Review

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Risk factors for adolescent obesity in LMICs: a meta-analysis using multiple adiposity indicators

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Abstract

Introduction: Adolescent obesity is an escalating public health challenge in low- and middle-income countries (LMICs). Most evidence has relied on body mass index (BMI), which may underestimate central adiposity. We conducted a systematic review and meta-analysis to synthesize risk factors using multiple anthropometric indicators.
Content: A systematic search of PubMed, Scopus, and Web of Science was conducted for studies published between January 2013 and December 2023. Studies were included if they reported adolescent obesity risk factors, were peer-reviewed, and published in English. Studies that did not assess risk factors, review articles, editorials, case reports, and animal studies were excluded. Data were extracted and synthesized both narratively and quantitatively, and the risk of bias of included studies was assessed using the Newcastle Ottawa Scale. From 196,775 records, 21 studies were included (n≈46,000 adolescents). Significant risk factors were genetic predisposition (OR 1.80; 95 % CI 1.35–2.40), socioeconomic status (OR 1.31; 95 % CI 1.13–1.52), unhealthy dietary patterns (OR 2.07; 95 % CI 1.11–3.88), environmental exposures (OR 1.25; 95 % CI 1.09–1.44), low physical activity (OR 1.14; 95 % CI 1.03–1.27), and psychosocial stress (OR 1.29; 95 % CI 1.08–1.54). Subgroup analyses revealed that the waist-to-height ratio was the most consistent predictor of obesity risk, whereas BMI exhibited more heterogeneous associations. Regional disparities were evident, with stronger associations in East Asia and Latin America.
Summary: Adolescent obesity in LMICs arises from intersecting biological, behavioral, and social determinants. The waist-to-height ratio may provide a more accurate measure of adiposity than the BMI. Effective prevention requires multisectoral policies addressing unhealthy diets, limited physical activity, psychosocial stress, and obesogenic environments.
Outlook: Further research is expected to involve interventions to address obesity in LMICs by considering measurements using the waist-to-height ratio to measure adiposity rather than using BMI.

Keywords: adolescent obesity; risk factors; LMICs; physical activity; environment; adiposity indicators

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Introduction

Adolescent obesity has become much more common worldwide in recent decades, especially in low- and middle-income nations (LMICs) [1], where it often coexists with undernutrition, creating malnutrition's dual burden [2]. This trend is driven by rapid urbanization, socioeconomic transitions, shifts in dietary patterns, and increasingly sedentary lifestyles [3, 4]. In Indonesia, for instance, approximately 18 % of adolescents aged 10–19 years were classified as obese in 2020 [5]. Type 2 diabetes mellitus, cardiovascular disorders, hypertension, osteoarthritis, and several types of cancer are among the non-communicable diseases that are linked to adolescent obesity [6, 7]. Additionally, it negatively impacts mental health, social development, and overall quality of life [8]. Given these broad consequences, identifying risk factors specific to adolescents in LMICs is essential for designing effective prevention strategies. Several modifiable and contextual factors have been linked to adolescent obesity. These include poor dietary habits, insufficient physical activity, psychosocial stress, low socioeconomic status, environmental exposures, and familial and peer influences [9, 10]. Because it does not distinguish between lean mass and fat mass, body mass index (BMI), which is still the accepted metric for determining obesity, has severe limitations, particularly during adolescence, a time of profound physiological change [11]. As a result, alternative anthropometric measures, such as waist circumference (WC) and waist-to-height ratio (WHtR), have been proposed as more accurate indicators of adiposity in this age group [12, 13]. Previous systematic reviews and meta-analyses have predominantly focused on high-income countries and relied solely on BMI-based definitions of obesity, highlighting the need for including multiple adiposity indicators. Unlike these studies, our review incorporates multiple adiposity indicators, examines behavioral, environmental, social, and genetic risk factors, and includes evidence from low and middle-income countries (LMIC), providing a more comprehensive and generalizable overview of adolescent obesity risk factors [14]. This work attempts to close this gap by conducting a comprehensive review and meta-analysis of the contextual and modifiable risk variables linked to adolescent obesity in LMICs, incorporating both conventional (BMI) and alternative adiposity indicators (WHtR and WC). The primary research question is: What are the significant risk factors contributing to adolescent obesity in LMICs, and how do these vary when using different adiposity indicators?

Methods

Study design and registration

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 standards were followed in the conduct of this systematic review and meta-analysis. With registration number CRD42024589445, the protocol was prospectively listed in the International Prospective Register of Systematic Reviews (PROSPERO). Ethical approval was not necessary because the study entailed the analysis of data that had already been published. We performed a meta-analysis and systematic evaluation of observational studies, including case-control, cohort, and cross-sectional studies, involving adolescents aged 10–19 years in LMICs. Seven databases and grey literature sources were searched. Screening, data extraction, and risk of bias evaluation were all carried out separately by two reviewers. Pooled odds ratios (ORs) with 95 % confidence intervals were estimated using random-effects models (Cis). We included studies that measured adolescent obesity using various adiposity indicators, including BMI-for-age z-scores, body fat percentage, and waist circumference. For each study, the indicator used was extracted and considered in subgroup or sensitivity analysis where feasible.

Information sources and search strategy

A systematic search of seven electronic databases (PubMed, Embase, Scopus, Web of Science, Science Direct, and others) will be conducted, supplemented by manual screening to identify additional eligible studies. The search strategy combines Medical Subject Heising (MeSH) and free text terms related to four core concepts: population (adolescent), exposure (risk factors), outcome (obesity or overweight), and setting (low -and middle-income countries). Searches will be limited to studies published between January 2013 and December 2023. Core Mesh terms include: ((“Adolescent”[MeSH Terms] OR “adolescent*”[All Fields] OR “teenager*”[All Fields] OR “youth*”[All Fields]) AND (“Obesity”[MeSH Terms] OR “Overweight”[MeSH Terms] OR “obes*”[All Fields] OR (“Overweight”[MeSH Terms] OR “Overweight”[All Fields] OR “overweighted”[All Fields] OR “overweightness”[All Fields] OR “overweights”[All Fields]) OR “Body Mass Index”[MeSH Terms] OR “Body Mass Index”[All Fields] OR “BMI”[All Fields] OR “waist circumference”[All Fields] OR “neck circumference”[All Fields] OR “waist-to-height ratio”[All Fields] OR “adiposity indicator*”[All Fields]) AND (“Risk Factors”[MeSH Terms] OR “determinant*”[All Fields] OR “predictor*”[All Fields] OR “correlate*”[All Fields] OR “association*”[All Fields]) AND (“Developing Countries”[MeSH Terms] OR “lmic*”[All Fields] OR “low-income countries”[All Fields] OR “middle-income countries”[All Fields] OR “resource-limited settings”[All Fields])). Search strategies will be adapted to the syntax of each database. The full search strategy for PubMed and other databases is provided in Supplementary File 1.

Eligibility criteria

The following inclusion criteria were satisfied by eligible studies: (1) observational design (cross-sectional, case–control, or cohort studies); (2) participants aged 10–19 years residing in LMICs, as defined by the World Bank; (3) examination of at least one modifiable or contextual risk factor associated with overweight or obesity; (4) inclusion of a comparison group (normal-weight adolescents); (5) use of recognized adiposity indicators such as BMI, waist circumference, WHtR, NC, or skinfold thickness; (6) published in English between January 2013 and December 2023. Studies were excluded if they focused on populations outside the target age range, did not assess any identifiable risk factors for adolescent obesity (behavioral, environmental, social, or genetic), or were inaccessible despite attempts to contact corresponding authors. Studies were excluded if they focused on populations outside the target age range, did not assess any identifiable risk factors for adolescent obesity (behavioral, environmental, social, or genetic), or were inaccessible despite attempts to contact corresponding authors.

Inclusion/exclusion criteria

Studies that satisfied the following requirements were included: they had to be original observational studies with a cross-sectional, case-control, or cohort design; they had to involve adolescents between the ages of 10 and 19; they had to be carried out in low- and middle-income nations as defined by the World Bank; and they had to look at relationships between biological, behavioral, social, or environmental risk factors and overweight or obesity in adolescents. Eligible studies were required to include a comparator group of adolescents with normal weight and to report effect estimates for overweight or obesity outcomes, using recognized adiposity indicators such as BMI, waist circumference, waist-to-height ratio, or skinfold thickness. Only studies published in English within the past 10 years were considered for inclusion. The researchers (Ee, IN, DN, and TW) conducted the data extraction independently and blindly after reviewing the abstracts and full texts of the publications. The three independent researchers evaluated the complete texts and abstracts of the articles and eliminated those with methodological issues. Due to insufficient information, papers whose entire texts we were unable to access completely or for which we were unable to contact their primary authors were excluded from our review.

Data extraction and risk of bias assessment

Using a pre-tested and standardized data extraction checklist, the two researchers separately extracted all the required data. The initial author of the study, the location in the LMIC where the study was done, the specific area where the study was conducted, the study design, the year the study was published, sample size, response rate, and risk factor obesity were among the relevant data that were retrieved from the publications. Any disagreements amongst the researchers about the extracted data were resolved by consensus and discussion, with the third reviewer's (TW) assistance.

The reviewers utilized the Newcastle-Ottawa quality evaluation tool. A cross-sectional study-specific scale to evaluate the research's quality [15]. Three significant indicators make up the instrument. The first section assesses the research's methodological characteristics and assigns a score based on five points (stars). The second section evaluates the studies' comparability and is rated with three stars. The tool's final portion assigns a score between two and eight, indicating how well the original research's statistical analyses performed. The two writers (Ee and IN) separately evaluated the quality of the primary studies using the tool as a guide. The following metrics were used to evaluate the studies' quality: studies that scored medium (satisfying 50 % of the quality evaluation criteria) or high (≥6 out of 10) were taken into consideration for inclusion in the meta-analysis. The two reviewers' mean scores were used to calculate the variations in their evaluation outcomes.

Exposure and outcome definitions

The primary exposures included six risk factor categories: genetic predisposition, unhealthy dietary patterns, physical activity, psychosocial stress, environmental exposures, and socioeconomic status. The primary outcome was adolescent overweight and obesity, assessed using validated anthropometric indicators such as BMI, waist circumference (WC), waist-to-height ratio (WHtR), neck circumference (NC), and skinfold thickness, classified according to WHO or regional criteria. Both BMI and non-BMI measures were analysed to provide a comprehensive assessment of adiposity. Secondary outcomes included the identification, categorization, and prevalence of modifiable and contextual risk factors associated with adolescent overweight or obesity, encompassing behavioral, environmental, social, and genetic determinants. These secondary outcomes were extracted and analysed to better understand the determinants and patterns of adolescent obesity in LMICs.

Data synthesis and analysis

Meta-analyses with random effects were conducted using the Der Simonian and Laird method to pool odds ratios (ORs) with 95 % confidence intervals (CIs). The I^2 statistic was used to measure heterogeneity, with values of 25 , 50, and 75 % denoting low, moderate, and high heterogeneity, respectively. To explore sources of heterogeneity, subgroup analyses were conducted based on two domains: (1) the type of adiposity indicator used and (2) the category of risk factor. We performed subgroup analyses based on adiposity indicators (BMI, WC, WHtR) and conducted sensitivity analyses to test the robustness of results. Although subgroup analyses by region were planned, the limited number of studies per region precluded formal meta-analyses. Descriptive comparison by country is presented in Table 1. Potential sources of heterogeneity, such as study design, sample size, and NOS quality score, were investigated using meta-regression. Using Egger's

Table 1: Characteristics of included studies (n=21).

No	Author (year)	Country	Study design	Sample size	Risk factor(s)
1	Li Y, et al. (2014) [16]	China	Case-control	401	Genetic
2	Rathnayake, K. M. et al. (2014) [17]	Sri Lanka	Case-control	100	Dietary pattern
3	Huriyati et al. (2016) [18]	Indonesia	Case-control	264	Genetic
4	Piryani et al. (2016) [19]	Nepal	Cross-sectional	360	SES, dietary pattern, physical activity
5	Pinto et al. (2017) [20]	Brazil	Cross-sectional	2,517	Physical stress
6	Ghosh et al. (2018) [21]	India	Cohort	1,283	Genetic
7	Khashayar et al. (2018) [22]	Iran	Cross-sectional	13,486	Dietary pattern, environment
8	Moges et al. (2018) [23]	Ethiopia	Cross-sectional	1,276	SES, physical activity
9	Florest (2019) [24]	Mexico	Cross-sectional	633	Physical stress
10	Jain et al. (2019) [25]	India	Cross-sectional	218	Genetic
11	Gul et al. (2020) [26]	Tokat	Case-control	268	Genetic
12	Totendi et al. (2020) [27]	Brazil	Cross-sectional	2,364	Genetic
13	Agustina et al. (2021) [28]	Indonesia	Cross-sectional	534	SES, environment, physical activity
14	Huang et al. (2021) [29]	China	Cross-sectional	407	SES, physical activity
15	Roy et al. (2021) [30]	Bangladesh	Cross-sectional	385	Physical stress, environment
16	Adeom et al. (2022) [31]	Nigeria	Cross-sectional	1,200	SES, physical activity
17	Anjum et al. (2022) [32]	Bangladesh	Cross-sectional	2,355	Physical stress
18	Hossain (2022) [33]	Bangladesh	Cross-sectional	730	Physical stress
19	Sarintohe et al. (2022) [34]	Indonesia	Cross-sectional	411	Environment
20	Hunegnaw et al. (2022) [35]	Ethiopia	Cross-sectional	1,018	SES, physical activity
21	Sitaul et al. (2023) [36]	Nepal	Cross-sectional	267	Dietary pattern

test and funnel plots, publication bias was evaluated. RevMan version 5.4 and R (version 4.3.0) with the “metaphor” package were used for all analyses.

Results

Study selection

A total of 8,096 records were identified through database and grey literature searches. 500 duplicates were removed, and 76,817 titles and abstracts were screened. Of the 696 full-text articles assessed, 21 studies met the inclusion criteria and were included in the final meta-analysis. Key risk factors significantly associated with adolescent obesity included genetic predisposition (OR: 1.80; 95 % CI: 1.35–2.40), socioeconomic status (OR: 1.31; 95 % CI: 1.13–1.52), unhealthy dietary patterns (2.07 (95 % CI: 1.11, 3.88), environmental exposures (OR: 1.25; 95 % CI: 1.09–1.44), low physical activity (OR: 1.14; 95 % CI: 1.03–1.27), psychosocial stress (OR: 1.09; 95 % CI: 0.96–1.24), several studies examined genetic predisposition as a risk factor for adolescent overweight and obesity (OR: 1.54; 95 % CI: 0.98–2.42) and physical stress (OR: 1.29; 95 % CI: 1.08–1.54). The pooled analysis demonstrated a significant association between genetic factors and obesity risk (p=0.0020) Regional disparities were notable, with stronger associations observed in East Asia and Latin America. Subgroup analyses revealed that the waist-to-height ratio (WHtR) was the most predictive adiposity indicator, while BMI yielded weaker and more heterogeneous associations. The study selection process is detailed in the PRISMA flow diagram (Figure 1).

Study characteristics and risk of bias

The 21 studies included in this review varied in design and geographical distribution, with the majority employing cross-sectional approaches. These studies were conducted across diverse LMIC settings, including South and Southeast Asia, and sub-Saharan Africa. The methodological quality of the studies was assessed using the Newcastle–Ottawa Scale (NOS). Of the included studies, 14 were judged to have low risk of bias (NOS score 7–9), while 7 were rated as having moderate risk of bias (NOS score 4–6), mainly due to limitations in sample selection and outcome ascertainment. Importantly, no study was classified as having a high overall risk of bias (NOS score<4). Indicating that the methodological quality of all included studies was generally acceptable. Most studies clearly defined exposures and outcomes, employed validated adiposity indicators, and demonstrated appropriate study design, supporting the reliability of the reported

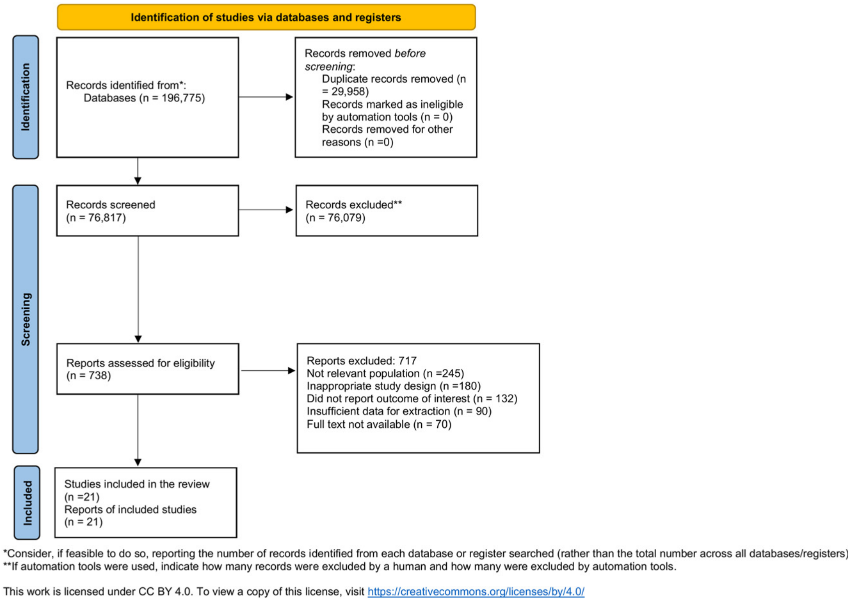

Figure 1: PRISMA 2020 flow diagram illustrating the study selection process for the systematic review and meta-analysis.

associations between risk factors and adolescent overweight or obesity. Overall, the studies demonstrated acceptable methodological quality. Most clearly defined exposures and outcomes, and employed validated adiposity indicators. Nonetheless, variation in measurement protocols and obesity classification cut-off values contributed to moderate heterogeneity in effect estimates. Descriptive differences were also observed across regions, with some stronger associations reported in studies from East Asia. However, formal meta-analyses by region were not performed due to the limited number of studies available per region.

Subgroup analysis by adiposity indicator

Pooled effect sizes differed by adiposity indicator, indicating variability in measurement performance and association strength. Studies using BMI demonstrated a significant association with adolescent obesity (OR: 1.30; 95 % CI: 1.06–1.60; p=0.010; I^2=76 %), albeit with high heterogeneity. Waist-to-height ratio (WHtR) showed a stronger and more consistent association (OR: 1.56; 95 % CI: 1.08–2.25; p=0.020; I^2=0 %). Waist circumference also showed a modest but significant association (OR: 1.09; 95 % CI: 1.02–1.17; p=0.010; I^2=0 %). These findings suggest the importance of adiposity indicator selection when evaluating obesity risk in adolescents (see Table 2 and Figure 2).

A Funnel plot was generated to assess publication bias across the included studies (Figure 3). The distribution of studies appeared generally symmetrical, indicating a low likelihood of publication bias. Minor asymmetry observed in the BMI subgroup may reflect small-study effects or underlying heterogeneity.

The meta-analysis identified several key risk factors significantly associated with adolescent obesity. Low physical activity (OR: 2.48; 95 % CI: 2.02–3.05) and environmental exposures (OR: 3.10; 95 % CI: 2.44–3.94) were the strongest correlates, suggesting their modifiability as intervention targets. Although dietary patterns (OR: 1.49; 95 % CI: 0.86–2.57) showed a positive trend, the association was not statistically significant. Socioeconomic status (OR: 0.94; 95 % CI: 0.74–1.18) showed no significant relationship, indicating a potentially complex or context-specific interaction. Genetic predisposition (OR: 1.54; 95 % CI: 0.98–2.42)

Table 2: Pooled odds ratios of risk factors for adolescent obesity by adiposity indicator.

Adiposity indicator	No. of studies	Pooled OR (95 % CI)	p-Value	I^2 (%)	Interpretation
BMI indicator	7	1.30 (1.06–1.60)	0.010	76	Significant association with obesity, but high heterogeneity (76 %).
WHR (waist-to-height ratio)	3	1.56 (1.08–2.25)	0.020	0	Significant association with obesity, with no heterogeneity (0 %).
Waist circumference	3	1.09 (1.02–1.17)	0.010	0	Modest significant association with obesity, with no heterogeneity (0 %).
Total (all indicators)	13	1.19 (1.08–1.30)	0.002	63	Significant association with obesity, with moderate heterogeneity (63 %).

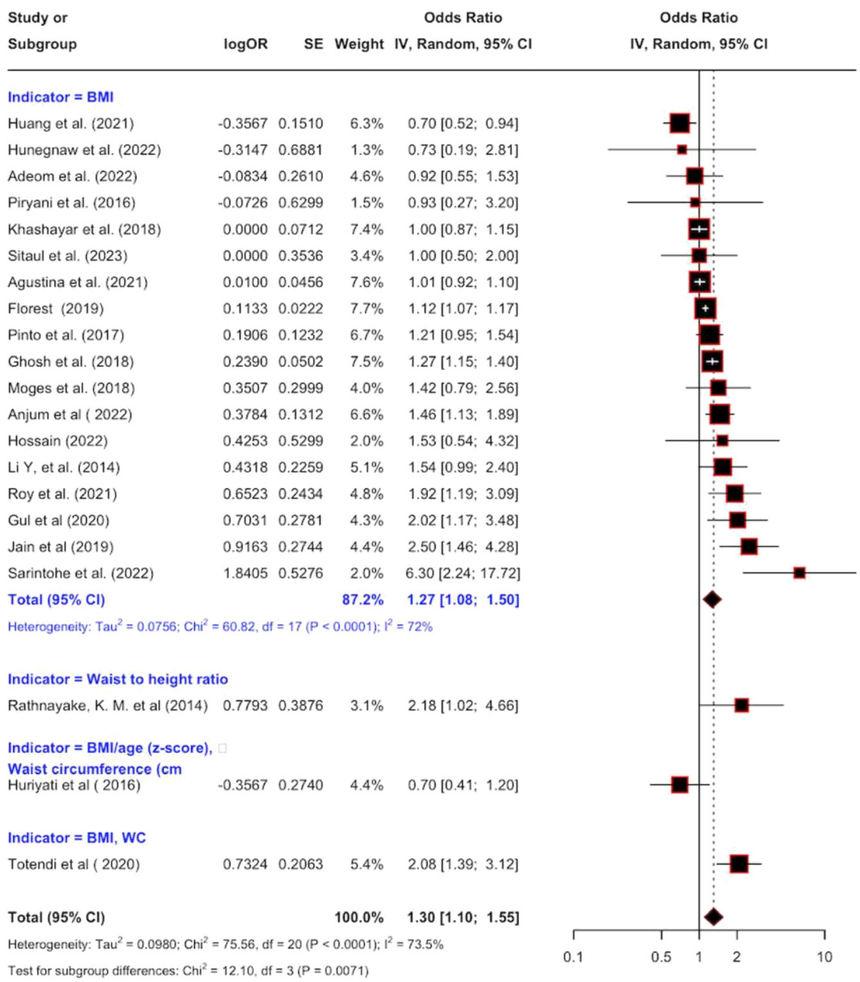

Figure 2: Forest plot of pooled odds ratios for adolescent obesity by adiposity indicators (subgroup analysis).

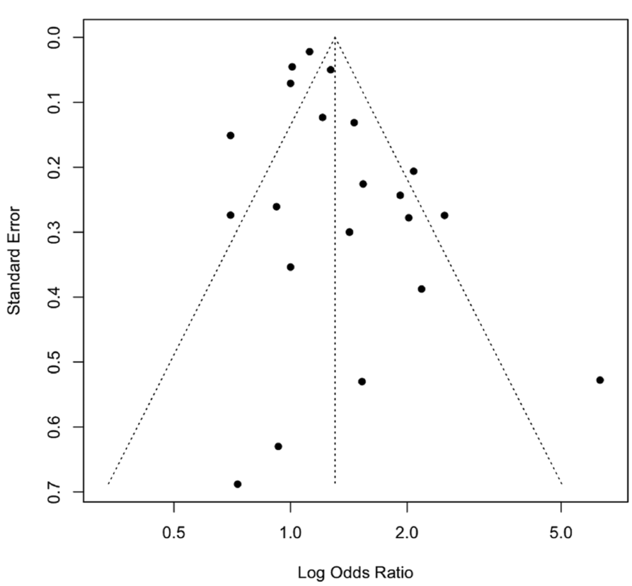

Figure 3: Funnel plot of studies assessing the association between contextual risk factors and adolescent obesity, stratified by adiposity indicator. Each marker represents a single study: Circles for BMI, triangles for WHtR, and crosses for waist circumference.

and physical stress (OR: 1.29; 95 % CI: 1.08–1.54) were also notable contributors, reinforcing the multifactorial aetiology of adolescent obesity. These findings highlight the need for integrative, multilevel strategies that address behavioral, environmental, and biological determinants in adolescent populations within LMICs (see Table 3 and Figure 4).

Publication bias assessment

Publication bias was evaluated through visual inspection of funnel plots (see Figure 2). The funnel plot for physical activity demonstrated a largely symmetrical distribution, indicating a low risk of publication bias. Similar patterns were observed for other major risk factors, including dietary patterns and socioeconomic status, suggesting minimal small-study effects. However, the interpretation of funnel plot asymmetry remains limited due to the small number of included studies for several risk factors (n<10), which may reduce the sensitivity of bias detection.

Table 3: Pooled odds ratios of adolescent obesity risk factors across adiposity indicators in LMICs (n=21 studies).

Risk Factor	No. of studies	Included studies	Pooled OR (95 % CI)	p-Value
Physical activity	6	Piryani (2016), Moges (2018), Agustina (2021), Huang (2021), Adeomi (2022), Hunegnaw (2022)	2.48 [2.02; 3.05]	0.1437
Environment	4	Khashayar (2018), Roy (2021), Agustina (2021), Sarintohe (2022)	3.10 [2.44; 3.94]	<0.0001
Dietary pattern	4	Rathnayake (2014), Priyani (2016), Khashayar (2018), Sitaula (2023)	1.49 [0.86; 2.57]	0.0116
Socioeconomic status (SES)	6	Piryani (2016), Moges (2018), Agustina (2021), Huang (2021), Adeomi (2022), Hunegnaw (2022)	0.94 [0.74; 1.18]	0.2091
Genetic	6	Li (2014), Huriyati (2016), Gul (2017), Ghosh (2018), Jain (2019), Todendi (2020)	1.54 [0.98; 2.42]	0.0020
Physical stress	5	Pinto (2017), Roy (2021), Anjum (2020), Hossain (2022), Plores (2019)	1.29 [1.08; 1.54]	0.0557

OR, odds ratio; CI, confidence interval; LMICs, low- and middle-income countries.

Discussion

This meta-analysis, based on 21 LMIC-based observational studies using multiple anthropometric indicators, advances understanding of adolescent obesity by situating risk within social-ecological frameworks and interacting social and health determinants. Our findings underscore that obesity is a result of interacting individual, environmental, and structural determinants. **Environmental determinants** demonstrated the strongest association with adolescent obesity (pooled OR: 3.10; 95 % CI: 2.44–3.94), reflecting the critical influence of built and food environments in shaping health behaviors. The absence of green spaces, pedestrian infrastructure, or recreational facilities, and the high prevalence of ultra-processed foods, are hallmarks of obesogenic environments in rapid urbanization contexts across LMICs [37]. These structures align with Swinburn et al.'s *obesogenic environment* theory, where urban infrastructure constrains active choices and facilitates sedentary, energy-dense lifestyles. **Low physical activity** also showed a significant association (OR: 2.48; 95 % CI: 2.02–3.05), consistent with evidence that more walkable urban environments lead to higher activity levels [38]. In LMIC contexts, barriers such as unsafe streets, pollution, and academic overload further suppress adolescent movement – underscoring a structural deficit rather than personal choice. **Psychosocial stress** (OR: 1.29; 95 % CI: 1.08–1.54) adds an important dimension reflecting allostatic load induced by poverty, family insecurity, and academic pressure. Chronic stress may trigger hormonal dysregulation and behavioral coping (e.g. emotional eating), which are often under addressed in LMIC health frameworks. **Dietary patterns** were moderately associated with obesity (OR: 1.49; 95 % CI: 0.86–2.57), albeit with heterogeneity in assessment. LMIC dietary transitions characterized by affordability and aggressive marketing of ultra-processed foods drive poor diet quality, especially among adolescents in urban poor settings [39]. **Genetic predisposition** (OR: 1.54; 95 % CI: 0.98–2.42) was also relevant, consistent with polymorphisms in genes such as UCP2, FTO, and MC4R influencing obesity. Importantly, genetic effects are context-dependent and may manifest strongly in obesogenic environments, highlighting the importance of **gene–environment interactions** [40]. This emphasizes that genetic susceptibility alone is insufficient to explain obesity risk; its impact is amplified by environmental and behavioral factors. Clustering of psychosocial stress, poor diet, and inactivity suggests synergistic interactions that amplify obesity risk, warranting integrated prevention approaches. **Socioeconomic status (SES)** was not significantly associated (OR: 0.94; 95 % CI: 0.74–1.18), diverging from high-income patterns. In early nutrition transition phases, higher SES may facilitate access to sedentary lifestyles and processed diets; this gradient often inverts at later stages of economic development. This complexity underscores the need for contextually nuanced SES measures and interpretations.

This meta-analysis based on Table 1 highlights the multilevel determinants of adolescent obesity in LMICs, consistent with the Social Ecological Model and the Global Syndemic framework. Risk factors span individual behaviors, family norms, built environment, and broader structural conditions such as food systems and urban design. Central adiposity indicators (BMI, WC, WHtR) showed stronger associations with environmental and psychosocial risks than BMI alone, suggesting the need for more sensitive anthropometric tools in LMICs. Heterogeneity in study design and regional disparities warrant cautious interpretation. Future research should standardize adiposity measurement, adopt longitudinal approaches, and address evidence gaps in underrepresented LMIC regions. These findings reinforce the urgency for multisectoral obesity prevention strategies in LMICs, targeting urban infrastructure, food policy, and adolescent mental health [41]. This meta-analysis identifies key modifiable and contextual risk factors contributing to adolescent obesity in LMICs. Physical inactivity, environmental influences, poor dietary habits, and genetic predisposition significantly

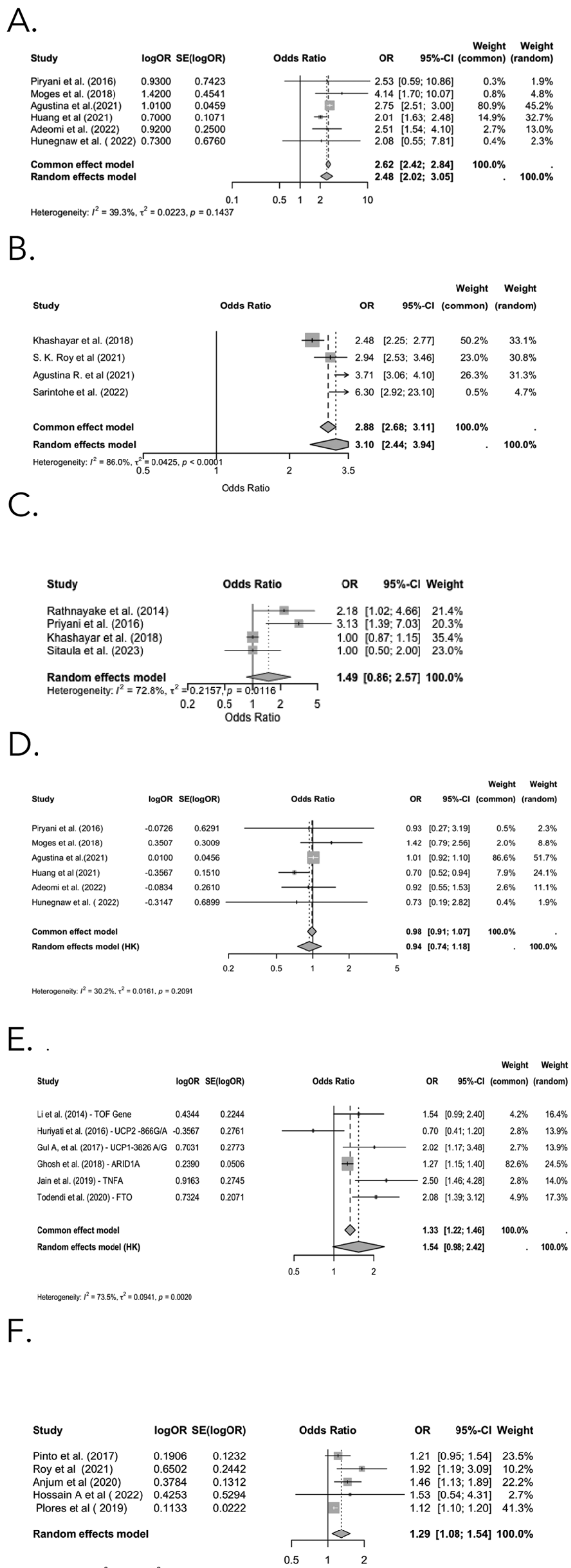

Figure 4: Forest plot illustrating the risk factors for adolescent obesity in LMICs, including are; (A) physical activity, (B) environment, (C) dietary pattern, (D) socioeconomic status (SES), (E) genetic, (F) physical stress.

increase obesity risk. Importantly, waist-based measures (WC, WHtR) outperform BMI in detecting adiposity. These findings support the development of integrated, youth-centered interventions that address behavioral, structural, and genetic determinants using appropriate anthropometric tools.

Strengths and limitations

This meta-analysis offers several strengths, including wide geographical representation across LMICs, incorporation of multiple adiposity indicators (BMI, WC, WHtR), and robust subgroup and sensitivity analyses. The inclusion of a broad spectrum of risk factors, genetic, behavioural, environmental, and socioeconomic, enhances contextual relevance. However, the predominance of cross-sectional designs limits causal inference. Heterogeneity in exposure assessment (diet, physical activity, stress) and adiposity measurement may introduce misclassification and limit comparability. Additionally, the genetic analysis may be limited by heterogeneity in genotyping methods and the lack of standardized genetic markers across studies. Although publication bias was assessed, it cannot be fully excluded. Regional gaps, particularly in Latin America and the Middle East, underscore the need for longitudinal, culturally tailored research to inform effective obesity prevention in LMIC adolescents. Future research should prioritize longitudinal designs and standardized risk factor assessment to strengthen causal interpretations and intervention development.

Ethical considerations

This study involved the secondary analysis of data from previously published peer-reviewed articles. Therefore, no ethical approval was required, and no patients or members of the public were directly involved in the conduct of this research.

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Research ethics: Not applicable. This study is a systematic review and meta-analysis and does not involve any individual human participants or identifiable data.

Informed consent: Not applicable.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission. Ee. conceptualized the review, conducted the literature search, and drafted the manuscript.

IN. and DN, TW. independently screened and extracted data. T.W. performed statistical analyses and reviewed the final draft.

Use of Large Language Models, AI and Machine Learning Tools: None declared.

Conflict of interest: The authors state no conflict of interest.

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Data availability: The data supporting the findings of this study are available within the article and its supplementary materials. Further details are available from the corresponding author on reasonable request.

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