparities and gaps in clinic-to-community settings. With respect to economic stability and access to healthcare, this could be reflected in policies designed to reduce poverty, expand access to healthcare coverage and opportunities for coordination between public health and healthcare coordination, addressing root causes of health disparities, and prioritizing SDOH strategies. Policies for addressing neighborhood and built environment have been discussed earlier in this article in the context of tackling the obesogenic environment, with improving food security also relating to social and community context. Community-focused interventions can also feed into these policies, such as Medicaid reimbursement for interventions such as "Food is Medicine" (132), which includes produce prescriptions. On the whole, future public health policies and approaches need to be geographically adaptable, in order to address the specific needs of individual communities. People with obesity living in rural areas are more likely to be affected by issues such as limited access to healthy foods, health services, and exercise facilities, whereas those living in urban areas are more likely to be affected by issues such as neighborhood safety (133, 134), and, in turn, these factors will dictate which public health changes will be more relevant and successful in different areas and for different populations.

We recognize that policy change is just as complex as healthcare change, and one of the key components of this is that public health officials do not have the sole authority to tackle crises, nor the input and infrastructure, with only 5% of the $4.5 trillion spent on health in 2022 in the US going toward targeted public health activities (135). Implementation of effective obesity-prevention policies based on recommendations from national and international organizations has been slow and inconsistent, and a report from *The Lancet* has recognized this by the collective term "policy inertia – the combined effects of inadequate political leadership and governance to enact policies, strong opposition to those policies by powerful commercial interests, and a scarcity of demand for policy action by the public" (136).

As demonstrated in Tables 1 and 2, innovative, evidence-based interventions have not been fully identified or systematically applied in public health to date. This is a crucial area for future research, in order for public health campaigns and interventions to have a scientific basis, with proven results. Besides funding clinical trials to evaluate the effects of drugs regulated by the FDA, the National Institutes of Health (NIH) also awards funds to clinical trials of other interventions that are not FDA-regulated (137). This could be a key area for stakeholders and policymakers to target in the future with respect to clinical trials investigating an MDT approach to obesity management and treatment.

## 3 Conclusion

It is clear from the evidence that a holistic integrated approach to obesity management results in better outcomes for people with obesity as it is a chronic, complex, and often relapsing disease. Existing measures and public health initiatives have limited reach, and, despite a long history of limited effectiveness, still have a predominant focus on the action of individuals. More work is needed to advocate the importance of changing strategies for obesity management to public health officials and enable them to adapt their strategies to take advantage of the new science on obesity e.g., campaigns fighting stigma, messaging encouraging the public to consider all levels of intervention, policy advocacy for AOM coverage, and

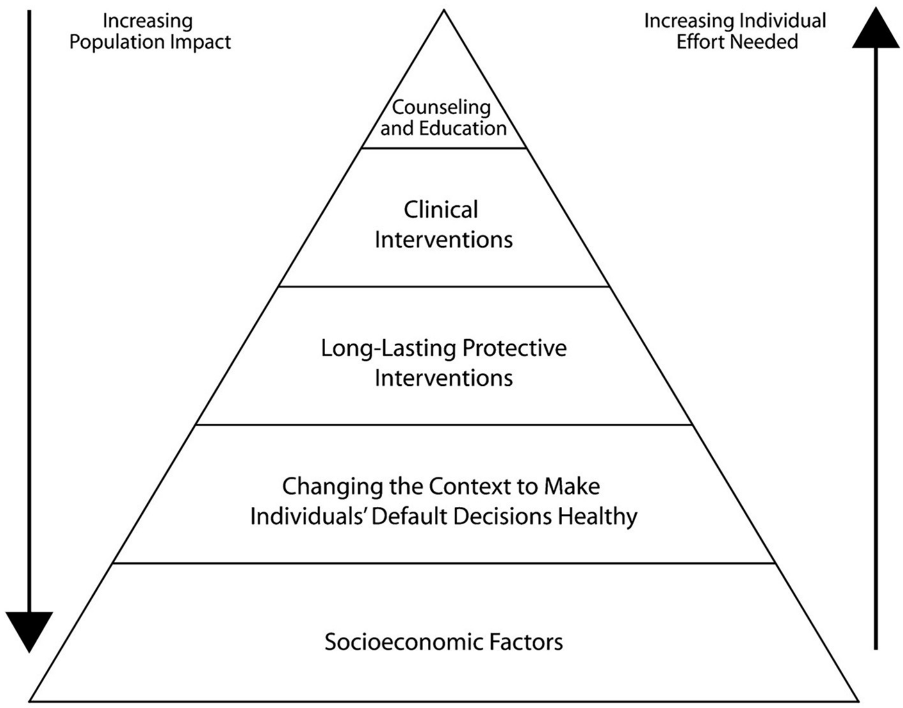


FIGURE 2
Health impact pyramid. Reproduced with permission from Frieden (128). AOM, anti-obesity medication; MBS, metabolic and bariatric surgery; SSB, sugar-sweetened beverage.

environmental change. PSE changes at the national, state, county, and city levels are key to tackling many of the barriers to obesity prevention and treatment, particularly with regard to making changes to SDOH; this can be achieved through increasing and improving public health funding and infrastructure for obesity prevention and management, which are currently insufficient. For the time being, existing models and recommendations identified in current clinical practice health guidelines, such as the AAC/AHA/TOS, AACE/ACE, and TFAH, have a strong foundation with sufficient evidence to guide clinical and public health strategies that can be refined in the future as further solutions are identified. Public health officials, stakeholders and policymakers must recognize that obesity is chronic disease that needs to be addressed now, for the sake of the US population and future generations.

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The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Exploring the multifaceted factors influencing overweight and obesity: a scoping review

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**Introduction:** Obesity and overweight problems in public health have substantial impacts which affect the health status of individuals and community well-being and healthcare service provision worldwide. This scoping review aims to identify and classify factors from social, technological, environmental, economic and political domains which influence obesity and overweight conditions. The systematic analysis of determinants in this study generates usable information to guide public health intervention design and obesity epidemic management strategies.

**Methods:** The study utilized the ProQuest, ISI Web of Science, PubMed, and Scopus databases, and it also included grey literature in its analysis. The research objectives focused on identifying factors that contribute to overweight or obesity issues. The researchers used framework analysis to examine the qualitative data collected from these studies.

**Results:** The synthesis incorporated 121 research studies which satisfied the established criteria. This comprised 98 studies from 46 different countries, 17 studies conducted at the international level, and 6 studies involving multiple countries. Eighty-two factors influencing overweight and obesity were identified as determinants and categorized into five main categories: sociocultural, economic, technological, environmental, and political. Most of the identified determinants belong to the socio-cultural category, which demonstrates their substantial impact on lifestyle and health behaviors.

**Conclusion:** The implementation of public health prevention and intervention programs depends on complete knowledge of all factors that affect overweight and obesity rates. This issue needs a comprehensive approach which analyzes sociocultural aspects together with economic, technological, environmental, and political factors, as well as other policy goals within defined societal challenges. Effective solutions to resolve this situation depend on multi-sectoral collaboration to tackle obesity and promote health-enhancing factors for the entire community.

KEYWORDS

**obesity, overweight, socio-cultural determinants, economic factors, technological influences, environmental factors, public health policy, scoping review**

## 1 Introduction

Overweight and obesity represent preventable health issues with multiple factors that have become prevalent in more than one-third of the global population worldwide (1–4). These conditions characterized by abnormal or excessive fat accumulation that poses a risk to health (5). A body mass index (BMI) over 25 is classified as overweight, while a BMI over 30 is classified as obese (2). The health risks from overweight and obesity exist, yet obesity leads to more severe and more frequent chronic diseases than overweight (5).

The issue represents a worldwide health concern which affects life quality throughout various population groups (6–9). Worldwide, at least 2.8 million people die annually as a result of overweight or obesity (10). The link between obesity and high-income countries used to exist (9–11) but the condition has become widespread throughout low- and middle-income countries as well (10–12). Overweight and obesity rates keep increasing at an alarming rate. Research shows that childhood and adolescent obesity rates among 5 to 19 years old increased four times between 1990 and 2022 from 2 to 8%. Similarly, the prevalence of obesity among adults aged 18 and older more than doubled, increasing from 7 to 16% (10). A total of 2.6 billion people suffered from obesity and overweight conditions during 2020. The global prevalence of overweight and obesity rates will rise from 38% in 2020 to surpass 50% in 2035. It is predicted that more than 4 billion individuals will experience overweight or obesity by 2035 (13). Specifically, the prevalence of obesity is expected to rise from 14 to 24 percent of the population over the same period, and nearly 2 billion adults, children and adolescents will be impacted by 2035 (13).

Overweight and obesity serve as main factors that lead to noncommunicable diseases, including cardiovascular disorders, diabetes, and cancer. These conditions lead to more than 5 million annual deaths with most fatalities happening before age 70 (3). Obesity-related health risks increase mortality rates and lead to severe reductions in quality of life through physical disabilities, as well as psychological conditions such as depression, self-esteem issues, and social discrimination. Because of their long-term nature these conditions trigger ongoing healthcare issues which create an enduring healthcare burden throughout the world (14, 15).

Healthcare costs associated with obesity treatments and their complications along with diminished productivity and earlier retirement and elevated mortality rates constitute the economic impact of overweight and obesity (13, 15–17). The projected costs for healthcare services will elevate from $1.96 trillion in 2020 to exceed $4 trillion by 2035. Furthermore, the economic effects of obesity will reduce global Gross Domestic Product (GDP) between 2.4 and 2.9% during the period from 2020 to 2035 (13). The economic decline during this period matched the estimated effects of the COVID-19 pandemic on the world economy during its most difficult year in 2020 that reduced GDP by 3% (13). The World Health Organization (WHO) has declared obesity as a significant public health emergency which demands swift worldwide intervention (2, 7, 15). Tackling the rise in obesity is vital for achieving the Sustainable Development Goals (SDGs) (3, 18–20). The SDG Target 3.4 sets a goal to decrease premature deaths from non-communicable diseases until 2030. The solution to the obesity crisis lies in addressing the root causes of obesity factors that are rapidly creating a global environment conducive to obesity (1).

Literature about obesity and overweight determinants establishes both genetic and biological elements as substantial components of this research field. However, Literature lacks comprehensive exploration of social, economic, environmental, technological and political aspects regarding these conditions. Therefore, to address this gap in knowledge, it seems necessary to conduct a scoping review. In order to combat the increasing prevalence of obesity and overweight, this scoping review systematically explores the social, technological, environmental, economic and political factors that increase obesity and overweight occurrences. The review establishes a complete framework through an analysis of current research about these determinants to support public health intervention planning and policy development. The holistic approach provides essential knowledge needed to develop effective strategies which address the worldwide obesity epidemic.

## 2 Methodology

The research methodology built by Arksey and O'Malley (21), received further development by Levac et al. (22), and followed Joanna Briggs Institute (JBI) protocols (23). A scoping review includes different study designs and contexts to create an organizational structure of existing research within a particular field and follows a five-step execution process (21):

1) Identifying the research question
2) Searching for relevant studies
3) Selecting studies
4) Charting the data
5) Collating, summarizing, and reporting the results

This paper discusses these stages in accordance with the current scoping review framework.

### 2.1 Step 1: Identifying the research question

The research question for this review study was defined as follows:

- Which factors from socio-cultural, economic, technological, environmental and political categories influence overweight and obesity?
- How does each category of factors contribute to the rising prevalence of overweight and obesity?
- What are the global trends in obesity research, and how do geographical and socioeconomic differences affect the understanding of obesity factors?
- What methodological approaches have been used in obesity research, and how can future studies improve the assessment of overweight and obesity factors?
- What gaps exist in our current understanding of the factors of overweight and obesity, and which future research should receive priority for optimizing obesity prevention and intervention approaches?

### 2.2 Step 2: Searching for relevant studies

The literature review included research from 2013 to December 2023 which was retrieved from electronic databases such as PubMed, Scopus, ISI Web of Science, and ProQuest. The search strategy utilized Boolean operators and key terms such as *factor*, *determinant*, *driver*, *obesity*, *overweight*, *social*, *technological*, *environmental*, *economic*, and *political*. The search strings were specifically designed for each database to maximize the retrieval of relevant studies, using the example shown in Table 1 for the PubMed search strategy. The initial search was performed on January 31, 2023, and an updated search was completed on April 7, 2023. To enhance comprehensiveness, backward and forward snowballing was employed by screening the reference lists of included studies.

## 2.3 Step 3: Selecting studies

The selection process is detailed in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart (Figure 1) (24), which illustrates the number of records identified, screened, excluded, and included in the review. The study selection process was managed using EndNote 21 to eliminate duplicates. The screening process consisted of two distinct stages for selection:

- A single researcher (M.J.) performed title and abstract screening as part of the relevance evaluation process to determine inclusion consistency with established criteria.
- Two reviewers (M.J. and S.G.) conducted separate evaluations of all potentially eligible studies in their full-text format. The reviewers reached agreement about any conflicting interpretations through discussion until they achieved consensus.

## 2.4 Eligibility criteria

The Population, Concept, Context (PCC) framework by JBI served to establish the eligibility criteria for this scoping review (25). The JBI recommendation of the PCC framework enables researchers to develop clear research questions while identifying suitable studies through its three essential elements:

- **Population (P)**: The research targets specific individual groups known as the population.
- **Concept (C)**: Relates to the primary phenomena of interest.
- **Context (C)**: The research environment where studies take place represents context.

Table 2 presents the complete eligibility criteria which the review team developed by conducting an initial exploratory search and subsequent discussions.

## 2.5 Step 4: Charting the data

A standardized data extraction form built in Microsoft Excel was used for the data collection process. The researchers extracted the following information from each study:

TABLE 1 Search strategy for the PubMed database.

| Search string record |
|---|
| ((“Social”[Title/Abstract] OR “cultural”[Title/Abstract] OR 1231 “socio-cultural”[Title/Abstract] OR “Technological”[Title/Abstract] OR “Economic”[Title/Abstract] OR “Political”[Title/Abstract] OR “ecological”[Title/Abstract] OR “environmental”[Title/Abstract]) AND (“factor”[Title/Abstract] OR “determinant”[Title/Abstract] OR “driver”[Title/Abstract]) AND (“obesity”[Title/Abstract] OR “overweight”[Title/Abstract])) |

- Study title
- Author(s) and publication date
- Country of origin
- Population characteristics (age, gender)
- Study design
- Study aims and research questions
- Key findings, factors, and determinants associated with obesity

M.J. and S.G. independently checked 20% of the studies to verify data extraction accuracy and consistency. The reviewers addressed any discrepancies by discussing them until both parties reached agreement. For additional details, the complete charting form is available in the Appendix section.

## 2.6 Step 5: Collating, summarizing and reporting the results

The research team analyzed extracted data using thematic analysis and an analytical framework to identify consistent patterns and relationships between the five Social, Technological, Economical, Environmental and Political (STEEP) categories. The research incorporated both qualitative and quantitative data findings to present a whole picture of obesity determinants. The thematic synthesis enabled researchers to uncover important factors while studying their relationships to one another.

## 2.7 Validity and reliability

This review adopted steps to guarantee its reliability and rigor, despite the typical absence of formal quality assessment for included studies in scoping reviews:

- The search strategy developed in partnership with an information science expert to achieve both high levels of inclusiveness and reduce potential bias.
- Data extraction performed independently by the reviewers, and any disagreements were resolved through discussion and agreement.
- The review team documented all methodology steps transparently to enhance the ability to replicate the findings.

# 3 Results

The characteristics of the studies included in the qualitative synthesis are summarized in Table 3, which details the geographic distribution, study design, and demographic focus of the included studies. As depicted in Figure 2, most research was conducted in North America, with the United States leading in the number of studies. A total of 30 studies (24.8%) which made up the majority were performed in North American territories. Studies from the United States made up the largest group, totaling 24 (19.8%; see Figure 2). Excluding globally conducted research (23 studies, 19%), the rest of the studies fell into three categories: 44.6% in high-income countries, 19% in upper middle-income countries and 12.4% in low middle-income countries. The research data show that studies

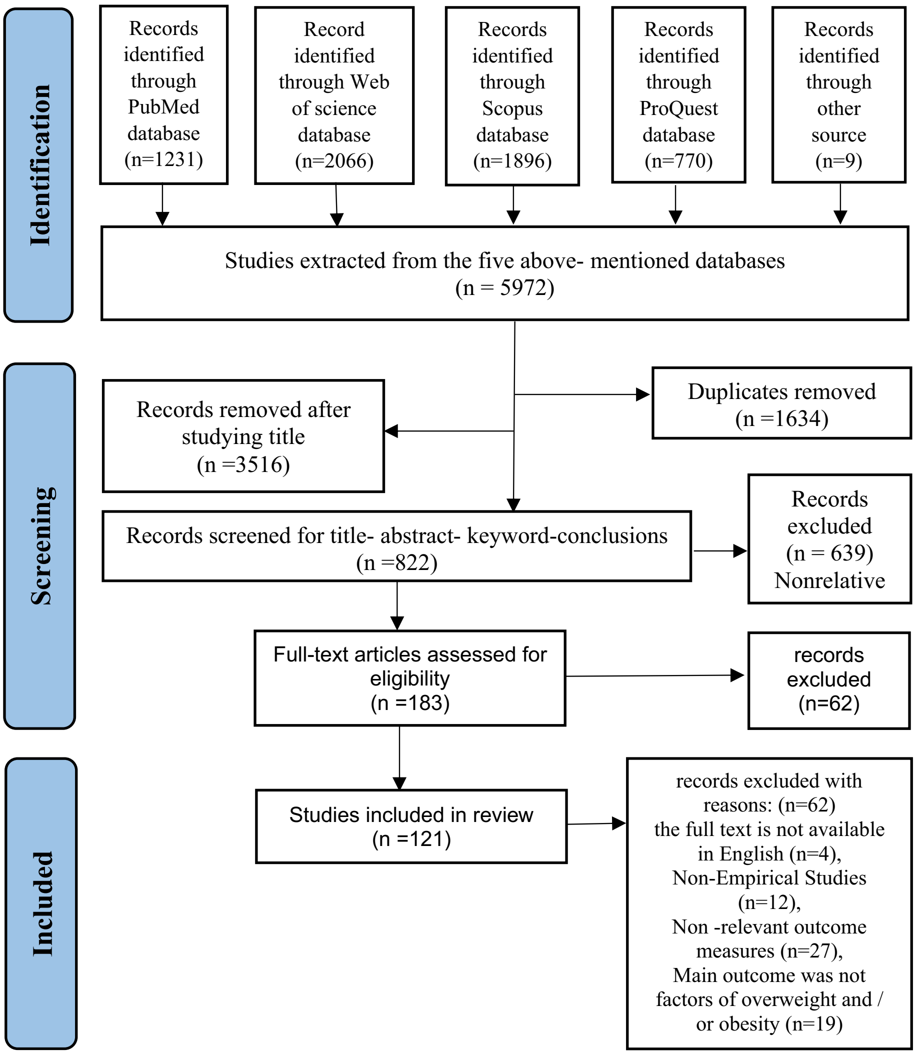


FIGURE 1
PRISMA flow diagram of the included studies.

conducted in low-income countries account for only 5% of the total investigations, as shown in Figure 2. The majority of research (61.2%) within the entire dataset employed a cross-sectional study design. Figure 3 shows that obesity-related research has experienced significant growth from 2019 to 2023. Most research studies were performed in 2022 according to the analysis of publication dates. Additionally, 36 studies (29.8%) were published between 2013 and 2018, while 85 studies (70.2%) were published from 2019 to 2023 (see Figure 3).

Adults received the most attention in obesity research studies, as 40.5% (49 studies) focused on this age group. Most research (106 studies, 87.6%) examines gender-specific patterns and determining factors that affect both men and women but demonstrates additional research interest in female groups.

The factors influencing obesity, categorized according to the STEEP framework, are presented in Table 4. The analysis identified 82 different factors that fall under the five main categories of the STEEP framework. The majority of factors fell under the socio-cultural category ($n = 24$), whereas the technological category contained the fewest factors ($n = 10$) (see Figure 4).

Out of 121 studies, 90 (74.4%) explored the relationship between socio-cultural factors and obesity or overweight. Among these, 59 studies focused on socio-demographic factors and their influence on overweight or obesity, with a consensus that these factors are of significant importance. Notably, age, gender, education level, residential areas, and marital status were identified as key factors associated with overweight and obesity, as reported in more reviewed studies. Another significant influencing factor for overweight and obesity, categorized under socio-cultural aspects, is the impact of family. The relationship between family influence factors and overweight and obesity was analyzed in 36 studies. The most notable factors associated with family influence, whose effects on the overweight and obesity of children were reported in multiple articles, include family income, parental education, and occupation. Twenty-six research studies examined the relationship between economic factors and overweight or obesity. Among these studies, the unemployment rate, low income, and GDP were identified as significant factors linked to overweight and obesity, with the highest occurrences reported in the article. Twenty-two studies analyzed technological

TABLE 2 Eligibility criteria.

| Inclusion criteria | |
|---|---|
| Source of information | Peer-reviewed journals and publicly available grey literature |
| Language | Studies published in English |
| Time frame | 2013 to December 2023 |
| Context | Global, without geographical restrictions |
| Study population | All age groups and genders |
| Phenomena of interest | Socio-cultural, technological, economic, environmental and political factors or determinants that influencing obesity or overweight |
| Type of studies | Any study that examined determinants or factors associated with obesity or overweight |
| Study Design | Quantitative, qualitative, mixed-method studies, and systematic reviews |
| Primary Outcomes Measured | Overweight and obesity classified according to the BMI index based on the World Health Organization (WHO) scale (2) |

| Exclusion criteria | |
|---|---|
| Phenomena of interest | Genetics and biological factors related to overweight and obesity |
| Type of studies | Methodological studies, discussion papers, general literature reviews, Case reports, case series, letters to editors, commentary pieces and study protocols |
| Excluded Outcome Measures | overweight and obesity based on other index (Waist circumference, Waist-to-hip ratio, Skinfold thickness) and not in accordance with the WHO scale |
| Language | Non-English studies |
| Time restriction | Before 2013 |

TABLE 3 Characteristics of the studies included in the qualitative synthesis.

| Characteristic | No. of studies (percent) |
|---|---|
| **Continent** | |
| North America | 30 (24.8%) |
| Asia | 28 (23.1%) |
| Europe | 20 (16.5%) |
| Africa | 17 (14.1%) |
| International | 17 (14.1%) |
| Australia | 5 (4.1%) |
| South America | 3 (2.5%) |
| Oceania | 1 (0.8%) |
| **Publication year** | |
| 2013–2014 | 13 (10.7%) |
| 2015–2016 | 8 (6.6%) |
| 2017–2018 | 15 (12.4%) |
| 2019–2020 | 29 (24%) |
| 2021–2022 | 41 (33.9%) |
| 2023 | 15 (12.4%) |
| **Sex Distribution** | |
| Both | 106 (87.6%) |
| Women | 12 (9.9%) |
| Nonreported | 3 (2.5%) |
| **Method** | |
| Cross-sectional | 74 (61.2%) |
| Review | 23 (19%) |
| longitudinal studies | 12 (9.9%) |
| qualitative studies | 11 (9.1%) |
| Mixed-Method | 1 (0.8%) |
| **Sample size** | |
| <100 | 8 (6.6%) |
| 101–1,000 | 22 (18.2%) |
| 1,001–10,000 | 29 (24%) |
| 10,001–100,000 | 23(19%) |
| > 00,000 | 22 (18.2%) |
| Nonreported | 17 (14%) |
| **Age group distribution** | |
| Adults | 49 (40.5%) |
| Children | 22 (18.2%) |
| Children and adolescents | 18(14.8%) |
| All age | 12 (9.9%) |
| Adolescents | 8(6.6%) |
| Adolescents and adults | 6(5%) |
| Nonreported | 6 (5%) |

factors in the development of overweight or obesity, confirming technological progress as a primary cause.

The most significant factors associated with technological advancement included television, the internet, video games, and social media, as well as digital marketing and advertising. Thirty-nine studies were reviewed to analyze the relationship between environmental factors and overweight or obesity. The most significant factors identified within the environmental category were the neighborhood food environment and the built environment, as reported in the majority of the articles. Eighteen research studies examined the association of political factors with overweight or obesity. The most prominent factors linked to overweight and obesity were food and nutrition policies, along with school food and physical activity policies, were the most prominent factors linked to overweight and obesity, as reported in most articles.

## 4 Discussion

This scoping review shows that overweight and obesity result from many intertwined factors which create such a complex issue. The research analysis detected 82 contributing factors that researchers grouped into five fundamental categories: socio-cultural, economic, technological, environmental and political. The most important factors leading to overweight and obesity stem from the socio-cultural category which demonstrates how family structures and social connections together with cultural values play a crucial role in these conditions. Research shows that

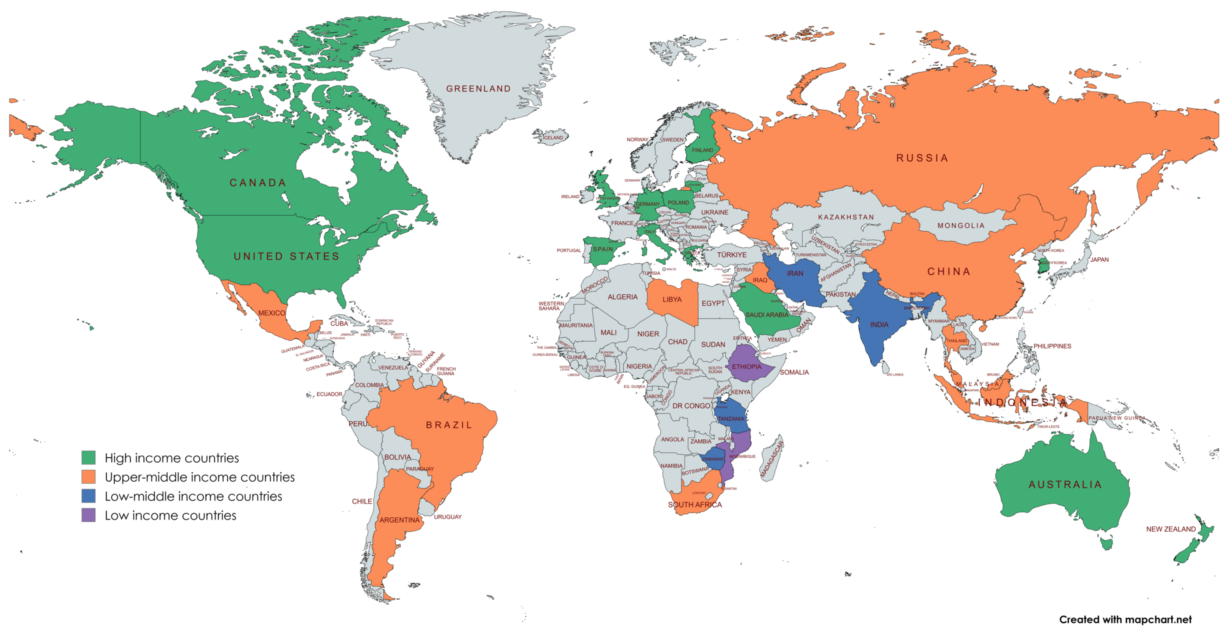


FIGURE 2
Geographical distribution of studies.

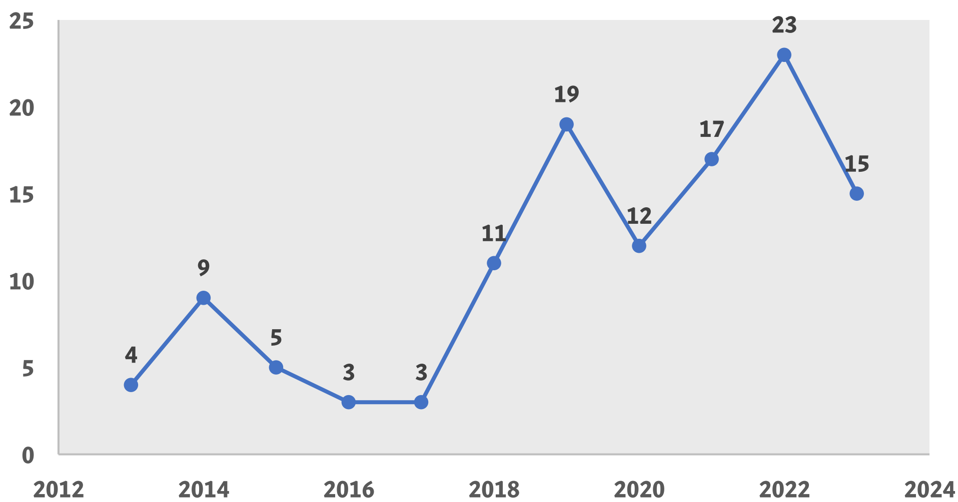


FIGURE 3
The time trend of included studies.

economic factors, along with advances in technology and environmental changes especially urbanization have a great impact on obesity patterns. Public health policies together with regulatory frameworks both serve as essential political factors that influence this problem.

Current global studies about obesity and overweight demonstrate that these problems exist throughout worldwide regions. The diverse geographical mapping of overweight and obesity research provides analysts and policymakers with enhanced knowledge about global challenges and solution possibilities although low-income and lower-middle-income countries have fewer studies.

Analysis of the distribution of research approaches used in obesity and overweight studies showed that various methods were used throughout the series, but cross-sectional studies were the predominant method, with 74 studies (61.2%) using a cross-sectional method in their studies. Research on obesity needs to establish longitudinal studies because its complex causes require long-term observation of weight change and other contributing factors. This research design allows researchers to detect connections between multiple influencing factors. Additionally, research that relies on qualitative methods which use lived experiences from individuals produces substantial understanding of the subject. Furthermore, a combination of quantitative and qualitative research approaches through mixed methods analysis provides an extensive examination of obesity and overweight causes and effects and intervention solutions. Based on age group distribution, the majority of studies concentrated on adults (40.5%). It appears essential to conduct further research, especially

TABLE 4 Factors influencing obesity categorized by STEEP framework.

| Category | Factors |
|---|---|
| Socio–cultural | • **Socio-demographic Factors:** (Age, Gender, Marital Status, Education Level)<br>• **Socioeconomic Status (SES):** (Income Levels, Employment Status, Urban or Rural Residence)<br>• **Social inequality** (disparities in income, education, and opportunities)<br>• **Family structure and size** (single-parent households, number of siblings)<br>• **Parental education and employment** (impact on children's dietary habits)<br>• **Peer and social support networks** (influence of friends, community support)<br>• **Early childhood development** (socioemotional learning, childhood adversity, peer interactions, Infant-feeding method)<br>• **Body weight stigma and discrimination** (negative societal attitudes toward overweight individuals)<br>• **Screen time and sedentary activities** (time spent on TV, computers, and video games)<br>• **Social norms around food** (e.g., food as reward, bonding or way to express love, family meals)<br>• **Parental perceptions and influence on child body weight (**parental attitudes toward child's weight and health)<br>• **Peer and family influence** (e.g., family diet habit, family income, family-related stress)<br>• **Social support**) e.g., community connection, global happiness, civic engagement, collective efficacy)<br>• **Social globalization** (exposure to global cultural norms through media and migration)<br>• **Social Opportunities** (Access to education, health insurance, access to health services, health literacy, Perceived discrimination)<br>• **Crime rate** (impact of unsafe neighborhoods on outdoor physical activity)<br>• **Human Development Index** (HDI) (a summary composite measure of a country's average achievements in three basic aspects of human development: health, knowledge and standard of living)<br>• **Women's empowerment** (gender equality and influence on health choices)<br>• **Ethnic, racial and religious differences** (cultural attitudes)<br>• **Gender roles affecting dietary choices and social expectations** (expectations influencing eating habits)<br>• **Cultural perceptions of obesity** (as a symbol of wealth or prosperity)<br>• **Beliefs about health and body weight** (cultural attitudes towards ideal body types)<br>• **Dimensions of national culture** (e.g., individualism, uncertainties or ambiguities, focus on freedom and happiness, focus on short-term goals,<br>• intolerant of inequalities and power hierarchies, less competitive and more feminine)<br>• **Dietary rituals and habits** (traditional food practices and meal patterns) |
| Technological | • **Influence of digital and social media on body image and diet choices** (e.g., exposure to ideal body types influencing self-perception)<br>• **Increased screen time and digital entertainment** (e.g., watching TV, using computers, playing video games)<br>• **Online food delivery services promoting processed foods** (e.g., fast food delivery apps increasing access to unhealthy options)<br>• **Dependency on passive transportation and reduced physical activity** (e.g., reliance on cars reducing physical activity)<br>• **Work-from-home and remote learning effects on sedentary behavior** (reduced movement due to telecommuting)<br>• **Increased access to technology for entertainment and digital advertising** (e.g., internet, social media)<br>• **Influence of digital advertising on dietary choices** (e.g., targeted ads promoting unhealthy foods)<br>• **Decrease in physical activity due to automation and modern conveniences** (e.g., household gadgets reducing manual work)<br>• **Digital advertising and targeted marketing** (impact of online ads on consumer behavior)<br>• **Widespread expansion of online educational programs** (reduced physical activity due to increased online learning) |
| Economic | • **National income per capita** (association with obesity prevalence in high- vs. low-income countries)<br>• **GDP** (gross domestic product as a marker of national wealth and health outcomes)<br>• **Decreasing purchasing power for healthy foods** (rising costs of nutritious foods)<br>• **Price index of food items** (impact of food pricing on dietary choices)<br>• **Poverty** (limited access to nutritious foods)<br>• **Prolonged Financial stress** (impact on eating habits and stress-related weight gain)<br>• **Economic shocks** (e.g., inflation, recession affecting food security)<br>• **Unemployment rate** (association with reduced access to healthy foods)<br>• **Job insecurity** (stress-related eating and reduced income for healthy food)<br>• **Gini coefficient** (measure of income inequality and its correlation with obesity)<br>• **Urbanization and rural residence disparities** (differences in food availability and physical activity opportunities)<br>• **Calorie intake per capita** (link between economic growth and increased caloric consumption)<br>• **Cost of exercise** (affordability of gym memberships and fitness activities)<br>• **Domestic expenditure on health and food** (impact of food pricing on dietary choices)<br>• **Housing insecurity** (impact on diet quality and food access)<br>• **Food insecurity and limited access to nutritious options** (association with high-calorie, low-nutrient diets)<br>• **Economic liberalization and trade effects on diet** (association with availability and quality of diet)<br>• **Costs of nutritious vs. processed foods**)The high cost of nutritious and healthy foods(<br>• **Access to healthy foods based on economic constraints** (limited access to nutritious foods) |

*(Continued)*

TABLE 4 (Continued)

| Category | Factors |
|---|---|
| Environmental | • **Climate and Geography** (temperature, harsh winter climate, humidity, latitude, dust)<br>• **Global warming and climate change limiting outdoor activities** (impact on outdoor physical activity and food supply)<br>• **Traffic** (e.g., air quality and traffic-related barriers to physical activity)<br>• **Pollution** (air, light, obesogenic chemicals with endocrine-disrupting properties in food production, packaging and environment, heavy metals, maternal second-hand smoking)<br>• **Built environment** (e.g., Infrastructure for active living, quality of roads, street connectivity, public transport, residential density)<br>• **neighborhood food environment** (availability of healthy food options in local stores)<br>• **Access to parks, green spaces, and recreational facilities** (impact on physical activity levels)<br>• **Neighborhood walkability and safety** (e.g., crime rates affecting willingness to exercise outdoors)<br>• **Availability of sidewalks, bike lanes, and traffic infrastructure**<br>• **Climate change impacting food supply** (e.g., availability of fresh produce)<br>• **COVID-19 pandemic effects on diet and physical activity** (lockdowns increasing sedentary behavior)<br>• **Overpopulation and reduced access to recreational areas**<br>• **Urban vs. rural residence** (differences in access to food and recreation)<br>• **Neighbourhood deprivation** (impact of socio-economic status on local food and exercise environments) |
| Political | • **National Obesity Strategy policies** (government frameworks targeting obesity prevention)<br>• **Influencing policymaking processes through lobbying** (e.g., through lobbying, "Big Food" has directly sought to influence policy and governance).<br>• **Government policies on food and physical activity** (Healthy food production and distribution policies, encouraging the reformulation of processed foods to be healthier, setting policies for food vendors, health regulations on the numbers, availability and distribution of high-calorie fast food restaurants (<br>• **Trade liberalization** (impact of global food trade on local diets)<br>• **School nutrition and physical activity policy** (e.g., mandating healthy school lunches, physical education programs)<br>• **Policy response to reduce the impact of advertising on children** (e.g., restrictions on marketing unhealthy foods to minors)<br>• **Regulations on food labeling and health standards** (mandatory calorie labeling on menus)<br>• **Policies supporting active transportation and recreation** (investment in public transport and green spaces)<br>• **Urban planning regulations** (e.g., green spaces, bike lanes)<br>• **Public health campaigns for obesity prevention** (government-sponsored initiatives promoting healthy lifestyles)<br>• **Taxation of unhealthy foods** (e.g., sugary beverage taxes to reduce consumption)<br>• **Subsidizing healthier and less dense foods** (financial incentives for purchasing nutritious food)<br>• **Urbanization and development policies** (shifts in dietary patterns and physical activity levels)<br>• **Food marketing and advertising regulations** (e.g., reduce advertisements for unhealthy foods)<br>• **Insufficient policies promoting physical activity in schools and communities** (Facilitating free exercise) |

concerning the children and adolescents age group. However, upon reviewing the history of these studies, it was discovered that 15 out of 22 studies (68%) in the children's age group were carried out in the last 5 years, from 2019 to 2023. This indicates the growing significance of research on obesity and overweight in children in recent years.

The socio-cultural category was the most dominant, as it encompassed a wide range of identified factors. The research demonstrates how sociodemographic factors together with family dynamics and social support systems, and cultural norms, directly affect weight-related behaviors and their corresponding results. The research analyzed age, gender, marital status, education level and socioeconomic status as socio-demographic factors. Multiple studies across the literature identified these factors as important variables. Education together with gender along with age and marital status and socioeconomic factors create a complex relationship that proves the need for specific interventions to fight obesity.

Research findings demonstrate that age has a positive relationship with obesity and overweight because BMI tends to rise as people grow older (26–57) while older age groups (36, 43, 49, 52) may show a decline. Research revealed that people under 35 years old demonstrated both a higher BMI transformation rate and a greater number of obesity and overweight cases (58). Maternal age during pregnancy has been recognized as a significant influencing factor in the likelihood of obesity in children, with offspring of mothers over 30 years old at the time of pregnancy being at a higher risk of developing obesity (26). Consequently, factors such as population aging, early obesity interventions due to the rapid increase in obesity rates among younger age groups, and later marriages and pregnancies among women should be considered as crucial age-related elements in the design and implementation of obesity interventions.

The literature demonstrates that women experience more BMI changes and show higher obesity rates than their male counterparts in multiple research studies (27–44), yet alternative findings exist (26, 45–49). Male individuals tend to experience higher rates of being overweight, while female individuals exhibit increased rates of obesity (50). The combination of sedentary work activities with dietary choices plays a significant role in creating weight differences between women and men in developed nations. The physical activity patterns in developing countries have undergone significant changes, which specifically affect women. The sedentary lifestyle of women compared to men makes them more susceptible to weight gain from energy-dense foods. Sociocultural beliefs and values related to physical activity and body weight have a more significant impact on gender differences in overweight and obesity in developing countries compared to developed countries (51).

The majority of studies reviewed indicate that being married is associated with a higher risk of overweight and obesity compared to

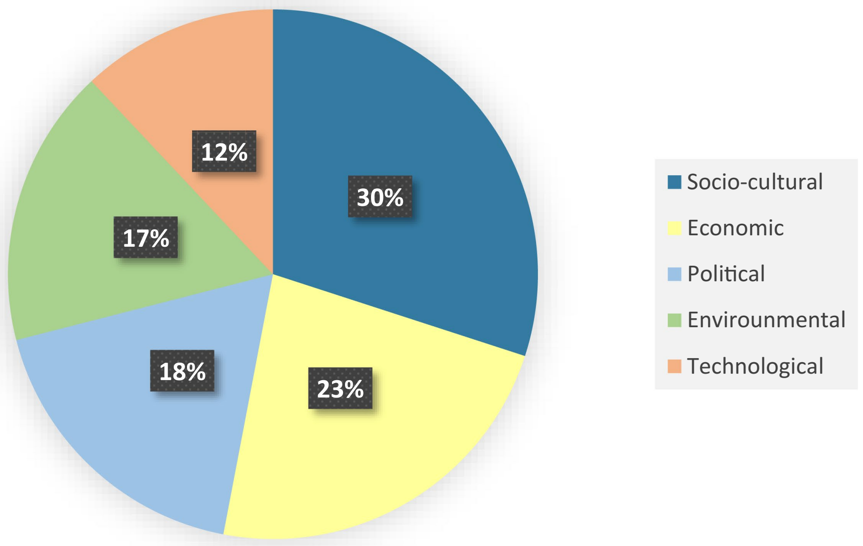


FIGURE 4
The percentage of determining factors based on the STEEP framework.

being single or unmarried (30–32, 34, 36, 38, 50, 52–58). However, some research have reported contrasting outcomes to this general trend (59, 60). Additionally, people who are divorced or widowed experience more chances of being overweight or obese than individuals who remain single (38). Single individuals usually take weight management seriously so they can appear more appealing to romantic prospects, yet married people tend to spend less time being active because they have more household responsibilities. After marriage, people tend to experience changes in their eating habits that create obstacles for weight management (61).

Education level, alongside economic status determines how people choose their food and how active they remain. The way educational background affects obesity shows diverse patterns depending on gender and age, along with socioeconomic situations. Studies have produced contradictory data about the connection between educational attainment and obesity prevalence. Research shows that higher education acts as a protective measure against overweight and obesity, while this pattern mostly occurs in younger and male populations (36–38, 49, 50, 57, 60, 62–67).

Conversely, other research has discovered that people with higher education levels tend to overweight and obesity problems more frequently and this impact is particularly strong for women (31, 33, 52, 53, 68–71). The relationship between education level and weight status can be affected by other variables such as income and occupation (27, 54, 67, 72). Research discrepancies about education and weight status emerge from different socio-cultural factors alongside economic and environmental conditions which affect this connection. People with advanced education benefits from better knowledge about healthy choices, yet face dual risks from inactive work settings and excessive high-calorie processed foods found in their neighborhoods.

The review demonstrates how living in urban or rural areas affects the prevalence rates of overweight and obesity. The studies consistently have indicated that residing in urban or metropolitan areas was associated with a higher risk of being overweight or obese compared to living in rural areas (31, 33, 34, 38, 47, 50, 52, 54, 68, 73–76). Some studies have also suggested that the urban–rural gap is narrowing due to the increasing prevalence of overweight and obesity among rural residents (28, 29, 70, 77–79). Rural food environments alongside lifestyle patterns have undergone a shift because unhealthy food choices have become more accessible and people spend less time engaging in physical activities.

Most factors related to the family influence factor were those that contributed to obesity and overweight in children and adolescents. Research shows that children whose parents have advanced education tend to maintain healthy body weight (73, 80–86). Research indicates that parents with higher education unintentionally guide their children toward a high-energy sedentary lifestyle, which raises their weight problem risk (66, 87). These findings demonstrate the intricate relationship between parental education and child weight status because protective and risk factors were discovered. It seems that additional investigation will be needed to explain the fundamental processes and place-specific factors which regulate this connection. Parental occupational status, including maternal employment (54, 66, 84, 85), dual parental employment (82, 85–87), and high parental occupational level (73, 82), has been reported to be increasingly linked to childhood obesity.

Another significant factor that numerous studies have indicated influences childhood overweight and obesity is family eating habits. These habits include limited time spent eating with children (80), frequency of breakfast during the week, the number of eating occasions throughout the day (81), the frequency of family meals (80–82), food choices made within the family (83), inadequate fruit and vegetable consumption (86), and the promotion of a healthy diet as a family (84), eating as an expression of love within the family, daily junk food consumption as a family activity and bonding opportunity

(85), using food as a reward (86–88) and eating as a means of controlling the parent–child relationship (86), have been linked to an increase in obesity among children.

There was a significant association between parental obesity or overweight and the prevalence of childhood obesity, as reported in studies (45, 74, 80, 81, 89–94). The link between parental obesity or overweight and child obesity results from both genetic and environmental influences. Family eating habits, together with living conditions and health-related behaviors, determine the weight of children. For instance, overweight or obese parents tend to show decreased attention to their children's weight problems (95).

According to studies, family income was inversely correlated with being overweight or obese. High rates of overweight and obesity among adults and children were linked to lower income levels (45, 49, 59, 60, 79, 96–98). However, some studies have found a linear positive relationship between family income and BMI (27, 99). Future research should develop longitudinal studies across different regions to track numerous participants because this approach will better understand the causal link between family income and obesity.

The role of economic factors stands essential in creating patterns of obesity beyond socio-cultural influences. The financial situation and food prices together with employment status control both diet choices and physical activity levels. Economic growth, income inequality, unstable economies, and poverty are important factors contributing to the obesity epidemic in the economic category. Studies show that economic growth and rising wealth levels increase overweight and obesity rates in low- and middle-income nations; yet, the connection remains intricate. National GDP levels influence the prevalence of obesity and overweight differently in low-income and high-income countries. The relationship between GDP growth and BMI demonstrates a positive correlation in low-income countries, whereas it exhibits but a negative correlation in high-income countries. (71, 100–103). Other factors such as unemployment (33, 54–56, 67, 77, 104, 105), and urbanization (101, 103), also influence obesity trends. Consumption of poor quality foods containing excess sugar, along with chemical additives associated with poverty, has led to increasing levels of obesity. (72). Factors such as food insecurity (75, 84), low income (32, 50, 64, 67, 79, 106), housing insecurity (67, 107) declining purchasing power (72), and high costs of exercise (108) have been identified as contributors to obesity and overweight, which are closely linked to poverty.

Modern technology has introduced new obstacles to the fight against obesity in the contemporary period. Screen time and food-related digital advertisements create negative impacts on how people conduct their everyday activities. The technology category explores how modern advancements lead to two major effects: simple access to high-calorie food and inactive lifestyles from excessive screen usage and decreased physical movement. Research shows that exposure to unhealthy food marketing through television and online media leads to increased overweight and obesity risks (82, 86, 88, 108–113). Children and teenagers now use modern technology for socializing outside their homes instead of outdoor games and physical activities, so their sedentary engagement with television watching, video games, internet activities and social media has increased. Raising obesity risk for children and adolescents stems from both their sedentary behavior and long periods spent looking at screens. Studies within this age range showed a direct relationship between obesity and lack of sedentary behavior (6, 67, 69, 81, 85, 86, 90, 91, 104, 109, 110, 113–117). Modern distribution systems along with advanced food production methods provide easy access to unhealthy foods that have high energy content in disadvantaged communities (114).

The environmental factors contributing to overweight and obesity include a diverse array of elements within both the built and natural environments that influence individual's lifestyle behaviors. These factors that affect health outcomes consist of recreational facilities, food access within neighborhoods and climate change and pollution, which directly influence eating patterns and physical activity levels. The environmental category highlighted the significance of the "built environment," neighborhood's food environment, pollution and climate, in contributing to obesity. Infrastructure for active living (6, 67, 82, 108), such as suitable sports and recreational facilities (50, 82, 86, 105, 118–121), bike lanes (114), sidewalks (114, 119), green spaces (50, 114, 122), road quality (6), street connectivity (120, 123), and public transport (30, 82, 120, 121, 124), as well as residential density (120) were factors within the "built environment" that effectively address overweight and obesity Another vital aspect in this category is the neighborhood food environment. Factors such as a higher prevalence of convenience stores (40, 125), food availability (28, 82, 86, 88), access to a grocery store (40), unavailability and lack of access to healthy food, availability and easy access to unhealthy foods (67, 68, 83, 85, 109, 112, 113, 125, 126), food environment around schools (127), access to fast-food restaurants (68, 109, 114), lack of healthy choices (83, 105), and access to takeaways (84) were identified as neighborhood food environment factors associated with overweight and obesity.

The political category recognizes that effective policies and regulations play a vital part in tackling obesity on a national scale. A total of six studies explored factors related to political categories. Food and nutrition policies, along with school policies, have been acknowledged as significant factors in the political aspect of obesity. Taxing unhealthy and high-calorie foods (76, 114, 120, 128), subsidizing healthier and less calorie-dense foods (76, 114, 128), implementing food labeling regulations (114), establishing policies for healthy food production and distribution (76), enforcing health regulations on the number, availability, and distribution of high-calorie fast food restaurants (76), promoting the reformulation of processed foods to be healthier (114), setting guidelines for food vendors (89), regulating marketing and advertising, and responding to reduce the impact of advertising on children (86) were identified as factors influencing food and nutrition policies related to overweight and obesity.

Several factors related to school policies that affect overweight and obesity have been recognized. These include implementing physical activity and nutrition guidelines such as conducting simple exercises before class, encouraging walking or cycling to school, eliminating the sale of high-calorie foods, providing healthy food and beverage options, enlisting the assistance of health professionals, and training teachers to utilize the school model BMI (88, 94, 110, 115, 119, 129).

Obesity prevention requires a comprehensive policy approach that encompasses nutritional, behavioral, physical activity, and technological interventions. Strict regulations about unhealthy food advertising should be implemented by governments and public health organizations to protect children from exposure to these unhealthy food advertisements. Government taxation of sugary beverages together with processed foods supports unhealthy food avoidance yet provides financial support for buying nutritious produce including fresh fruits and vegetables and whole grains and lean protein. These measures specifically benefit low-income families in accessing quality food. The prevention of obesity requires equal focus on physical activity promotion. Urban infrastructure expansion through pedestrian-friendly pathways and cycling lanes and green spaces distribution will offer additional exercise possibilities to people. Educational institutions need to create mandatory daily physical education curricula to teach children healthy life practices at their formative stages. Financial benefits that cover gym memberships and weight-loss program discounts would motivate people to integrate physical activity into their daily routine. Employers should support physical activity at work by creating wellness initiatives and establishing standing workstations as well as offering exercise-related rewards to their staff. Lifestyle changes over a long period require behavioral and educational interventions to be successful. The curriculum of schools must incorporate nutrition and health education for teaching students about fundamental balanced diet principles along with physically active living. Behavioral counseling must be accessible to people who experience emotional eating problems and stress-induced eating or struggle with unhealthy food choices. Mental health services through stress management programs and sleep quality improvement and positive self-image promotion can assist obesity prevention goals by minimizing behavioral factors which lead to weight increase. The use of modern digital platforms along with technology-based tools can be helpful in obesity intervention plans. Governments should invest in mobile application development to assist people in monitoring their food intake and exercise activities. The government should establish rules to monitor unhealthy food product advertisements that appear on digital platforms and social media. Additionally, artificial intelligence and big data analytics can be used to monitor obesity trends and design personalized intervention programs based on risk factors in different populations. The interventions need to focus on different population groups for maximum effectiveness. Schoolchildren along with adolescents are among the most vulnerable populations, need protection from unhealthy food marketing and enhanced access to nutritious school meals. Pregnant women and mothers with young children should receive guidance on proper nutrition to prevent childhood obesity from an early stage.

People who are overweight or obese require structured weight-loss programs yet financial incentives help them join lifestyle modification plans. The government should direct subsidies toward low-income communities while expanding healthy grocery options in their residential areas. Workplace policies which promote physical activity while encouraging healthier eating habits will enable employees and workers to become active participants in obesity prevention.

The achievement of obesity prevention policies requires multiple stakeholders to work together. Governments and public health policymakers must take the lead in regulating, allocating resources, and designing national health programs. Healthcare providers who include doctors and nutritionists and mental health professionals should provide counseling and medical care to individuals who risk becoming obese. Schools and educational institutions must ensure that students have access to the necessary education on nutritious food and physical education. The food and beverage industry needs support to reformulate products containing less sugar and fat while practicing responsible marketing methods. Media platforms need to limit unhealthy food advertising while they should promote healthy life benefits. Employers should establish workplace health plans, and non-profit organizations, along with local communities, can play an important role in raising awareness and supporting at-risk populations.

Obesity prevention programs will become more effective and sustainable when these strategies are implemented at various levels starting from government regulations down to community-based programs. The implementation of a multisectoral coordinated strategy reduces obesity rates and overweight while simultaneously improving public health results and decreasing health care expenses and boosting overall life quality.

## 4.1 Strengths and limitations

The scoping review examines multiple factors which influence overweight and obesity across socio-cultural, technological, economic, environmental and political domains. The main research strength emerges from its transparent methodological procedures and rigorous approach. The research design followed the frameworks provided by Arksey and O'Malley and JBI guidelines to execute systematic identification and synthesis of relevant literature. A combination of quantitative and qualitative research with different databases increases the reliability and generalizability of the results discovered. Additionally, the thematic synthesis approach provides an in-depth evaluation of how various significant factors associate with one another which generates essential information for designing public health interventions and policies.

Several limitations need attention when considering this information. The methodology of scoping reviews does not involve a quality assessment of the included studies, so this could introduce variability in the reliability of the findings. Additionally, there is an inherent limitation in the geographical distribution of the included studies. Research mainly took place in high-income countries throughout North America and Europe without sufficient investigation in low-income nations. The limited participation of low-income countries in the research sample accounts for only 5% while this underrepresentation could affect the applicability of study results to those specific regions. Moreover, the unequal geographical distribution reveals an existing knowledge gap in academic research about the special socio-economic and environmental difficulties experienced by low-income populations. Additional research should focus on the neglected areas because it will help develop an inclusive understanding of the worldwide obesity crisis.

# 5 Conclusion

Research studies on obesity and overweight distribution show increasing prevalence worldwide but these studies remain scarce in low- and lower-middle-income countries. The majority of studies in the literature include cross-sectional analyses, but longitudinal surveys combined with qualitative and mixed methods help to understand the complex nature of obesity. The trends of obesity demonstrate strong links to socio-demographic factors which include age, gender, marital status, education and socioeconomic status. Obesity rates are higher among younger age groups even though older people tend to have higher BMI values which emphasizes the need for prevention programs at an early age. Men tend to be overweight more often than women yet women face greater obesity challenges because of their inactive lifestyles and sociocultural norms. Marital status impacts weight gain differently since married people and those who are divorced or widowed experience more obesity risks because of their altered lifestyles. Education and economic status play crucial roles in dietary choices and physical activity levels, though their impacts vary across different demographic groups. Rural areas are now facing increasing obesity rates despite their historical association with lower obesity levels due to changes in food environments and reduced physical activity. Early-life interventions must focus on families because their education level and occupation status, income, and eating habits, along with their financial situation and dietary practices directly affect childhood obesity rates. The economic factors including GDP growth, unemployment and food insecurity affects obesity occurrence particularly within low- and middle-income nations. Modern technological developments intensify obesity patterns because they lead to higher screen usage and food marketing and less physical activity particularly impacting young people. Environmental factors including built environments, food accessibility as well as climate-related determine obesity rates because they influence lifestyle behaviors. Finally, the prevention of obesity benefits from political interventions including food taxation in addition to subsidies for nutritious choices and requirements for food labeling and physical activity education in schools.

The worldwide goal to lower obesity levels faces multiple connected obstacles making this health issue especially challenging to tackle. Cheap and readily available unhealthy food products currently control the market with their high energy density, and advertisers specifically target children (130, 131). The lack of safe places for physical exercise combined with declining active lifestyles that substitute walking with driving creates a more severe problem in urban settings (128, 129). Additionally, the higher prices of nutritious foods restrict access for numerous people including low-income groups at high risk of obesity (132). Healthcare systems struggle with funding obesity-related diseases which hinders their ability to establish preventive measures (133, 134). The experience of social stigma stops many individuals from getting assistance because it produces feelings both of shame and low self-esteem (135, 136). The normal acceptance of obesity within certain cultures presents an additional challenge when trying to change social perspectives about weight health (135). Despite numerous prevention programs, many face a major challenge since they approach obesity solely through diet or physical activity while failing to combine these strategies (7, 136). Despite the implementation of policies such as food labeling and taxes on sugary drinks, their success is often undermined by inconsistent implementation and a lack of public support in the long term (137, 138). Lastly, individuals maintain overeating patterns because of behavioral triggers while their psychological factors include emotional eating and the comfort of high-calorie foods (139, 140). The strong relation between emotions and psychology and food consumption demonstrates why comprehensive weight management solutions must target bodily needs as well as emotional aspects of obesity.

This study highlights the multifactorial nature of obesity and the complex interactions among its numerous contributing factors. A total of 82 factors influencing overweight and obesity were identified and categorized using the STEEP framework into five major groups: sociocultural, economic, technological, environmental, and political. The sociocultural category, as one of the most important determinants of overweight and obesity, included the highest number of influencing factors. This highlights the significant impact that family structure, social support, and cultural norms have on health behaviors. Environmental factors along with technological developments combined with economic circumstances have strongly influenced the increasing incidence of obesity. Concurrently, political influence such as public health policies together with regulatory frameworks operate as political factors that are essential in establishing the broader framework for obesity prevention initiatives.

A holistic comprehensive strategy needs to address overweight and obesity issues stemming from multiple influencing factors. Such an approach requires coordinating evidence-based interventions from numerous sectors to tackle all factors that affect obesity at individual and different societal levels and create sustainable change. The approach requires multi-sectoral interventions that analyze the various sociocultural along with economic and environmental and political dynamics across essential domains such as health, education, transport, agriculture and the environment. The strategy needs to include all age groups and social classes but specifically target vulnerable population groups. The approach should merge educational programs for individual health with environmental changes that promote healthier decisions. A meaningful outcome requires collaboration between stakeholders including government, private sector, food industry and educators, planners, schools, local communities and media. Lastly, it is important to continue evaluation process through policy monitoring together with data-based decision-making for adjusting strategies.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

MJ: Writing – original draft, Writing – review & editing. SG: Writing – original draft, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2025.1540756/full#supplementary-material

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# Relationship between child opportunity index and body mass index *z*-score: a mixed-effects analysis with data from a lifestyle intervention with Hispanic children

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**Background:** The Childhood Opportunity Index (COI) is a relatively new measure for assessing opportunity across education, health and environment, and socio-economic context. Research indicates that higher COI is associated with lower obesity risk; however, existing research offers no evidence for differences, or lack thereof, across racial/ethnic groups. The larger body of research on the relationship between neighborhood environments and obesity risk among Hispanic children with low-income between 5 and 11-year-olds is limited. The study aims to further explore the relationship between neighborhood opportunities, measured by the COI, and children's body mass index *z*-scores (BMIz), adjusted for age and sex.

**Materials and methods:** The data are from a sample of Hispanic child-parent dyads ($n = 253$) who participated in a 1-year family lifestyle intervention. A linear mixed-effects model was fitted, with BMIz as the dependent variable, COI categorized into four levels, time, parent BMI, family income, adult education, child age, child sex, calories, language spoken in the household, physical activity, group condition, and a time*group condition interaction. Predicted probabilities were also produced.

**Results:** After adjusting for covariates, children in the second ($\beta = -.15$, 95% CI = −0.27, −0.03), third ($\beta = -.19$, 95% CI = −0.31, −0.06), and fourth ($\beta = -.15$, 95% CI = −0.28, −0.02) quartiles of the COI quartiles had significantly lower BMIz compared to those in the first (lowest) COI quartile. Predicted probabilities show the different predictive margins of BMIz at each time point for each quartile compared to the first quartile.

**Conclusions:** All the higher COI levels were linked to healthier weight status compared to the lowest COI level, though the pattern was not linear for any of the observed associations. Further investigation into the impact of different COI levels may be warranted to assess each quartile's impact against each other, which was outside the scope of the current study. Results also provide evidence for potentially strengthening intervention supports for those at the lowest COI level, respective to those from all other COI levels.

KEYWORDS

**environmental factors, body mass index *z*-score, intervention, Hispanic, multilevel model**

## Introduction

Childhood obesity remains a significant public health challenge in the United States (U.S.). Hispanic youth aged 2–19 years exhibit a higher obesity prevalence (26.2%) compared to non-Hispanic White (16.6%), non-Hispanic Black (24.8%), and non-Hispanic Asian youth (9.0%) (1). These rates underscore the disparities in obesity prevalent among different racial/ethnic groups, with Hispanic and Black children bearing a disproportionate burden. Hispanic and Black families are more likely to live in disadvantaged obesogenic neighborhoods with increased risk for early onset of obesity compared to their White peers (2, 3). Hispanic children in south Texas have the highest rates of childhood obesity among all their peers and greatly exceed national averages (4). Prior studies have found household characteristics and social environment factors significantly influence the body mass index (BMI) of Hispanic children (5); though, the research on the relationship between neighborhood environments and obesity risk among low-income Hispanic children between 5 and 11-years-old is limited (6). The combination of this evidence, or lack thereof, warrants further study on the relationship between neighborhood opportunities for healthy development and childhood obesity among Hispanic children. The current study focuses on further understanding how neighborhood opportunities, via the Child Opportunity Index (COI), are related to childhood BMI among Hispanic children who participated in a family lifestyle intervention over 1 year.

In the U.S., several factors are generally associated with obesity in youth. For example, school-aged boys have a higher obesity rate (20.4%) than girls (16.3%) (7). Dietary habits (8), sedentary behavior (9, 10), parental education level (11), and low socioeconomic status (SES) (7) are all also related to the higher prevalence of obesity among Hispanic children. Parental weight status is also related to childhood obesity (12). Along with this, cultural factors too play a role, such as Hispanic parents underestimating their child's weight status, not believing it is a problem, or being adverse to healthy behaviors including physical activity (13–16).

Existing literature on childhood obesity primarily relies on cross-sectional individual level data to establish associations between sociodemographic factors and behaviors (17). The sparse literature using neighborhood level data provides some insights for the current study. Studies have shown that residing in high-poverty or high-crime neighborhoods is associated with an increased risk of high BMI or childhood obesity (18). Another study by Theall et al. (19) identified an association between neighborhood violent crime and negative outcomes for obesity-related outcomes like BMI, overweight/obesity, and waist circumference. Research has also found that broader factors such as higher average SES of a child's school is linked to lower BMIz, among pre-kindergarten students (20). Similarly, research shows that children from low-income communities exhibit lower levels of physical activity, poor dietary habits, with increased consumption of fried food and sugary beverages along with spending more time in sedentary activities (21). Finally, a meta-analysis of 58 randomized controlled trials (RCTs) in the US showed that interventions with a higher number of young children of racial/ethnic minority or lower socioeconomic status were less effective in lowering obesity measures signifying the influence of community context on the uptake of evidence-based obesity prevention strategies (22). All these factors are associated with higher BMI and obesity. The literature highlights the importance of assessing neighborhood factors that influence the level of protection against childhood obesity.

The COI is a publicly available cumulative indicator of the many positive and negative attributes of neighborhood conditions and resources that greatly influence healthy child development (23). The COI index is built using 44 indicators that span over three domains: education, health and environment, and socio-economic context and 14 sub-domains (24). The indicators are associated with children's health and economic outcomes. The COI is a multidimensional measure which incorporates data from the US Census Bureau's American Community Survey and other sources capturing inequities in distribution of opportunity across neighborhoods (23). The COI is unique from other census tract-based opportunity indices as it utilizes a wide range of novel negative factors such as exposure to toxic waste, school poverty, and supportive factors such as access to nutritious food and green spaces. Studies have linked high COI scores with decreased risk of acute care visits (25), asthma-related hospitalizations (26), and improved preventive care metrics in pediatric primary care (23). Additionally, research suggests associations between higher COI and lower risk of obesity and cardiometabolic risk in children (17). Aris et al. (17) found that exposure to a high COI score at birth significantly affects mean BMI and obesity risk compared to exposure at later life stages. The COI is a relatively newer index and evidence suggests it can be a valuable tool for identifying children at risk of progressing towards a trajectory of high BMI as it incorporates various neighborhood characteristics relevant to children's health. The current study focuses on the relationship between baseline COI and obesity over a 1-year period. Based on existing literature, it is expected that lower COI scores will be related to higher BMI; however, previous studies have not examined this with BMI over time and with an all-Hispanic sample of 5- to 11-year-olds. An additional justification for this study is that it is not clear if COI is related to BMI for Hispanic children in the same way as children in samples from other studies above. It may be the case that Hispanic children, particularly those in south Texas, who live in a neighborhood with others that share contextual factors (i.e., similar COI) may be protected against adverse effects on weight status (27, 28). This would result in no differences by COI. In addition to adding to the limited literature on COI, the current study adds rigor with the rich individual- and family-level control variables to more effectively isolate the community effect.

## Materials and methods

### Data

The current study is a secondary analysis of data extracted from a family-based obesity management study, "Health4Kids" (H4K), in

Hispanic children ages 5–11 years and their parents ($N = 253$ dyads). Considering the strong cultural value of familism within Hispanic communities, where family takes central importance, family-focused obesity prevention strategies may be particularly effective (29). This randomized controlled trial aimed to examine the efficacy of "Health4Kids" (H4K), a family-focused intervention promoting healthy eating and physical activity for Hispanic children aged 5–11 years with overweight/obesity. The program utilized family-centered behavioral counseling, text messages, and newsletters to encourage healthier eating habits and increased physical activity among participants. The study was conducted in south-central Texas. The families were randomized into the standard care group ($n = 128$) or the H4K treatment group ($n = 125$). The participants completed assessments at baseline ($n = 253$), 1-month ($n = 179$), 6-month ($n = 184$), and 12-month ($n = 153$). Activities and assessments were available in Spanish and English both oral and written. More information about the design, data, IRB approval, and materials can be found elsewhere (NCT02343367).

## Variables

In this paper, the dependent variable was child BMI z-score for age and sex (BMIz), a continuous variable measured at four time points (baseline, 1-month, 6-month, and 12-month). The primary independent variable was the COI measured at baseline. We use baseline COI because COI would not change over a 1-year period unless a family moved, and COI is only calculated by external researchers every 5 or so years. The COI ranges from 1 to 100 and is used as an indicator of the amount of opportunity that children have in their neighborhoods in their social and economic domains (30). The COI has been used in other studies as a predictor or covariate of child BMI (17). In the current study, the COI national adjusted z-score (COIz) is used. COIz, as a continuous variable, did not have a strong linear relationship with BMIz. The path was more of an upside-down checkmark as opposed to a straight line so it was divided into quartiles for the analyses to address the non-linearity problem. The four quartiles represent very low, low, high, and very high as has been used in previous studies (17). The study data and COI variable were linked via geocoding. The families represented 14 census tracts.

The following section provides a brief explanation for the inclusion of some of the control variables. Variables for child age, sex, physical activity, diet, and parent BMI, income, education were included as they are consistently associated with BMI differences in childhood (28, 31). Additionally, language spoken in the home was relevant given the sample are south Texan Hispanics where this is a high prevalence of Spanish speakers. Language spoken in the home has been included in several childhood obesity studies with mixed findings as language can be tied to acculturation, and can be both a protective or risk factor for healthy behaviors (32–34).

Other covariates considered in the analysis included time, a categorical variable representing the wave of data collection [0 = baseline, 1 = 1 month, 6 = 6 months, 12 = 12 months] and child age ranging from 5 to 11 years old, held fixed at baseline to avoid multicollinearity with time. Child demographics also included binary child sex [0 = female (reference), 1 = male], child time spent in moderate-to-vigorous physical activity (MVPA; minutes/day), a continuous variable using an ActiGraph triaxial accelerometer (GX3). Each participant wore the monitor for 7 days and 6 days of data were collected, accelerometer counts were recorded in 60-s time increments (35). Ranges were 0–5,725+, with inactivity (0–99 counts/min), light (100–759 counts/min), moderate-intensity lifestyle activities (760–5,724 counts/min), moderate-intensity walking activities (1,952–5,724 counts/min), and vigorous intensities (5,725 or more counts/min) (35). Additionally, the average daily calories for each child were measured using the Block Food Screeners for Ages 2–17, which included the average daily calories for each child as a continuous covariate (36). The validated screener was designed to be self-administered by children with the assistance of parent or caregiver, as needed.

Parental factors included parent BMI, a continuous variable, parent education, a categorical variable [0 = high school education or less (reference), 1 = some college, and 2 = four-year college degree or higher], and parent income, a categorical variable of income levels [0 = <$10,000 (reference), 1 = $10,001–$15,000, 2 = $15,001–$20,000, 3 = $20,001–$25,000, 4 = $25,001–$35,000, 5 = $35,001–$50,000, 6 = ≥$50,001, and 7 = Missing]. Spanish spoken at home was coded as a binary variable [0 = households speaking only English (reference), 1 = households where Spanish is spoken, either mixed with English or exclusively]. Finally, treatment group was coded as a binary variable [0 = standard care (reference), 1 = group condition].

## Analyses

Data was cleaned, prepared, and analyzed using STATA/SE version 17 (37). For each wave, we examined sample size and descriptive statistics across the total sample and for COI quartiles. To assess baseline characteristics differences across COI quartiles groups, ANOVA, Chi-square test or Fisher's exact were used. Full information maximum likelihood (FIML) method was used to handle missing data in the outcome variable, BMIz. This approach was chosen because the amount of missing data was relatively low. Specifically, all covariates had less than 10% missing data, with the exception of parent income. For parent income, a missing category was added as the final category in the nominal variable. To test for changes in children's BMIz, we used linear growth curve models constructed in a sequential bottom-up approach: An unconditional growth model, followed by a combined fixed effects model, random slopes testing, interaction testing, and evaluation of different within-subject covariance matrices.

The unconditional growth model was first estimated using time as a continuous variable with a quadratic term, but due to non-significance and worsened model fit, it was ultimately used as a categorical variable. Time points and child ID were treated as random effects to obtain random intercepts for child participants and estimate the random slope of time for each child ID. For the next two steps, COI quartiles and covariates were incorporated into the model as fixed effect individual-level predictors. To avoid multicollinearity with the time variable, child age at baseline was used as a fixed effect. Additionally, MVPA scale, calories, and adult BMI were also grand mean centered.

Several interactions were tested, including COI*Group condition, COI*MVPA scale, and COI*Time, but were excluded from the final model due to non-significance and worsened fit. The Time*Group condition interaction, although non-significant, was retained on a theoretical basis.

This process culminated in two final models: an unconditional growth model and a linear mixed-effects model with a random slope. The latter included the Time*Group condition interaction term, a random slope for time within child participants, and an independent covariance structure. Except for the unconditional growth model, all covariates were included in the models.

Model fit was assessed by comparing improvements in -2LL, AIC, and BIC indices relative to previously nested models, ensuring a comprehensive evaluation of the model's performance and appropriateness for the data. Models were fitted using Stata's mixed command with default REML estimation.

## Results

The final sample was $n = 253$ children. Child baseline BMI ranged from 16.52 to 34.25 (between the 73rd and 99th percentile), and baseline BMIz ranged from 0.62 to 2.68. The mean BMIz ranged from 1.74 to 1.80 across waves. The mean child BMI in each wave ranged from 22.73 to 23.86 (the 95.00th and 95.50th percentiles, respectively), with a 39.5% attrition reduction in child BMI in the final wave of data collection. Just over half of both the treatment and control groups were comprised of female children. The most common family income bracket was $10,001–$15,000. Over 60% of the sample had a Spanish speaking household or a mixed Spanish and English-speaking household. As far as parental education level, approximately 40% of the children's parents had some college/technical school, 30% had a high school or less education, and 13% had a four-year degree or more. Just over 49% of the sample were in the H4K treatment group. The mean average daily calories for children were 1,145 kcal (SD = 458.03) and the mean MVPA score was 252.60 (SD = 153.73). The COIz ranged from −0.08 to 0.027. This represented families with very low to very high COI. All sample demographics by COI quartile are reported in Table 1. Only parent education level was significantly different $\chi^2$ (6, $N = 224$) = 15.92, $p = 0.014$ at baseline across the COI quartiles. There were more parents with a four-year degree or more in the 3rd and 4th quartiles.

### Unconditional model

The unconditional model (Table 2) showed that, on average, BMIz was significantly higher at 1-month compared to baseline ($\beta = .05$, 95% CI = 0.03, 0.07). No significant differences were observed between baseline and the other time points. This model also revealed a high intraclass correlation of 0.89, as expected.

### Final model

The final model included the following variables: categorical time, COI (in quartiles), parent BMI, family income, adult education, child age, child sex, average daily calories, language spoken in the household, MVPA, group condition, and Time*Group condition (Table 2). Among children in the control group, wave 1 BMIz differed significantly compared to baseline in that wave 1 BMIz was higher at wave 1 compared to baseline ($\beta = .08$, 95% CI = 0.04, 0.11). The coefficient for the intervention group was $\beta = .04$ and this was statistically significant compared to the control group (95% CI = −0.10, 0.01). The other waves were not significantly different from baseline. Compared to children in the first (lowest) COI quartile, being in the second ($\beta = -.15$, 95% CI = −0.27, −0.03), the third ($\beta = -.19$, 95% CI = −0.31, −0.06), and the fourth ($\beta = -.15$, 95% CI = −0.28, −0.02) quartiles were associated with lower BMIz. Generally, each higher neighborhood opportunity level was associated with lower BMIz values when compared to the lowest opportunity level. Figure 1 shows the model-based estimated margins of BMIz at each time point by COI quartiles. Being male was significantly associated with a higher BMIz in children ($\beta = .18$, 95% CI = 0.09, 0.28). An increase in child age was significantly associated with an increase in BMIz ($\beta = .03$, 95% CI = 0.00, 0.06). Additionally, higher adult BMI was positively associated with an increase in child BMIz ($\beta = .01$, 95% CI = 0.00, 0.02). Parents with some college education had a higher BMIz compared to those with a high school or less level of education ($\beta = .11$, 95% CI = 0.01, 0.21). Regarding income, only the "$20,001–$25,000" ($\beta = 0.23$, 95% CI = 0.06, 0.39) and "≥$50,001" ($\beta = .22$, 95% CI = 0.02, 0.42) brackets were significantly associated with increased BMIz in children compared to the reference group of less than $10,000. No significant effects were found for the MVPA scale, average daily calories, or language spoken in household.

## Discussion

The current study focused on further understanding how neighborhood opportunities, via the COI, are related to childhood weight status among Hispanic children in south-central Texas who participated in a family lifestyle intervention over 1 year. Notably, though not all individual children fell into this category, the mean BMIz for this sample ranged in the obese category across the waves, which was expected due to criteria and focus of the larger study. This sample also represented a diverse range of COI levels. The current study findings appear to align with COI and BMI studies with non-Hispanic samples that do not necessarily represent a high-risk and diverse COI population (17). Compared to children in the lowest COI quartile, being in the second, third, or fourth quartile was

TABLE 1 Sample means, frequencies, and characteristics by child opportunity index (COI) quartiles ($n = 253$).

| Variables | Total | 1st quartile | 2nd quartile | 3rd quartile | 4th quartile |
|---|---|---|---|---|---|
| | Mean (SE) | Mean (SE) | Mean (SE) | Mean (SE) | Mean (SE) |
| Child BMI *z*-score at wave 0* | 1.74 (0.35) | 1.82 (0.35) | 1.75 (0.37) | 1.69 (0.32) | 1.72 (0.36) |
| Child BMI *z*-score at wave 1 | 1.80 (0.35) | 1.88 (0.34) | 1.76 (0.36) | 1.77 (0.33) | 1.80 (0.39) |
| Child BMI *z*-score at wave 6 | 1.75 (0.40) | 1.82 (0.37) | 1.76 (0.40) | 1.72 (0.37) | 1.71 (0.45) |
| Child BMI *z*-score at wave 12 | 1.74 (0.41) | 1.77 (0.37) | 1.74 (0.40) | 1.64 (0.42) | 1.82 (0.43) |
| Overall child BMI score** | 22.73 (3.21) | 23.44 (3.16) | 22.90 (3.41) | 22.24 (2.81) | 22.27 (3.34) |
| Adult BMI***, **** | 33.19 (7.00) | 33.75 (7.70) | 33.41 (6.61) | 33.24 (7.50) | 32.51 (7.39) |
| Child age, year***, ***** | 8.74 (1.67) | 8.94 (1.58) | 8.86 (1.64) | 8.69 (1.71) | 8.45 (1.82) |
| MVPA scale***, ****** | 252.60 (153.73) | 232.49 (145.78) | 270.25 (170.91) | 231.78 (128.79) | 277.04 (163.72) |
| Child average daily calories***, ******* | 1,145.38 (458.03) | 1,209.60 (470.02) | 1,087.79 (506.74) | 1,070.18 (353.04) | 1,220.02 (480.84) |
| **Overall *N* (%)** | | | | | |
| | | 66 (26.09) | 65 (25.69) | 64 (25.30) | 58 (22.92) |
| **Group condition********** | | | | | |
| Treatment group | 125 (49.41) | 34 (48.48) | 32 (50.77) | 30 (46.88) | 29 (50.00) |
| Control group | 128 (50.60) | 34 (51.52) | 33 (49.23) | 34 (53.12) | 29 (50.00) |
| **Household language*********** | | | | | |
| Only English | 74 (29.25) | 22 (33.33) | 18 (27.69) | 20 (31.25) | 14 (24.14) |
| Only Spanish/Mixed Spanish and English | 160 (63.24) | 37 (56.06) | 42 (64.62) | 39 (60.94) | 42 (72.41) |
| **Adult education level************ | | | | | |
| High school or less | 86 (33.99) | 22 (33.33) | 27 (41.54) | 18 (28.12) | 19 (32.76) |
| Some college/technical school | 105 (41.50) | 31 (46.97) | 28 (43.08) | 26 (40.62) | 20 (34.48) |
| Four year college degree or more | 33 (13.04) | 5 (7.58) | 2 (3.08) | 13 (20.31) | 13 (22.41) |
| **Child sex************* | | | | | |
| Male | 125 (49.41) | 33 (50.00) | 26 (40.00) | 37 (57.81) | 29 (50.00) |
| Female | 128 (50.59) | 33 (50.00) | 39 (60.00) | 27 (42.19) | 29 (50.00) |
| **Family income************** | | | | | |
| <$10,000 | 35 (13.83) | 12 (18.18) | 6 (9.23) | 9 (14.06) | 8 (13.79) |
| $10,001–$15,000 | 43 (17.00) | 12 (18.18) | 14 (21.54) | 11 (17.19) | 6 (10.34) |
| $15,001–$20,000 | 26 (10.28) | 6 (9.09) | 8 (12.31) | 7 (10.94) | 5 (8.62) |
| $20,001–$25,000 | 33 (13.04) | 7 (10.61) | 9 (13.85) | 8 (12.50) | 9 (15.52) |
| $25,001 –$35,000 | 33 (13.04) | 8 (12.12) | 10 (15.38) | 8 (12.50) | 7 (12.07) |
| $35,001–$50,000 | 26 (10.28) | 4 (6.06) | 8 (12.31) | 8 (12.50) | 6 (10.34) |
| $50,001 or more | 17 (6.72) | 5 (7.58) | 1 (1.54) | 4 (6.25) | 7 (12.07) |
| Missing | 40 (15.81) | 12 (18.18) | 9 (13.85) | 9 (14.06) | 10 (17.24) |

Footnotes provided here represent *p*-values for analysis of variance (ANOVA) or Pearson's chi-squared results for each variable by quartiles.
*$p = .19$.
**$p = .10$.
***Indicates a grand mean centered variable.
****$p = .82$.
*****$p = 0.38$.
******$p = .24$.
*******$p = .14$.
********$p = .96$.
*********$p = .53$.
**********$p = .01$.
***********$p = .25$.
************$p = .90$.

associated with lower BMIz. Though these findings are not novel, Figure 1 shows the nuance of this finding as the predictive margins for BMIz at each time point follow different patterns for each quartile relationship observed. Follow up studies can further investigate what about each level of opportunity [i.e., what value (s) of COI] may be associated with risk or protection against poorer weight status.

The main effects align with some existing literature on global patterns, suggesting that being male (38) and higher parent BMI are associated with increased BMIz (12). Age as a predictor of increased BMI is not always conclusive, though the significant finding from the current study aligns with the literature for children of this age and developmental period (38). The literature typically finds higher parent education and higher income to be associated with lower BMI; however, the inverse was found here. This is not surprising when one considers the overall average level of education and income for this group, which was low, and the overall relationship between socioeconomic status and childhood obesity. Evidence exists to support that when comparing groups of similar SES, slight

TABLE 2 Growth curve models with fixed effects, random effects, and interaction effects on child BMI $z$-score ($n = 253$).

| Fixed effects | Unconditional growth model | | Final model | |
|---|---|---|---|---|
| | Estimate [95% Confidence interval] | $p$-value | Estimate [95% Confidence interval] | $p$-value |
| Intercept | 1.74 [1.70, 1.79] | $p < .001$ | 1.28 [0.97, 1.60] | $p < .001$ |
| **Time** | | | | |
| 0 | – | | – | |
| 1 | 0.05 [0.03, 0.07] | $p < .001$ | 0.08 [0.04, 0.11] | $p < .001$ |
| 6 | 0.01 [−0.01, 0.04] | $p = 0.32$ | −0.01 [−0.05, 0.04] | $p = 0.79$ |
| 12 | −0.00 [−0.04, 0.04] | $p = 0.97$ | −0.02 [−0.09, 0.04] | $p = 0.46$ |
| **Child opportunity index (COI)** | | | | |
| 1st quartile | | | – | |
| 2nd quartile | | | −0.15 [−0.27, −0.03] | $p = 0.02$ |
| 3rd quartile | | | −0.19 [−0.31, −0.06] | $p = 0.003$ |
| 4th quartile | | | −0.15 [−0.28, −0.02] | $p = 0.02$ |
| Adult BMI[a] | | | 0.01 [0.00, 0.02] | $p = 0.002$ |
| Child Age[a] | | | 0.03 [0.00, 0.06] | $p = 0.03$ |
| MVPA Scale[a] | | | −0.00 [−0.00, 0.00] | $p = 0.22$ |
| Child average daily calories[a] | | | −0.00 [−0.00, 0.00] | $p = 0.13$ |
| **Household language** | | | | |
| Only English | | | – | |
| Only Spanish/Mixed Spanish and English | | | 0.02 [−0.08, 0.11] | $p = 0.72$ |
| **Adult education level** | | | | |
| High school of less | | | – | |
| Some college/technical school | | | 0.11 [0.01, 0.21] | $p = 0.03$ |
| Four year college degree or more | | | 0.09 [−0.05, 0.24] | $p = 0.21$ |
| **Child sex** | | | | |
| Female | | | – | |
| Male | | | 0.18 [0.09, 0.28] | $p < .001$ |
| **Group condition** | | | | |
| Control group | | | – | |
| Treatment group | | | 0.07 [−0.02, 0.16] | $p = 0.15$ |
| **Family income** | | | | |
| <$10,000 | | | – | |
| $10,001–$15,000 | | | 0.09 [−0.06, 0.25] | $p = 0.22$ |
| $15,001–$20,000 | | | 0.06 [−0.11, 0.23] | $p = 0.51$ |
| $20,001–$25,000 | | | 0.23 [0.06, 0.39] | $p = 0.007$ |
| $25,001–$35,000 | | | 0.15 [−0.01, 0.32] | $p = 0.07$ |
| $35,001–$50,000 | | | 0.04 [−0.14, 0.21] | $p = 0.69$ |
| $50,001 or more | | | 0.22 [0.02, 0.42] | $p = 0.03$ |
| Missing | | | 0.12 [−0.07, 0.31] | $p = 0.22$ |
| **Time *Group condition** | | | | |
| 1 | | | −0.04 [−0.10, 0.01] | $p = 0.11$ |
| 6 | | | 0.01 [−0.05, 0.07] | $p = 0.76$ |
| 12 | | | 0.02 [−0.08, 0.11] | $p = 0.75$ |
| **Random parts** | | | | |
| $\mu_{0j}$ | 0.00 [0.00, 0.00] | $p < .001$ | 0.00 [0.00, 0.00] | $p < .001$ |
| $\mu_{1j}$ | 0.11 [0.09, 0.13] | $p < .001$ | 0.09 [0.07, 0.11] | $p < .001$ |
| $e_{ij}$ | 0.01 [0.01, 0.02] | $p < .001$ | 0.01 [0.01, 0.02] | $p < .001$ |
| -2LL deviance | 48.91 | | 62.45 | |
| AIC | −83.81 | | −72.22 | |
| BIC | −51.29 | | 55.05 | |
| ICC | 0.8871 | | | |

[a]Indicates a grand mean centered variable.

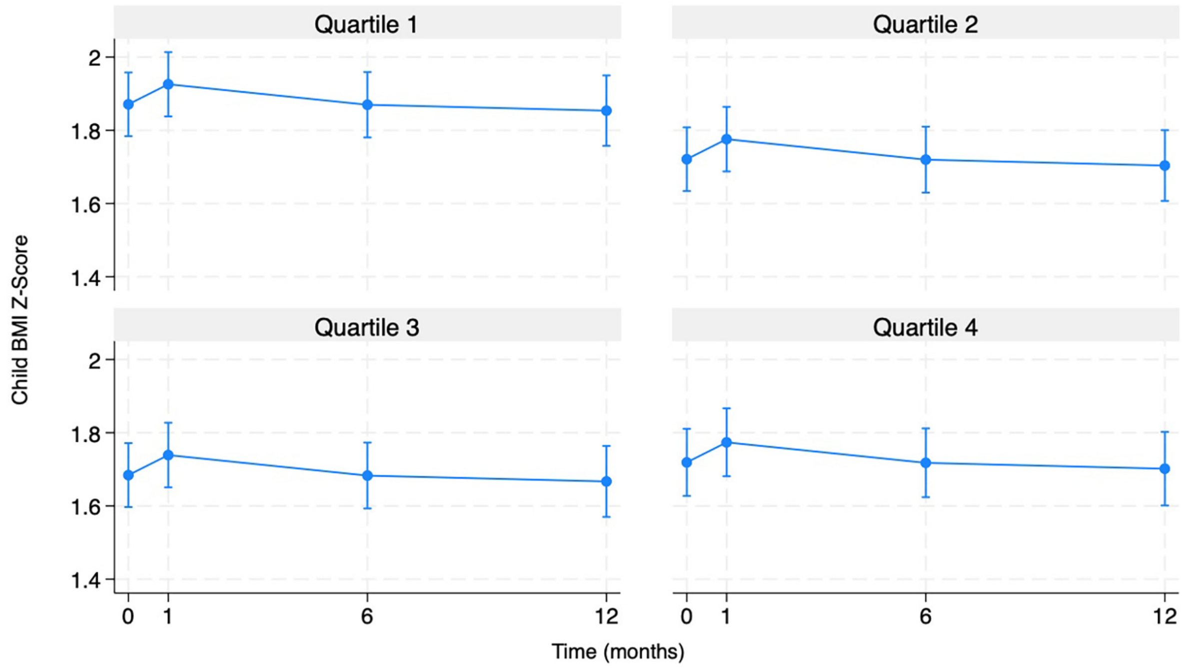


FIGURE 1
Predicted child BMI $z$-scores by child opportunity index (COI) quartiles over time ($n = 253$).

differences appear such that those at lower levels of what might be considered poverty fare better than those at the higher end or those in higher SES neighborhoods who are at the higher end of wealth fare better than those at lower end of what is considered to be wealthy even though they are in the same neighborhood (27, 28). This maps on to the findings from Figure 1. For example, if a household is significantly economically disadvantaged, they may benefit from safety net programs that provide needed resources but if the household is just over the eligibility threshold, then they may not benefit from extra support though there may be a clear need for it. However, the data does not have the information to capture and compare varying levels and if they match eligibility levels. Further, there may be a protective factor of feeling like you belong in your neighborhood, though that was not measured in the current study. No statistically significant effects were found for other factors that have been found in the literature such as physical activity, child calorie intake, and language spoken in household.

The current study also did not find any BMIz differences between treatment groups. It should be acknowledged that this is not uncommon with an intervention sample of this size. Further, the descriptive statistics did indicate substantial variability in BMIz at the baseline across different groups so any potential differences may have been attributed to other statistically significant factors above. Additionally, Wave 1 BMIz differed significantly compared to baseline in that wave 1 BMIz was higher at wave 1 compared to baseline but there was no difference throughout the rest of the time points. It could be the case that the sample gained weight for any number of reasons but looking at the trends of the data, the intervention may have been working for certain groups though perhaps a longer follow up or intervention period would have produced significant results. The analysis also did not detect interaction effects for COI*Group condition, COI*physical activity, and Time*Group condition. This may be attributed to power, but further investigation is warranted given what is seen in Figure 1.

The lack of a treatment effect finding is consistent with the findings of Yin et al. (39), which emphasized the need for multi-level and multi-behavioral approaches to effectively address obesity among young children from low-income families. Though the current study addressed various factors, the results may indicate the importance of considering even broader social determinants of health (SDOH) in obesity-based interventions (40, 41). Still, the current study findings suggest that intervening on the areas measured by the COI could be an effective strategy for reducing obesity risk among Hispanic children, thereby supporting the call for multi-level interventions and changes in SDOH.

## Limitations

As with any study using BMI as an outcome measure there are limitations in what the real-life implications are given the known challenges with this measure (42). However, the use of standardized measurement and use of $z$-score help strengthen the rigor of the variable. Though the findings align with other published studies (17), the current findings may only hold true among Hispanic 5- to 11-year-olds in south-central Texas. As noted above, there might not have been enough power in this study to detect certain difference at the $p < .05$ level. This was a diverse but relatively low COI sample and including another group with starker differences could elucidate more information about varying levels of COI, though that was outside the scope of the parent study. Notably, while not all children in the sample had baseline BMIz scores within the range or overweight or obese, all children participated in a family lifestyle intervention aimed at improving health lifestyle behaviors such as physical activity and dietary habits. Still, the analysis controlled for treatment and time to account for participation in the intervention.

## Conclusions

The research on the relationship between neighborhood environments and obesity risk among low-income Hispanic children between 5 and 11-years-old continues to be limited. The current study suggests that there are potential healthy weight differences across levels of child opportunity, using a robust measure of the environmental context, though further research is needed to understand causal relationships. Understanding which indicators within the COI to intervene on for the largest impact would be helpful to further refine family and multi-level interventions. Finally, though the patterns of low opportunity remain linked to unhealthy weight status, there are nuances to be examined to further understand what protective factors can be drawn out of each COI group to utilize a strengths-based approach to good health.

## Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: The University of Texas at Austin Latino Research Institute Data Repository—https://liberalarts.utexas.edu/lri/research/completed-studies/health4kids.html. Further data can be requested from the PI of the parent study, D. Parra-Medina at deborah.parra-medina@cuanschutz.edu.

## Ethics statement

The studies involving humans were approved by The University of Texas at Austin IRB. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

## Author contributions

CV: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing. BW: Methodology, Software, Writing – original draft, Writing – review & editing. SH: Writing – original draft, Writing – review & editing. YL: Formal analysis, Methodology, Supervision, Writing – review & editing. ZY: Supervision, Writing – review & editing. DP-M: Data curation, Funding acquisition, Resources, Supervision, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

## Publisher's note

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# Abdominal obesity and osteoarthritis risk: evaluating the association of lipid accumulation product, body roundness index, and waist triglyceride index with osteoarthritis in U.S. adults

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**Objective:** This study explored the associations between lipid accumulation product (LAP), body roundness index (BRI), and waist triglyceride index (WTI) and osteoarthritis (OA) in U.S. adults, using data from National Health and Nutrition Examination Survey (NHANES) 2015–2018.

**Methods:** This cross-sectional analysis included 3,611 participants aged ≥20 years. Using survey-weighted procedures, multivariable logistic regression assessed associations between anthropometric indices and OA. Smooth curve fitting evaluated non-linear relationships and threshold effects. Segmented linear regression was applied to identify potential inflection points. Subgroup analyses explored demographic and health-related variations, while receiver operating characteristic (ROC) curves assessed the discriminative capacity of these anthropometric indices.

**Results:** Among participants, 517 (14.31%) had OA. All indices showed positive associations with OA after adjustment: LAP (OR: 1.19, CI: 1.13–1.25), BRI (OR: 1.02, CI: 1.01–1.02), and WTI (OR: 3.72, CI: 2.25–6.16). LAP significantly increased OA risk below 131.16 (OR: 1.02, $p < 0.001$) but not above. BRI demonstrated a linear relationship with OA without significant threshold effects ($p = 0.190$). WTI demonstrated dramatically increased risk above 8.72 (OR: 74.40) vs. below (OR: 4.70). Significant interactions were observed for gender with BRI ($p = 0.0145$) and hyperlipidemia with LAP ($p = 0.0024$). Stronger associations appeared in participants with lower education, non-smokers (for BRI), and those with hypertension (for WTI). BRI showed higher diagnostic accuracy [area under the curve (AUC): 0.6588].

**Conclusion:** Central obesity-related indices demonstrate significant associations with OA prevalence in U.S. adults, with distinct threshold effects for LAP and WTI. These indices, particularly BRI, may serve as valuable screening tools for OA risk assessment in clinical practice.

KEYWORDS

**osteoarthritis, lipid accumulation product, body roundness index, waist triglyceride index, abdominal obesity, visceral fat**

## Introduction

Osteoarthritis (OA) is a prevalent degenerative joint disorder characterized by articular cartilage deterioration, osteophyte formation, and subchondral bone changes (1) that imposes substantial economic and healthcare burdens globally (2). As populations age and obesity rates rise, OA prevalence is projected to increase significantly, making the identification of modifiable risk factors crucial for public health interventions (3).

Among these risk factors, abdominal obesity has emerged as particularly significant, extending beyond mechanical loading to include complex inflammatory and metabolic pathways (4, 5). Visceral adipose tissue (VAT) functions as an active endocrine organ secreting pro-inflammatory cytokines, including tumor necrosis factor-alpha and interleukin-6 (IL-6) which promote chondrocyte apoptosis and cartilage matrix degradation (6, 7). These inflammatory processes accelerate joint degeneration and contribute to OA pathogenesis (8).

Traditional measures of obesity such as body mass index (BMI) and waist-to-hip ratio have notable limitations in accurately reflecting abdominal fat distribution and its metabolic effects (9, 10). BMI fails to account for individual fat distribution patterns, while waist circumference only partially captures abdominal adiposity, especially in the context of increasing sedentary behaviors (11). These limitations have prompted the development of novel anthropometric indices that better reflect central adiposity.

The lipid accumulation product (LAP), which combines waist circumference with triglyceride (TG) levels, has demonstrated strong predictive capability for visceral fat levels and obesity-related diseases (12). LAP provides a physiologically based metric reflecting the accumulation of lipids and their metabolic consequences, which may directly impact joint health through increased inflammatory signaling pathways. The body roundness index (BRI) offers a more comprehensive evaluation of body fat distribution by considering body width-to-height ratio (13), potentially capturing mechanical stress distribution patterns that conventional measures miss. The waist triglyceride index (WTI) offers a practical and easy composite measure that combines lipid profile with central adiposity (14).

These indices may provide more insights into OA pathogenesis than traditional measures because they better reflect the metabolically active visceral fat compartment. Elevated LAP, BRI, and WTI values potentially indicate excess visceral adiposity, which produces pro-inflammatory adipokines and cytokines (15, 16). These inflammatory mediators penetrate joint tissues, triggering cartilage degradation through increased expression of matrix metalloproteinases and promoting chondrocyte senescence and apoptosis (17). Additionally, visceral adiposity also disrupts metabolic homeostasis through insulin resistance and lipid metabolism dysregulation, leading to oxidative stress and advanced glycation end-products accumulation in joint tissues, and finally aggravates joint inflammation (18). While these indices have been associated with various health conditions including cardiovascular disease and diabetes, their relationship with OA remains underexplored (19, 20).

The National Health and Nutrition Examination Survey (NHANES) provides comprehensive health data from a representative U.S. sample, offering an opportunity to investigate these relationships (21). However, no study has comprehensively examined the associations between LAP, BRI, WTI, and OA using NHANES data.

Therefore, this study aims to explore the potential associations between these central obesity-related indices and OA among U.S. adults using NHANES 2015–2018 data. We hypothesize that elevated central obesity-related indices significantly affect OA prevalence, with potential threshold effects that could serve as clinical markers for OA risk assessment, ultimately contributing to the development of targeted prevention and treatment strategies.

## Materials and methods

### Data sources and study participants

The NHANES dataset which was utilized in this population-based cross-sectional study comprises five main components: demographic, questionnaire, laboratory, dietary, and examination data (https://www.cdc.gov/nchs/nhanes/). Data collected from the NHANES dataset (2015–2018), which is publicly available for download on the website, initially included 20,768 participants.

### Inclusion/exclusion criteria

Eligibility criteria included adults ≥20 years with complete OA diagnostic data. Exclusion criteria encompassed pregnancy, cancer diagnoses, and inflammatory arthritis (ICD-10 codes M05b-M14).

### Variables and covariates

This study considered LAP, BRI, and WTI as independent variables, with OA as the outcome of interest. Formulas of three anthropometric indexes are as follows (12–14):

$$\begin{aligned} \text{LAP} &= (\text{Waist circumference (cm)} - \text{X}) \\ &\quad \times \text{Triglycerides (mmol/L) (X} \\ &= \text{65 for males and 58 for females)} \end{aligned} \tag{1}$$

$$\text{BRI} = 364.2 - 365.5 \times \sqrt{1 - \left(\frac{\text{(Waist circumference (m)}/2\pi}{0.5 \times \text{Height (m)}}\right)^2} \tag{2}$$

$$\begin{aligned} \text{WTI} &= \text{Ln [Triglycerides (mg/dl)} \\ &\quad \times \text{Waist circumference (cm)/2].} \end{aligned} \tag{3}$$

All formulas were applied using standardized measurements to ensure consistency and accuracy. These indicators were chosen for their capacity to represent central obesity and the pattern of body fat, particularly in the visceral abdominal region, which is closely associated with osteoarthritis.

OA was defined based on diagnosis and recorded data. Participants who met the following criteria were considered to have OA:

(1) Diagnosis as osteoarthritis made by a healthcare professional. Documentation of OA-related symptoms, including joint pain, stiffness, or swelling lasting for more than 3 months.
(2) Use of OA-specific medications or treatments. The definition used in this study aligns with standardized diagnostic criteria to ensure consistency and accuracy in identifying participants with OA (22).

When investigating the association between LAP, BRI, WTI, and OA, considering the potential influence and moderating effects of multiple covariates on these relationships is crucial. Therefore, we carefully selected 17 potential confounding variables: demographic factors (age, gender, race/ethnicity, education level, and income-to-poverty ratio), laboratory measurements [aspartate aminotransferase (AST), alanine aminotransferase (ALT), uric acid, low-density lipoprotein, high-density lipoprotein, total cholesterol (TC), blood urea nitrogen], clinical comorbidities (hypertension, diabetes, hyperlipidemia), and lifestyle behaviors (consumption, smoking status). This comprehensive adjustment approach, supported by previous epidemiological studies (2, 3, 5), helps isolate independent relationships between primary variables while minimizing confounding bias.

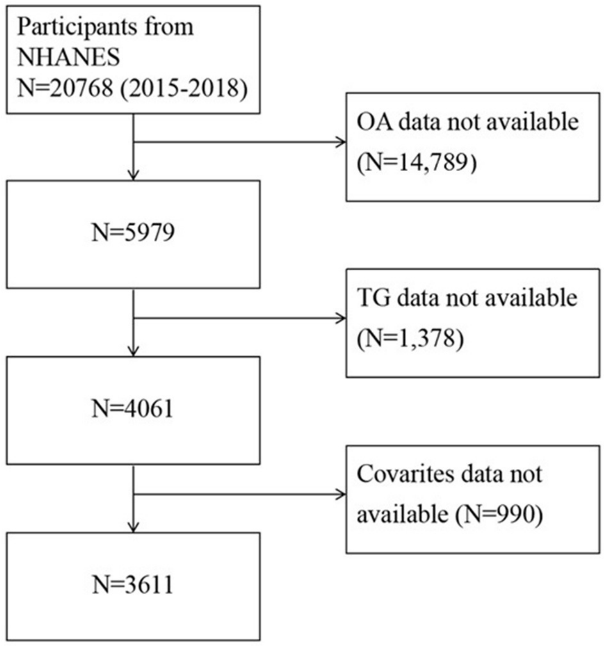


FIGURE 1
Flow chart of patient screening.

## Statistical analysis

R software (version 4.3.3, available at http://www.R-project.org) and EmpowerStats (version 2.0) (23). Given NHANES' complex multistage probability sampling design, appropriate survey weights were applied to all analyses to ensure nationally representative estimates. The normality of continuous variables was assessed using the Shapiro–Wilk test. Variables following normal distribution were analyzed using Student's *t*-test, while non-normally distributed variables were evaluated using the Mann–Whitney *U* test. Weighted chi-square tests were conducted to evaluate baseline characteristics across populations. To evaluate linear relationships between anthropometric indices (LAP, BRI, and WTI) and OA, multivariable logistic regression was employed as OA diagnosis is a binary outcome variable. The linearity of the relationship between continuous predictors and the logit of the outcome was examined using Box–Tidwell tests. Multicollinearity among covariates was assessed by calculating variance inflation factors (VIF), with VIF $\geq 5$ indicating significant multicollinearity. When detected, redundant variables were removed from the model.

After adjusting for covariates in Model 3, Smooth curve fitting was performed to evaluate non-linear relationships between these indices and OA. Additionally, segmented linear regression models were applied to assess potential non-linear associations between OA and the three indices, identify threshold effects, and calculate inflection points. Subgroup analyses and interaction tests were conducted according to gender, race, education level, smoking, alcohol consumption, hypertension, diabetes, and hyperlipidemia to explore potential differences between different populations. Subgroup-specific interactions were tested through generalized linear models incorporating multiplicative interaction terms, with Bonferroni correction to account for multiple comparisons. Discriminative capacity was evaluated through receiver operating characteristic (ROC) curve analysis with area under the curve (AUC) comparisons to assess diagnostic performance. Statistical significance was defined as a *p*-value $<0.05$. For detailed information on the adjusted models, please refer to the table notes.

# Results

## Baseline information

After exclusion inaccessible data (Figure 1), the final analysis included a total of 3,611 participants (1,754 men and 1,857 women). The baseline information of these participants is shown in Table 1. Among them, 172 males (33.27%) and 345 females (66.73%) were diagnosed with osteoarthritis (OA). The average age was 45.96 ± 16.88 in the non-OA group and 62.57 ± 12.82 in the OA group.

Participants with OA displayed significantly higher levels of triglycerides (TG) and total cholesterol (TC) compared to the non-OA. Additionally, as indicated in Table 1, the OA group had significantly elevated values for all three anthropometric measures—LAP, BRI, and WTI. BMI, WC, height, and weight, were also higher in the OA group. The prevalence of smoking, alcohol consumption, hypertension, hyperlipidemia and diabetes were notably higher in OA participants.

## Associations between three anthropometric indexes and OA

Table 2 presents result after adjustments for potential confounding factors. It is apparent that with significant increases

TABLE 1 Based on the baseline characteristics of the study population ascertained by NHANES from 2015 to 2018.

| Characteristics | Total ($N$ = 3,611) | Non-osteoarthritis ($N$ = 3,094) | Osteoarthritis ($N$ = 517) | $p$-value |
|---|---|---|---|---|
| Age (years) | 48.33 ± 17.36 | 45.96 ± 16.88 | 62.57 ± 12.82 | **<0.001** |
| Poverty-to-income ratio | 2.51 ± 1.52 | 2.50 ± 1.52 | 2.60 ± 1.51 | 0.140 |
| Body mass index (kg/m$^2$) | 29.22 ± 6.98 | 28.86 ± 6.81 | 31.34 ± 7.59 | 0.180 |
| AST | 23.55 ± 12.82 | 23.54 ± 12.79 | 23.60 ± 12.99 | **<0.001** |
| ALT | 25.44 ± 10.69 | 25.49 ± 10.84 | 25.16 ± 9.78 | 0.488 |
| Blood urea nitrogen | 14.35 ± 5.58 | 14.01 ± 5.26 | 16.40 ± 6.87 | **<0.001** |
| Uric acid | 5.43 ± 1.42 | 5.43 ± 1.42 | 5.42 ± 1.46 | 0.579 |
| Total cholesterol | 188.48 ± 41.23 | 187.61 ± 40.37 | 193.71 ± 45.69 | 0.021 |
| Triglyceride | 106.91 ± 64.50 | 105.51 ± 65.00 | 115.24 ± 60.83 | **<0.001** |
| Low-density lipoprotein | 112.34 ± 36.06 | 112.29 ± 35.41 | 112.62 ± 39.77 | **0.046** |
| High-density lipoprotein | 54.76 ± 16.64 | 54.21 ± 16.07 | 58.04 ± 19.40 | **<0.001** |
| Height | 166.63 ± 9.88 | 166.96 ± 9.87 | 164.66 ± 9.74 | **<0.001** |
| WC | 99.37 ± 16.68 | 98.24 ± 16.32 | 106.10 ± 17.25 | **<0.001** |
| Gender (%) | | | | **<0.001** |
| Male | 1,754 (48.57%) | 1,582 (51.13%) | 172 (33.27%) | |
| Female | 1,857 (51.43%) | 1,512 (48.87%) | 345 (66.73%) | |
| Race (%) | | | | **<0.001** |
| Mexican American | 568 (15.73%) | 519 (16.77%) | 49 (9.48%) | |
| Other Hispanic | 420 (11.63%) | 369 (11.93%) | 51 (9.86%) | |
| Non-Hispanic White | 1,209 (33.48%) | 941 (30.41%) | 268 (51.84%) | |
| Non-Hispanic Black | 742 (20.55%) | 650 (21.01%) | 92 (17.79%) | |
| Other race | 672 (18.61%) | 615 (19.88%) | 57 (11.03%) | |
| Education level (%) | | | | **0.013** |
| <9th Grade | 313 (8.67%) | 280 (9.05%) | 33 (6.38%) | |
| 9–11th Grade | 419 (11.60%) | 365 (11.80%) | 54 (10.44%) | |
| High school grade | 814 (22.54%) | 685 (22.14%) | 129 (24.95%) | |
| Some college or AA degree | 1,095 (30.32%) | 915 (29.57%) | 180 (34.82%) | |
| College graduate or above | 970 (26.86%) | 849 (27.44%) | 121 (23.40%) | |
| Alcohol drinking (%) | | | | **<0.001** |
| Yes | 457 (12.66%) | 366 (11.83%) | 91 (17.60%) | |
| No | 2,505 (69.37%) | 2,147 (69.39%) | 358 (69.25%) | |
| Other | 649 (17.97%) | 581 (18.78%) | 68 (13.15%) | |
| Hypertension (%) | | | | **<0.001** |
| Yes | 1,192 (33.01%) | 877 (28.35%) | 315 (60.93%) | |
| No | 2,419 (66.99%) | 2,217 (71.65%) | 202 (39.07%) | |
| Diabetes | | | | **<0.001** |
| Yes | 495 (13.71%) | 374 (12.09%) | 121 (23.40%) | |
| No | 3,017 (83.55%) | 2,648 (85.59%) | 369 (71.37%) | |
| Other | 99 (2.74%) | 72 (2.33%) | 27 (5.22%) | |
| Smoking status (%) | | | | **0.001** |
| Yes | 1,487 (41.18%) | 1,221 (39.46%) | 266 (51.45%) | |
| No | 2,124 (58.82%) | 1,873 (60.54%) | 251 (48.55%) | |

*(Continued)*

TABLE 1 (Continued)

| Characteristics | Total ($N$ = 3,611) | Non-osteoarthritis ($N$ = 3,094) | Osteoarthritis ($N$ = 517) | $p$-value |
|---|---|---|---|---|
| Hyperlipidemia | | | | **0.009** |
| Yes | 2,124 (58.82%) | 1,793 (57.95%) | 331 (64.02%) | |
| No | 1,487 (41.17%) | 1,301 (42.05%) | 186 (35.98%) | |
| LAP | 53.02 ± 42.14 | 51.02 ± 41.53 | 64.95 ± 43.85 | **<0.001** |
| BRI | 5.57 ± 2.40 | 5.38 ± 2.31 | 6.69 ± 2.60 | **<0.001** |
| WHTR | 0.60 ± 0.10 | 0.59 ± 0.10 | 0.65 ± 0.10 | **<0.001** |
| WTI | 8.40 ± 0.64 | 8.37 ± 0.65 | 8.57 ± 0.58 | **<0.001** |

All values are presented as proportion (%) or mean (standard error); to analyze the continuous variables, a weighted Student's $t$-test was employed, while for categorical variables, a chi-square test was utilized. Significant values are in bold. AST, aspartate aminotransferase; ALT, alanine aminotransferase; WC, waist circumference; LAP, lipid accumulation product; BRI, body roundness index; WHtR, waist-to-height ratio; WTI, waist triglyceride index.

TABLE 2 Multivariable logistic regression models for the association between LAP, BRI, and WTI and osteoarthritis in adults in the NHANES 2015–2018.

| Exposure | Crude model (model 1) OR (95% CI) $p$-value | Partially adjusted model (model 2) OR (95% CI) $p$-value | Fully adjusted model (model 3) OR (95% CI) $p$-value |
|---|---|---|---|
| LAP | 1.01 (1.00, 1.01) <0.0001 | 1.01 (1.00, 1.01) <0.0001 | 1.02 (1.01, 1.02) <0.0001 |
| BRI | 1.22 (1.18, 1.27) <0.0001 | 1.18 (1.13, 1.23) <0.0001 | 1.19 (1.13, 1.25) <0.0001 |
| WTI | 1.64 (1.41, 1.90) <0.0001 | 1.53 (1.28, 1.83) <0.0001 | 3.72 (2.25, 6.16) <0.0001 |

Model 1, no covariates were adjusted.
Model 2, age, gender, and race were adjusted.
Model 3, age, gender, race, education level, income-to-poverty ratio, hypertension, AST, ALT, uric acid, diabetes, alcohol drinking, smoking status, low-density lipoprotein, high-density lipoprotein, blood urea nitrogen, total cholesterol, and hyperlipidemia were adjusted.
OR, odds ratio; 95% CI, 95% confidence interval.

in OA risk associated with higher LAP, BRI, and WTI ($p$ < 0.0001): For LAP the ORs were 1.01 (CI: 1.00–1.01) in model 1, 1.01 (CI: 1.00–1.01) in model 2 and 1.02 (CI: 1.01–1.02) in model 3. For BRI, the ORs were 1.22 (CI: 1.18–1.27) in model 1, 1.18 (1.13, 1.23) in model 2 and 1.19 (1.13, 1.25) in model 3. For WTI, the ORs were 1.64 (CI: 1.41–1.90) in model 1, 1.53 (CI: 1.28–1.83) in model 2 and 3.72 (CI: 2.25–6.16) in model 3.

## Analysis of non-linearity and threshold effects between LAP, BRI, WTI, and osteoarthritis

A significant threshold effect for LAP was identified at 131.16 (Table 3, log-likelihood ratio test, $p$ < 0.001). Below this value, LAP was positively associated with the likelihood of osteoarthritis [1.02 (CI: 1.02–1.03), $p$ < 0.001], while no significant relationship was found above this threshold [1.00 (CI: 0.99–1.01), $p$ = 0.826].

For BRI, the standard linear model showed a significant positive association with osteoarthritis risk [1.19 (CI: 1.14–1.25), $p$ < 0.0001]. The threshold effect was not statistically significant (log-likelihood ratio test, $p$ = 0.191).

For WTI, a significant threshold effect was confirmed at 8.72 (log-likelihood ratio test, $p$ < 0.001). Below this threshold, a strong positive correlation with osteoarthritis was observed [4.70 (CI: 2.84–7.78), $p$ < 0.001], with the association becoming dramatically stronger above the threshold [74.40 (CI: 22.91–241.60), $p$ < 0.001] (Figure 2).

## Subgroup analysis of LAP, BRI, WTI, and osteoarthritis prevalence

Significant positive associations between LAP, BRI, WTI, and the prevalence of osteoarthritis were consistently observed across subgroups categorized by gender, race, education, smoking status, alcohol intake, hypertension, and diabetes ($p$ < 0.01 for most subgroups) (Supplementary Table S1). Significant interactions were identified for gender with BRI ($p$ interaction = 0.0145), race with BRI ($p$ interaction = 0.0394), smoking status with BRI ($p$ interaction = 0.0348), hypertension with WTI ($p$ interaction = 0.0438), and hyperlipidemia with LAP ($p$ interaction = 0.0024).

The associations were significant in both males and females, with males showing slightly stronger associations for BRI (OR 1.29, 95% CI: 1.19–1.41) and WTI (OR 4.80, 95% CI: 2.66–8.66) compared to females (BRI: OR 1.15, 95% CI: 1.09–1.22; WTI: OR 3.29, 95% CI: 1.98–5.46). Across racial categories, Mexican Americans showed the strongest association with WTI (OR 6.40, 95% CI: 2.30–17.50), while Non-Hispanic Black people had the strongest association with BRI (OR 1.31, 95% CI: 1.18–1.46).

Participants with lower education levels (<9th grade) showed notable associations with LAP (OR 1.03, 95% CI: 1.01–1.04) and WTI (OR 6.40, 95% CI: 1.70–23.90). For smoking status, non-smokers demonstrated stronger associations with BRI (OR 1.24, 95% CI: 1.17–1.32) compared to smokers (OR 1.13, 95% CI: 1.06–1.21).

The association between WTI and OA was significantly stronger in individuals with hypertension (OR 4.90, 95% CI:

2.70–8.60) compared to those without (OR 3.30, 95% CI: 1.90–5.40). For hyperlipidemia, a significant interaction was observed with LAP ($p$ interaction = 0.0024), with stronger associations in participants without hyperlipidemia (OR 1.028, 95% CI: 1.019–1.031) compared to those with the condition (OR 1.016, 95% CI: 1.010–1.021).

TABLE 3 Threshold effect analysis of LAP, BRI, and WTI and osteoarthritis using a two-piecewise logistic regression model in adults in the NHANES 2015–2018.

| Threshold effect analysis | Cataract OR (95%CI) $p$-value |
|---|---|
| LAP | |
| Fitting by the standard linear model | 1.02 (1.01, 1.02) <0.001 |
| Inflection point of LAP (K) | 131.16 |
| <K slope | 1.02 (1.02, 1.03) <0.001 |
| >K slope | 1.00 (0.99, 1.01) 0.826 |
| Log-likelihood ratio test | <0.001 |
| BRI | |
| Fitting by the standard linear model | 1.19 (1.14, 1.25) <0.0001 |
| Inflection point of VAI (K) | 2.88 |
| <K slope | 0.63 (0.26, 1.54) 0.315 |
| >K slope | 1.20 (1.14, 1.26) <0.001 |
| Log-likelihood ratio test | 0.191 |
| WTI | |
| Fitting by the standard linear model | 3.63 (2.20, 5.99) <0.001 |
| Inflection point of AIP (K) | 8.72 |
| <K slope | 4.70 (2.84, 7.78) <0.001 |
| >K slope | 74.40 (22.91, 241.60) <0.001 |
| Log-likelihood ratio test | <0.001 |

Age, gender, race, education level, income-to-poverty ratio, hypertension, AST, ALT, uric acid, diabetes, alcohol drinking, smoking status, low-density lipoprotein, high-density lipoprotein, blood urea nitrogen, total cholesterol, and hyperlipidemia were adjusted.
Non-linear relationships, including threshold and saturation effects, were explored using generalized additive models (GAMs).
95% CI, 95% confidence interval; OR, odds ratio.

ROC curve analysis was performed to evaluate the diagnostic utility of the adiposity indices for OA. The BRI showed an area under the curve (AUC) of 0.6588 (95% CI: 0.6341–0.6835, $p < 0.001$), the LAP demonstrated an AUC of 0.6098 (95% CI: 0.5844–0.6351, $p < 0.001$), and the WTI had an AUC of 0.5898 (95% CI: 0.5643–0.6152, $p < 0.001$). Additional performance metrics are presented in Table 4.

## Discussion

Obesity has long been established as a primary modifiable risk factor for OA development and progression (3). Traditional obesity metrics like body mass index (BMI) have demonstrated consistent associations with OA risk across populations (10). However, these conventional indicators have significant limitations in differentiating between adipose tissue distribution patterns, particularly failing to accurately quantify visceral adiposity (9), which may play a crucial role in OA pathogenesis beyond simple mechanical loading effects.

Increasing evidence suggests that visceral adiposity contributes to OA through multiple pathophysiological mechanisms. Visceral adipose tissue functions as an active endocrine organ, secreting pro-inflammatory adipokines and cytokines that promote systemic low-grade inflammation (6, 7). This inflammatory state can directly impact articular cartilage metabolism, synovial inflammation, and subchondral bone remodeling, accelerating joint degeneration independent of mechanical factors (8). Recent studies have demonstrated that even individuals with normal BMI but metabolic syndrome (MetS) exhibit significantly higher OA prevalence and progression rates compared to metabolically healthy counterparts, highlighting the strong connection between lipid metabolism dysregulation and OA pathogenesis regardless of overall weight status (24).

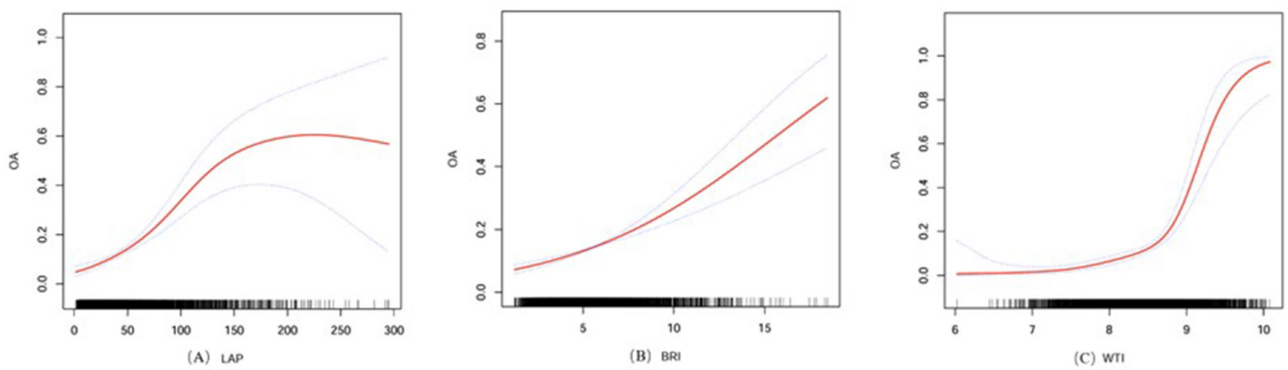


FIGURE 2
The nonlinear associations between the LAP **(A)**, BRI **(B)**, WTI **(C)** and OA. The solid red line represents the smooth curve fit between variables. Blue bands represent the 95% confidence interval from the fit. Age, gender, race, education level, income-to-poverty ratio, hypertension, AST, ALT, uric acid, diabetes, alcohol drinking, smoking status, low-density lipoprotein, high-density lipoprotein, blood urea nitrogen, total cholesterol, and hyperlipidemia were adjusted.

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TABLE 4 ROC curves of LAP, BRI and WTI index for OA.

| Variable | Sensitivity | Specificity | ROC area (AUC) | 95%CI low | 95%CI up | *p*-value |
|---|---|---|---|---|---|---|
| LAP | 0.4642 | 0.7001 | 0.6098 | 0.5844 | 0.6351 | <0.001 |
| BRI | 0.5880 | 0.6464 | 0.6588 | 0.6341 | 0.6835 | <0.001 |
| WTI | 0.3946 | 0.7346 | 0.5898 | 0.5643 | 0.6152 | 0.050 |

AUC, area under curve; ROC, receiver operating characteristics curve; 95% CI, 95% confidence interval.

While the link between obesity and OA is well-established, recent advances in research methodologies have provided deeper insights into the specific metabolic mechanisms involved. Metabolomics research has identified distinct lipid profiles in OA patients that correlate with disease severity, indicating that lipid metabolism abnormalities may contribute to OA pathogenesis (25). Interestingly, these metabolic disturbances appear to precede radiographic OA changes, suggesting they may serve as early biomarkers for OA risk assessment (26). Additionally, epidemiological studies have consistently reported that central obesity metrics, including waist circumference and waist-to-hip ratio, demonstrate stronger associations with OA risk than BMI alone, particularly for knee OA (27). These observations highlight the importance of comprehensively evaluating both lipid metabolism parameters and abdominal fat distribution patterns when assessing OA risk, suggesting that indices incorporating both elements may offer superior predictive value.

Based on these findings, researchers have developed more sophisticated metrics that better capture both metabolic dysfunction and fat distribution patterns relevant to OA pathogenesis. LAP, BRI, and WTI—offer potentially superior methods for quantifying metabolically active visceral adiposity compared to traditional anthropometric measures (12–14). Each index incorporates different components of body fat distribution and metabolic parameters, potentially capturing unique aspects of adiposity-related OA risk. Previous investigations have demonstrated strong correlations between these indices and various cardiometabolic conditions including diabetes, hypertension, cardiovascular disease, and even acute pancreatitis, many of which share inflammatory pathways with OA (19, 28). However, comprehensive research examining these specific indices in relation to OA risk remains limited.

Given these established connections between visceral adiposity, metabolic dysfunction, and OA, we hypothesized that LAP, BRI, and WTI would demonstrate significant associations with OA risk in a nationally representative sample. This cross-sectional study aims to investigate these relationships while identifying potential threshold effects and subgroup variations that might inform clinical risk assessment strategies. Our findings demonstrate significant associations between three readily accessible abdominal fat distribution indices—LAP, BRI, and WTI—and osteoarthritis risk in U.S. adults. Participants with OA exhibited markedly higher values for all three indices compared to non-OA counterparts, even after adjusting for covariates which is consistent with the results reported by previous studies (29, 30). Importantly, LAP showed a positive association with OA risk up to 131.16, beyond which the relationship became non-significant; BRI demonstrated no significant association below 2.88, but a strong positive correlation above this threshold; and WTI revealed a dramatic increase in association strength after exceeding 8.72, with the odds ratio jumping from 4.70 below the threshold to 74.40 above it. Subgroup analyses confirmed robust associations across demographic and clinical characteristics, with specific interactions observed for gender with BRI and hyperlipidemia with LAP. Stronger associations were observed in participants with lower education levels, non-smokers (for BRI), individuals with hypertension (particularly for WTI), and participants without hyperlipidemia (for LAP).

Among the three indices examined, each demonstrated distinct patterns of association with OA that warrant detailed examination. LAP, a composite indicator combining waist circumference and triglyceride levels, represents a powerful marker for assessing central lipid accumulation and metabolic dysfunction. Recent research from NHANES 2017–2020 revealed an inverse U-shaped association between LAP levels and OA prevalence, with LAP functioning as an independent risk factor for OA when below 120.00 cm × mmol/L (31). Our findings further establish its relationship with OA, particularly below the threshold value of 131.16, beyond which the association plateaus. This threshold phenomenon likely reflects the biological concept of "adiposity threshold" where adipose tissue expansion exceeds its vascular supply, triggering hypoxia-induced adipocyte dysfunction (32). The resulting cellular stress activates the unfolded protein response and stimulates NOD-, LRR- and pyrin domain-containing protein 3 (NLRP3) inflammasome activation, perpetuating synovial inflammation through pro-IL-1β processing and adipokine dysregulation (e.g., leptin resistance, adiponectin suppression) (33). Mechanistically, elevated LAP values are associated with visceral adiposity functioning as an active endocrine organ (15), secreting pro-inflammatory cytokines that contribute to systemic low-grade inflammation. Chondrocytes exposed to high triglyceride concentrations exhibit increased oxidative stress markers and reduced expression of cartilage matrix components (17), directly impacting cartilage homeostasis (34). Additionally, lipid toxicity from excessive triglycerides can impair mitochondrial function in joint tissues (6), accelerating cellular senescence and apoptosis of chondrocytes through ceramide accumulation and endoplasmic reticulum stress (35).

While LAP captures important aspects of lipid accumulation, BRI offers complementary insights by focusing on anatomical dimensions of adiposity. BRI combines height and central body fat percentage, reflecting anatomical stress on joints which is relevant to structural damage in OA (13). The biomechanical significance of BRI lies in its ability to capture alterations in body mass distribution that affect joint loading patterns (36), with odds ratios as high as 2.235 (95% CI: 1.796–2.781) for identifying metabolic syndrome risk (37). The elliptical nature of the BRI calculation specifically accounts for how abdominal fat shifts the center of gravity anteriorly, increasing anterior-posterior shear forces on weight-bearing joints, particularly knees and hips (38). Beyond purely mechanical effects, these altered loading patterns stimulate chondrocyte mechanoreceptors, particularly ion channels such as transient receptor potential vanilloid 4 (TRPV4) and Piezo 1/2, which respond to abnormal pressure by initiating inflammatory signaling pathways that further contribute to matrix degradation (39). Furthermore, central obesity, which BRI specifically targets, induces a chronic inflammatory state characterized by abnormal adipokine profiles, including leptin, adiponectin, and resistance (40). These adipokines have been consistently detected at elevated levels in the synovial fluid of OA patients and directly influence cartilage metabolism. Our study provides additional support for BRI as a valuable tool in OA risk stratification.

Beyond the mechanical factors captured by BRI, metabolic aspects of adiposity are further illuminated by examining WTI, which offers yet another perspective on OA risk. WTI, combining waist circumference and triglycerides through logarithmic transformation and less prone to confounding by lean mass (41), may offer complementary information to both LAP and BRI. Our study revealed a notable threshold effect where WTI values exceeding 8.72 were associated with a dramatic increase in OA risk, with the odds ratio jumping from 4.70 below the threshold to 74.40. above it. This non-linear relationship might correspond with a metabolic switch from subcutaneous to ectopic fat deposition, including muscle, and synovial tissues (42). Such ectopic deposition in joint-adjacent tissues alters the local lipid profile of synovial fluid, disrupting lubrication properties and increasing friction coefficients within the joint (43). The logarithmic transformation applied in WTI calculation may capture these non-linear relationships between visceral adiposity, lipid metabolism, and inflammatory pathways, potentially amplifying its association with OA compared to other indices. WTI can easily identify individuals who have significant visceral fat accumulation and metabolic disruptions which are key contributors to joint degeneration, even when they may not exhibit high overall body mass (41).

The differential associations observed across these three indices highlight the multifaceted nature of adiposity's contribution to OA risk. Meta-analyses comparing various adiposity indicators have demonstrated that indices incorporating both anthropometric measurements and lipid profiles often provide superior diagnostic accuracy compared to traditional measures such as BMI, waist circumference, or waist-to-height ratio alone (44). LAP, BRI, and WTI each capture distinct aspects of metabolic health—LAP excels at assessing visceral lipid accumulation, BRI provides superior body shape assessment, and WTI offers enhanced sensitivity to triglyceride-related metabolic dysfunction (45). By examining all three indices concurrently, clinicians can more comprehensively evaluate metabolic profiles and accurately identify patients at elevated OA risk. From a clinical perspective, the identified thresholds for LAP (131.16) and WTI (8.72) serve as valuable screening tools in primary care and rheumatology settings. These thresholds can inform risk stratification protocols, helping determine which patients might benefit most from preventive interventions targeting joint protection and weight management (21). Using routine laboratory tests and simple anthropometric measurements, these indices are easily implemented in clinical practice, supporting our understanding of OA as a multifactorial condition influenced by diverse metabolic and inflammatory pathways.

Our subgroup analyses revealed remarkable consistency in the associations between adiposity indices and OA across diverse demographic and clinical subpopulations, reinforcing the generalizability of our findings. Notably, gender-specific interactions with BRI suggest potential hormonal or body composition influences on adiposity's relationship with OA risk (46). The stronger associations observed in participants with lower education levels highlight important socioeconomic dimensions in OA risk profiling, while the significant interaction between hyperlipidemia and LAP provides additional insights. This finding suggests that in patients with pre-existing dyslipidemia, additional fat accumulation (as measured by LAP) may have a smaller contribution to OA risk, possibly because hyperlipidemia has already activated inflammatory and metabolic pathways that promote OA development (12, 32). In contrast, in metabolically healthy individuals, an increase in LAP values may represent a more significant transition from normal to pathological states, thus showing a stronger association with OA risk.

Regarding discriminative capacity, ROC analysis showed BRI had the highest association strength, followed by LAP and WTI. BRI's higher AUC in this cross-sectional analysis may reflect its ability to better capture central adiposity distribution patterns that are associated with joint loading and inflammatory processes relevant to OA. To address collinearity, we calculated variance inflation factors (VIF $\geq$ 5) and removed problematic variables, while our sequential adjustment across multiple models assessed estimate stability. This rigorous approach to multicollinearity assessment is widely accepted in epidemiological research and provides sufficient protection against inflated standard errors and unstable coefficient estimates (23).

This study has several strengths. First, we utilized data from NHANES, a nationally representative survey with standardized protocols for data collection, enhancing the generalizability of our findings. Second, we comprehensively analyzed three indices (LAP, BRI, and WTI) that reflect different aspects of abdominal adiposity and lipid metabolism in relation to OA, providing multifaceted evidence on the associations between metabolic and anatomical components of obesity and OA prevalence. Third, we employed sophisticated statistical methods to explore both linear and non-linear relationships, identify threshold effects, and assess diagnostic performance through ROC analysis and extensive subgroup evaluations. However, there are some limitations. First, the cross-sectional design prevents establishing causality between these adiposity indices and OA. We cannot determine whether abnormal LAP, BRI, and WTI values precede OA development or result from post-diagnosis lifestyle changes. Second, self-reported OA diagnosis may introduce recall bias (47). Third, while we addressed multicollinearity using variance inflation factors, our analysis was limited to conventional regression models. Future studies comparing multiple regression approaches could further validate the robustness of these associations. Finally, we lacked information on OA severity and joint-specific involvement, which may have provided additional insights.

## Conclusions

This cross-sectional study elucidates the significant associations between three abdominal fat distribution indices—LAP, BRI, and WTI—and osteoarthritis (OA) risk in U.S. adults. Participants with OA exhibited markedly higher values for all three indices compared to non-OA counterparts, even after adjusting for covariates. Non-linear threshold effects were identified for LAP and WTI: LAP demonstrated a saturation point (131.16) beyond which the association with OA risk became non-significant, while WTI showed a threshold (8.72) above which OA risk escalated exponentially (from OR 4.70 to 74.40). In contrast, BRI showed a linear relationship with OA risk, with no significant threshold effect (log-likelihood ratio test, $p = 0.190$). Subgroup analyses confirmed robust associations across diverse demographic and clinical characteristics, with specific interactions observed for gender with BRI and hyperlipidemia with LAP. Stronger associations were noted in participants with lower education levels, non-smokers (for BRI), individuals with hypertension (particularly for WTI), and participants without hyperlipidemia (for LAP). The identified thresholds for LAP and WTI may serve as practical screening tools for identifying individuals at higher OA risk and as targets for risk stratification in clinical settings. Since these indices can be easily calculated from routine laboratory tests and anthropometric measurements, they offer a potentially cost-effective approach to risk assessment. In future research, it would be valuable to explore whether different management approaches, such as dietary modifications for individuals with elevated LAP values or specific exercise programs for those with high WTI values. While our cross-sectional design limits causal inference, these results generate important hypotheses for future longitudinal and interventional studies examining.

## Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://www.cdc.gov/nchs/nhanes/.

## Ethics statement

The studies involving humans were approved by https://www.cdc.gov/nchs/nhanes/index.htm. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

YL: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. CLa: Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. ZP: Investigation, Methodology, Project administration, Writing – review & editing. YH: Methodology, Software, Writing – review & editing. CLi: Supervision, Validation, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2025.1570740/full#supplementary-material

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# Rural, urban and suburban differences in the prevalence of metabolic syndrome in individuals aged ≥50 years in Northwest China

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**Background:** Metabolic syndrome (MetS) is a significant risk factor for type 2 diabetes and cardiovascular disease. The aim of this study was to identify the characteristics of MetS in northwest China.

**Methods:** Three thousand and one adults were included (1,915 females, 1,086 males). The prevalence of MetS analysis was stratified according to gender, age and the region of residence.

**Results:** MetS prevalence in females and males was 49.7 ± 9.8% and 32.0 ± 9.0%, respectively ($p < 0.001$). MetS prevalence in females increased with age and was greater in rural ($n = 217$) females (53.6%) compared to urban ($n = 754$) (45.5%) or suburban ($n = 818$) females (52.0%) ($p = 0.003$). Regression analysis revealed that rural region, age, half-meat and half-vegetable dietary style, never dieted, weight increase in the previous year and a family history of high blood pressure were independent risk factors for the development of MetS, particularly in women aged ≥50 years.

**Conclusion:** MetS prevalence in women was greater than for men, increased with age and occurred more frequently in rural compared to urban and suburban females.

KEYWORDS

**metabolic syndrome, type 2 diabetes, rural, suburban, urban**

## 1 Introduction

Metabolic syndrome (MetS) is associated with an increased risk of type 2 diabetes, cardiovascular disease and overall mortality (1). In particular, older adult women are at heightened risk, with several studies showing a strong correlation between MetS and the subsequent development of type 2 diabetes and cardiovascular disease (2, 3). A national Chinese survey of 15,540 participants reported an age-standardized MetS prevalence of 17.8%

in women and 9.8% in men (4). One significant factor contributing to MetS in women aged ≥50 years was the menopause. Hormonal changes, including decreased estrogen and increased testosterone have been identified as key contributors to MetS development during and after menopause (5–7).

While MetS has been widely studied in general populations, regional and residential distinctions – particularly among rural, suburban, and urban populations – remain underexplored. Emerging evidence suggests that these differences may significantly affect MetS prevalence and progression due to variations in socioeconomic status, lifestyle, health literacy and access to healthcare. In particular, older adult women in rural areas may face elevated risks, yet they have been underrepresented in existing studies. For example, compared to men, women show lower rates of MetS resolution when overweight, while factors such as low income and current employment influence MetS differently across genders (8). Historically, rural areas in China have exhibited lower MetS prevalence compared to urban regions. However, recent studies indicate a significant rise in MetS cases in rural communities. A study in rural northeast China found MetS prevalence rates comparable to, or even exceeding, those in some urban areas, with rates reaching 24.2% in 2014, up from 4.3% in 2002 (9). In rural Xinjiang, a multi-ethnic region, age-standardized MetS prevalence ranged from 14.43 to 26.50%, depending on the diagnostic criteria use (10). Suburban areas, often representing transitional zones between rural and urban settings, show intermediate MetS prevalence rates. A study that compared two types of urbanization in China – rural-to-urban migration and *in situ* urbanization – found varying impacts on metabolic health. In rapidly urbanizing areas, the prevalence of diabetes, obesity and non-alcoholic fatty liver disease increased significantly (11). Proposed contributing factors were that transition from agricultural to industrial jobs reduced physical activity, adoption of urban dietary patterns, sedentary behaviors and improved healthcare infrastructure compared to rural areas, but may still lag behind urban centers. Urban residents in China have traditionally exhibited higher MetS prevalence due to lifestyle factors such as higher consumption of high-calorie processed foods, sedentary occupations and reduced physical activity levels, but better access to healthcare services has facilitated the diagnosis and management of MetS components. Studies have reported the prevalence of MetS among urban residents ranging from 17.91 to 35.10% in men and 26.04 to 32.50% in women (12). Lifestyle factors such as diet, physical activity and substance use also play a critical role in the risk of developing MetS, with regional differences in lifestyle habits influencing its prevalence and characteristics, and also in other countries (13–16).

Despite this growing body of research, most studies have focused on urban populations, leaving rural women underrepresented. Recent evidence has challenged earlier assumptions, indicating a higher prevalence of MetS in rural areas – possibly driven by dietary transitions and socioeconomic changes. Rural women, in particular, often experience lower health literacy, poorer dietary habits and reduced participation in preventive health behaviors such as diet control. The data derived from the Community-Based Management of Diabetes in the Elderly (CBMDE) project, an epidemiological and prospective cohort study, which employed a community-based multi-stage, stratified, cluster sampling method whose first step, covered between June 2014 and September 2016, was analyzed in order to achieve the prevalence data of diabetes in the northwest, representing Shaanxi Province in China. To address an existing research gap, we analyzed data from the CBMDE survey, focusing on individuals aged ≥50 years in northwest China. The present study was centered on a high-risk yet under-studied group – rural women over 50 years old – highlighting unique risk factors and evolving epidemiological patterns. Our findings contribute not only to the academic literature on MetS distribution but also provide practical guidance for designing targeted public health interventions and informing regional and national health policy.

Abbreviations: ANOVA, analysis of variance; CBMDE, community-based management of diabetes in the elderly; CI, confidence interval; FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol; IDF, International Diabetes Federation; IQR, interquartile range; ORs, odds ratios; MetS, metabolic syndrome; SD, standard deviation.

## 2 Methods

### 2.1 Study population

This was a cross-sectional epidemiology investigation based on community populations and is part of the CBMDE project in Xi'an. The CBMDE project is a prospective, community-based, multi-stage, stratified and cluster-sampled epidemiological and prospective cohort study that is focused on diabetes. Its aims were to select a representative sample of middle-aged and older adults (aged ≥50 years) with diabetes from both urban and rural communities in Xi'an and its surrounding areas for long-term follow-up and management. The goals were to investigate the risk factors and preventive strategies related to diabetes and other metabolic disorders in this population. The survey was conducted from June 2014 to September 2016, in order to determine the prevalence data of diabetes and MetS in northwest China, mainly the Shaanxi Province (17). This study was reviewed and approved by the Ethics Committee of Xijing Hospital (approval number 20130925-8). All participants signed informed consent before being included in the study.

### 2.2 Data collection

The definitions of urban, rural and suburban areas refers to the "Regulation on Classification of Urban and Rural Areas for Statistics" issued by the National Bureau of Statistics of China (18). The questionnaire was completed by study participants, assisted by an inquirer and included demographic data, current disease information, family history of disease and life-style information. The data collection was conducted as follows:

#### 2.2.1 Determination of the data acquisition areas

In the first stage, a selection of urban, suburban and rural areas was performed. Four urban districts, three suburban areas and two rural regions (one affluent and one economically disadvantaged) in Xi'an and its surrounding areas were selected. This stage was non-random. In the second stage specific communities and villages were selected. Within the selected urban, suburban and rural areas, seven communities and seven villages were chosen, including four urban communities, three suburban communities, one affluent large village and six smaller or less affluent villages. This stage was also non-random.

### 2.2.2 Data collection from the participants living in the areas determined in stage 1 and 2

In the third stage a stratified cluster sampling within communities or villages was conducted. In each selected community or village, stratification was carried out based on the local population distribution. Within each stratum, clusters (residential buildings or natural villages) were randomly selected using a simple random sampling method. The study population included individuals aged ≥50 years old.

### 2.2.3 Specific data collection regarding health status

Physical examinations included height (standing barefoot), weight, waist circumference (standing feet separated) and the circumference of the hip (at the level of the greatest protrusion of the buttocks, standing feet separated) were measured when the subjects wore underwear; the average blood pressure of 2 measurements taken from the right arm in a resting state was calculated. Venous blood was collected in 5 mL aliquots after the subjects had fasted overnight. Plasma concentrations of glucose and lipids were assessed on the same day at each sub-center using a standardized automated analyzer. The diagnostic criteria for MetS that originally followed the 2013 Chinese Diabetes Society criteria (19) were again analyzed in the present study according to the International Diabetes Federation (IDF) criteria (20): central obesity was defined as a circumference of the waist ≥80 cm for women and ≥90 cm for men. In addition, 2 of various criteria were taken into consideration including: (1) a triglyceride level ≥1.7 mmol/L or the participant was receiving specific treatment for this lipid abnormality; (2) a decrease in high-density lipoprotein cholesterol (HDL-C) concentrations: men a value <1.03 mmol/L, women a value <1.29 mmol/L, or given treatment; (3) raised systolic blood pressure ≥130 mmHg, diastolic blood pressure ≥85 mmHg or had received therapy for hypertension; (4) a fasting plasma glucose (FPG) concentration ≥5.6 mmol/L or the participant was diagnosed as having type 2 diabetes. Health status was not included as an inclusion criterion, as this was a cross-sectional study that aimed to estimate the prevalence of MetS in the general population. Applying health-related restrictions would have biased the results and affected the representativeness of the findings.

## 2.3 Statistical analyses

All data were independently entered by two researchers and verified for consistency. The final dataset was constructed using EpiData version 3.1 and statistical analyses were performed using SPSS version 18.0 (IBM Corp., Armonk, NY, USA). A two-sided $p$-value < 0.05 was considered to be statistically significant.

Descriptive statistics were used to summarize the characteristics of study participants. Categorical variables are expressed as frequencies and percentages, and continuous variables as the mean ± standard deviation (SD) or median with interquartile range (IQR), depending on the nature of the distribution. Group comparisons for categorical variables were conducted using the Chi-squared ($\chi^2$) test. For continuous variables, one-way analysis of variance (ANOVA) was applied when normality (Shapiro–Wilk test) and homogeneity of variance (Levene's test) assumptions were met. Non-parametric comparisons were performed using the Kruskal–Wallis test when these assumptions were violated.

To assess factors independently associated with the prevalence of MetS, multivariable logistic regression analysis was conducted. The dependent variable was the presence or absence of MetS (binary outcome). Independent variables were selected based on prior literature and biological plausibility, and included: age group (50–59, 60–69, ≥70 years); the place of residence (rural, urban, suburban); educational attainment (primary school or below, junior high school, high school or above); household income (≤¥10,000 [$ ≈ 1,400], ¥10,000–30,000 [$ ≈ 1,400–4,200], >¥30,000 [$ ≈ 4,200]/year); delayed menarche (yes/no); dietary pattern (meat-based, mixed, vegetable-based), salt intake (high, normal, low); type of meat consumed (fatty, mixed, lean); dietary control (yes/no); sleep duration (≤6 h, 6–8 h, >8 h); sedentary time (≤7 h/day, 7–9 h/day, >9 h/day); body weight change over the past year (increased, decreased, unchanged); and family history of diabetes, hypertension and dyslipidemia (all yes/no). Categorical variables were coded using dummy variables. Continuous metabolic parameters such as waist circumference and blood pressure, used to define MetS, were not included as predictors in the regression model. Associations were reported as odds ratios (ORs) with 95% confidence intervals (CIs) and Wald tests were used to evaluate statistical significance between individual predictors.

Missing data were excluded from the analysis if determined to be non-ignorable (e.g., lifestyle variables prone to recall bias). No data imputation was performed.

Sample size estimation was based on an assumed diabetes prevalence of 25%, with a 2.5% margin of error and 95% confidence level. Adjusting for an expected response rate of 85% and applying a design effect of 2.0 due to multistage sampling, the target sample size was 2,800. A total of 3,119 participants were ultimately enrolled. Given the higher-than-expected observed MetS prevalence (49.7% in females, 32.0% in males), the study was deemed adequately powered to detect significant associations for both the estimation and regression analyses.

# 3 Results

In the first stage of the study, 2 rural areas, 3 suburbs and 4 urban districts were selected. In the second stage, 7 representative rural villages and 7 communities were chosen from the areas mentioned above, including 1 large and 6 small-to-medium rural villages, and 3 suburban and 4 urban communities (Figure 1). In the third stage, the population was chosen using stratified random sampling by community, buildings and the living unit in each community or village. The response rate was 75.45% and 3,119 participants aged ≥50 years were selected from which 3,001 with complete data were finally included in the analyses. In total, 118 participants lacked key data on FPG, 2-h postprandial plasma glucose and glycated hemoglobin, and were excluded from further analyses.

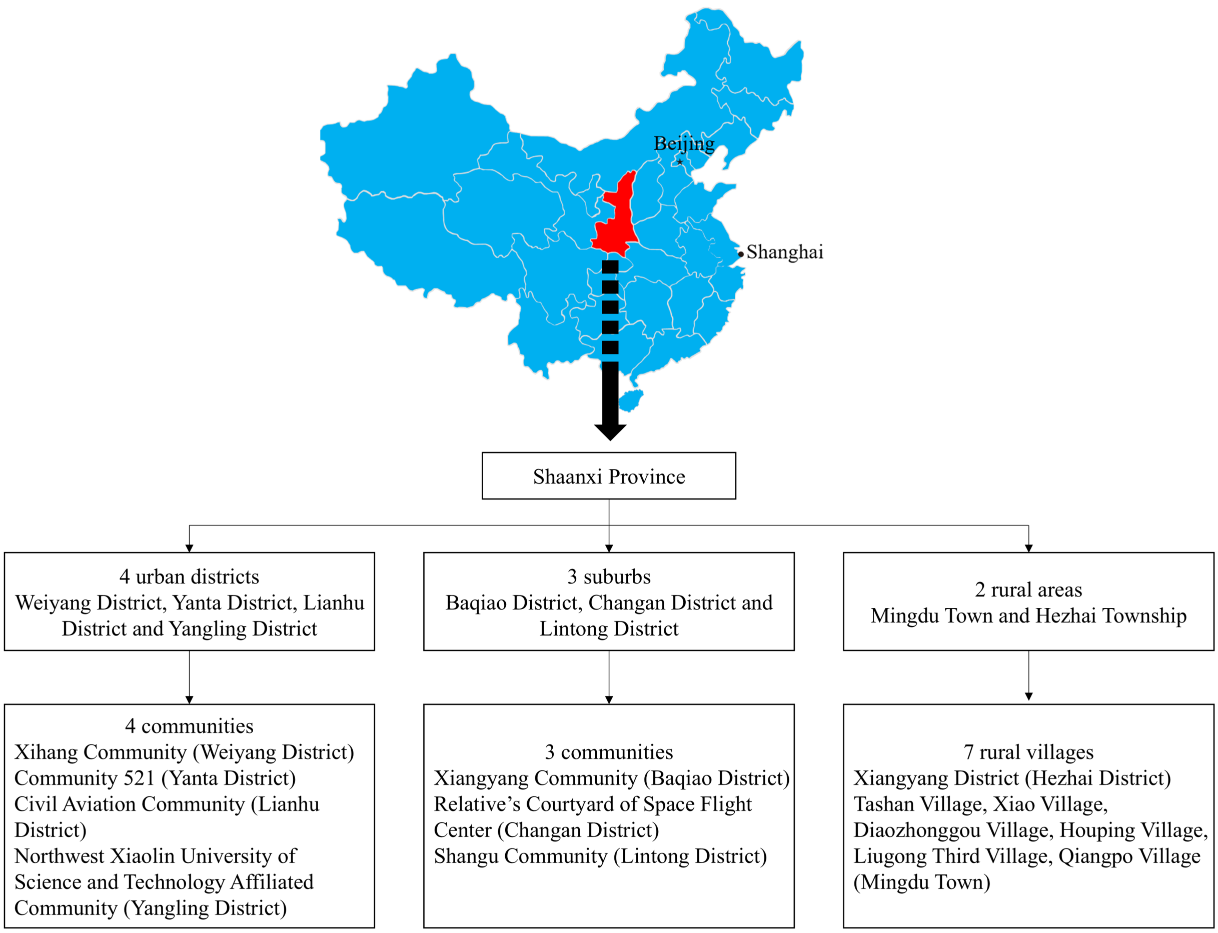


FIGURE 1
Study sampling procedure and location of Shaanxi province in mainland China.
Stage 1: Selection of urban, suburban and rural areas. A total of 4 urban districts, 3 suburban areas and 2 rural areas (including one affluent rural area and 1 underdeveloped rural area) were selected. Stage 2: Within the selected urban, suburban and rural areas, specific communities and villages were further selected. A total of 7 communities and 7 villages were included, consisting of 4 urban communities, 3 suburban communities, 1 affluent village (large village) and 6 underdeveloped villages (small to medium-sized villages).

## 3.1 General information about the study participants

The study involved a cohort of 3,001 participants, aged ≥50 years who had full physical examination and complete laboratory data, and was comprised of 1,915 females and 1,086 males (Table 1).

## 3.2 The prevalence of MetS according to gender

According to the diagnostic criteria of the IDF, the prevalence of MetS was greater in women aged ≥50 years than in men (49.7 ± 9.8% *vs.* 32.0 ± 9.0%, $p < 0.001$). Similarly, using IDF diagnostic criteria, the prevalence rate for MetS in females was greater than for men in the 50–59 years old group (39.9 ± 4.7% *vs.* 33.1 ± 10.3%, $p = 0.024$), the 60–69 years group (54.8 ± 5.2% *vs.* 29.5 ± 6.3%, $p < 0.001$) and the ≥70 years group (59.6 ± 7.0% *vs.* 35.5 ± 9.6%, $p < 0.001$). There was a difference in prevalence among female age groups ($p < 0.001$), which increased with age. There was also a difference for men aged 50–59 years, 60–69 years and ≥70 years ($p = 0.035$), but no significant increase in prevalence with age was found (Figure 2).

## 3.3 Regional differences in the prevalence of MetS in women aged ≥50 years

According to IDF criteria, MetS prevalence was greater in rural region females than in urban region and suburban region females 53.6% *vs.* 45.5 and 52.0%, ($p = 0.003$). The same trend was also found for the 50–59 and ≥70 year age groups. MetS prevalence increased with age in urban and suburban areas, but in rural areas this trend was only detected for ages up to 69 years, with, interestingly, less prevalence in over 70-year-old wives (Table 2).

Comparing the prevalence of single MetS components, central obesity and hypertension rates were highest in rural areas, but hyperglycemia and decreased HDL-C values were lowest. In urban females, hypertriglyceridemia occurred most frequently but the central obesity prevalence was lowest. Suburban females had the most decreased HDL-C values and highest prevalence of hyperglycemia, but the lowest hypertriglyceridemia and hypertension rates (Table 3).

TABLE 1 General clinical characteristics of the sample population.

| Index | Total $N$ = 3,001 | Women $N$ = 1,915 | Men $N$ = 1,086 | $p$-value |
|---|---|---|---|---|
| Age (years) | 62.8 ± 7.9 | 62.4 ± 7.6 | 63.5 ± 8.1 | <0.001 |
| Body mass index (kg/m²) | 25.0 ± 3.5 | 24.9 ± 3.7 | 25.1 ± 3.2 | 0.074 |
| Waist circumference (cm) | 87.3 ± 9.8 | 86.1 ± 9.7 | 89.5 ± 9.7 | <0.001 |
| Hip circumference (cm) | 97.5 ± 10.4 | 97.3 ± 11.6 | 97.7 ± 7.8 | 0.376 |
| Systolic blood pressure (mmHg) | 128.7 ± 18.6 | 128.7 ± 19.1 | 128.7 ± 17.9 | 0.098 |
| Diastolic blood pressure (mmHg) | 79.3 ± 10.6 | 78.6 ± 10.3 | 80.5 ± 11.0 | <0.001 |
| FPG (mmol/L) | 5.9 ± 1.9 | 5.8 ± 1.8 | 6.0 ± 2.0 | 0.029 |
| Blood triglycerides (mmol/L) | 1.8 ± 1.0 | 1.8 ± 1.0 | 1.7 ± 1.0 | 0.054 |
| Blood HDL-C (mmol/L) | 1.3 ± 0.4 | 1.4 ± 0.4 | 1.2 ± 0.3 | <0.001 |

Data are presented as the mean ± SD.
FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol.

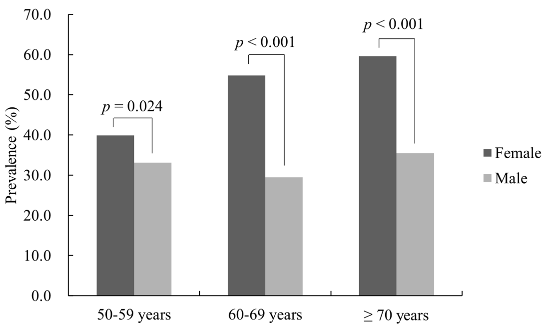


FIGURE 2
MetS prevalence in females and males aged ≥50 years stratified by age.

## 3.4 Demographic and lifestyle characteristics of females in different regions

The ratio of a low level of education plus a low family income of women aged ≥50 years living in a rural region was greater than for urban and suburban women (50.7% *vs.* 19.0 and 25.3% for low education level, 65.4% *vs.* 21.9 and 13.4% for low family income, $p < 0.001$). The rural population experienced delayed menarche and earlier menopausal ages compared to urban and suburban females (16.5 ± 2.2 *vs.* 14.9 ± 2.1 and 15.2 ± 2.0 for menarche age, $p < 0.001$; 48.5 ± 4.5 *vs.* 49.6 ± 3.9 and 49.1 ± 4.2 for menopause age, $p = 0.001$). The proportion of menarches occurring later was higher in rural women aged ≥50 years than in urban and suburban women (12.1% *vs.* 4.0 and 4.8%, respectively, $p < 0.001$).

Compared to suburban and urban women, rural women were more likely to have a diet mainly based on vegetables (86.2% in rural areas *vs.* 56.1% in urban areas and 56.6% in suburban areas, $p < 0.001$), meals containing high salt (26.1% in rural areas *vs.* 16.7% in urban areas and 18.7% in suburban areas, $p < 0.001$) and moderately fatty meat (64.7% in rural areas *vs.* 48.2% in urban areas and 41.2% in suburban areas, $p < 0.001$). However, only approximately 19.2% of rural women tried diet control compared to a greater proportion of urban and suburban women (45.0 and 40.3%, $p < 0.001$).

Women who live in rural regions exhibited different work and rest schedules, since they had more sleep time ($p < 0.001$), while the sedentary time which rural women aged ≥50 years spent was equivalent to that of urban women. Regarding weight, about 25.2% of rural women had gained weight in the past year before the investigation, which was essentially higher than for the 17.9% of suburban and 17.6% of urban females ($p = 0.009$).

Interestingly, in rural females aged ≥50 years the family history of type 2 diabetes (8.2% *vs.* 21.1 and 21.0%, $p < 0.001$), hypertension (34.7% *vs.* 46.9 and 45.4%, $p < 0.001$) and dyslipidemia (5.0% *vs.* 21.5 and 20.7%, $p < 0.001$) were all lower compared to urban and suburban females. Compared to those living in urban and suburban regions, rural women had a greater waist circumference (87.7 ± 8.9 *vs.* 84.1 ± 9.7 and 87.2 ± 10.1 cm, $p < 0.001$), systolic blood pressure (133.3 ± 21.6 *vs.* 130.2 ± 18.8 and 125.7 ± 17.7 mmHg, $p < 0.001$), diastolic blood pressure (82.2 ± 10.0 *vs.* 78.8 ± 10.6 and 77.0 ± 9.7 mmHg, $p < 0.001$), triglyceride level (1.9 ± 1.3 *vs.* 1.8 ± 0.9 and 1.7 ± 1.0, $p = 0.005$) and the lowest plasma glucose concentration (5.5 ± 1.9 *vs.* 5.9 ± 2.0 and 5.8 ± 1.5 mmol/L, $p = 0.001$), findings which are consistent with the data reported for the highest abdominal obesity, hypertension and hypertriglyceridemia prevalence (Table 4).

After comparative analysis, logistic regression was performed for the evaluation of possible risk factors (Table 5). Age, rural area, half-meat and half-vegetable dietary style, no diet control, weight increase in the past year and hypertension in the family history were found to be important risk factors for MetS.

# 4 Discussion

As shown in Table 5, our study revealed that age, rural area, half-meat and half-vegetable dietary style, diet control, weight increase in the past year and hypertension in the family history were important risk factors for MetS. These findings are consistent with those of previous studies (5, 21, 22). According to IDF criteria, MetS prevalence was greater in rural region females than in urban and suburban region females 53.6% *vs.* 45.5 and 52.0%, ($p = 0.003$) (Table 2). Comparing the prevalence of single MetS components, central obesity and hypertension rates were highest in rural areas, but hyperglycemia and decreased HDL-C values were lowest. In urban females, hypertriglyceridemia occurred most frequently but the central obesity prevalence was lowest.

TABLE 2 Prevalence of MetS in females over 50 stratified by age and the region of residence.

| Variable | Rural | | Urban | | Suburban | | *p*-value[†] |
|---|---|---|---|---|---|---|---|
| | *n*/*N* | % | *n*/*N* | % | *n*/*N* | % | |
| Total | 184/217 | 53.6 | 343/754 | 45.5 | 425/818 | 52.0 | 0.003 |
| 50–59 years | 65/139 | 46.8 | 127/337 | 37.7 | 113/288 | 39.2 | 0.045 |
| 60–69 years | 84/140 | 60.0 | 150/294 | 51.0 | 209/375 | 55.7 | 0.096 |
| ≥70 years | 35/64 | 54.7 | 66/123 | 53.7 | 103/155 | 66.5 | 0.005 |
| *p*-value[‡] | | <0.004 | | <0.001 | | <0.001 | |

[†]Represents the comparison of prevalence in the same age group in different areas; [‡]Represents the comparison of prevalence in different age groups in the same area.
HDL-C, high-density lipoprotein cholesterol; MetS, metabolic syndrome.

TABLE 3 Frequency of MetS components in females aged ≥50 years stratified by their region of residence.

| Component | Rural | | Urban | | Suburban | | *p*-value | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *N* = 343 | | *N* = 754 | | *N* = 818 | | | | | |
| | *n* | % | *n* | % | *n* | % | Overall | Rural *vs.* urban | Rural *vs.* suburban | Urban *vs.* suburban |
| Central obesity | 289 | 84.8 | 520 | 69.5 | 653 | 80.8 | <0.001 | <0.001 | 0.022 | <0.001 |
| Hypertriglyceridemia | 166 | 48.4 | 372 | 49.3 | 343 | 41.9 | <0.001 | 0.752 | 0.003 | <0.001 |
| Decreased HDL-C level | 113 | 32.9 | 324 | 43.0 | 375 | 45.8 | <0.001 | <0.001 | <0.001 | 0.168 |
| Hypertension | 234 | 68.4 | 441 | 58.5 | 448 | 54.8 | <0.001 | <0.001 | <0.001 | 0.078 |
| Hyperglycemia | 91 | 26.5 | 275 | 36.5 | 343 | 41.9 | <0.001 | <0.001 | <0.001 | 0.009 |

HDL-C, high-density lipoprotein cholesterol; MetS, metabolic syndrome.

Suburban females had the most decreased HDL-C values and highest prevalence of hyperglycemia, but the lowest hypertriglyceridemia and hypertension rates (Table 3). Historically, most Chinese studies have previously reported higher MetS prevalence in urban residents than in rural residents (4, 23–26). However, the results of a 2013–2014 nationwide MetS epidemiology study and a more recent Taiwanese study showed higher prevalence of MetS in rural than in urban populations (27, 28), which is in agreement with the present findings. Since the prevalence of MetS in the present study was influenced by the degree of urbanization, with rural and suburban regions experiencing significant increases, area specific factors like rapid economic development, dietary transitions and lifestyle modifications might be the reasons. With economic development, the food supplied to rural people became apparently different from traditional food, such as animal fat, simple carbohydrates (particularly fructose) and energy-dense foods (e.g., sugary drinks, biscuits) (29–31).

However, the findings that a half-meat, half-vegetable dietary pattern and dietary control were risk factors for MetS, remain difficult fully to explain. Previous studies have suggested that both of these factors may help prevent or improve MetS, but this hypothesis requires verification in prospective or retrospective population-based studies. Given that the present study was cross-sectional, it could not confirm any causal or temporal relationships. It is possible that participants with MetS began dietary control and adjusted their diet composition after being diagnosed, which may have led to these factors appearing as potential risk factors in the cross-sectional analysis. Unfortunately, this study did not collect information on the timing of dietary adjustments or when individuals started dietary control, preventing us from performing further analyses to clarify the issue. Another factor might be that with economic development the awareness of health management became higher, which might have resulted in stabilization and a gradual decline of obesity and MetS prevalence in Chinese urban areas (32). Therefore, the higher prevalence of MetS in rural women may be a historical phenomenon in the economic developing process, which might disappear when the economy and awareness of health are better developed.

The influence of economic development on dietary shifts and health awareness is important since there is epidemiological evidence of a link between income and MetS (33–35). However, in the regression analysis of the present study there was no significant correlation between family income and MetS. An explanation might be that during the development, especially of suburban areas, affordable fast food chain shops were established rapidly and the shift from traditional meals to fast food was income, independently taking place and therefore not an individual but rather a regional factor. Hypertension in the family history may suggest genetic factors for MetS (21, 36–38) and it is proposed that individuals with hypertension in the family history should focus on timely lifestyle changes to reduce the MetS risk, especially when weight increase occurs rapidly. However, these factors might mainly play a role and be regulated by health awareness, which might be attributed to the educational level, which is higher in urban adults compared to those in rural habitats.

Activity habits and awareness of health management might be improved as advocated by Japanese and Mexican researchers (31, 39). Also, in China, prevention-control measures have been established in the past 10 years but need further improvements (27, 30). It is noteworthy that there have been recent studies about successful public health interventions in Africa that reduced the incidence of MetS through community-based lifestyle interventions (40–42).

The limitations of the present study were that for certain small effect sizes or in analyses involving specific subgroups with limited

TABLE 4 Characteristics of females aged ≥50 years from different regions of residence.

| Variable | Rural | Urban | Suburban | *p*-value | | | |
|---|---|---|---|---|---|---|---|
| Number | 343 | 754 | 818 | Overall | Rural *vs.* urban | Rural *vs.* suburban | Urban *vs.* suburban |
| Age, years | 62.4 ± 7.9 | 61.9 ± 7.5 | 63.1 ± 7.7 | 0.008 | 0.305 | 0.164 | 0.002 |
| Education level, *n* (%) | *n* = 341 | *n* = 748 | *n* = 813 | | | | |
| Elementary school or below | 173 (50.7) | 142 (19.0) | 206 (25.3) | <0.001 | <0.001 | <0.001 | 0.003 |
| Secondary school | 165 (48.4) | 493 (65.9) | 534 (65.7) | <0.001 | <0.001 | <0.001 | 0.957 |
| College or above | 3 (0.9) | 113 (15.1) | 73 (9.0) | <0.001 | <0.001 | <0.001 | <0.001 |
| Yearly family income, *n* (%) | *n* = 332 | *n* = 684 | *n* = 729 | | | | |
| ≤¥10,000 (≤$1,400$) | 217 (65.4) | 150 (21.9) | 98 (13.4) | <0.001 | <0.001 | <0.001 | <0.001 |
| ¥10,000–30,000 ($1,400–4,200$) | 98 (29.5) | 192 (28.1) | 297 (40.7) | <0.001 | 0.657 | <0.001 | <0.001 |
| ≥¥30,000 (≥$4,200$) | 17 (5.1) | 342 (50.0) | 334 (45.8) | <0.001 | <0.001 | < 0.001 | 0.122 |
| Age of menarche, years | 16.5 ± 2.2 | 14.9 ± 2.1 | 15.2 ± 2.0 | <0.001 | <0.001 | <0.001 | 0.006 |
| Menstruation delay (>18 years old), *n* (%) | 41/339 (12.1) | 29/730 (4.0) | 38/796 (4.8) | <0.001 | <0.001 | <0.001 | 0.456 |
| Age of menopause, years | 48.5 ± 4.5 | 49.6 ± 3.9 | 49.1 ± 4.2 | 0.001 | <0.001 | 0.032 | 0.030 |
| Menopause, *n* (%) | 329/343 (95.9) | 714/754 (94.7) | 781/818 (95.5) | 0.617 | | | |
| Premature menopause (≤40 years old), *n* (%) | 22/324 (6.8) | 26/688 (3.8) | 33/755 (4.4) | 0.095 | | | |
| Dietary style, *n* (%) | *n* = 333 | *n* = 742 | *n* = 738 | | | | |
| Meat-based | 5 (1.5) | 20 (2.7) | 19 (2.6) | 0.512 | | | |
| Half and half | 41 (12.3) | 306 (41.2) | 301 (40.8) | <0.001 | <0.001 | <0.001 | 0.874 |
| Vegetable-based | 287 (86.2) | 416 (56.1) | 418 (56.6) | <0.001 | <0.001 | <0.001 | 0.834 |
| Dietary salt consumption, *n* (%) | *n* = 333 | *n* = 742 | *n* = 738 | | | | |
| High-salt | 87 (26.1) | 124 (16.7) | 138 (18.7) | 0.001 | <0.001 | 0.006 | 0.340 |
| Normal-salt | 145 (43.5) | 364 (49.1) | 304 (41.2) | 0.004 | 0.064 | 0.504 | 0.001 |
| Low-salt | 101 (30.3) | 254 (34.2) | 296 (40.1) | 0.004 | 0.233 | 0.003 | 0.021 |
| Dietary meat consumption, *n* (%) | *n* = 323 | *n* = 734 | *n* = 728 | | | | |
| Fatty meats | 6 (1.9) | 19 (2.6) | 12 (1.6) | 0.451 | | | |
| Moderately fatty meat | 209 (64.7) | 354 (48.2) | 300 (41.2) | <0.001 | <0.001 | <0.001 | 0.007 |
| Lean meats | 108 (33.4) | 361 (49.2) | 416 (57.1) | <0.001 | <0.001 | <0.001 | 0.002 |
| Dietary control, *n* (%) | *n* = 333 | *n* = 742 | *n* = 734 | | | | |
| Ever | 64 (19.2) | 334 (45.0) | 296 (40.3) | <0.001 | <0.001 | <0.001 | 0.074 |
| Never | 269 (80.8) | 408 (55.0) | 438 (59.7) | | | | |
| Sleep duration, h | 8.5 ± 1.2 | 8.2 ± 3.0 | 7.7 ± 1.7 | <0.001 | 0.102 | <0.001 | <0.001 |
| Sleep duration, *n* (%) | *n* = 343 | *n* = 754 | *n* = 818 | | | | |
| ≤6 h | 27 (7.9) | 94 (12.5) | 190 (23.2) | <0.001 | 0.029 | <0.001 | <0.001 |
| 6–8 h | 135 (39.4) | 399 (52.9) | 394 (48.2) | <0.001 | <0.001 | 0.007 | 0.062 |
| >8 h | 181 (52.8) | 261 (34.6) | 234 (28.6) | <0.001 | <0.001 | <0.001 | 0.011 |
| Sedentary time, h | 8.5 ± 3.9 | 8.7 ± 4.1 | 10.0 ± 4.8 | <0.001 | 0.700 | <0.001 | <0.001 |
| Sedentary time, *n* (%) | *n* = 332 | *n* = 740 | *n* = 757 | | | | |
| ≤7 h/day | 140 (42.2) | 305 (41.2) | 243 (32.1) | <0.001 | 0.789 | 0.002 | <0.001 |
| 7–9 h/day | 45 (13.6) | 105 (14.2) | 57 (7.5) | <0.001 | 0.849 | 0.002 | <0.001 |
| >9 h/day | 147 (44.3) | 330 (44.6) | 457 (60.4) | <0.001 | 0.947 | <0.001 | <0.001 |
| Weigh change in past year, *n* (%) | *n* = 330 | *n* = 738 | *n* = 741 | | | | |
| Increase | 83 (25.2) | 130 (17.6) | 133 (17.9) | 0.009 | 0.005 | 0.008 | 0.892 |
| Decrease | 58 (17.6) | 95 (12.9) | 133 (17.9) | 0.017 | 0.047 | 0.931 | 0.008 |
| No change | 189 (57.3) | 513 (69.5) | 475 (64.1) | <0.001 | <0.001 | 0.035 | 0.027 |

*(Continued)*

TABLE 4 (Continued)

| Variable | Rural | Urban | Suburban | *p*-value | | | |
|---|---|---|---|---|---|---|---|
| Number | 343 | 754 | 818 | Overall | Rural *vs.* urban | Rural *vs.* suburban | Urban *vs.* suburban |
| Family history of diabetes, *n* (%) | 28/343 (8.2) | 159/754 (21.1) | 172/818 (21.0) | <0.001 | <0.001 | <0.001 | 1.000 |
| Family history of hypertension, *n* (%) | 119/343 (34.7) | 354/754 (46.9) | 371/818 (45.4) | <0.001 | <0.001 | 0.001 | 0.544 |
| Family history of dyslipidemia, *n* (%) | 17/343 (5.0) | 162/754 (21.5) | 169/818 (20.7) | <0.001 | <0.001 | <0.001 | 0.710 |
| Waist circumference, cm | 87.7 ± 8.9 | 84.1 ± 9.7 | 87.2 ± 10.1 | <0.001 | <0.001 | 0.460 | <0.001 |
| Systolic blood pressure, mmHg | 133.3 ± 21.6 | 130.2 ± 18.8 | 125.7 ± 17.7 | <0.001 | 0.022 | <0.001 | <0.001 |
| Diastolic blood pressure, mmHg | 82.2 ± 10.0 | 78.8 ± 10.6 | 77.0 ± 9.7 | <0.001 | <0.001 | <0.001 | <0.001 |
| Serum triglycerides, mmol/L | 1.9 ± 1.3 | 1.8 ± 0.9 | 1.7 ± 1.0 | 0.005 | 1.146 | 0.003 | 0.032 |
| Serum HDL-C, mmol/L | 1.4 ± 0.3 | 1.4 ± 0.3 | 1.4 ± 0.5 | 0.125 | | | |
| FPG, mmol/L | 5.5 ± 1.9 | 5.9 ± 2.0 | 5.8 ± 1.5 | 0.001 | 0.001 | 0.001 | 0.360 |

Data are presented as the mean ± SD or *n* (%).
FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol; MetS, metabolic syndrome.

TABLE 5 **Results of logistic regression analysis.**

| IDF | | | | | |
|---|---|---|---|---|---|
| Variable | Category | Ref. | OR | 95% CI | *p*-value |
| Age (years) | 50–59 | 1.000 | | | |
| | 60–69 | | 1.831 | 1.444–2.323 | <0.001 |
| | >70 | | 2.454 | 1.792–3.362 | <0.001 |
| Location | Urban | 1.000 | | | |
| | Rural | | 1.528 | 1.090–2.142 | 0.014 |
| | Suburban | | 1.092 | 0.859–1.387 | 0.473 |
| Education level | College and above | 1.000 | | | |
| | Middle school | | 1.306 | 0.909–1.876 | 0.149 |
| | Elementary school and below | | 1.425 | 0.934–2.175 | 0.100 |
| Family income | >¥30,000 (≥$4,200)/year | 1.000 | | | |
| | ¥10,000–30,000 ($1,400–4,200)/year | | 1.122 | 0.871–1.447 | 0.372 |
| | ≤¥10,000 (≤$1,400)/year | | 1.105 | 0.816–1.495 | 0.520 |
| Menstruation delay | No | 1.000 | | | |
| | Yes | | 1.042 | 0.665–1.631 | 0.858 |
| Dietary style | Meat-based | | 1.822 | 0.909–3.649 | 0.091 |
| | Half and half | | 1.400 | 1.107–1.770 | 0.005 |
| | Vegetable-based | 1.000 | | | |
| Dietary salt consumption | High-salt | | 1.064 | 0.784–1.445 | 0.690 |
| | Normal-salt | | 0.866 | 0.684–1.096 | 0.231 |
| | Low-salt | 1.000 | | | |
| Dietary meat consumption | Fatty meats | | 1.141 | 0.550–2.368 | 0.723 |
| | Moderately fatty meat | | 0.878 | 0.703–1.096 | 0.250 |
| | Lean meats | 1.000 | | | |
| Diet control | No | 1.000 | | | |
| | Yes | | 1.555 | 1.242–1.947 | <0.001 |
| Sleep duration | ≤6 h | 1.000 | | | |
| | 6–8 h | | 1.198 | 0.890–1.613 | 0.234 |
| | >8 h | | 1.303 | 0.943–1.801 | 0.109 |

*(Continued)*

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TABLE 5 (Continued)

| IDF | | | | | |
|---|---|---|---|---|---|
| Variable | Category | Ref. | OR | 95% CI | *p*-value |
| Sedentary time | ≤7 h/day | 1.000 | | | |
| | 7–9 h/day | | 1.043 | 0.732–1.486 | 0.815 |
| | >9 h/day | | 1.112 | 0.883–1.401 | 0.368 |
| Weight change in the past year | No change | 1.000 | | | |
| | Increase | | 1.725 | 1.312–2.268 | <0.001 |
| | Decrease | | 1.169 | 0.873–1.566 | 0.293 |
| Family history of diabetes | No | 1.000 | | | |
| | Yes | | 1.117 | 0.847–1.473 | 0.434 |
| Family history of hypertension | No | 1.000 | | | |
| | Yes | | 1.854 | 1.483–2.319 | <0.001 |
| Family history of dyslipidemia | No | 1.000 | | | |
| | Yes | | 1.060 | 0.794–1.417 | 0.691 |

sample sizes (e.g., women of a specific age group in a particular region), non-significant results may be influenced by limited statistical power. As we did not exclude participants who had already initiated dietary management due to pre-existing chronic conditions, it was found during data analysis that the prevalence of MetS was actually higher among individuals who reported engaging in dietary management compared to those who did not. Moreover, dietary management emerged as a significant risk factor for MetS in the regression analysis. This finding is counterintuitive and prompted further reflection. One plausible explanation is that participants may have adopted dietary management in response to a prior diagnosis of a chronic disease. Given the cross-sectional nature of our study, it was not possible to establish the temporal sequence of exposure and outcome, which could have led to this unexpected association. The root of this limitation lies in the lack of detailed survey items capturing the reasons for dietary management. As a result, we were unable to exclude or appropriately classify participants who initiated dietary management due to prior health conditions during analysis, which is a methodological shortcoming. Furthermore, excluding all participants with chronic diseases who reported dietary management could substantially reduce the sample size and affect the representativeness of our findings, as the proportion of individuals aged ≥50 years without chronic diseases was relatively low. In future studies with similar designs, we plan to incorporate specific questions regarding the motivation for dietary management (e.g., whether it was initiated due to a diagnosed illness) to allow more accurate data classification and interpretation. We also intend to develop analytical strategies that better elucidate the relationship between dietary management and the occurrence of MetS.

# 5 Conclusion

The present study highlights a significantly higher prevalence of MetS among rural women aged ≥50 years in northwest China compared to their urban and suburban counterparts. Key risk factors identified include an older age, rural residence, dietary habits and weight gain in the past year. The elevated MetS rates among rural women appear to be linked to distinct socioeconomic and lifestyle characteristics, including limited health literacy and reduced engagement in dietary control. These findings emphasize the urgent need for region-specific public health strategies targeting metabolic health, especially among aging rural female populations. Addressing health disparities through education, early screening and lifestyle interventions will be crucial for mitigating MetS-related risks and promoting equitable health outcomes across diverse populations in China.

# Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

# Ethics statement

The studies involving humans were approved by the Ethics Committee of Xijing Hospital. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

# Author contributions

YJ: Conceptualization, Data curation, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. CZ: Data curation, Investigation, Visualization, Writing – review & editing. JM: Conceptualization, Data curation, Formal analysis, Investigation, Visualization, Writing – review & editing. SX: Conceptualization, Data curation, Formal analysis, Investigation, Visualization, Writing – review & editing. YW: Conceptualization, Visualization, Writing – review & editing. XY:

Conceptualization, Visualization, Writing – review & editing. AJ: Data curation, Investigation, Visualization, Writing – review & editing. HL: Data curation, Investigation, Visualization, Writing – review & editing. JS: Data curation, Investigation, Visualization, Writing – review & editing. JQ: Data curation, Investigation, Visualization, Writing – review & editing. WL: Data curation, Investigation, Visualization, Writing – review & editing. HZ: Data curation, Investigation, Visualization, Writing – review & editing. XZ: Data curation, Investigation, Visualization, Writing – review & editing. XX: Conceptualization, Funding acquisition, Project administration, Supervision, Visualization, Writing – review & editing. QJ: Conceptualization, Funding acquisition, Project administration, Supervision, Visualization, Writing – review & editing.

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## Conflict of interest

JQ and WL were employed by Staff Hospital of Shaanxi Blower (Group) Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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# Exploring the mediating role of serum vitamin D in the link between dietary live microbes intake and obesity: a cross-sectional real-world study

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**Background:** Existing research results suggest a correlation between body mass index (BMI) and serum vitamin D levels, as well as the intake of live microbes from dietary sources. However, it is essential to further investigate whether serum vitamin D could serve as a mediator in the relationship between the consumption of dietary live microbes and obesity, as this connection remains to be elucidated.

**Methods:** We analyzed data from 18,099 participants in the 2007–2018 National Health and Nutrition Examination Survey (NHANES), focusing on obesity [assessed via BMI and waist circumference (WC)], serum vitamin D levels, and the dietary intake of live microbes (evaluated both as a continuous variable and a three-level categorical variable). A composite category "MedHi" was used to reflect the intake of foods containing medium ($10^4$–$10^7$ colony-forming units (CFU/g)) or high (>$10^7$ CFU/g) levels of live microbes. Mediation analysis was conducted to explore how serum vitamin D potentially mediates the relationship between the dietary intake of live microbes and obesity.

**Results:** After adjusting for potential confounding factors, it was found that both vitamin D and the MedHi consumption were strongly and negatively associated with obesity. Mediation analysis revealed that serum vitamin D mediated the relationship between the dietary intake of live microbes and BMI, WC, obesity, and abdominal obesity with mediated proportions of 14.6, 12.5, 13.0, and 12.5%, respectively.

**Conclusion:** The positive association between the dietary intake of live microbes and obesity risk is partly mediated by serum vitamin D. Foods with higher microbial concentrations could be beneficial.

KEYWORDS

live microbes intake, NHANES, vitamin D, obesity, mediation analysis

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# 1 Introduction

Obesity, traditionally defined as a body mass index (BMI) ≥30 kg/m$^2$, has experienced a steady annual increase in recent years (1). This condition is crucially linked to a higher incidence of cardiovascular, digestive, respiratory, nervous, musculoskeletal, and infectious diseases (2). Moreover, compared with individuals with a normal weight, those with obesity are at a significantly greater risk of developing multiple diseases. In summary, the escalating prevalence of obesity and the consequent increase in disease burden pose critical challenges that urgently require attention.

Generally, overweight and obese individuals have three clinical weight loss options: (a) lifestyle changes (diet, exercise, and behavioral therapy), (b) pharmacotherapy, and (c) bariatric surgery (3). Previous research has shown that incorporating probiotics can help reduce the obesity index (4). Interestingly, an association has been observed between the consumption of foods rich in live microbes and lower measures of BMI and WC (5). Additionally, observational studies have linked low vitamin D levels with obesity (6, 7). Experimental research has further demonstrated that low vitamin D may contribute to obesity by affecting adipose tissue differentiation and growth through the regulation of gene expression or the modulation of parathyroid hormone, calcium, and leptin levels (8). Some findings suggest a relationship between vitamin D status and the composition and diversity of the gut microbiota (9).

Vitamin D, a pleiotropic steroid hormone, plays a crucial role in regulating calcium homeostasis and bone mineralization. Recent research has broadened our understanding of its functions, linking vitamin D to various conditions such as obesity, diabetes (DM), cardiovascular diseases (CVD), immune regulation, and cancer (10–12). While there is no consensus on the optimal levels of 25-hydroxyvitamin D in serum, most experts define vitamin D deficiency as a level below 20 ng/mL (50 nmol/L) (13). Causes of vitamin D deficiency include reduced skin synthesis, impaired absorption, and both acquired and heritable disorders affecting vitamin D metabolism and responsiveness (14).

To investigate the potential relationships among dietary intake of live microbes, serum vitamin D levels, and obesity, we conducted a comprehensive analysis using data from a nationally representative sample of the U.S. population. Multiple statistical approaches were employed, including regression and mediation analyses, to assess both direct and indirect associations. Specifically, we explored whether serum vitamin D levels could serve as a mediating factor in the relationship between live microbe intake and obesity outcomes. A conceptual framework illustrating this hypothesized mediation pathway is presented in Figure 1.

**Abbreviations:** NHANES, National Health and Nutrition Examination Survey; BMI, Body mass index; WC, Waist circumference; CFU, colony-forming units; GLM, Generalized linear model; RCS, Restricted cubic spline; NCHS, National Center for Health Statistics; USDA, US Department of Agriculture; PFP, Pentafluorophenyl; TC, Total cholesterol; TG, Triglycerides; UA, Uric acid; HbA1c, Glycosylated hemoglobin; FPG, Fasting plasma glucose; CVD, Cardiovascular disease; CHF, Congestive heart failure; CHD, Coronary heart disease; PIR, Poverty income ratio; SCFAs, Short-chain fatty acids; VIFs, Variance inflation factors.

# 2 Methods

## 2.1 Study design and participants

The study utilized participants from the National Health and Nutrition Examination Survey (NHANES) program,[1] a series of biennial cross-sectional health surveys conducted among the general U.S. population since 1999. We selected NHANES because it provides nationally representative, population-based data on dietary intake, biochemical indicators, and anthropometric measures, with rigorous quality control and standardized data collection protocols. This makes NHANES highly suitable for examining the complex relationships between nutrition, biomarkers (such as vitamin D), and obesity outcomes in a real-world context. These surveys gather comprehensive data on nutritional intake, health behaviors, and medical conditions. Trained interviewers performed in-home interviews, collecting detailed demographic, dietary, socioeconomic, and health-related information using standardized questionnaires (15). Physical examinations were conducted at a mobile examination center, as described in the NHANES documentation. We included data from six cycles spanning from 2007 to 2018. We chose this period because it ensured consistent measurement of serum vitamin D using liquid chromatography–tandem mass spectrometry (LC-MS/MS) and provided comprehensive and comparable data on dietary intake, anthropometry, and relevant covariates. All participants provided written informed consent, and the National Center for Health Statistics (NCHS) Research Ethics Review Board approved the survey protocol. As this study constituted a secondary analysis of deidentified data, it did not require additional institutional review board approval.

## 2.2 Study population

We restricted our study sample to adults aged ≥20 years to ensure comparability with previous research on obesity and vitamin D status in adult populations. Pregnant participants were excluded due to altered vitamin D metabolism and body composition during pregnancy, which could confound the analysis. Specifically, individuals with outlier values in BMI and WC were identified through distributional diagnostics and excluded from the final analysis. Participants with missing data on key exposure, mediator, or outcome variables were excluded to maintain the integrity of the mediation analysis. Participants with extreme outlier values in the exposure (MedHi), mediator (serum vitamin D), and outcome variables (BMI and WC) were excluded based on visual inspection of their distributions and standardized thresholds. Our final analytical sample comprised 18,099 participants. The inclusion and exclusion criteria are summarized in Figure 2.

## 2.3 Dietary intakes and live microbial category

Dietary intake data were obtained by comparing the 24-h dietary recall with the USDA Food and Nutrient Database. Marco et al. (16)

1 http://www.cdc.gov/nchs/nhanes/

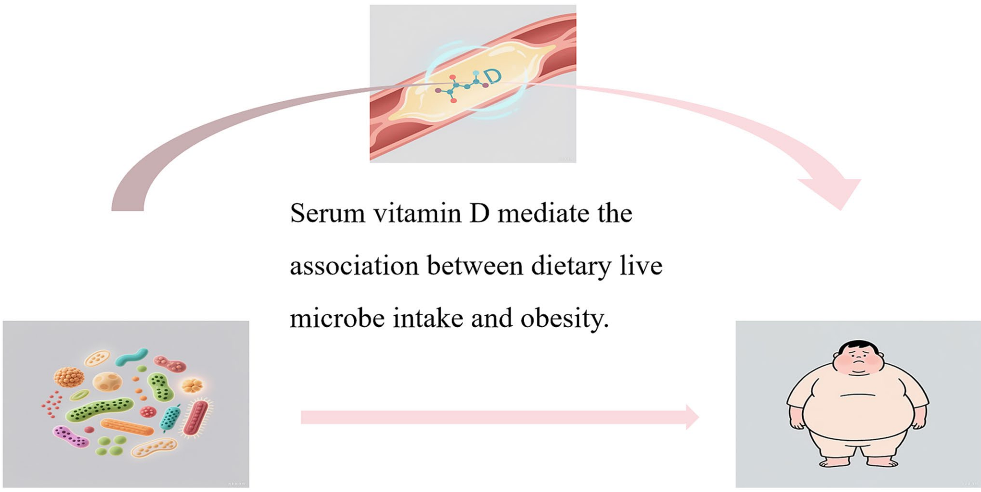


FIGURE 1
Hypothetical conceptual framework diagram.

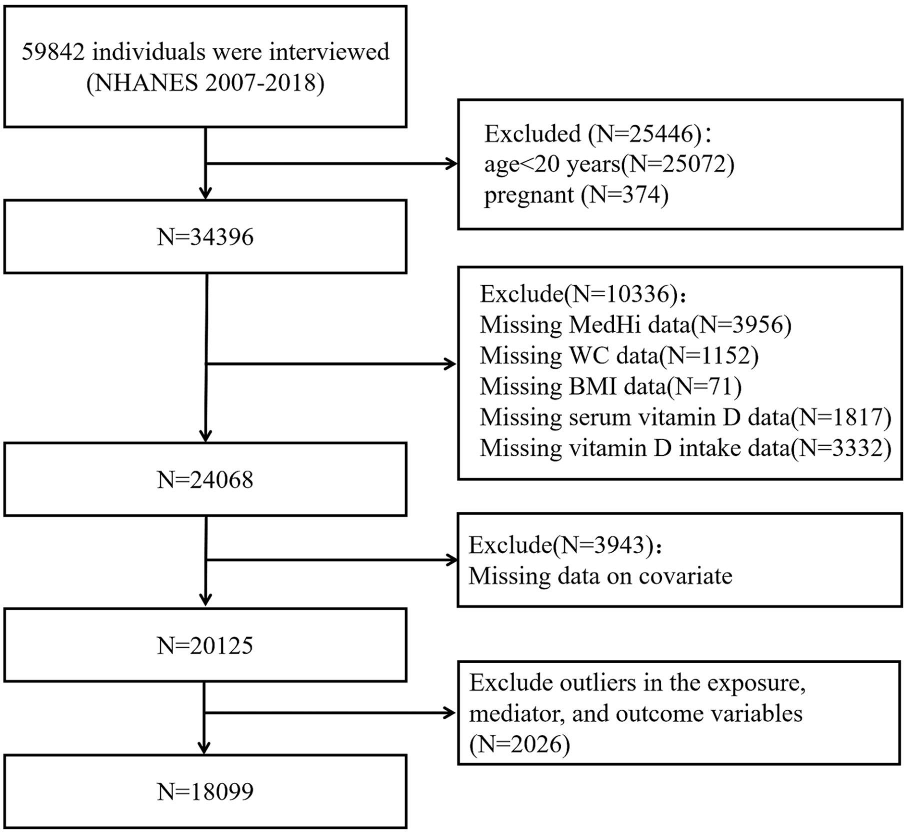


FIGURE 2
Study flowchart of the participants.

developed a method to estimate live microbial content in 9,388 food codes from NHANES, classifying foods into three categories: low ($<10^4$ CFU/g), medium ($10^4$–$10^7$ CFU/g), and high ($>10^7$ CFU/g) microbial levels. According to the classification system developed by Marco et al. (16), fermented dairy products comprised the majority of foods assigned to the high microbial (Hi) category. Specifically, yogurts and other cultured milks were typically classified as Hi unless consumed as a minor ingredient in composite dishes. Most cheeses, including fresh and soft varieties, were also assigned to the Hi category, with exceptions for long-aged cheeses (e.g., Parmesan), processed cheeses (e.g., American cheese), and cheeses in cooked items such as pizza. Cheese-containing sandwiches were classified as Hi only if they contained non-processed cheese and were not heated before consumption. These classification criteria were used to estimate the microbial exposure for each food item in NHANES dietary recalls.

A composite category, "MedHi," was created to represent individuals consuming foods from either the medium or high microbial content groups. This classification was based on a literature review and expert consensus, considering microbial viability after food processing.

Participants were then grouped using two approaches. First, based on MedHi intake, they were categorized into G1 (no MedHi intake), G2 (intake >0 but < median), and G3 (intake ≥ median). Second, based on overall dietary microbial exposure, participants were grouped as low (only Lo-category foods), moderate (Med-category but no Hi-category foods), or high (any Hi-category foods). These groupings were used in both continuous and categorical analyses.

## 2.4 Obesity

Obesity was defined as BMI ≥30 kg/m$^2$ and abdominal obesity as WC >102 cm in men and >88 cm in women based on World Health Organization (WHO) criteria (17). BMI was calculated as weight (kg) divided by height (m$^2$).

Anthropometric data, such as height, weight, and WC, were obtained by trained technicians following standardized NHANES protocols. Although these measurements are considered highly reliable, we did not apply formal corrections for measurement error. All analyses assume non-differential error across exposure groups.

## 2.5 Measurement of vitamin D serum levels

The total serum vitamin D levels were measured using ultra-high-performance liquid chromatography–tandem mass spectrometry. The analytes were separated using either a pentafluorophenyl (PFP) column (Hypersil GOLD PFP, 2.1 mm × 100 mm, 1.9 μm) from Thermo Scientific (Waltham, MA, United States) or a Kinetex PFP column (2.1 mm × 100 mm, 1.7 μm) from Phenomenex (Torrance, CA, United States). For a comprehensive description of the methodology, please refer to the CDC's analytical notes available at www.cdc.gov/nchs/nhanes/vitamind/analyticalnote.aspx or www.cdc.gov/nchs/data/nhanes/nhanes_05_06/vid_d.pdf (18). According to the Endocrine Society Clinical Practice Guidelines, vitamin D status was categorized into three groups: deficiency (<49.9 nmol/L; to convert from nmol/L to ng/mL, divided by 2.5), insufficient (50.0–74.9 nmol/L), and sufficient (≥75.0 nmol/L) (13).

## 2.6 Covariates

Potential confounders were evaluated as covariates. Questionnaires collected information on age, sex, race (Non-Hispanic White, Non-Hispanic Black, Mexican-American, other Hispanic, or other race), educational level (less than high school, high school or equivalent, college or above), family income-to-poverty ratio (PIR) (<1.3, 1.3–3.5, or >3.5), smoking status (never smoker, former smoker, or current smoker), and leisure-time physical activity (inactive, moderately active, or vigorously active). Drinking status was categorized into four groups following prior NHANES-based studies (19): never (fewer than 12 drinks in a lifetime), former (no drinking in the past year but ≥12 drinks previously), light (up to 1 drink/day for women or 2 for men), and heavy (more than 1 drink/day for women or 2 for men). Laboratory analysis covariates included serum total cholesterol (TC), triglycerides (TG), serum uric acid (UA), and glycosylated hemoglobin (HbA1c). Hypertension was defined based on previous NHANES research (20) as any of the following: self-reported physician diagnosis, current use of antihypertensive medication, systolic blood pressure ≥140 mmHg, or diastolic blood pressure ≥90 mmHg. DM status was defined according to prior NHANES research (21) as either a self-reported physician diagnosis or current use of insulin or oral hypoglycemic agents. CVD was defined based on self-reported history of coronary heart disease, angina, myocardial infarction, or stroke, following previous studies using NHANES data (22). The participants were asked, "Has a doctor or other health professional ever told you that you have congestive heart failure (CHF)/coronary heart disease (CHD)/angina/heart attack/stroke?" Participants who answered "yes" to any of the above questions were considered patients with CVD. Daily dietary variables assessed included dietary vitamin D intake, total energy, protein, carbohydrates, total sugars, and total fat.

## 2.7 Statistical analyses

As the microbial intake variable was derived from the first 24-h dietary recall only, we used the corresponding Day 1 dietary weights (WTDRD1), in accordance with NHANES analytic guidelines. Continuous variables are presented as the mean (standard deviation) or median (interquartile range), while categorical variables are presented as a number (percentages).

To facilitate the analysis, the dietary intake of MedHi underwent $\log_{10}$-transformation after adding 0.1 g and was then analyzed as a continuous variable. For log-transformed MedHi intake, regression coefficients represent the absolute change in the outcome (e.g., BMI and WC) associated with each 1-unit increase in $\log_{10}$ (MedHi + offset), which corresponds to a 10-fold increase in dietary live microbe intake. These regression models were adjusted for covariates as outlined in Tables 1–4. For regression models that measure grams MedHi consumed as a continuous exposure, regression coefficients are reported as one-unit increment in $\log_{10}$-transformation. These coefficients indicate the adjusted mean difference in the outcome for a one-unit increment in the $\log_{10}$-transformation of exposure. In regression models using the three-level classification of patients based on dietary intakes, non-consumers (G1) serve as the reference group. Regression coefficients are reported for the two indicator variables: one for participants with intakes above zero but below the median (G2) and another for participants with intakes at or above the median (G3), both included simultaneously in the model.

Generalized linear regression models and restricted cubic spline (RCS) models were employed to evaluate the associations between obesity and dietary intake of MedHi, obesity and serum vitamin D levels, and the relationship between serum vitamin D levels and dietary intake of MedHi.

To account for NHANES's complex sampling design, Day 1 dietary weights (WTDRD1) were applied during model estimation.

TABLE 1 Regression analysis showing the association between log10-transformed MedHi (g) and BMI, WC.

| Variables | Per one-unit increment in log10-transformed MedHi | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
| | $\beta$ (95% CI) | $p$ | $\beta$ (95% CI) | $p$ | $\beta$ (95% CI) | $p$ | $\beta$ (95% CI) | $p$ |
| BMI | −0.26 [−0.34, −0.17] | <0.001 | −0.21 [−0.29, −0.13] | <0.001 | −0.17 [−0.25, −0.10] | <0.001 | −0.15 [−0.22, −0.08] | <0.001 |
| WC | −0.69 [−0.90, −0.47] | <0.001 | −0.56 [−0.75, −0.37] | <0.001 | −0.48 [−0.65, −0.32] | <0.001 | −0.42 [−0.58, −0.26] | <0.001 |

Model 1: Crude model. Model 2: Adjusted for age, sex, race, education, smoking status, drinking status, and PIR. Model 3: Adjusted for Model 2 plus energy intake (kcal/day), CHOL, TG, HbA1c, uric acid, diabetes, hypertension, CVD, and months of blood collection. Model 4: Adjusted for Model 3 plus serum vitamin D.

Consistent with previous NHANES-based mediation studies, weights were incorporated at the estimation stage rather than during resampling, ensuring population-level interpretability. Covariates were selected *a priori* based on previous NHANES-based studies, biological plausibility, and their known associations with dietary intake, vitamin D metabolism, and obesity outcomes. This analysis was conducted using the mediation package in R software (version 4.5.0) to estimate the indirect, direct, and total effects (23). Both the mediator and outcome models were specified using linear regression (svylm()), and bootstrapped confidence intervals were computed based on 1,000 simulations. In the mediation model, the total effect (c) of dietary live microbe intake on obesity was decomposed into a direct effect (c′) not mediated by serum vitamin D, and an indirect effect (a × b) mediated through serum vitamin D. Here, "a" represents the association between live microbe intake and serum vitamin D, and "b" represents the association between serum vitamin D and obesity, adjusting for the exposure. The same set of covariates was consistently adjusted in each path (a-path, b-path, c-path, and c′-path), including: age, sex, race, education, smoking status, drinking status, PIR and recreational activity, energy intake (kcal/day), CHOL, TG, HbA1c, uric acid, diabetes, hypertension, CVD, and months of blood collection and dietary vitamin D intake. The mediated proportion was calculated as the ratio of the indirect effect to the sum of the indirect and direct effects, multiplied by 100%. Two-sided $p$-values less than 0.05 were considered statistically significant.

We hypothesized that serum vitamin D levels mediate the association between dietary live microbe intake and obesity based on previous evidence, suggesting that both live microbial intake and vitamin D are associated with adiposity, and that gut microbiota may influence vitamin D absorption or metabolism.

## 2.8 Assessment of multicollinearity

To address potential multicollinearity among covariates, especially among dietary variables, we calculated variance inflation factors (VIFs) in the regression models. As shown in Supplementary Table S5, several dietary intake variables—including protein, carbohydrate, total sugars, total fat, and dietary fiber—exhibited high VIF values (e.g., VIF for energy intake = 55.54; carbohydrate = 36.96), indicating substantial collinearity. To mitigate this issue and avoid model overfitting, we included only total energy intake (kcal/day) in the final multivariable models, which showed acceptable collinearity (VIF = 1.57). This approach ensured model stability while retaining relevant nutritional adjustment.

# 3 Results

## 3.1 Participant characteristics

The demographic characteristics of 18,099 participants from the NHANES, surveyed between 2007 and 2018, are detailed in Table 5. The average age was 47.64 ± 0.27 years, with males comprising 54.79% of the cohort. A majority, 95.74%, had received education at a high school level or higher. The racial composition was predominantly White (69.76%) and Black (10.09%), with 79.85% identifying as non-Hispanic. Mexican Americans represented 7.91%, other Hispanics 5.31%, and other racial groups 6.93%. Additionally, 44.57% of participants had a history of tobacco use and 77.31% reported alcohol consumption. Prevalence rates for DM and CVD were 13.70 and 8.33%, respectively, while hypertension was reported by 35.73%. The average BMI was 28.64 ± 0.08 kg/m$^2$, with no significant difference between men (28.63 ± 0.09) and women (28.65 ± 0.11; $p$ = 0.85). In contrast, the mean waist circumference (WC) differed significantly by sex, measuring 101.51 ± 0.25 cm in men and 96.13 ± 0.26 cm in women ($p$ < 0.001). Detailed sex-specific anthropometric data are presented in Supplementary Table S6. Across live microbe intake groups, race (SMD = 0.306), education (0.277), and income-to-poverty ratio (0.278) showed notable differences. High intake was more common among non-Hispanic White, and among those with higher education and income. Smaller imbalances were seen in sex, physical activity, and serum vitamin D levels. Overall, most SMDs were <0.2, indicating minimal baseline differences between groups.

To further explore group differences by obesity status, baseline characteristics are presented in Supplementary Table S1.

## 3.2 Association between dietary intake of live microbes with obesity

Multivariable generalized linear regression analysis reveals a negative association between MedHi consumption and body metrics. We used a series of progressively adjusted models to examine the robustness of these associations: Model 1: Crude

TABLE 2 Regression analysis showing the association between dietary live microbe intake and obesity, and abdominal obesity.

| Variables | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---|---|---|---|---|---|---|---|---|
| | OR (95% CI) | *p* | OR (95% CI) | *p* | OR (95% CI) | *p* | OR (95% CI) | *p* |
| **Obesity** | | | | | | | | |
| Log10 transformed MedHi (g) | | | | | | | | |
| | 0.91 [0.89, 0.94] | <0.001 | 0.93 [0.90, 0.96] | <0.001 | 0.93 [0.90, 0.96] | <0.001 | 0.94 [0.91, 0.97] | <0.001 |
| Categories | | | | | | | | |
| G1 | 1 | | 1 | | 1 | | 1 | |
| G2 | 0.95 [0.83, 1.09] | 0.497 | 0.99 [0.86, 1.14] | 0.862 | 1.01 [0.87, 1.16] | 0.941 | 1.01 [0.87, 1.18] | 0.849 |
| G3 | 0.75 [0.68, 0.83] | <0.001 | 0.80 [0.72, 0.88] | <0.001 | 0.81 [0.73, 0.89] | <0.001 | 0.82 [0.74, 0.91] | <0.001 |
| *p* for trend | <0.001 | | <0.001 | | <0.001 | | <0.001 | |
| Dietary live microbe intake group | | | | | | | | |
| Low | 1 | | 1 | | 1 | | 1 | |
| Moderate | 0.83 [0.75, 0.91] | <0.001 | 0.85 [0.77, 0.95] | 0.003 | 0.86 [0.77, 0.95] | 0.005 | 0.88 [0.79, 0.98] | 0.018 |
| High | 0.74 [0.67, 0.81] | <0.001 | 0.81 [0.73, 0.89] | <0.001 | 0.83 [0.74, 0.92] | 0.001 | 0.84 [0.75, 0.94] | 0.002 |
| *p* for trend | <0.001 | | <0.001 | | <0.001 | | <0.001 | |
| **Abdominal obesity** | | | | | | | | |
| Log10 transformed MedHi (g) | | | | | | | | |
| | 0.96 [0.93, 0.98] | 0.003 | 0.92 [0.90, 0.95] | <0.001 | 0.93 [0.90, 0.96] | <0.001 | 0.94 [0.91, 0.97] | <0.001 |
| Categories | | | | | | | | |
| G1 | 1 | | 1 | | 1 | | 1 | |
| G2 | 1.02 [0.91, 1.14] | 0.733 | 0.99 [0.87, 1.12] | 0.851 | 1.00 [0.88, 1.14] | 0.993 | 1.01 [0.88, 1.16] | 0.904 |
| G3 | 0.88 [0.81, 0.96] | 0.005 | 0.79 [0.72, 0.87] | <0.001 | 0.81 [0.73, 0.89] | <0.001 | 0.83 [0.75, 0.91] | <0.001 |
| *p* for trend | 0.004 | | <0.001 | | <0.001 | | <0.001 | |
| Dietary live microbe intake group | | | | | | | | |
| Low | 1 | | 1 | | 1 | | 1 | |
| Moderate | 0.93 [0.84, 1.02] | 0.13 | 0.83 [0.75, 0.92] | 0.001 | 0.84 [0.75, 0.93] | 0.001 | 0.86 [0.77, 0.96] | 0.006 |
| High | 0.88 [0.79, 0.97] | 0.01 | 0.83 [0.74, 0.92] | 0.001 | 0.85 [0.76, 0.96] | 0.01 | 0.87 [0.77, 0.98] | 0.021 |
| *p* for trend | 0.009 | | <0.001 | | 0.007 | | 0.017 | |

Model 1: Crude model. Model 2: Adjusted for age, sex, race, education, smoking status, drinking status, PIR, and recreational activity. Model 3: Adjusted for Model 2 plus energy intake (kcal/day), CHOL, TG, HbA1c, uric acid, diabetes, hypertension, CVD, and months of blood collection. Model 4: Adjusted for Model 3 plus serum vitamin D.

model; Model 2: Adjusted for age, sex, race, education, smoking status, drinking status, income, and recreational activity; Model 3: Adjusted for Model 2 plus energy intake (kcal/day), CHOL, TG, HbA1c, uric acid, diabetes, hypertension, CVD, and months of blood collection; Model 4: Adjusted for Model 3 plus serum vitamin D. In the fully adjusted model (Model 4), each one-unit increment in $\log_{10}$-transformed MedHi corresponds to a decrease of 0.15 kg/m$^2$ in BMI (95% CI: −0.22, −0.08) and a reduction of 0.42 cm in WC (95% CI: −0.58, −0.26), as shown in Table 1. Furthermore, adjusted RCS models revealed a nonlinear association between MedHi consumption and BMI, with significant nonlinearity observed (Figure 3A), while the relationship between MedHi consumption and WC appeared linear (Figure 3B).

Figures 3C,D demonstrate a dose–response relationship between MedHi intake and both obesity and abdominal obesity. After

TABLE 3 Regression analysis showing the association between serum vitamin D (nmol/L) and obesity.

| Variables | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---|---|---|---|---|---|---|---|---|
| | β (95% CI) | p | β (95% CI) | p | β (95% CI) | p | β (95% CI) | p |
| Per ten-unit increment in serum vitamin D (nmol/L) | | | | | | | | |
| BMI | −0.41 [−0.47, −0.36] | <0.001 | −0.43 [−0.49, −0.37] | <0.001 | −0.34 [−0.40, −0.29] | <0.001 | −0.34 [−0.39, −0.28] | <0.001 |
| WC | −0.78 [−0.92, −0.65] | <0.001 | −1.06 [−1.19, −0.92] | <0.001 | −0.84 [−0.97, −0.72] | <0.001 | −0.83 [−0.95, −0.70] | <0.001 |

| Variables | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---|---|---|---|---|---|---|---|---|
| | OR (95% CI) | p | OR (95% CI) | p | OR (95% CI) | p | OR (95% CI) | p |
| Obesity | | | | | | | | |
| Per ten-unit increment in serum vitamin D (nmol/L) | | | | | | | | |
| | 0.87 [0.85, 0.89] | <0.001 | 0.87 [0.85, 0.89] | <0.001 | 0.88 [0.86, 0.90] | <0.001 | 0.88 [0.86, 0.90] | <0.001 |
| Serum vitamin D group (nmol/L) | | | | | | | | |
| <50 | 1 | | 1 | | 1 | | 1 | |
| 50–74.9 | 0.66 [0.59, 0.73] | <0.001 | 0.68 [0.61, 0.77] | <0.001 | 0.73 [0.64, 0.82] | <0.001 | 0.73 [0.65, 0.82] | <0.001 |
| ≥75 | 0.44 [0.40, 0.49] | <0.001 | 0.44 [0.39, 0.50] | <0.001 | 0.48 [0.42, 0.54] | <0.001 | 0.48 [0.42, 0.55] | <0.001 |
| *p* for trend | <0.001 | | <0.001 | | <0.001 | | <0.001 | |
| Abdominal obesity | | | | | | | | |
| Per ten-unit increment in serum vitamin D (nmol/L) | | | | | | | | |
| | 0.93 [0.92, 0.95] | <0.001 | 0.87 [0.85, 0.89] | <0.001 | 0.88 [0.86, 0.90] | <0.001 | 0.88 [0.86, 0.90] | <0.001 |
| Serum vitamin group D (nmol/L) | | | | | | | | |
| <50 | 1 | | 1 | | 1 | | 1 | |
| 50–74.9 | 0.73 [0.66, 0.80] | <0.001 | 0.70 [0.63, 0.78] | <0.001 | 0.73 [0.65, 0.82] | <0.001 | 0.73 [0.65, 0.83] | <0.001 |
| ≥75 | 0.65 [0.58, 0.72] | <0.001 | 0.46 [0.40, 0.52] | <0.001 | 0.50 [0.43, 0.58] | <0.001 | 0.50 [0.43, 0.59] | <0.001 |
| *p* for trend | <0.001 | | <0.001 | | <0.001 | | <0.001 | |

Model 1: Crude model. Model 2: Adjusted for age, sex, race, education, smoking status, drinking status, PIR, and recreational activity. Model 3: Adjusted for Model 2 plus energy intake (kcal/day), CHOL, TG, HbA1c, uric acid, diabetes, hypertension, CVD, and months of blood collection. Model 4: Adjusted for Model 3 plus dietary live microbe intake.

TABLE 4 Regression analysis showing the association between log10-transformed MedHi (g) and serum vitamin D.

| Variables | Per one-unit increment in log10-transformed MedHi | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
| | β (95% CI) | p | β (95% CI) | p | β (95% CI) | p | β (95% CI) | p |
| Serum vitamin D (nmol/L) | 2.34 [2.01, 2.68] | <0.001 | 0.90 [0.58, 1.23] | <0.001 | 0.77 [0.45, 1.09] | <0.001 | 0.70 [0.38, 1.02] | <0.001 |

Model 1: Crude model. Model 2: Adjusted for age, sex, race, education, smoking status, drinking status, PIR, and recreational activity. Model 3: Adjusted for Model 2 plus energy intake (kcal/day), CHOL, TG, HbA1c, uric acid, diabetes, hypertension, CVD, and months of blood collection. Model 4: Adjusted for Model 3 plus dietary vitamin D intake.

multivariate adjustment, a nonlinear association was observed between MedHi intake and obesity, and a similar situation occurred with MedHi and abdominal obesity. Each one-unit increment in the $\log_{10}$-transformed MedHi was associated with a 6% reduced risk of both obesity and abdominal obesity, as detailed in Table 2.

Additionally, when MedHi consumption was categorized, the risk of both obesity and abdominal obesity was significantly lower in the G3 group (highest consumption category) compared to the G1 group (non-consumers) across all four models. The analysis revealed that the risks of both obesity and abdominal

TABLE 5 The clinical characteristics of participants stratified by dietary live microbe intake groups.

| Variables | Total | Live microbe intake | | | *p* | SMD |
|---|---|---|---|---|---|---|
| | | Low | Moderate | High | | |
| Age (years) | 47.64 (0.27) | 45.87 (0.35) | 49.18 (0.34) | 47.63 (0.41) | <0.0001 | 0.094 |
| Sex (*N*, %) | | | | | <0.0001 | 0.116 |
| Male | 9,024 (49.56) | 3,655 (54.79) | 3,551 (47.95) | 1,818 (45.37) | | |
| Female | 9,075 (50.44) | 3,135 (45.21) | 3,732 (52.05) | 2,208 (54.63) | | |
| Race (*N*, %) | | | | | <0.0001 | 0.306 |
| Non-Hispanic White | 8,056 (69.76) | 2,678 (63.69) | 3,196 (69.10) | 2,182 (78.24) | | |
| Non-Hispanic Black | 3,653 (10.09) | 1,884 (15.30) | 1,257 (8.78) | 512 (5.50) | | |
| Mexican-American | 2,629 (7.91) | 874 (7.87) | 1,279 (9.64) | 476 (5.49) | | |
| Other Hispanic | 1,815 (5.31) | 645 (5.63) | 770 (5.53) | 400 (4.59) | | |
| Other race | 1,946 (6.93) | 709 (7.51) | 781 (6.96) | 456 (6.18) | | |
| Education (*N*, %) | | | | | <0.0001 | 0.277 |
| Less than high school | 1,545 (4.26) | 652 (5.39) | 709 (4.88) | 184 (1.99) | | |
| High school or equivalent | 6,585 (33.00) | 2,888 (41.30) | 2,547 (31.15) | 1,150 (25.37) | | |
| College or above | 9,969 (62.73) | 3,250 (53.31) | 4,027 (63.97) | 2,692 (72.64) | | |
| PIR (*N*, %) | | | | | <0.0001 | 0.278 |
| <1.3 | 5,534 (20.35) | 2,526 (27.38) | 2,073 (18.40) | 935 (14.43) | | |
| 1.3–3.5 | 6,891 (35.82) | 2,657 (38.57) | 2,816 (35.82) | 1,418 (32.42) | | |
| >3.5 | 5,674 (43.82) | 1,607 (34.05) | 2,394 (45.78) | 1,673 (53.15) | | |
| Smoking status (*N*, %) | | | | | <0.0001 | 0.176 |
| Never | 9,976 (55.43) | 3,470 (50.35) | 4,140 (57.10) | 2,366 (59.35) | | |
| Former | 4,465 (25.36) | 1,530 (22.95) | 1,920 (27.16) | 1,015 (25.77) | | |
| Current | 3,658 (19.21) | 1,790 (26.70) | 1,223 (15.74) | 645 (14.88) | | |
| Drinking status (*N*, %) | | | | | <0.0001 | 0.16 |
| Never alcohol intake | 2,412 (10.18) | 949 (11.13) | 1,019 (10.88) | 444 (8.00) | | |
| Former alcohol intake | 2,783 (12.51) | 1,195 (14.34) | 1,104 (12.65) | 484 (10.03) | | |
| Mild alcohol intake | 6,447 (38.64) | 2,144 (33.48) | 2,671 (39.64) | 1,632 (43.61) | | |
| Heavy alcohol intake | 6,457 (38.67) | 2,502 (41.06) | 2,489 (36.82) | 1,466 (38.36) | | |
| Recreational activity (*N*, %) | | | | | <0.0001 | 0.193 |
| No | 9,139 (44.49) | 3,870 (52.87) | 3,545 (42.43) | 1,724 (37.04) | | |
| Moderate | 4,925 (29.45) | 1,639 (26.16) | 2,067 (30.24) | 1,219 (32.40) | | |
| Vigorous | 4,035 (26.06) | 1,281 (20.97) | 1,671 (27.33) | 1,083 (30.56) | | |
| Diabetes (*N*, %) | | | | | <0.0001 | 0.085 |
| No | 14,788 (86.30) | 5,534 (86.38) | 5,835 (84.71) | 3,419 (88.46) | | |
| Yes | 3,311 (13.70) | 1,256 (13.62) | 1,448 (15.29) | 607 (11.54) | | |
| Hypertension (*N*, %) | | | | | 0.17 | 0.059 |
| No | 10,762 (64.27) | 3,969 (63.66) | 4,267 (63.68) | 2,526 (65.85) | | |
| Yes | 7,337 (35.73) | 2,821 (36.34) | 3,016 (36.32) | 1,500 (34.15) | | |
| CVD | | | | | <0.001 | 0.081 |
| No | 16,181 (91.67) | 5,989 (90.88) | 6,494 (91.10) | 3,698 (93.46) | | |
| Yes | 1,918 (8.33) | 801 (9.12) | 789 (8.90) | 328 (6.54) | | |
| Obesity (*N*, %) | | | | | <0.0001 | 0.082 |

*(Continued)*

TABLE 5 (Continued)

| Variables | Total | Live microbe intake | | | $p$ | SMD |
|---|---|---|---|---|---|---|
| | | Low | Moderate | High | | |
| No | 11,239 (62.81) | 4,039 (59.11) | 4,567 (63.66) | 2,633 (66.18) | | |
| Yes | 6,860 (37.19) | 2,751 (40.89) | 2,716 (36.34) | 1,393 (33.82) | | |
| Months of blood collection (*N*, %) | | | | | 0.001 | 0.068 |
| May–October | 9,426 (56.20) | 3,345 (52.57) | 3,894 (57.74) | 2,187 (58.52) | | |
| November–April | 8,673 (43.80) | 3,445 (47.43) | 3,389 (42.26) | 1,839 (41.48) | | |
| BMI (kg/m$^2$) | 28.64 (0.08) | 29.09 (0.11) | 28.49 (0.10) | 28.30 (0.13) | <0.0001 | 0.072 |
| WC (cm) | 98.80 (0.21) | 100.03 (0.30) | 98.40 (0.26) | 97.85 (0.34) | <0.0001 | 0.084 |
| TC (mmol/L) | 5.03 (0.01) | 4.97 (0.02) | 5.03 (0.02) | 5.09 (0.02) | 0.002 | 0.052 |
| TG (mmol/L) | 1.74 (0.02) | 1.78 (0.02) | 1.75 (0.03) | 1.68 (0.03) | 0.02 | 0.024 |
| UA (μmol/L) | 5.43 (0.02) | 5.54 (0.03) | 5.40 (0.03) | 5.34 (0.03) | <0.0001 | 0.099 |
| HbA1C (%) | 5.61 (0.01) | 5.64 (0.01) | 5.65 (0.01) | 5.54 (0.02) | <0.0001 | 0.094 |
| Dietary vitamin D intake (mcg) | 4.58 (0.04) | 4.27 (0.07) | 4.68 (0.07) | 4.82 (0.10) | <0.0001 | 0.085 |
| Serum vitamin D (nmol/L) | 64.94 (0.53) | 60.73 (0.65) | 66.59 (0.59) | 67.80 (0.57) | <0.0001 | 0.195 |
| Energy (kcal/day) | 2098.05 (8.99) | 2063.07 (15.37) | 2091.90 (11.54) | 2150.20 (16.08) | <0.001 | 0.102 |
| MedHi (g/day) | 0.98 (0.02) | 0.00 (0.00) | 1.34 (0.02) | 1.68 (0.03) | <0.0001 | 1.334 |
| Protein (g/day) | 81.84 (0.36) | 78.14 (0.52) | 82.09 (0.58) | 86.07 (0.69) | <0.0001 | 0.157 |
| Carbohydrate (g/day) | 248.86 (1.11) | 250.00 (2.01) | 249.11 (1.44) | 247.11 (2.01) | 0.52 | 0.029 |
| Total sugars (g/day) | 108.52 (0.72) | 111.42 (1.35) | 106.59 (0.91) | 107.67 (1.21) | 0.01 | 0.025 |
| Total fat (g/day) | 81.12 (0.43) | 78.13 (0.68) | 80.93 (0.58) | 85.11 (0.74) | <0.0001 | 0.144 |

PIR, poverty income ratio; CVD, cardiovascular disease; BMI, body mass index; WC, waist circumference; TC, total cholesterol; TG, triglyceride; UA, uric acid. Data are presented as means (SE) for continuous measures and numbers (percentages) for categorical measures.

obesity were significantly lower in the moderate and high intake groups compared with the low intake group.

## 3.3 Association between serum vitamin D with obesity

Table 3 presents the results of multivariable generalized linear regression analyses assessing the associations between serum vitamin D levels and obesity-related indicators. In the fully adjusted model, each 10 nmol/L increase in serum vitamin D was significantly associated with a decrease in BMI ($\beta = -0.34$, $p < 0.001$) and WC ($\beta = -0.83$, $p < 0.001$), indicating a strong inverse relationship. This linear association was further supported by adjusted RCS models (Figures 4A,B).

Additionally, univariate and multivariable weighted logistic regression analyses showed that higher serum vitamin D levels were significantly associated with lower odds of both general obesity and abdominal obesity. The RCS curves (Figures 4C,D) confirmed robust negative dose–response relationships between vitamin D levels and both outcomes. When serum vitamin D was categorized into deficiency, insufficiency, and sufficiency groups, participants in the higher-level categories consistently showed lower risks of obesity and abdominal obesity across all four models. Full model specifications and estimates are provided in Table 3.

## 3.4 Association between dietary intake of live microbes with serum vitamin D

The multivariable generalized linear regression coefficients for serum vitamin D levels, corresponding to a one-unit increment in the $\log_{10}$-transformed MedHi, are detailed in Table 4. The results consistently show a positive association across all four models. Specifically, each one-unit increment in the $\log_{10}$-transformed MedHi consumption was associated with increases in serum vitamin D levels of 2.34 nmol/L (95% CI: 2.01, 2.68), 0.90 nmol/L (95% CI: 0.58, 1.23), 0.77 nmol/L (95% CI: 0.45, 1.09), and 0.70 nmol/L (95% CI: 0.38, 1.02), respectively. Further analysis using adjusted RCS models indicated that the relationship between MedHi consumption and serum vitamin D levels is nonlinear, with a significant test for nonlinearity as shown in Figure 5.

## 3.5 Mediation analysis

Mediation analyses were conducted to assess the potential mediation effects of serum vitamin D on the relationships between dietary intake of live microbes and various obesity-related metrics. The analysis revealed significant mediation effects of serum vitamin D on the associations with BMI, WC, obesity, and abdominal obesity. The proportions of mediation were 14.6, 12.5, 13.0, and 12.5%

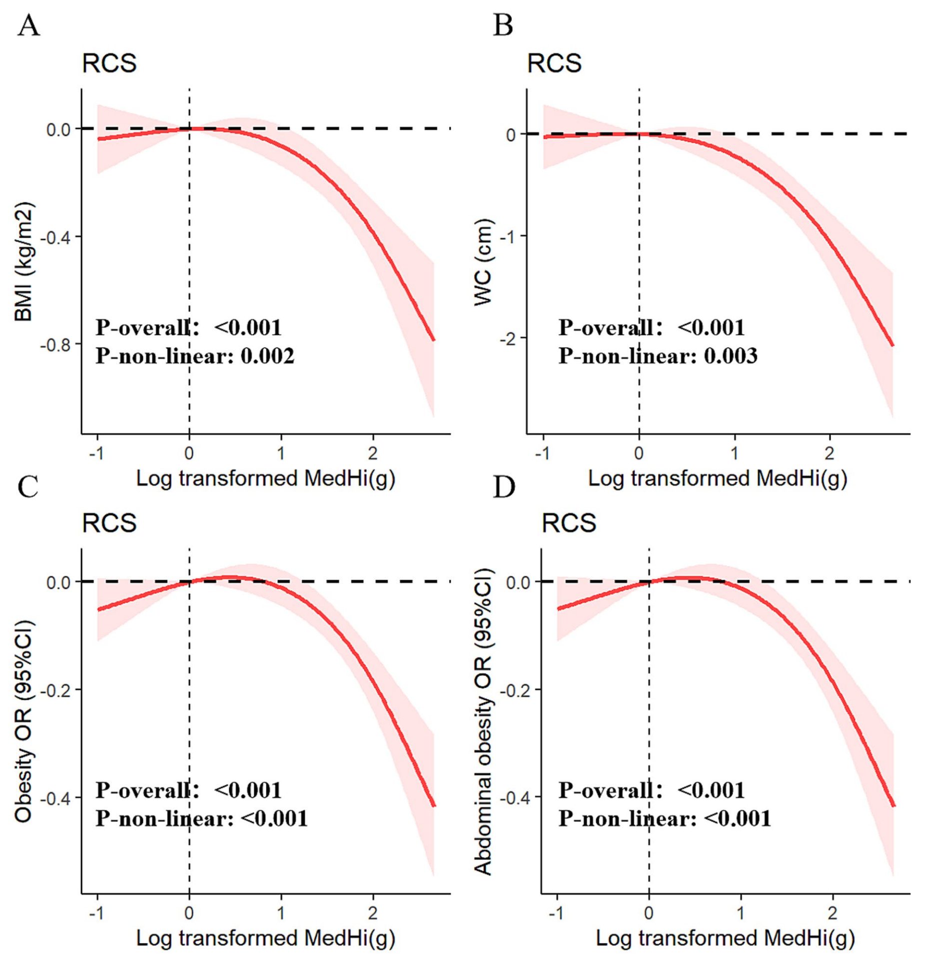


FIGURE 3
Dose−response relationships of MedHi intake with BMI **(A)**, WC **(B)**, obesity **(C)**, and abdominal obesity **(D)**.

respectively, all achieving statistical significance ($p < 0.001$), as shown in Figures 6A–D. To evaluate the role of vitamin D in the interaction between MedHi intake and obesity metrics, mediation models were thoroughly adjusted for a comprehensive set of variables. These included age, sex, race, education, smoking status, drinking status, PIR and recreational activity, energy intake (kcal/day), CHOL, TG, HbA1c, uric acid, diabetes, hypertension, CVD, and months of blood collection and dietary vitamin D intake.

## 3.6 Sensitivity analyses

To assess the robustness of our findings, we performed sensitivity analyses. First, we tested for effect modification by baseline vitamin D status (deficient vs. sufficient) by including an interaction term between MedHi intake and vitamin D status. No significant interaction was observed for obesity, indicating consistency across subgroups (Supplementary Figures S1, S2).

To test the robustness of the log-transformation applied to MedHi intake, we conducted sensitivity analyses using alternative offset values. Specifically, MedHi was log-transformed using three approaches: $\log_{10}$ (MedHi + 0.01), $\log_{10}$ (MedHi + 0.001), and ln (MedHi + 0.1). As shown in Supplementary Table S2, all models yielded consistent and statistically significant associations with both general and abdominal obesity, indicating that our findings are not sensitive to the specific offset used. Similarly, the results of the mediation analyses remained stable across these transformations (Supplementary Figures S4A–F).

Additionally, to further test the robustness of our findings, we conducted a sensitivity analysis excluding participants with implausible total energy intake values (<800 kcal/day or >4,200 kcal/day for men; <600 kcal/day or >3,500 kcal/day for women). The associations between dietary live microbe intake, serum vitamin D levels, and obesity remained consistent with the main analyses. Importantly, the mediation effect of serum vitamin D persisted after excluding these extreme values, as shown in Supplementary Table S3 and Supplementary Figures S4G,H. These results indicate that our findings are not driven by outliers or potential misreporting in dietary intake data.

As part of the sensitivity analyses, we explored whether our findings were robust under alternative obesity definitions. Specifically, we applied the Chinese diagnostic criteria for obesity (BMI $\geq$28 kg/m$^2$) in place of the WHO cutoff (BMI $\geq$30 kg/m$^2$). The results remained directionally consistent with the main analysis, indicating that the observed associations and mediation effects were not sensitive to the choice of obesity classification. Detailed findings are provided in Supplementary Table S4 and Supplementary Figure S3.

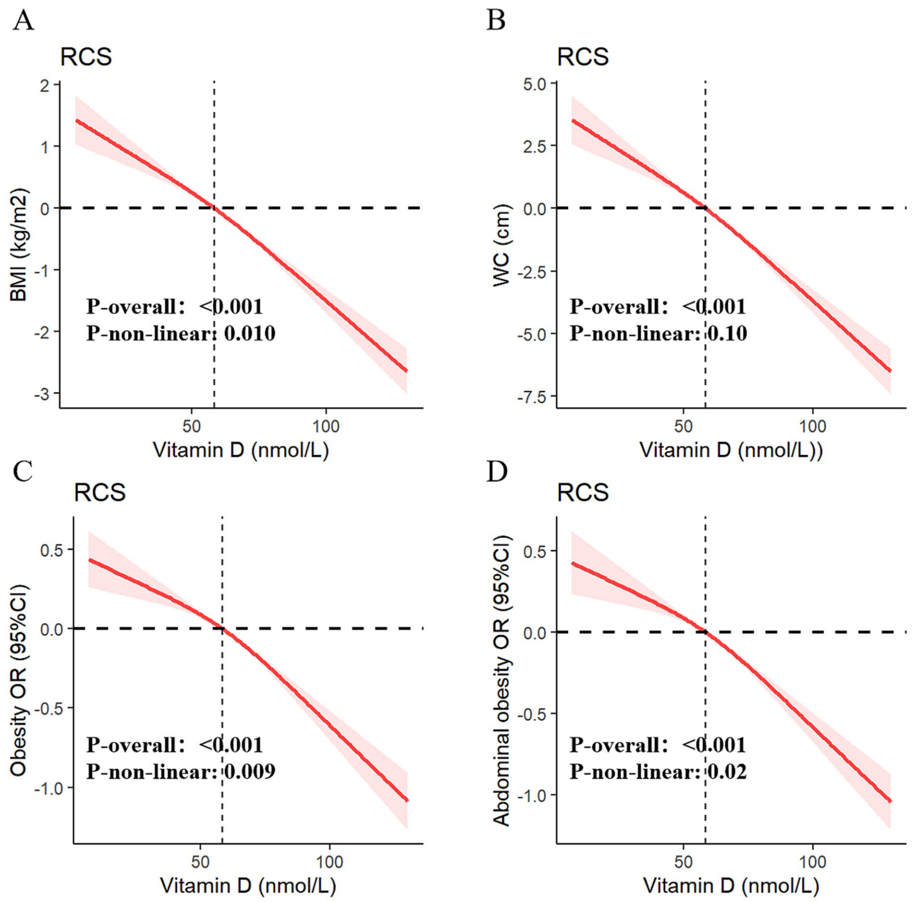


FIGURE 4
Dose–response relationships of serum vitamin D with BMI **(A)**, WC **(B)**, obesity **(C)**, and abdominal obesity **(D)**.

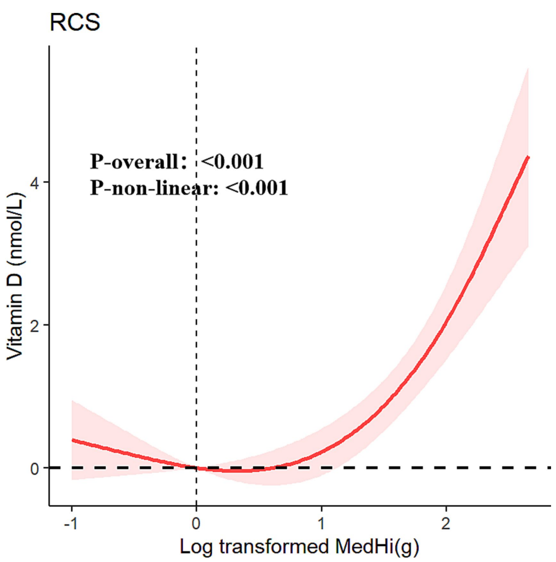


FIGURE 5
Restricted cubic spline fitting for the association between dietary live microbe intake with serum vitamin D adjusted for all covariables.

To examine the robustness of the mediation model, we tested for exposure-mediator interaction by including an interaction term between dietary live microbe intake and serum vitamin D levels. The interaction was not statistically significant ($p$ for interaction = 0.89), suggesting that the effect of dietary live microbes on obesity does not differ across serum vitamin D levels. Detailed results are presented in Supplementary Figures S1, S2.

## 4 Discussion

NHANES provides extensive data critical for shaping nutrition and health policies. In this study, we integrated this data to conduct a comprehensive assessment of a large cohort. For the first time, our mediation analysis demonstrated that serum vitamin D levels can partially mediate the relationship between dietary intake of live microorganisms and obesity in a nationally representative sample of U.S. adults.

The gut microbiota is increasingly recognized as a crucial regulator of host health, akin to the role of vitamin D in linking various metabolic pathways. Probiotics, which modulate the gut microbiome, have been shown to influence host health and potentially reduce obesity risk (24). Consumption of yogurt has been associated with reductions in adiposity factors such as BMI and WC (25), as well as improvements in cardio-metabolic risk factors, including blood pressure, lipid profiles, and glucose levels (26). Importantly, foodborne microbes have been found to survive transit through the digestive system and remain metabolically active within the gut, illustrating how the gut microbiome can rapidly respond to dietary changes (27).

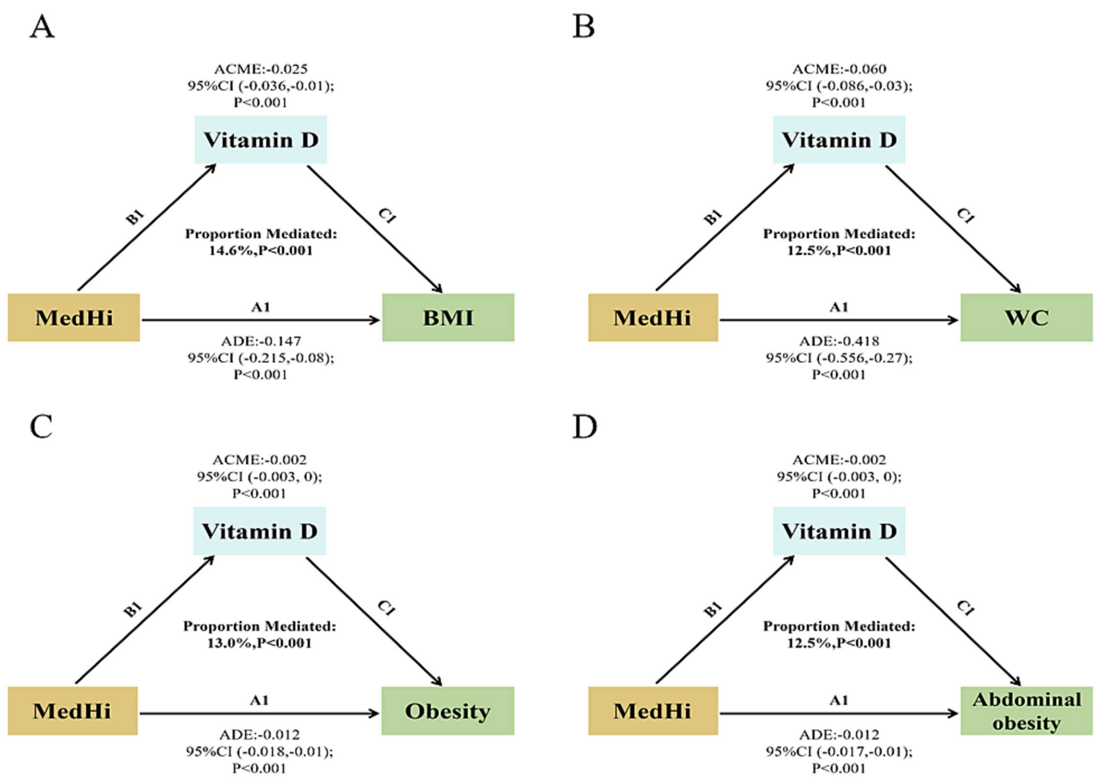


FIGURE 6
Path diagram of the mediation effect. **(A)** Serum vitamin D mediated effects on the associations of dietary live microbe intake with BMI. **(B)** Serum vitamin D mediated effects on the associations of dietary live microbe intake with WC. **(C)** Serum vitamin D mediated effects on the associations of dietary live microbe intake with obesity. **(D)** Serum vitamin D mediated effects on the associations of dietary live microbe intake with abdominal obesity.

Specifically, each one-unit increase in log10-transformed MedHi intake was associated with a 0.15 kg/m$^2$ reduction in BMI, which equates to approximately 0.43 kg of body weight for an individual 1.70 m in height—highlighting the potential for modest but meaningful public health impact at the population level. Dietary live microbes may influence obesity risk via modulation of gut microbiota and subsequent effects on vitamin D metabolism. Beneficial microbes such as *Lactobacillus* and *Bifidobacterium* can enhance intestinal barrier integrity and vitamin D receptor expression (28). They also produce short-chain fatty acids (SCFAs), which improve vitamin D absorption and activation (29). In addition, gut microbiota influence bile acid metabolism, further facilitating vitamin D uptake (30). Both SCFAs and vitamin D possess anti-inflammatory and anti-adipogenic properties (31). A bidirectional relationship may also exist, as vitamin D can shape gut microbiota through immunomodulatory effects (32). These interconnected pathways support the observed mediation effect.

The meta-analysis results (33, 34) support an inverse relationship between obesity measures and vitamin D levels. Historically, research has primarily focused on the intake of vitamin D and its role in obesity management, with less emphasis on enhancing serum vitamin D levels through alternative means. Our study clarifies that the intake of live microbes unidirectionally influences vitamin D levels and obesity, establishing a potential causal relationship between live microbe intake and these factors. We found that the relationship between live microbe intake and obesity is mediated by serum vitamin D levels, highlighting mediating factors that elucidate the biological pathways connecting live microbe intake to obesity outcomes. Although we adjusted for several dietary and lifestyle factors, it is possible that the observed associations may partially reflect overall diet quality rather than the specific effects of live microbes. Individuals with high live microbe intake often consume diets richer in fiber, fruits, and fermented foods, which are independently associated with improved vitamin D status and reduced obesity risk. Future studies should incorporate formal diet quality indices to help disentangle these overlapping dietary influences. Furthermore, although many vitamin D supplementation trials (35–37) successfully raised vitamin D concentrations, they often failed to yield the anticipated health benefits. This discrepancy suggests that a diet rich in live microbes might be more effective in reducing obesity incidence than relying solely on vitamin D supplementation.

Importantly, the observed mediation proportions by serum vitamin D in our study (12.5–14.6%) fall within the range reported by other nutritional epidemiology studies using NHANES data. For example, Lin et al. (38) found that BMI mediated approximately 21.3% of the total effect of sugar-sweetened beverage intake on decreased serum 25(OH)D levels in U.S. adults. Similarly, Yang et al. (39) reported that BMI partially mediated the relationship between sodium intake and systolic blood pressure, contributing a substantial proportion of the total effect (based on NHANES 2007–2016 data). These comparisons suggest that mediation proportions

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in the 10–20% range are plausible and meaningful in complex dietary pathways, supporting the role of vitamin D as a modest yet biologically relevant mediator in the link between live microbe intake and obesity.

Our study has several limitations. First, its cross-sectional design limits causal inference. Although we hypothesized a directional pathway—from dietary live microbe intake to serum vitamin D levels and then to obesity—based on prior biological and longitudinal evidence, the temporal sequence cannot be firmly established using NHANES data. Reverse causality remains possible, though we attempted to mitigate this through sensitivity analyses and flexible modeling. Prospective studies are needed to validate these associations. Second, the diversity of geographic regions, dietary patterns, and lifestyle behaviors may jointly influence the mediating variable (serum vitamin D), thereby affecting multiple interrelated factors in our model. Third, although our microbial exposure classification was based on a validated methodology, it did not differentiate among specific types of live microbes. Certain strains—particularly those with probiotic properties—may exert more pronounced metabolic or anti-inflammatory effects than others. Future research incorporating strain-level microbial identification and functional analysis is needed to clarify these differential effects. Third, the diversity of geographic regions, diets, and lifestyles might synergistically influence the "mediation variable" in our analysis, affecting multiple interrelated factors. Fourth, another potential explanation for our findings is the presence of co-occurring nutrients in live microbe-rich foods. For instance, yogurt and other fermented dairy products not only contain probiotics but are also rich in calcium, protein, and bioactive peptides, which may independently impact adiposity and vitamin D metabolism. Similarly, fermented vegetables and soy-based foods contain fiber, vitamins, and phytonutrients that may act as confounders. Although our models adjusted for total energy intake, residual confounding by specific co-nutrients cannot be fully excluded. Fifth, differences in vitamin D metabolism across racial and ethnic groups may influence the observed associations. For example, non-Hispanic Black individuals typically exhibit lower circulating 25(OH)D concentrations without corresponding increases in adverse health outcomes—likely due to differences in vitamin D-binding protein levels and tissue-level sensitivity to vitamin D (40). Such physiological variations may influence vitamin D bioavailability and its biological activity, potentially modifying its mediating role. While our analyses adjusted for race/ethnicity, stratified mediation analyses were not performed due to limited statistical power in certain subgroups. Future studies with larger and more diverse populations are warranted to explore potential effect modification by racial/ethnic group. Finally, longitudinal studies are essential to clarify the long-term interplay between live microbe intake, vitamin D status, and obesity outcomes.

## 5 Conclusion

This study revealed that the negative correlation between dietary intake of live microbes and obesity is mediated by vitamin D. Foods with higher microbial concentrations could be beneficial in reducing the incidence of obesity.

## Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary material.

## Ethics statement

The studies involving humans were approved by the National Center for Health Statistics (NCHS) Ethics Review Board (ERB). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

CL: Data curation, Methodology, Writing – original draft. HZ: Data curation, Writing – original draft, Formal analysis, Resources, Software. WX: Project administration, Supervision, Validation, Writing – review & editing. XZ: Writing – original draft. ML: Conceptualization, Supervision, Writing – review & editing. LL: Supervision, Writing – review & editing, Funding acquisition.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Publisher's note



## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2025.1588700/full#supplementary-material

SUPPLEMENTARY FIGURE S1
Association between dietary live microbe intake with obesity, stratified by age, gender, race, vitamin D status and months of blood collection.

SUPPLEMENTARY FIGURE S2
Association between dietary live microbe intake with abdominal obesity, stratified by age, gender, race, vitamin D status and months of blood collection.

SUPPLEMENTARY FIGURE S3
Path diagram of the mediation effect. Serum vitamin D mediated effects on the associations of dietary live microbe intake with obesity (Chinese obesity diagnostic criteria: BMI ≥28 kg/m²).

SUPPLEMENTARY FIGURE S4
Path diagram of the mediation effect. **(A,B)** Dietary intake of MedHi underwent log10-transformation after adding 0.01 g. **(C,D)** Dietary intake of MedHi underwent log10-transformation after adding 0.001 g. **(E,F)** Dietary intake of MedHi underwent natural log-transformation after adding 0.1 g. **(G,H)** Excluded participants with implausible energy intake.

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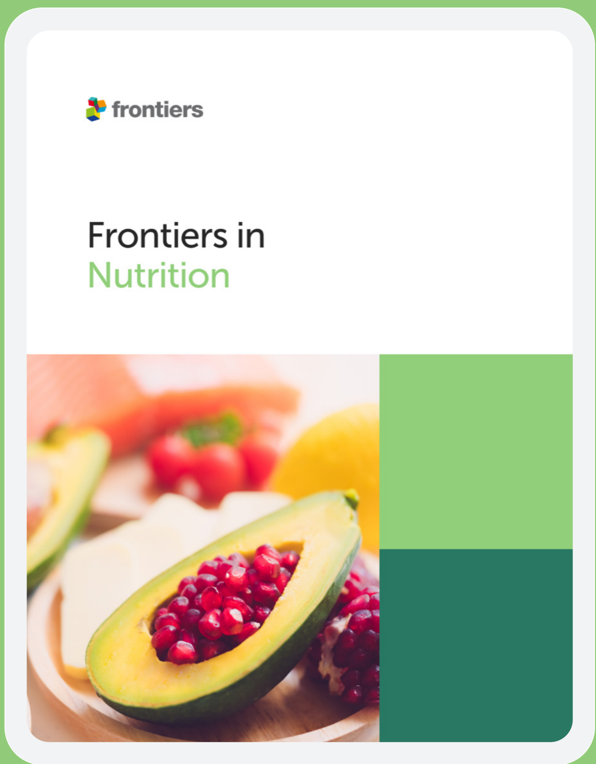



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