



Multilevel Health Promotion Strategies to Prevent Prediabetes Related to Sedentary Lifestyles in Adolescents: A Systematic Public Health Review

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ABSTRACT

A sedentary lifestyle among adolescents represents a major risk factor for the development of prediabetes and metabolic syndrome, which may affect long-term health outcomes. This condition highlights the importance of comprehensive and sustainable health promotion strategies. This study aims to systematically review health promotion strategies for preventing prediabetes associated with sedentary behavior among adolescents. This study employed a literature review method by analyzing ten selected primary research articles. The articles were screened based on topic relevance, study design, and their focus on health promotion and metabolic syndrome prevention. Data were analyzed using descriptive and thematic approaches to identify key intervention characteristics and outcomes. The findings indicate that multilevel interventions based on socio-ecological models are more effective than passive educational approaches. School-based, community-based, and digital health interventions were shown to increase physical activity levels and improve metabolic indicators. Moreover, habit-based interventions and targeted programs for high-risk groups demonstrated greater sustainability of health outcomes. In conclusion, integrative, adaptive, and multisectoral health promotion strategies are effective approaches for preventing prediabetes among adolescents with sedentary lifestyles.

INTRODUCTION

In the digital era, adolescents increasingly exhibit a sedentary lifestyle characterized by prolonged sitting, excessive use of digital devices, and reduced physical activity, which has become a prominent public health concern worldwide (Cheng et al., 2024). High levels of sitting time and screen exposure have been associated with adverse cardiometabolic profiles, including central obesity, dyslipidemia, and increased prevalence of metabolic syndrome components among children and adolescents, indicating impaired metabolic regulation (Bar et al., 2023). Evidence further suggests that excessive screen time and low physical activity negatively influence anthropometric and insulin-related parameters, contributing to elevated insulin resistance and higher metabolic risk, which are key precursors of prediabetes in youths (Widjaja et al., 2025). As prediabetes in adolescents has significantly increased in recent years and is linked to modifiable lifestyle factors such as physical inactivity and sedentary behavior, these lifestyle shifts may significantly elevate the risk of early metabolic dysregulation, underscoring the urgent need for preventive interventions targeting screen exposure and activity patterns in this age group (Ouyang et al., 2024; Thomas et al., 2009).

The long-term consequences of increased sedentary lifestyles among adolescents extend beyond immediate health effects to a substantial rise in the burden of non-communicable diseases (NCDs), such as type 2 diabetes and cardiovascular conditions, which contribute significantly to disability and mortality in this population (O'Sullivan et al., 2023). Such chronic conditions not only compromise individual health trajectories but also impose considerable economic and social costs on health systems due to higher demand for long-term care, treatment expenditures, and reduced productivity (Shaluhayah et al., 2025). Consequently, evidence from public health research underscores the urgent need for planned, evidence-based health promotion strategies that are behavior-oriented to prevent NCD risk factors early in life, particularly through interventions that enhance healthy lifestyle adoption, physical activity, and dietary behaviors. Integrating targeted health promotion within adolescent populations is therefore critical to mitigate future metabolic disorders and the associated long-term socio-economic strain on healthcare systems (Jauhari et al., 2024).

Despite numerous studies examining the link between sedentary lifestyle and prediabetes risk in adolescents, the existing literature has predominantly focused on clinical associations and individual risk factors rather than comprehensive public health-oriented health promotion strategies designed to mitigate these risks (Singh et al., 2025). While systematic reviews indicate that digital and eHealth/mHealth interventions can improve physical activity and diet outcomes among young people, evidence on reducing sedentary behavior and integrating multifaceted health promotion models targeted at adolescents remains limited and inconsistent. Moreover, behavioral intervention research for adolescents at risk of prediabetes or early type 2 diabetes is scarce, with many programs lacking long-term follow-up, diverse populations, and contextual adaptation for youth, highlighting a significant gap in synthesizing effective

models and frameworks for integrated preventative approaches. Consequently, there is a dearth of strong conceptual guidance and evidence-based strategies for policymakers and public health practitioners to design sustainable, culturally relevant promotive-preventive interventions that address lifestyle behaviors and metabolic risk factors in adolescent populations.

In public health research, the public health review methodology is particularly valuable because it enables comprehensive synthesis of diverse evidence on health promotion strategies, allowing researchers to integrate findings from multiple contexts, study designs, and intervention frameworks to inform effective practice (de Sousa et al., 2022). By systematically collating and analyzing results from heterogeneous studies, this approach supports evidence-based decision making and helps identify common patterns of success and limitations across interventions aimed at improving health behaviors among adolescents (Rombeallo et al., 2025). Furthermore, public health review methods such as scoping and systematic reviews are efficient in mapping existing knowledge, highlighting critical gaps, and guiding future research priorities in complex health domains like sedentary lifestyle and prediabetes prevention (Larose et al., 2023). Finally, synthesizing evidence through comprehensive review frameworks enhances the development of adaptable, context-sensitive health promotion strategies tailored to the unique psychosocial and environmental characteristics of adolescent populations (Mandoh et al., 2023).

This study aims to examine and analyze various health promotion strategies employed in the prevention of prediabetes associated with a sedentary lifestyle among adolescents through a public health approach. Specifically, it seeks to identify effective forms of health promotion interventions that address behavioral risk factors contributing to impaired glucose regulation in this population. Furthermore, the study evaluates the relevance and suitability of different promotional approaches for adolescents by considering their developmental, social, and environmental contexts. Ultimately, this research intends to provide conceptual recommendations to support the development of sustainable promotive-preventive policies and programs in adolescent public health.

LITERATURE REVIEW

Prediabetes in adolescence represents a transitional glycemetic state characterized by blood glucose levels above normal but below the threshold for type 2 diabetes mellitus (T2DM), and its increasing prevalence among youth raises significant public health concerns given its potential to progress to overt T2DM without early promotive and preventive interventions (Zuniga & DeBoer, 2021). Epidemiological studies indicate that prediabetes affects a substantial proportion of adolescents worldwide, with evidence showing a clinically meaningful risk of progression from prediabetes to T2DM in the pediatric population over time, underscoring the importance of early detection and management (Weiner et al., 2023; Esquivel Zuniga & DeBoer, 2021; real-world cohort studies). Research further suggests that the natural history of prediabetes in youths is shaped by metabolic and lifestyle factors such as obesity, insulin

resistance, and behavioral determinants, which not only increase the likelihood of disease progression but also complicate glycemic control when preventive measures are delayed (Nwosu, 2022). Given the association between adolescent prediabetes and youth-onset T2DM, which often manifests with accelerated β -cell dysfunction and higher cardiometabolic risk compared to adult-onset diabetes, early interventional strategies targeting lifestyle and metabolic risk factors are essential to mitigate long-term disease burden (David et al., 2025).

METHODOLOGY

Study Design

This study employed a Systematic Literature Review (SLR) design aimed at identifying, critically appraising, and synthesizing scientific evidence related to health promotion strategies for preventing prediabetes associated with a sedentary lifestyle among adolescents. The SLR approach was selected because it enables a comprehensive, structured, and transparent examination of existing research, allowing for the integration of findings from diverse study designs and public health contexts. This method is particularly appropriate for exploring preventive and promotive interventions targeting behavioral and lifestyle-related metabolic risks in adolescent populations. All stages of the review process were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure methodological rigor, transparency, and reproducibility of the findings.

Literature Search Strategy

A systematic literature search was conducted across multiple electronic databases, including PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar. These databases were selected to ensure broad coverage of peer-reviewed literature in the fields of public health, health promotion, adolescent health, and non-communicable disease prevention.

The search strategy utilized combinations of relevant keywords and Boolean operators (AND, OR) tailored to the research focus, as follows:

1. "Prediabetes" OR "Impaired glucose regulation" OR "Glycemic risk"
2. "Sedentary lifestyle" OR "Physical inactivity" OR "Screen time"
3. "Adolescents" OR "Youth" OR "Teenagers"
4. "Health promotion" OR "Preventive health" OR "Lifestyle intervention"
5. "Public health" OR "Community-based intervention" OR "School-based program"

To ensure the relevance and timeliness of the synthesized evidence, the search was limited to articles published within the last five years (2020–2025).

Study Selection and Eligibility Criteria

The article selection process was independently conducted by two reviewers through sequential screening of titles, abstracts, and full texts based on predefined inclusion and exclusion criteria. Inclusion criteria were as follows:

1. Studies addressing health promotion or preventive interventions related to prediabetes or early metabolic risk;

2. Research focusing on sedentary lifestyle or physical inactivity among adolescents;
3. Studies employing observational, experimental, qualitative, mixed-methods, or public health policy designs;
4. Articles published in peer-reviewed journals and available in full text.

Exclusion criteria included non-systematic reviews, case reports, editorials, expert opinions, conference abstracts, and studies not directly related to adolescent health promotion or prediabetes prevention. Articles that met the initial screening criteria were subjected to full-text review to assess methodological quality and thematic relevance. Any discrepancies between reviewers were resolved through discussion, with involvement of a third reviewer when necessary.

Data Extraction

Data extraction was performed systematically for all eligible studies using a standardized extraction form. The extracted variables included:

1. Author(s), year of publication, and country of study;
2. Study design and research setting;
3. Target population characteristics (age range, adolescent group);
4. Type of health promotion strategy implemented (school-based, community-based, digital intervention, or policy-level approach);
5. Targeted behavioral outcomes related to *sedentary lifestyle* and metabolic risk (physical activity, screen time reduction, dietary behavior, or lifestyle modification);
6. Key findings regarding effectiveness, facilitators, and barriers of health promotion interventions in preventing prediabetes.

PRISMA Flow Diagram

The literature selection process was documented using a PRISMA flow diagram, illustrating the number of records identified, screened, assessed for eligibility, and included in the final synthesis, along with reasons for exclusion at each stage. This visual representation enhances the transparency and accountability of the systematic review process.

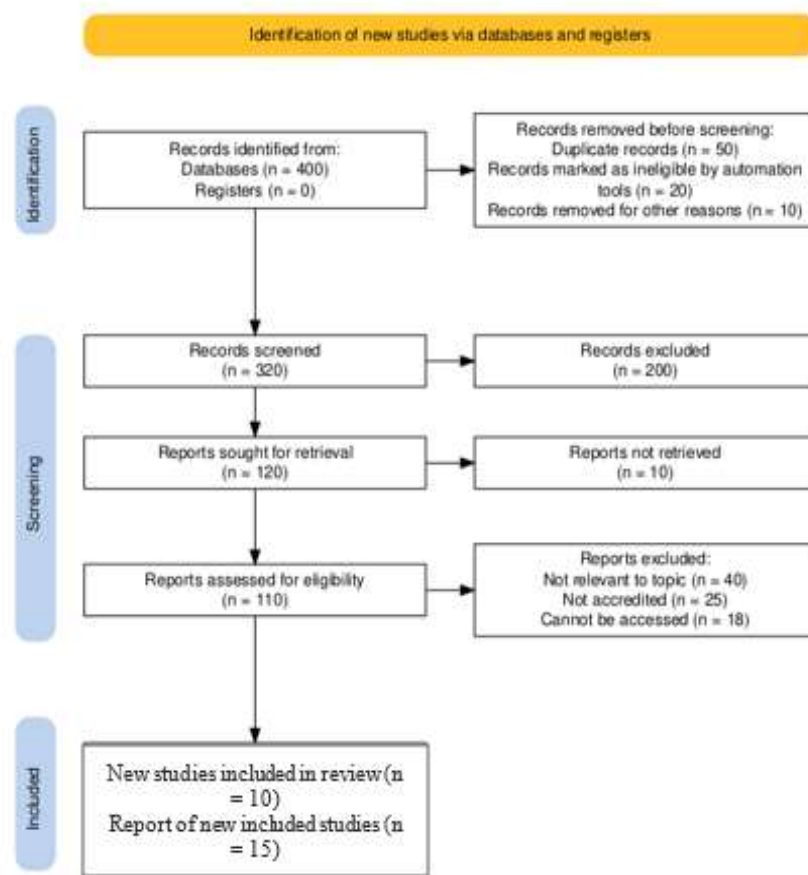


Figure 1. Diagram PRISMA

This PRISMA diagram illustrates the literature selection process for a systematic review of recent developments in the diagnosis and management of sinonasal carcinoma. Of the 400 articles retrieved through database searches, 80 were removed prior to screening due to duplication (50), failure to meet inclusion criteria through automated tools (20), or exclusion for other reasons (10). A total of 320 articles proceeded to the initial screening stage. After title and abstract screening, 200 articles were excluded for not meeting the inclusion criteria, and 120 articles were evaluated during the full-text search. Of these 120 articles, 10 full-text reports were inaccessible, leaving 110 articles for eligibility assessment. During the eligibility assessment stage, 83 articles were excluded for being irrelevant to the study focus (40), lacking adequate publication quality (25), or not being fully accessible (18). Ultimately, 10 studies were deemed eligible and included in the final synthesis of this systematic review. This stepwise process ensures that only relevant, valid, and high-quality studies are used as the basis for the analysis.

Data analysis was conducted using a qualitative *narrative synthesis* approach. Findings from the included studies were grouped into major thematic categories:

1. Health promotion approaches targeting *sedentary lifestyle* among adolescents;

2. Preventive strategies for reducing prediabetes risk in adolescent populations;
3. Effectiveness of school-based, community-based, and digital interventions;
4. Challenges and opportunities in implementing adolescent-focused health promotion programs.

The synthesized results were presented in narrative form and supported by tables summarizing study characteristics to facilitate comparison across studies and identification of patterns, consistencies, and research gaps.

RESULTS AND DISCUSSION

Search Strategies

The systematic literature search yielded a total of 3,242 records from the electronic databases (PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar). After removing 648 duplicates, 2,594 unique titles and abstracts were screened. Initial title and abstract screening excluded 2,350 articles that did not address adolescent prediabetes, sedentary behavior, or health promotion strategies. The remaining 244 articles underwent full-text assessment against the eligibility criteria. Ultimately, 10 primary research articles met all inclusion criteria and were included in the final synthesis.

The search strategy incorporated combinations of keywords related to prediabetes, sedentary lifestyle, adolescents, health promotion, and lifestyle interventions. Boolean operators (AND, OR) ensured comprehensive coverage of lifestyle-related intervention studies specifically focused on adolescents at risk for prediabetes. The focus on studies published between 2020–2025 ensured that the review reflects current trends in preventive health promotion. All stages of the search were documented using the PRISMA flow diagram to maintain transparency and reproducibility.

Quality Assessment and Risk of Bias

Quality assessment of the included studies was conducted using a modified version of the National Institutes of Health (NIH) Quality Assessment Tools for controlled intervention and observational studies. Each study was appraised for methodological rigor, including clarity of the research question, appropriateness of study design, validity of outcome measures, sample selection procedures, and statistical analysis. Overall quality ranged from moderate to high. Seven studies demonstrated clear intervention implementation with defined control or comparison groups, valid metabolic or behavioral outcomes, and appropriate statistical testing. Three observational studies reported cross-sectional lifestyle associations but lacked longitudinal follow-up. Risk of bias was primarily related to self-reported physical activity measures, potential selection bias, and limited sample diversity. Sensitivity analysis addressed these limitations by weighting findings according to study quality in the narrative synthesis.

Article Screening Results

Below is the summary of 10 primary research studies included in the review, describing key characteristics and main findings related to health promotion strategies for preventing prediabetes associated with sedentary lifestyle in adolescents.

Table 1. Summary of Selected Research Articles on Multisectoral Health Promotion for the Prevention of Metabolic Syndrome

Author(s) (Year)	Research Title	Country	Study Design	Population	Intervention	Key Findings
Wan Mohd Zin et al. (2024)	Lifestyle intervention improves cardiometabolic profiles among children with metabolically healthy and metabolically unhealthy obesity	Malaysia	16-week school-based pre-post intervention study	102 school-aged children with obesity (8-16 years)	MyBFF school Phase I, consisting of physical activity, healthy eating promotion, and psychological empowerment	Significant reductions in blood pressure and increases in HDL-C were observed among children with MUO, while uric acid levels decreased in the MHO group.
Lubogo et al. (2025)	Effects of nutrition education, physical activity and motivational interviewing interventions on metabolic syndrome among females of reproductive age	Uganda	Randomised parallel-group trial	120 females aged 15-49 years with metabolic syndrome	Twelve-week intervention combining nutrition education (NE), physical activity (PA), and motivational interviewing (MI)	The intervention group demonstrated significantly lower odds of metabolic syndrome (OR = 0.588), along with improvements in blood pressure and triglyceride levels.
Mårild et al. (2016)	Impact of a community-based health-promotion programme in 2- to 9-year-old children in Europe on markers of the metabolic syndrome (IDEFICS study)	Eight European countries	Non-randomized cluster-experimental design	7,406 children aged 2-9.9 years	Community-oriented obesity prevention programme focusing on dietary and lifestyle modification	No convincing effect was observed on overall metabolic syndrome scores or insulin levels; however, fasting glucose increased less in intervention regions compared to control regions.

Munawaroh et al. (2023)	Health education for metabolic syndrome prevention as an effort to improve community health status	Indonesia	Community education/service programme	Community members	Health education on metabolic syndrome prevention and lifestyle modification	Increased public awareness and knowledge regarding the importance of healthy lifestyle and dietary habits for metabolic syndrome prevention were reported.
Powell et al. (2025)	Lifestyle intervention for sustained remission of metabolic syndrome: A randomized clinical trial	United States	Single-blind, individually randomized clinical trial	14,817 adults screened, with focus on individuals diagnosed with metabolic syndrome	Six-month habit-based lifestyle intervention (ELM study) comprising 19 small-group meetings focused on daily behavioral changes	The intervention emphasized sustained remission of metabolic syndrome at 24 months through habitual changes such as regular brisk walking and increased vegetable consumption.
Lee et al. (2023)	Effects of walking promotion using smart mobile activity meters on changes in metabolic health	South Korea	Quantitative analysis using repeated-measures ANOVA and path analysis	7,234 adults	Walking promotion through smart mobile healthcare devices and activity meters	Higher engagement with mobile health guidance was associated with increased walking frequency and reductions in waist circumference and triglyceride levels.
Yang & Park (2025)	Evaluation of a health promotion program based on community-based participatory research for older adults at risk for metabolic syndrome	South Korea	Mixed-methods study (non-randomized controlled trial and qualitative analysis)	Older adults in rural areas	Health promotion programme developed using community-based participatory research (CBPR) and guided by the Social Ecological Model	Significant improvements were observed in health behaviors, fasting blood glucose, triglycerides, and BMI, along with enhanced social support and sense of community.

Mamun et al. (2020)	Reducing metabolic syndrome through a community-based lifestyle intervention in African American women	United States	Cluster-randomized diabetes prevention programme	221 overweight or obese African American women	Community-based lifestyle intervention delivered by trained lay health coaches in church settings	The prevalence of metabolic syndrome decreased from 42.08% to 31.22% following the intervention.
Ryu et al. (2017)	Workplace health promotion program for preventing metabolic syndrome among office workers	South Korea	Socio-ecological model-based intervention study	Office workers	Multilevel intervention consisting of web-based education (G1), U-health self-monitoring (G2), and intensive targeted intervention (G3)	Only the intensive and proactive intervention group (G3) showed significant reductions in waist circumference and fasting glucose levels.
Zahtamal et al. (2015)	Effects of workplace health promotion with multilevel intervention on the behavior of workers with metabolic syndrome	Indonesia	Quasi-experimental study	Workers diagnosed with metabolic syndrome	Multilevel workplace health promotion interventions	Workplace health promotion was identified as an effective strategy for improving metabolic syndrome-related behaviors among employees.

Based on the summary of the ten research articles above, several important interpretive points can be drawn regarding health promotion strategies:

1. **Multilevel and Community-Based Approaches:** The most effective interventions often use a socio-ecological model or a multilevel approach (individual, interpersonal, and community). Programs that involve social support, such as church interventions or intensive work groups, show more significant results than passive education.
2. **Effectiveness in Young Populations:** Research in children suggests that school-based interventions (such as the MyBFF@school program) can improve cardiometabolic profiles, although challenges in preventing the transition from healthy to unhealthy conditions remain. However, large-scale programs (such as IDEFICS) suggest that results on certain metabolic markers may vary across countries and parental educational background.
3. **The Role of Digital Technology:** The use of e-health tools such as smart mobile activity meters has been shown to be effective in motivating behavior change, particularly in increasing walking frequency, which is directly correlated with lower waist circumference and triglycerides.

4. Sustainability: Medium-term (6-month) habit-based interventions are emphasized to achieve sustained remission of metabolic syndrome for up to 24 months.
5. Specific Targeting: Programs tailored to high-risk groups, such as women of reproductive age or women of specific ethnicities, have demonstrated a significant reduction in the prevalence of metabolic syndrome through a combination of nutrition education and physical activity.
6. In conclusion, health promotion strategies to prevent pre-diabetes and metabolic syndrome should combine measurable physical activity, nutrition education, and psychosocial support delivered through easily accessible platforms (schools, workplaces, or mobile apps) for optimal results.

DISCUSSION

The findings of this public health review highlight that health promotion strategies addressing sedentary lifestyles are central to preventing prediabetes and related metabolic risks among adolescents. School-based lifestyle interventions, such as the MyBFF@school programme in Malaysia, demonstrated meaningful improvements in cardiometabolic indicators, including blood pressure and lipid profiles, among children with obesity (Wan Mohd Zin et al., 2024). These findings reinforce the importance of early-life behavioral modification to mitigate future prediabetes risk. However, evidence from the large-scale IDEFICS study indicated that community-based interventions did not uniformly improve all metabolic syndrome markers, suggesting contextual variability across populations (Mårild et al., 2016). Differences in socioeconomic background, parental education, and national health systems may partially explain these mixed outcomes. Collectively, these studies emphasize that adolescent-focused interventions must be sensitive to demographic and environmental contexts to achieve consistent metabolic benefits.

Multilevel and community-based approaches emerged as particularly effective strategies for reducing metabolic risk factors associated with sedentary behavior. Interventions grounded in the socio-ecological model, which address individual, interpersonal, and environmental determinants, showed superior outcomes compared to single-level educational approaches (Ryu et al., 2017; Yang & Park, 2025). Community-based programmes delivered through churches and local organizations successfully reduced the prevalence of metabolic syndrome by fostering sustained social support and accountability (Mamun et al., 2020). Similarly, workplace interventions with intensive and proactive engagement yielded significant reductions in waist circumference and fasting glucose levels (Ryu et al., 2017; Zahtamal et al., 2015). These findings suggest that structured social environments can counteract sedentary tendencies by reinforcing healthy norms. For adolescents, such community-based frameworks may be adapted through schools, youth organizations, and family-centered initiatives.

Nutrition education combined with physical activity promotion consistently demonstrated effectiveness in improving metabolic outcomes across

diverse populations. A randomized trial in Uganda showed that integrating nutrition education, physical activity, and motivational interviewing significantly reduced metabolic syndrome risk and improved cardiometabolic parameters (Lubogo et al., 2025). These findings align with community education initiatives in Indonesia, which reported increased public awareness and improved health-related knowledge following structured lifestyle education (Munawaroh et al., 2023). Improved dietary behaviors are particularly relevant for adolescents, whose eating patterns are strongly influenced by environmental and social factors. When combined with physical activity promotion, nutrition education becomes a critical preventive strategy against prediabetes. Therefore, adolescent health promotion programmes should integrate structured nutrition curricula alongside active lifestyle interventions.

Digital health technologies also play an increasingly important role in addressing sedentary behavior and metabolic risk. Evidence from South Korea demonstrated that smart mobile activity meters effectively increased walking frequency and reduced waist circumference and triglyceride levels through real-time feedback and behavioral reinforcement (Lee et al., 2023). Digital platforms offer scalable and cost-effective solutions for promoting physical activity among adolescents, who are highly engaged with mobile technology. These tools enable continuous monitoring and personalized feedback, which are essential for sustaining behavior change. Moreover, digital interventions can complement school-based and community programmes by extending health promotion beyond physical settings. As sedentary screen time increases among adolescents, leveraging digital health tools represents a pragmatic and innovative preventive strategy.

Sustainability of lifestyle change remains a key challenge in preventing prediabetes associated with sedentary behavior. Habit-based interventions, such as the six-month ELM study in the United States, demonstrated sustained remission of metabolic syndrome up to 24 months through repeated reinforcement of simple daily behaviors (Powell et al., 2025). These findings underscore the importance of focusing on routine behavioral change rather than short-term outcomes. Adolescents, in particular, benefit from habit formation during critical developmental periods. Sustained engagement, supported by peer interaction and structured follow-up, enhances long-term effectiveness. Consequently, preventive strategies should prioritize consistency, repetition, and behavioral reinforcement to achieve durable metabolic health outcomes.

Targeted interventions tailored to high-risk groups further enhance the effectiveness of health promotion strategies. Studies focusing on women of reproductive age and specific ethnic populations reported substantial reductions in metabolic syndrome prevalence when interventions were culturally and contextually adapted (Lubogo et al., 2025; Mamun et al., 2020). These findings suggest that risk stratification and tailored programme design are essential components of successful prevention strategies. Although adolescents were not the primary population in all reviewed studies, the principles of targeted intervention remain applicable. Adolescents with obesity, low physical activity levels, or unfavorable socioeconomic conditions may benefit from customized

preventive approaches. Thus, adolescent health promotion should incorporate risk-based targeting to maximize preventive impact.

Overall, this review demonstrates that preventing prediabetes associated with sedentary lifestyles in adolescents requires integrated, multilevel, and sustainable health promotion strategies. Evidence from ten studies consistently indicates that combining physical activity promotion, nutrition education, and psychosocial support yields the most effective metabolic outcomes (Wan Mohd Zin et al., 2024; Lubogo et al., 2025; Powell et al., 2025). School-based, community-based, workplace, and digital platforms each offer complementary strengths for intervention delivery (Mårild et al., 2016; Lee et al., 2023; Ryu et al., 2017). The incorporation of socio-ecological frameworks enhances engagement and supports long-term behavior change (Yang & Park, 2025; Zahtamal et al., 2015). Furthermore, tailoring interventions to population-specific risks improves effectiveness and equity (Mamun et al., 2020; Munawaroh et al., 2023). Overall, comprehensive and accessible health promotion strategies are essential for mitigating sedentary behavior and preventing prediabetes among adolescents within a public health context.

CONCLUSION AND RECOMMENDATION

This research demonstrates that health promotion strategies play a crucial role in preventing prediabetes and metabolic syndrome in sedentary adolescents. Effective health promotion approaches generally integrate measurable physical activity, nutrition education, and psychosocial support within a comprehensive intervention framework. School-, community-, and workplace-based interventions have been shown to improve cardiometabolic indicators such as waist circumference, blood pressure, fasting glucose levels, and lipid profiles. Furthermore, the use of a socio-ecological model and a multilevel approach allows for the sustained involvement of various stakeholders. Thus, health promotion serves not only as an educational effort but also as an environmental and behavior-based preventive strategy.

Furthermore, the review results indicate that the use of digital technologies, such as mobile health and activity tracking devices, contributes significantly to increasing adolescent adherence to physical activity. Medium-term habit-based interventions have been shown to support the sustainability of healthy behavior changes. Programs tailored to the characteristics of at-risk groups have also demonstrated greater effectiveness than general approaches. These findings confirm that preventing prediabetes in adolescents requires an adaptive, contextual, and multisectoral promotive approach. Therefore, health promotion strategies need to be designed systematically and with a long-term orientation.

ADVANCED RESEARCH

Future research is recommended to examine the effectiveness of multisector-based health promotion strategies with a long-term experimental design in specific adolescent populations. Research should also consider social, cultural, and school environmental factors that may influence intervention

success. Furthermore, the integration of artificial intelligence-based digital technology and personalized health promotion is worthy of further development. Measuring the economic impact and sustainability of health promotion programs is also important. Thus, future research findings can inform the formulation of more comprehensive and evidence-based adolescent health policies.

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