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DETERMINANTS OF DIABETES MELLITUS PREVENTION IN ADOLESCENTS: A SYSTEMATIC REVIEW

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ABSTRACT

Prediabetes and type 2 diabetes mellitus (DM) in adolescents are increasing globally, highlighting the need for early prevention. This study aimed to synthesize evidence on determinants of DM prevention among adolescents. A systematic review following PRISMA guidelines was conducted on studies published between 2020 and 2025. The results show that DM prevention is influenced by multilevel factors, including individual (knowledge and self-efficacy), behavioral (diet and physical activity), family support, school environments, and sociocultural context, with lifestyle and school-based interventions demonstrating the most consistent improvements in behavioral and metabolic outcomes. In conclusion, effective DM prevention in adolescents requires integrated, multilevel strategies that address behavioral, psychosocial, and environmental determinants.

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1. INTRODUCTION

Prediabetes in adolescents has become a global public health issue that has increased significantly over the past two decades, along with the rising prevalence of obesity in younger age groups. National trend data in the United States show that the prevalence of prediabetes in adolescents aged 12–19 years increased from around 12% in the 1999–2002 period to more than 28% in 2015–2018, with the most notable increase among male adolescents and those who are obese [1]. This finding emphasizes that adolescence is a critical period for early intervention in preventing the development of long-term metabolic disorders.

Biologically, obesity in adolescents directly contributes to the occurrence of insulin resistance, which is the main mechanism in the development of prediabetes and type 2 diabetes mellitus. This condition is further exacerbated by hormonal changes during puberty that increase susceptibility to glucose metabolism disorders. In addition, the

latest global reports indicate that the prevalence of overweight and obesity in children and adolescents continues to rise until 2023, especially in middle- and high-income countries [2]. This indicates that the burden of diabetes disease in the future has the potential to increase if early intervention is not carried out.

The impact of prediabetes in adolescents is not limited to glycemic disorders, but is also closely related to an increased risk of other cardiometabolic conditions, such as dyslipidemia, hypertension, and central obesity. Longitudinal and cross-sectional studies show that adolescents with prediabetes have a worse cardiometabolic risk profile compared to normoglycemic adolescents [3]. This condition increases the likelihood of chronic complications occurring earlier in life, thereby reinforcing the importance of preventive efforts from adolescence.

In addition to biological factors, behavioral and psychosocial determinants also play an important role in the development of prediabetes in adolescents. Unhealthy eating patterns, low physical activity, as well as psychosocial factors such as stress, health perceptions, and social support have been shown to affect the risk and management of prediabetes [1]. Lifestyle-based interventions that include nutrition education, physical activity, and behavioral support have been shown to be effective in improving metabolic outcomes and quality of life in adolescents with prediabetes [3]. However, most research still focuses on biological outcomes, while broader determinant factors especially psychosocial and environmental aspects have not been comprehensively examined.

Although various studies have identified individual risk factors and evaluated the effectiveness of specific interventions, there is still a gap in the synthesis of evidence that systematically integrates the various determinants of diabetes prevention in adolescents. Most studies tend to examine factors separately, thus not providing a comprehensive picture of the interaction between biological, behavioral, and psychosocial factors in the context of prevention. Additionally, the increasing trend of prediabetes in adolescents indicates the urgency of understanding prevention determinants more comprehensively to support the design of effective and sustainable interventions.

Therefore, this systematic review aims to identify and analyze various determinants involved in the prevention of diabetes mellitus in adolescents, including biological, behavioral, and psychosocial factors. The results of this review are expected to provide a stronger scientific basis for the development of comprehensive and evidence-based prevention strategies to reduce the burden of diabetes in the future [4].

2. RESEARCH METHOD

2.1 Research Design

This study employed a Systematic Literature Review (SLR) design following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a transparent, structured, and reproducible review process. The PRISMA framework guided all stages of the review, including study identification, screening, eligibility assessment, and final inclusion. In addition, the review protocol was prospectively developed to enhance methodological rigor and minimize potential bias. Although prospective registration in public databases such as PROSPERO or the Open Science Framework (OSF) is considered a best practice, this study did not undergo formal registration due to time constraints and administrative limitations. Nevertheless, all review procedures were predefined and consistently applied to maintain methodological transparency and reduce the risk of bias.

The SLR approach was selected to systematically collect, critically evaluate, and synthesize empirical evidence related to diabetes mellitus (DM) prevention among adolescents. This design allows for a comprehensive understanding of existing research findings while minimizing bias through a rigorous and standardized procedure. The review specifically focused on prevention-related evidence, emphasizing modifiable risk factors, behavioral interventions, and early metabolic indicators relevant to adolescent populations, rather than treatment outcomes.

2.2 Clinical Question and Framework (PICO)

To identify the clinical questions, the researchers employed PICO (Population, Intervention, Comparison, and Outcomes). The research question was formulated using the PICO framework, which is widely applied in evidence-based health research to structure clinical:

Population	Adolescents aged approximately 10–19 years, the population included adolescents at risk for DM, such as those with overweight or obesity, impaired glucose tolerance, prediabetes, or general adolescent populations targeted for preventive education.
Intervension	Interventions and exposure factors related to DM prevention, including but not limited to: Lifestyle and health education programs, Physical activity interventions, etc.
Comparison	Usual care
Outcomes	Preventive outcomes relevant to DM risk reduction such us: knowledge, behavior change and perception.

2.3 Search Strategy

A comprehensive and systematic search was conducted across multiple international electronic databases, including PubMed, ScienceDirect, EBSCOhost, CINAHL, Scopus, and Google Scholar, to identify relevant studies on diabetes mellitus (DM) prevention among adolescents. The search covered publications from 2020 to 2025. The search was restricted to English-language articles to ensure consistency and accuracy in data interpretation; however, this restriction may introduce language bias and limit the generalizability of findings to non-English-speaking contexts.

Search terms were developed using a combination of Medical Subject Headings (MeSH) and free-text keywords. Boolean operators (AND/OR) were applied to refine the search strategy. An example of the search string used was: ("adolescent" OR "teenager") AND ("diabetes prevention" OR "type 2 diabetes risk") AND ("lifestyle intervention" OR "behavioral change"). To enhance the comprehensiveness of the review, manual screening of reference lists from selected articles was also performed to identify additional relevant studies. However, grey literature sources (such as conference proceedings, dissertations, and institutional reports) were not systematically searched, and no direct contact with field experts was undertaken. These limitations may have resulted in the omission of potentially relevant unpublished or non-indexed studies.

All retrieved records were exported and duplicate studies were removed prior to screening. The screening process was conducted in three stages: title screening, abstract screening, and full-text review. To enhance reliability, the screening and selection of studies were performed independently by two reviewers. Any disagreements between reviewers were resolved through discussion, and when necessary, consultation with a third reviewer. In addition, the reference lists of all included studies were manually screened to identify potentially relevant articles not captured in the initial database search.

Study quality was assessed using standardized and design-specific critical appraisal tools to ensure methodological rigor. The Joanna Briggs Institute (JBI) Critical Appraisal Checklists were applied for cross-sectional, cohort, and quasi-experimental studies, while the Cochrane Risk of Bias 2 (RoB 2) tool was used for randomized controlled trials. These instruments evaluate key domains such as selection bias, measurement validity, and confounding. The risk of bias assessment was conducted independently by two reviewers, with discrepancies resolved through consensus. The use of clearly defined and internationally recognized appraisal tools enhances transparency, allows reproducibility, and strengthens the credibility of the synthesized evidence.

2.4 Eligibility Criteria

Studies were included if they met all of the following criteria: (1) original empirical research published in international peer-reviewed journals, (2) study populations including adolescents or adolescent-relevant subgroups, (3) focus on diabetes mellitus (DM) prevention or reduction of diabetes risk factors, (4) reported behavioral, anthropometric, or metabolic preventive outcomes, (5) employed quantitative designs such as randomized controlled trials (RCTs), quasi-experimental studies, cohort studies, or cross-sectional studies, and (6) full-text articles available in English. Studies were excluded if they met any of the following criteria: (1) scoping reviews or protocol-only papers, (2) studies involving adult-only populations, (3) treatment-focused studies targeting adolescents with established DM without a prevention component, (4) conference abstracts, editorials, commentaries, or non-peer-reviewed literature, and (5) articles with non-accessible full text.

Following study selection, a structured data extraction process was conducted to ensure consistency and transparency. A standardized data extraction form was developed and pilot-tested on a subset of included studies to ensure clarity and completeness. The extracted data included key study characteristics such as author(s), year of publication, country, study design, sample size and participant characteristics, type of intervention or exposure, outcome measures (behavioral, anthropometric, and metabolic), and main findings related to DM prevention. Where applicable, effect sizes and statistical significance were also recorded. Data extraction was performed independently by two reviewers to minimize bias and enhance reliability. Any discrepancies in the extracted data were resolved through discussion and consensus, and when necessary, consultation with a third reviewer. This rigorous and transparent data extraction process enhances the reproducibility and methodological quality of the systematic review.

3. RESULT AND ANALYSIS

The study selection process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (Figure 1). A total of 1,248 records were identified across all databases. After duplicate removal and initial screening based on titles and abstracts, 111 articles were assessed for full-text eligibility. Of these, 15 studies met the predefined inclusion criteria and were included in the final synthesis.

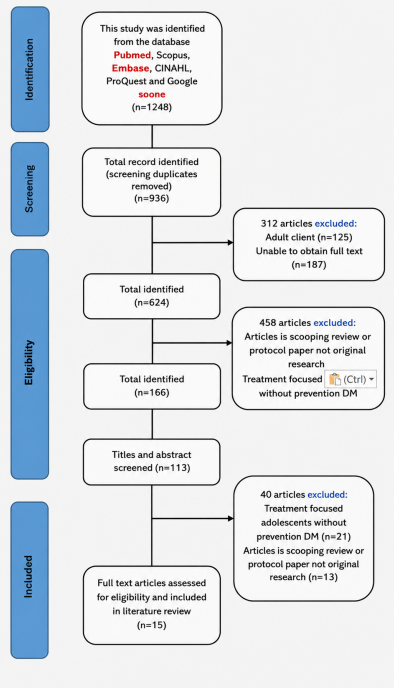

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA)

To improve transparency and interpretability, the included studies were synthesized using a narrative thematic synthesis approach, grouping evidence into four main domains: (1) individual and behavioral factors, (2) lifestyle and metabolic determinants, (3) family and household influences, and (4) school and sociocultural contexts. Given the heterogeneity of study designs (randomized controlled trials, quasi-experimental studies, cohort studies, and cross-sectional studies), a meta-analysis was not feasible. Instead, findings were interpreted by prioritizing higher levels of evidence, with greater weight given to randomized controlled trials and longitudinal intervention studies, followed by observational studies.

In addition, the methodological quality of each study was appraised using a standardized critical appraisal tool, and the risk of bias was evaluated across key domains such as selection bias, measurement bias, and confounding. Studies with higher methodological rigor and lower risk of bias were given greater consideration in drawing conclusions, thereby strengthening the validity of the synthesis. Across the 15 included studies, evidence consistently demonstrates that diabetes mellitus (DM) prevention among adolescents is influenced by multilevel determinants.

At the individual level, several high-quality intervention studies indicate that knowledge, risk perception, and self-efficacy are critical drivers of preventive behavior. Peer-led and theory-based educational interventions showed strong and consistent effects in improving diabetes-related knowledge, health beliefs, and behavioral intentions. These findings were particularly robust in randomized and school-based trials, suggesting moderate-to-high confidence in this domain. Regarding lifestyle and metabolic factors, there is strong evidence from intervention and systematic review studies that diet quality, physical activity, and sedentary behavior are key modifiable determinants. Interventions promoting balanced diets (e.g., reduced sugar intake and increased fiber consumption) and structured physical activity—especially combined aerobic and resistance training—were consistently associated with improvements in glycemic control, insulin sensitivity, and body composition. Evidence in this domain is supported by multiple higher-level study designs, indicating a relatively high level of confidence, although some variability exists in intervention duration and intensity.

The family and home environment emerged as an important reinforcing factor, particularly in studies involving adolescents with overweight or prediabetes. Family-based interventions demonstrated improved adherence and sustainability of lifestyle changes. However, as much of this evidence is derived from observational and quasi-experimental studies, the strength of evidence is considered moderate, with potential influence from confounding factors.

At the school and community level, multicomponent interventions integrating education, environmental modification, and social support showed consistent positive outcomes. Schools serve as effective platforms for large-scale prevention strategies. Additionally, culturally tailored and community-engaged interventions were associated with higher participation and acceptability, particularly among high-risk and minority populations. While findings are consistent, some studies show moderate risk of bias due to limited sample sizes or short follow-up periods.

Despite overall consistency, several limitations should be noted. The included studies varied in design, pop-

ulation characteristics, and outcome measures, which may affect comparability. Although efforts were made to assess study quality and risk of bias, residual bias cannot be fully excluded. Therefore, while the findings support a comprehensive, multilevel approach to DM prevention in adolescents, the strength of conclusions varies across domains, and results should be interpreted with consideration of the underlying evidence quality.

No	Title/Authors/ Year	Design	Participants	Key findings related to diabetes prevention in adolescents
1	High Prevalence of Prediabetes Among Asian and Pacific Islander Adolescents With Overweight or Obesity in a Primary Care Population [5]	Retrospective cross-sectional (EHR)	Adolescents aged 10–17 years with overweight/obesity; Asian/PI ($n = 16,508$) vs White ($n = 20,540$)	Prediabetes (HbA1c 5.7–6.4%) was higher in Asian/PI (26.9%) vs White (11.9%); aPR ~1.7–2.8 depending on ethnicity → highlights the need for targeted screening among high-risk adolescents.
2	The Prevalence of and Factors Associated with Prediabetes Among Adolescents in Central Sudan: A Community-Based Cross-Sectional Study [6]	Community-based cross-sectional	379 adolescents (~10–19 years) in East Gezira, Sudan; outcome: prediabetes HbA1c 5.7–6.4%	Prediabetes prevalence was 17%; independently associated factor: female sex (AOR 1.80). Implication: screening and prevention programs should be gender-sensitive.
3	A feasibility study investigating the risk of prediabetes among children in New Zealand [7]	Feasibility cross-sectional (2 phases: questionnaire screening + targeted testing including HbA1c)	276 children aged 11–13 years in the Wellington region, NZ; focus on Pacific, Māori, and non-Māori non-Pacific; risk criteria: APEG (plus risk factors)	35% were identified as at risk for prediabetes; risk was more prominent among Pacific and Māori children, linked to obesity, household crowding, and deprivation. A "high snack/takeaway/sugary drinks" dietary pattern was common in at-risk groups → recommends early opportunistic screening (e.g., via school-based services) plus healthy nutrition promotion and lifestyle interventions, especially for vulnerable groups.
4	Prevalence of and Factors Associated with Pre-diabetes Among Adolescents in Eastern [8]	Community-based cross-sectional	387 adolescents aged 10–19 years in Gadarif, Eastern Sudan; HbA1c 5.7–6.4%	Prediabetes prevalence was 30.0% (T2DM 2.6%); associated factor: father's employment (AOR 1.70). Implications: early community-/school-based screening and lifestyle interventions to prevent progression to diabetes.
5	Trends and risk factors of diabetes and prediabetes in US adolescents, 1999–2020 [9]	Trend analysis (serial cross-sectional) using NHANES 1999–2020	6,936 adolescents aged 12–19 years (fasting $\geq$ 8 hours) with FPG and HbA1c data	Prediabetes increased from 11.5% (1999–2002) to 36.3% (2015–2020); diabetes remained ~1% and did not increase significantly. Main risk factors: obesity (OR 2.01 for prediabetes; OR 3.79 for diabetes), male sex (OR 2.53 for prediabetes), and Mexican American ethnicity (OR 1.29). Prevention implications: focus on obesity prevention/management and early screening in high-risk adolescent groups.

6	The Effect of a Multidisciplinary Lifestyle Intervention Program on Apelin-12, Vaspin and Resistin Concentrations in Children and Adolescents with Overweight and Obesity [10]	Prospective lifestyle intervention (before–after, 1 year)	106 children and adolescents aged 2–18 years with overweight/obesity in Greece	A diet–sleep–physical activity intervention reduced BMI, HbA1c, and HOMA-IR, decreased apelin-12 and resistin, and increased vaspin → improved insulin sensitivity and metabolic profile, supporting diabetes prevention in adolescents with obesity.
7	Impact of a post-lifestyle modification program in circulating angiopoietin-like proteins in Arab adolescents [11]	12-month lifestyle intervention (pre–post follow-up; health education on calorie restriction, physical activity, and behavioral modification; hybrid with digital follow-ups)	218 Saudi adolescents aged 12–17 years recruited from schools in Riyadh; BMI groups: normal ($n = 45$), overweight (n=77), obese ($n = 96$); glycemic groups: HbA1c $< 5.7 (n = 174)$ vs HbA1c ≥ 5.7/ prediabetes ($n = 44$). Outcomes included ANGPTL3/4/8, insulin, fasting glucose, HbA1c, and lipid profile	After 12 months, circulating ANGPTL8 significantly decreased in adolescents with prediabetes (0.7 → 0.2 ng/mL; p=0.002) alongside a significant HbA1c reduction (6.6ß5.5; $p < 0.001$), suggesting improved glycemic control and potentially improved insulin resistance, supporting lifestyle programs for preventing progression to diabetes. ANGPTL8 also decreased in the obese group (0.7ß0.5; $p = 0.03$). Implication: medium-term lifestyle modification may benefit high-risk adolescents, and ANGPTL8 could be a useful biomarker/target to monitor prevention response.
8	The effects of exercise training on insulin resistance in children and adolescents with overweight or obesity, a Systematic Review and Meta Analysis [12]	a Systematic Review and Meta Analysis, (35 studies; publications through Oct 2022)	Total 1,550 children and adolescents with overweight/obesity; exercise interventions vs control	Exercise training reduced fasting glucose (WMD 2.52 mg/dL), fasting insulin (SMD 0.77), HOMA-IR (WMD 0.82), and body weight (WMD 1.51 kg) versus control → supports type 2 diabetes prevention by improving insulin resistance in overweight/obese youth. Benefits were most consistent for aerobic and combined (aerobic+resistance) training; resistance-only training showed less consistent effects on IR markers.
9	Health beliefs on type 2 diabetes: development and psychometric evaluation of "DIABA" [13]	Methodological study (instrument development & psychometric evaluation)	770 male and female adolescents aged 13–15 years (junior high schools) in Tehran; without type 1 or type 2 diabetes	The DIABA questionnaire (16 items, 4 domains: self-efficacy, behavioral beliefs, perceived susceptibility, perceived severity) showed good validity and reliability (Cronbach's $\alpha = 0.78$; ICC=0.73). This tool supports early assessment of health beliefs, providing a foundation for education and prevention of type 2 diabetes in adolescents.
10	School-based peer-led diabetes intervention among female adolescents: a cluster randomized trial [14]	School-based cluster randomized trial	168 eighth-grade female students (~14 years) in Tehran; 84 intervention vs 84 control	Peer-led education (8×90-min sessions; lectures, discussion, Q&A, pamphlets, video clips, SMS) significantly improved at 2 months: knowledge, health beliefs (self-efficacy, behavioral beliefs, perceived susceptibility, perceived severity), and preventive behaviors (stress prevention, healthy diet, reduced unhealthy diet, reduced high-risk behaviors, self-care) vs control ($P < 0.001$).

11	Feasibility Study of Constructing a Screening Tool for Adolescent Diabetes Detection Applying Machine Learning Methods [15]	Feasibility study developing a supervised machine-learning screening tool using a national survey dataset; feature selection (LASSO, Random Forest importance, Gradient Boosted Tree importance) and model evaluation (LR, SVM, RF, XGB, Weighted Voting Classifier)	NHANES 2005–2016, adolescents 12–20 years ($n = 2569; 750$ labeled preDM/DM, 1819 non-diabetes); preDM/DM label based on biomarkers (FPG/2hrPG/HbA1c)	Best model (Weighted Voting Classifier) achieved AUC 0.71, supporting the feasibility of ML-assisted youth diabetes risk screening. Key predictors: physical characteristics (e.g., waist, leg length, sex, BMI), dietary factors (water, protein, sodium, etc.), and demographics. Prevention implication: earlier, easier risk identification can enable more timely targeted lifestyle interventions for at-risk adolescents.
12	Effect of two-weeks of school-based sprint training on physical fitness, risk factors for cardiometabolic diseases and cognitive function in adolescent girls [16]	Randomized controlled pilot trial (school-based; 2-week sprint interval training)	16 adolescent girls (~11–12years) in the UK; 8 intervention vs 8 control	A short, school-based sprint training program improved working memory and increased BDNF concentrations, but did not change glycaemic or insulin-related cardiometabolic markers (fasting glucose, insulin, HOMA-IR). Prevention implication: feasible and enjoyable high-intensity physical activity at school may contribute to long-term diabetes prevention through cognitive and lifestyle pathways, even if short-term metabolic effects are limited in healthy adolescents.
13	A Pilot Study to Examine the Feasibility and Acceptability of a Virtual Adaptation of an In-Person Adolescent Diabetes Prevention Program Islam [17]	Qualitative pilot study (feasibility & acceptability); virtual adaptation of a peer-led diabetes prevention program	14 adolescents with prediabetes (HbA1c 5.7–6.4%), aged ~13–19 years, BMI $> 85th$ percentile; predominantly Latino and Black youth, New York	A 12-session peer-led virtual program was feasible and well accepted. The virtual format successfully delivered lifestyle content (healthy eating, physical activity, goal setting, problem solving) comparable to in-person delivery. Participants reported improved nutrition knowledge, behavioral skills, and positive engagement. Implication: virtual peer-led interventions may support diabetes prevention among at-risk adolescents, especially where in-person programs are limited.
14	Effects of a Diabetes Prevention Program on Type 2 Diabetes Risk Factors and Quality of Life Among Latino Youths With [3]	Randomized clinical trial (parallel 2-group; 2:1 allocation; 6- and 12-month follow-up)	117 Latino adolescents aged 12–16 years with prediabetes and obesity (BMI $95th$ percentile) in Phoenix, Arizona	Both the lifestyle intervention and usual care significantly improved glucose tolerance over 12 months. However, the lifestyle intervention led to a significantly greater improvement in weight-related quality of life (YQOL-W). Implication: expanding access to diabetes prevention services for high-risk adolescents may help reduce future type 2 diabetes risk, particularly in underserved populations.

15	Prevalence of and Risk Factors for Diabetes Mellitus in the School-Attending Adolescent Population of the United Arab Emirates [18]	Population-based cross-sectional study (secondary analysis of a national survey)	6,365 school-attending adolescents aged 12–22 years across 7 emirates of the UAE	Overall self-reported diabetes prevalence was 0.9%, higher in males (1.5%) than females (0.5%). Significant associated factors included male sex, non-married parental status, and smoking/illegal drug use. Prevention implications: need for early school-based screening, behavioral and mental health interventions, and strong parental support to reduce diabetes risk among adolescents.

3.1 DISCUSSION

This review highlights that diabetes mellitus (DM) prevention among adolescents is influenced by multilevel determinants. While the overall findings are broadly consistent, the strength of evidence varies across domains, and several methodological limitations should be considered when interpreting the results.

3.1.1 Individual Factors: Knowledge, Risk Perception, and Self-Efficacy

Evidence regarding individual cognitive and motivational factors is relatively strong and consistent, particularly from randomized controlled trials and structured school-based interventions. Across these studies, peer-led education and theory-driven approaches—especially those grounded in the Health Belief Model—consistently demonstrate significant improvements in diabetes-related knowledge, perceived susceptibility, perceived severity, and self-efficacy. This convergence of findings across higher-quality study designs increases confidence that these constructs play a central role in shaping preventive behaviors among adolescents.

Importantly, the effectiveness of these interventions appears to be mediated by the developmental characteristics of adolescents. Interactive, peer-based, and contextually relevant strategies are more effective than traditional didactic methods because they align with adolescents' need for social validation, autonomy, and identity formation. Evidence from cluster randomized trials suggests that peer-led models not only improve cognitive outcomes but also foster stronger engagement and behavioral intention, indicating both educational and psychosocial benefits.

However, despite this consistency, the strength of evidence is not uniform across all outcomes. While improvements in knowledge and health beliefs are robust, the translation of these cognitive gains into sustained behavioral change remains less certain. Several studies report significant short-term improvements in dietary intentions and physical activity, yet only a limited number provide long-term follow-up data to confirm persistence of these behaviors. This creates a gap between proximal outcomes (e.g., knowledge, attitudes) and distal outcomes (e.g., long-term lifestyle change and metabolic improvement).

Furthermore, many studies rely on self-reported measures, which are susceptible to social desirability bias and recall bias, particularly in adolescent populations. This may lead to overestimation of intervention effectiveness. In addition, variations in measurement tools and outcome indicators reduce comparability across studies, making it difficult to standardize conclusions regarding effect size. Another limitation lies in the contextual variability of interventions. Studies conducted in controlled school environments with structured facilitation tend to report stronger effects compared to those implemented in less controlled or community-based settings. This suggests that intervention fidelity and implementation context may significantly influence outcomes, yet these factors are not consistently reported or analyzed.

Taken together, the evidence supports a high level of confidence in the short-term effectiveness of interventions targeting knowledge, risk perception, and self-efficacy. However, due to limitations related to measurement methods, follow-up duration, and contextual variability, the evidence for long-term behavioral impact remains moderate. Future research should prioritize longitudinal designs, objective behavioral measures, and standardized assessment tools to better establish causal pathways between cognitive change and sustained diabetes prevention outcomes.

3.1.2 Behavioral Factors: Diet, Physical Activity, and Sedentary Behavior

The evidence linking lifestyle behaviors to diabetes mellitus (DM) prevention among adolescents is robust and relatively high in confidence, supported by systematic reviews, meta-analyses, and multiple intervention studies. Across these studies, there is strong and consistent agreement that dietary quality, physical activity, and

sedentary behavior are key modifiable determinants of metabolic risk. In particular, interventions emphasizing balanced nutrition—such as reducing sugar-sweetened beverage intake, improving fiber consumption, and adopting low–glycemic index diets—are associated with measurable improvements in fasting glucose, insulin sensitivity, and body composition.

Similarly, the role of physical activity is supported by high-quality evidence, especially from meta-analyses and controlled trials. Combined exercise interventions (aerobic and resistance training) consistently demonstrate greater metabolic benefits compared to single-modality approaches. This suggests a synergistic effect in improving insulin resistance and cardiometabolic profiles. In contrast, resistance-only interventions show more variable outcomes, indicating that exercise composition is an important determinant of effectiveness.

An important and often underemphasized finding is the independent role of sedentary behavior, particularly screen time, in influencing metabolic risk. Several studies indicate that reducing sedentary time contributes to improved metabolic outcomes even in the absence of significant increases in structured physical activity. This highlights that DM prevention strategies should not only promote active behaviors but also explicitly target reductions in inactivity.

Despite this overall consistency, the strength of evidence varies depending on outcome type and study design. While behavioral changes (e.g., improved diet and increased activity levels) are frequently reported, evidence for significant improvements in clinical metabolic markers (such as HbA1c or insulin resistance indices) is more mixed. Short-term and pilot studies often report limited or non-significant metabolic effects, suggesting that intervention duration and intensity are critical factors in achieving physiological changes. This indicates a temporal gap between behavioral modification and measurable metabolic improvement.

Moreover, there is considerable heterogeneity across studies in terms of intervention design, duration, frequency, and outcome measurement. Some studies rely on self-reported dietary intake and physical activity, which may introduce reporting bias, while others use objective measures such as biomarkers or accelerometry. This variation reduces comparability and complicates the ability to draw standardized conclusions regarding effect size and optimal intervention parameters.

Another limitation relates to population differences and contextual factors. Interventions conducted among adolescents with overweight or prediabetes tend to show more pronounced metabolic improvements compared to those involving general adolescent populations. This suggests that baseline risk level may moderate intervention effectiveness. However, not all studies adequately control for confounding variables such as socioeconomic status, baseline health status, or environmental influences, which may affect both behavior and outcomes.

In summary, there is strong and consistent evidence supporting lifestyle modification as a cornerstone of adolescent DM prevention, particularly in relation to behavioral outcomes. However, evidence for sustained and clinically meaningful metabolic improvements is moderate and somewhat inconsistent, largely due to short intervention durations, methodological heterogeneity, and variability in outcome measures. Future research should prioritize longer-term interventions, standardized outcome metrics, and the use of objective behavioral and metabolic assessments to strengthen causal inference and improve comparability across studies.

3.1.3 Family Factors: Home Support and Parental Involvement

Findings related to family involvement in adolescent diabetes mellitus (DM) prevention are generally consistent, indicating that the home environment plays a crucial role in shaping and sustaining health behaviors. Across the reviewed studies, parental support, family routines, and household norms are repeatedly associated with improved adherence to dietary modifications, increased physical activity, and greater sustainability of lifestyle changes. This pattern is particularly evident among high-risk adolescents (e.g., those with overweight, obesity, or prediabetes), where family engagement appears to amplify the effectiveness of intervention programs.

A key strength of the evidence lies in its conceptual consistency: adolescents do not operate independently, and their health behaviors are embedded within family systems. Interventions that incorporate parental involvement—such as family-based counseling, shared goal-setting, and home environment modification—tend to report better adherence and longer-lasting behavioral outcomes compared to adolescent-only approaches. In particular, culturally tailored family interventions show promise in reinforcing behavior change by aligning health practices with existing family values and routines.

However, despite this consistent pattern, the overall strength of evidence remains moderate due to methodological limitations. A substantial proportion of the included studies employ observational or quasi-experimental designs, which limit the ability to establish causal relationships. The observed associations between family involvement and improved outcomes may be influenced by uncontrolled confounding variables, such as socioeconomic status, parental education, health literacy, and access to resources. For example, families with higher socioeconomic status may be more capable of providing healthy food options and supporting structured physical activity, thereby independently contributing to better outcomes.

In addition, there is variation in how "family involvement" is defined and measured across studies. Some studies assess parental support through self-reported questionnaires, while others examine structural components such as family participation in interventions or changes in the home food environment. This heterogeneity reduces comparability and makes it difficult to determine which specific aspects of family involvement are most influential.

Another limitation is the limited number of rigorous, long-term intervention studies that directly evaluate family-based approaches. While short-term improvements in adherence and behavior are frequently reported, fewer studies assess the durability of these effects over extended periods. Moreover, the degree of parental engagement and intervention fidelity is not always consistently reported, which may influence the observed effectiveness.

Despite these limitations, the direction of evidence is coherent and theoretically grounded, supporting the role of family as a critical reinforcing system in adolescent DM prevention. The findings suggest that interventions targeting adolescents in isolation may be less effective than those adopting a family-centered approach. However, due to the moderate level of evidence and potential confounding influences, conclusions regarding causality should be interpreted with caution.

Future research should prioritize rigorous experimental designs, such as randomized controlled trials with family-based components, and incorporate standardized measures of family involvement. Additionally, controlling for socioeconomic and contextual variables will be essential to better isolate the true effect of family support on prevention outcomes.

3.1.4 School Factors: Enabling Environments

Evidence supporting school-based interventions for diabetes mellitus (DM) prevention among adolescents is relatively strong, particularly from cluster randomized trials and structured intervention studies. Across the reviewed literature, schools consistently emerge as strategic settings for implementing multicomponent prevention programs, including nutrition education, structured physical activity, behavioral skill development, and environmental modifications such as improving the availability of healthy foods and limiting access to unhealthy options.

A key strength of school-based approaches lies in their population-level reach and structural influence. Unlike clinical or family-based interventions, schools provide access to a broad and diverse adolescent population regardless of health status or socioeconomic background. This allows for the simultaneous delivery of preventive strategies at scale, as well as the shaping of social norms and peer environments that reinforce healthy behaviors. Evidence from higher-quality studies indicates that such integrated interventions can produce consistent improvements in dietary behavior, physical activity levels, and, in some cases, intermediate metabolic indicators.

Furthermore, interventions embedded within the school system benefit from routine exposure and institutional support, which can enhance adherence and program consistency. Programs that integrate health promotion into the curriculum, school policies, and daily routines tend to demonstrate stronger and more sustainable behavioral outcomes compared to isolated or short-term initiatives. This suggests that the institutionalization of health-promoting environments is a critical factor in the success of school-based interventions.

However, despite these strengths, several methodological and practical limitations affect the interpretation of findings. First, many studies are characterized by short follow-up periods, which limits the ability to assess whether observed behavioral and metabolic improvements are sustained over time. While short-term changes are frequently reported, evidence for long-term impact remains limited and somewhat uncertain.

Second, there is considerable variability in program design and implementation, including differences in intervention components, duration, intensity, and delivery methods. This heterogeneity reduces comparability across studies and makes it difficult to identify which specific elements are most effective. Additionally, intervention fidelity—the extent to which programs are implemented as intended—is not consistently reported, potentially influencing outcomes.

Another important consideration is the role of contextual and resource-related factors. The effectiveness of school-based interventions may depend on factors such as teacher training, institutional support, infrastructure, and policy alignment. Schools with greater resources and administrative commitment may achieve better outcomes, introducing potential bias and limiting generalizability to lower-resource settings.

Moreover, while behavioral outcomes are generally consistent, the evidence for metabolic improvements is more mixed, particularly in studies involving general adolescent populations rather than high-risk groups. This suggests that school-based interventions may be more effective in influencing preventive behaviors than in producing immediate physiological changes, which may require longer intervention duration or additional support outside the school environment.

In summary, there is strong evidence supporting the feasibility and effectiveness of school-based interventions in improving behavioral determinants of DM prevention. However, due to limitations related to follow-up duration, implementation variability, and contextual differences, the evidence for sustained and generalized impact remains moderate. Future research should focus on long-term evaluations, standardized intervention frameworks, and

rigorous reporting of implementation fidelity to strengthen the evidence base and enhance scalability.

3.1.5 Sociocultural and Community Context

Evidence related to sociocultural and community-based factors in adolescent diabetes mellitus (DM) prevention shows generally consistent positive trends, particularly in terms of improving participation, engagement, and intervention acceptability. Studies indicate that interventions incorporating cultural tailoring, community engagement, and participatory approaches tend to achieve higher adherence and relevance, especially among high-risk and marginalized populations. This suggests that the social and cultural context plays an important role in determining the success of the implementation of prevention programs.

A key strength of this body of evidence lies in its emphasis on contextual relevance. Interventions that align with adolescents' cultural values, dietary practices, and social realities are more likely to be accepted and sustained. Community-based participatory approaches—such as co-designing programs with adolescents, families, and local stakeholders—have been shown to enhance trust, ownership, and long-term feasibility. In diverse populations, particularly those facing socioeconomic or structural disadvantages, these approaches help bridge gaps that are often not addressed by standardized interventions.

However, compared to other domains, the overall strength of evidence in this area is more limited and heterogeneous. Many studies employ qualitative, pilot, or feasibility designs with relatively small sample sizes, which restricts generalizability and limits the ability to draw strong causal inferences. While findings consistently suggest improved engagement and perceived effectiveness, fewer studies provide robust quantitative evidence on clinical or long-term behavioral outcomes.

In addition, there is variability in how sociocultural adaptation is defined and implemented. Some interventions focus on language and communication adjustments, while others incorporate deeper cultural elements such as beliefs, norms, and community practices. This lack of standardization makes it difficult to determine which components of cultural tailoring are most impactful. Furthermore, the measurement of outcomes in this domain often prioritizes acceptability and participation rather than objective health indicators, limiting the ability to directly link sociocultural strategies with metabolic improvements.

Another important limitation is the influence of broader structural and environmental factors, such as access to healthy foods, safe spaces for physical activity, and healthcare services. These determinants are often intertwined with sociocultural context but are not consistently controlled for in study designs, introducing potential confounding effects. As a result, it is challenging to isolate the specific contribution of sociocultural interventions from underlying structural inequalities.

Despite these limitations, the direction of evidence remains coherent, highlighting the importance of integrating sociocultural and community perspectives into adolescent DM prevention strategies. Interventions that fail to consider these factors may face lower engagement and reduced effectiveness, particularly in diverse or underserved populations.

In conclusion, while sociocultural and community-based approaches demonstrate strong potential in enhancing engagement and contextual relevance, the current evidence base is moderate in strength due to methodological limitations and heterogeneity. Future research should prioritize larger-scale, rigorously designed studies that incorporate standardized frameworks for cultural adaptation and include both behavioral and clinical outcome measures. This will be essential to establish stronger causal evidence and to support the scalability of culturally responsive DM prevention programs.

3.2 Limitations

This systematic review has several limitations related to both methodological aspects and the clarity of its scientific contribution. Although it synthesizes recent evidence (2020–2025) on diabetes mellitus (DM) prevention among adolescents, the novelty of this review is not fully explicit. Previous reviews have addressed similar topics, such as prediabetes prevalence and lifestyle interventions in youth. While this study integrates multilevel determinants (individual, behavioral, family, school, and sociocultural factors) within a PRISMA-based framework, it does not clearly establish a distinct research gap. Therefore, its contribution should be viewed as an updated and integrative synthesis, rather than a fundamentally novel approach.

In addition, the findings are limited by the heterogeneity of included studies, including variations in study design, population characteristics, and definitions of adolescence, which may affect comparability and generalizability. Many studies rely on surrogate or self-reported outcomes (e.g., BMI, HbA1c, behavior), with limited long-term follow-up, restricting causal inference regarding sustained prevention effects. Differences in intervention duration, implementation, and contextual factors (e.g., family and school environments) further complicate interpretation.

Finally, restricting the search to English-language publications and database-indexed studies may introduce publication bias. Therefore, the results should be interpreted with cautious confidence, and future research should emphasize more rigorous, longitudinal designs and clearer articulation of research novelty.

4. CONCLUSION

This systematic literature review demonstrates that the prevention of diabetes mellitus (DM) among adolescents is a complex and multifactorial process that extends beyond biological risk factors alone. Evidence consistently indicates that effective DM prevention in this population is shaped by the interaction of individual-level determinants (such as knowledge, risk perception, and self-efficacy), lifestyle behaviors (including diet quality, physical activity, and sedentary behavior), family support, school environments, and broader sociocultural contexts.

The findings highlight that interventions focusing solely on metabolic outcomes are insufficient. Programs that integrate health education tailored to adolescents, peer influence, and psychosocial support are more likely to achieve meaningful and sustainable behavior change. Lifestyle interventions emphasizing healthy dietary patterns, regular physical activity particularly structured and resistance-based exercise and reductions in sedentary behavior show consistent benefits for improving insulin sensitivity and other cardiometabolic risk markers relevant to DM prevention.

Moreover, family involvement and supportive home environments play a critical role in reinforcing and sustaining preventive behaviors, especially among adolescents at high risk due to obesity or prediabetes. Schools emerge as a particularly effective setting for population-level prevention, as they enable simultaneous modification of curricula, physical activity opportunities, and social norms that shape adolescent health behaviors. Culturally adapted and community-engaged approaches further enhance program relevance, engagement, and acceptability across diverse adolescent populations.

Overall, this review underscores the need for multilevel, developmentally appropriate, and culturally sensitive prevention strategies that address both behavioral and psychosocial determinants of diabetes risk in adolescence. Early, comprehensive prevention efforts implemented in schools and communities, and reinforced by families, are essential to reducing the future burden of type 2 diabetes and promoting long-term metabolic health across the life course.

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