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The effectiveness of lifestyle interventions in reducing cardiovascular risk and risk factors in people with prediabetes: A systematic review and meta-analysis

Getu Debalkie Demissie [a,b,c,*], Josephine Birungi [a,b,d], Abha Shrestha [a,b,e], Tilahun Haregu [b,f], Sathish Thirunavukkarasu [b,g,h], Brian Oldenburg [a,b]

[a] *School of Psychology & Public Health, La Trobe University, Melbourne, Victoria, Australia*
[b] *Baker Heart and Diabetes Institute, Melbourne, Victoria, Australia*
[c] *Institute of Public Health, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia*
[d] *Medical Research Council/Uganda Virus Research Institute & London School of Hygiene and Tropical Medicine (MRC/UVRI & LSHTM), Uganda Research Unit, Uganda*
[e] *Dhulikhel Hospital, Kathmandu University School of Medical Sciences, Nepal*
[f] *Melbourne School of Population and Global Health, University of Melbourne, Melbourne, Australia*
[g] *Department of Family and Preventive Medicine, School of Medicine, Emory University, Atlanta, GA, USA*
[h] *Emory Global Diabetes Research Centre, Woodruff Health Sciences Centre, Emory University, Atlanta, GA, USA*

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ABSTRACT

Aim: This systematic review and meta-analysis examined the effectiveness of lifestyle interventions in reducing cardiovascular disease (CVD) risk, CVD events, and related risk factors among individuals with prediabetes.
Data synthesis: We conducted a search of the MEDLINE, Embase, PsycINFO, CENTRAL, and Scopus databases, along with ClinicalTrials.gov, for lifestyle-based randomized controlled trials (RCTs) involving individuals with prediabetes. Our focus was on interventions that lasted at least six months and were published between 1997 and April 2024. Two authors independently screened the abstracts and titles of the retrieved articles, followed by full-text reviews and data extraction from forty-two eligible studies. The primary outcomes examined were changes in CVD risk and CVD events, and the secondary outcomes were changes in CVD risk factors. We utilized random-effects meta-analysis to calculate pooled effects.
Forty-two studies (n=18,615, mean age =54.9, male (45.4 %)) were included. Lifestyle interventions reduced CVD risk (standardized mean difference (SMD): -1.91; 95 % CI: -2.89, -0.93, p<0.010) among the intervention group compared to the control group. Lifestyle interventions have also been shown to reduce various CVD risk factors, including the incidence of type 2 diabetes.
Conclusion: This review demonstrates more evidence to support lifestyle interventions being an important strategy for individuals with prediabetes to reduce their risk of developing CVD and its associated risk factors.
PROSPERO registration Number: CRD42023429869.

1. Introduction

Individuals with prediabetes face an increased risk of cardiovascular disease (CVD), such as coronary heart disease, stroke, heart failure, peripheral artery disease, and cerebrovascular disease, compared to the general population [1,2]. While individuals with prediabetes have higher-than-normal blood sugar levels, they are not yet high enough for a diabetes diagnosis [3]. However, prediabetes significantly increases the risk of progressing to T2DM, with up to 50 % developing the condition within five years [4]. If T2DM remains untreated for an extended period, it can lead to severe complications, including CVD, retinopathy, and neuropathy [5,6]. Furthermore, the metabolic changes associated with prediabetes, such as insulin resistance, hyperinsulinemia, inflammation, and dyslipidemia, create a harmful internal environment that accelerates atherosclerosis and raises blood pressure [7]. These factors collectively damage blood vessels and hinder circulation, directly contributing to the development of CVD, including coronary artery

* Corresponding author. 99 Commercial Road, The Alfred Centre, Level 4 Melbourne VIC 3004 Office of the Provost, La Trobe University, Melbourne, Australia
E-mail address: 21377861@students.latrobe.edu.au (G.D. Demissie).

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Lists of abbreviations

ADA:	American Diabetes Association
BP:	Blood Pressure
CVD:	cardiovascular disease
DPP:	Diabetes Prevention Program
DPS:	Diabetes Prevention Study
GRADE:	Grading of Recommendations, Assessment, Development and Evaluation
PICOS:	Population, Intervention, Outcome, Comparator, and Study Design
PRISMA:	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PRISMA-P:	Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols
SCORE2:	Systematic Coronary Risk Evaluation 2
SMD:	Standardized Mean Difference
RCT:	Randomized Controlled Trial
ROB2:	Risk of Bias Assessment Revised Tool
RR:	Relative Risk
T2DM:	Type 2 Diabetes Mellitus
WHO:	World Health Organization

disease, heart attack, and stroke [8].

Preventing CVD and T2DM in individuals with prediabetes requires a comprehensive approach that combines lifestyle modifications with effective risk factor management [9]. Key lifestyle changes, such as adopting the Mediterranean diet [10] and engaging in regular physical activity [11] work together to improve insulin sensitivity, reduce body weight, lower blood pressure and lipid levels, and ultimately decrease the risk of progression to T2DM and developing CVD complications [12, 13]. Studies such as the Finnish Diabetes Prevention Study (DPS) [14, 15], the US Diabetes Prevention Program (DPP) [16], and the Da Qing Diabetes Prevention study in China [17] demonstrated that diet and exercise interventions significantly reduced the incidence of type 2 diabetes in individuals with prediabetes.

Previous systematic reviews and meta-analyses have explored the reduction in absolute CVD risk through lifestyle interventions among individuals with type 2 diabetes, the general population, or high-risk groups for CVD, including those with hypertension, obesity, or elevated total cholesterol levels [18-20]. However, none of these reviews specifically evaluated the effect of lifestyle interventions on CVD risk in people with prediabetes.

This systematic review and meta-analysis aims to synthesize the evidence on the effects of lifestyle interventions in reducing absolute CVD risk, CVD events, and CVD risk factors among individuals with prediabetes.

2. Methods

2.1. Study design and eligibility criteria

This study followed the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guideline for reporting [21]. This review has been registered in the International Prospective Register of Systematic Reviews (PROSPERO) (No. CRD42023429869). The details of the inclusion and exclusion criteria have been described in the published protocol paper [22]. Briefly, the inclusion criteria were based on the PICOS framework (population, intervention, comparison, outcome, and study design).

- Population: Individuals (aged ≥18 years) with prediabetes, including impaired fasting glucose, impaired glucose tolerance, or elevated hemoglobin A1c based on the criteria set by the World Health Organization (WHO) and the American Diabetes Association (ADA) [23-25].
- Intervention: Structured lifestyle intervention programs lasting 6 months or more and designed to improve diet quality, increase physical activity, support smoking cessation, reduce alcohol consumption, or provide advice on other healthy lifestyle choices.
- Comparator: Usual or standard care with or without minimal intervention (e.g., providing health education booklets)
- Outcomes: The primary outcomes measured were the predicted 10-year CVD risk and occurrences of CVD events. To incorporate a study that reported a predicted 5-year CVD risk [26] in the meta-analysis, we converted the mean 5-year predicted CVD risk to a 10-year predicted CVD risk using an exponential method. We calculated the standard deviation for the mean changes in CVD risk in the intervention and control groups using the formula for the pooled standard deviation of paired samples. Secondary outcomes include changes in clinical, biochemical, behavioral, and psychosocial measures.
- Study design: RCTs

We excluded studies conducted among individuals with diagnosed diabetes or gestational diabetes, pharmacological or surgical interventions, non-RCT studies, and articles not published in English.

2.2. Data sources and search strategy

Five databases, including Ovid MEDLINE, Embase, Cochrane Central, PsycINFO, Scopus, and ClinicalTrials.gov, were searched for articles reporting on the effects of lifestyle interventions to reduce absolute CVD risk, CVD events, and risk factors in individuals with prediabetes. Our search strategy utilized a combination of Medical Subject Headings (MeSH) and free-text terms, such as "cardiovascular disease", "cardiovascular risk", "cardiovascular risk scores", "lifestyle interventions", "diet", "physical activity", "prediabetes", "impaired fasting glucose", "Impaired glucose tolerance", "hba1c", "Cardiovascular risk factors", "psychosocial risk factors", "depression", "anxiety", "stress" and "diabetes prevention". A comprehensive search strategy for each bibliographic database was developed by consulting a librarian and experts in the field of diabetes and CVD prevention. A sample of the search strategy is provided in the supplementary file 1. The databases and trial registers were searched for articles published from 1997 to April 17, 2024.

2.3. Study selection

All identified articles were exported to Covidence software (Veritas Health Innovation, Melbourne, Australia [27] and duplicates were removed. GDD and JB independently screened the titles and abstracts of the articles. Full-text reviews were conducted by the same two reviewers, applying the established inclusion and exclusion criteria. Disagreements during study selection were resolved by a third reviewer (AS), who independently assessed the contested items and made the final decision based on predefined criteria.

2.4. Data extraction

Two independent reviewers (GDD and JB) extracted data from eligible studies using a template designed by the Covidence software. The extracted data included specific details such as author information, study participants, lifestyle interventions, study methods (e.g., study setting and follow-up duration), and effect estimates of the outcomes. Lifestyle interventions were categorized into three groups: (1) diet alone, including interventions focused exclusively on dietary changes such as calorie restriction, nutrition counseling, or specific diet plans; (2) physical activity alone, involving structured or unstructured exercise programs without dietary components; and (3) combined interventions, which included both dietary and physical activity components with behavioral support. Categorization was based on the primary focus and content described in each included study, and also aligned with the core components of lifestyle interventions outlined in the WHO's Essential Package of NCD interventions and Global Action Plan documents [28].

2.5. Risk of bias and certainty of evidence

Two reviewers (GDD and JB) independently assessed the potential risk of bias in the included studies using the revised risk of bias assessment tool (ROB2) from Cochrane's Collaboration [29]. The results were presented using the Robvis tool [30]. The study was deemed to have a high risk of bias if at least one domain was classified as "high risk" or if there were indications of "some concern" across multiple domains. Disagreements during study selection were settled by a third reviewer (AS), who independently evaluated the disputed items and made the final decision according to predefined criteria.

The Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) framework [31] was employed, and GRADEpro software was utilized to assess the certainty of the evidence for each outcome across all the included studies. The GRADE approach evaluates the overall confidence in the estimated effect based on five key domains: risk of bias, imprecision, inconsistency, indirectness, and publication bias [31]. Each outcome was graded into one of four levels of certainty (high, moderate, low, and very low). Lower certainty ratings highlight areas where future research is needed to strengthen the evidence base [31].

2.6. Synthesis of evidence

After data extraction, we described the final list of selected studies based on the location of the study, the components of lifestyle interventions, the age distribution of participants, and the duration of follow-up. To estimate the pooled effects of the interventions on the outcomes, we conducted a DerSimonian and Laird random effects meta-analysis, which accounts for both within-study and between-study variability [32]. We chose the random-effects model due to the expected clinical and methodological heterogeneity among the included studies [33]. Forest plots were created to visually represent the pooled effect sizes [34]. For dichotomous and continuous outcomes, we reported the pooled relative risk (RR) and the standardized mean difference (SMD) along with 95 % confidence intervals (CIs), respectively.

Heterogeneity among the included studies was quantified using the I^2 statistic, which reflects the percentage of variability in effect estimates attributed to heterogeneity rather than to random chance [35]. However, thresholds for interpreting I^2 values should be treated with caution, as the importance of heterogeneity depends on factors such as study context and magnitude of effects. As a general guide in meta-analyses of randomized trials, I^2 values of 0–40 % might not be important, 30–60 % may represent moderate heterogeneity, 50–90 % substantial heterogeneity, and 75–100 % considerable heterogeneity [35]. We also conducted Cochran's Q test to determine if there was statistically significant heterogeneity present, considering a p-value of less than 0.10 as indicative of substantial heterogeneity [35]. To assess potential publication bias, we visually examined funnel plots when at least 10 studies were available for a given outcome [36]. Furthermore, we employed Egger's regression test to statistically evaluate the asymmetry in effect sizes, with a p-value of less than 0.05 suggesting the presence of publication bias [37]. All analyses were performed using STATA version 18 (StataCorp, College Stayion, TX, USA) [38].

Meta-analysis was not done for the outcome of CVD events due to the limited number of studies (three). Although a meta-analysis can technically be conducted with as few as two studies, most methodologists recommend including at least five to ensure more reliable and precise pooled estimates, a more accurate assessment of between-study heterogeneity, and the feasibility of meaningful subgroup or sensitivity analyses [33,39]. Meta-analysis was not also conducted for behavioral risk factors, including diet and physical activity, due to differences in outcome definitions and measurement methods. For example, dietary outcomes varied across studies, ranging from fruit and vegetable intake to fiber, saturated fat, and total calorie consumption, while physical activity was assessed using self-reports in some studies and objective tools such as accelerometers or Metabolic Equivalent of Task (METs) in others. This variability and small number of studies with similar outcomes made statistical pooling inappropriate, as combining such heterogeneous measures could lead to misleading conclusions [40].

Moreover, we categorized the included studies narratively based on follow-up timing as short-term (<2 years), medium-term (2–5 years), and long-term (>5 years), and synthesized them to compare the intervention effects across different follow-up periods. A meta-analysis was not conducted for the follow-up timing categories because the studies within each follow-up category reported heterogeneous outcomes, including predicted CVD risk, incidence of type 2 diabetes, and various CVD risk factors such as BMI and systolic blood pressure. Due to this variability in outcome measures, statistical pooling was not appropriate, as combining effect sizes from fundamentally different outcomes can lead to misleading conclusions [40].

3. Results

3.1. Search results

We identified a total of 1,935 articles through our database search. After excluding 122 duplicates, we screened the titles and abstracts of 1,813 articles. Based on this initial screening, 1,689 articles were excluded. Following a full-text review of 124 articles, 82 were further excluded that did not meet the eligibility criteria. Finally, 42 articles were deemed eligible for inclusion in this review. The study selection process is summarized in the PRISMA flow diagram shown in Fig. 1.

3.2. Studies' characteristics

The 42 eligible studies had a total of 18,615 participants, with a mean age of 54.9 years, and 45.4 % of participants were male. The detailed characteristics of the included studies are summarized in Table 1. Of the 42 studies, 19 (45.2 %) were conducted in low and middle-income countries (LMICs); nine in China [17,41-48], five in India [49-53], two in Thailand [54,55], two in Bangladesh [56,57] and one in Brazil [58]. The remaining 23 studies were from high-income countries such as Finland, England, Japan, Australia, and the US [26,59-62]. The majority of the included studies (83.3 %) implemented combined dietary and physical activity interventions, and 52.4 % were conducted in clinical settings [58].

3.3. Effects of lifestyle interventions

3.3.1. Primary outcomes (CVD risk and CVD events)

The pooled estimate from six studies reported CVD risk as an outcome [26,41,49,50,60,63] showed that lifestyle interventions led to a reduction in the 10-year predicted CVD risk by 1.91 points (SMD= -1.91; 95 % CI:-2.89, -0.93, p<0.010) in the intervention groups compared to the control groups (See Forest plot in the supplementary file 2). Among these studies, four utilized the Framingham Risk Score [26,41,49,60] while the other two applied the UK Prospective Diabetes Study engine [50] and the Atherosclerotic CVD risk calculator [63], respectively. Significant differences in the 10-year predicted CVD risk between treatment groups were observed in four studies [26,41,49,50], but no significant difference was found in the remaining two studies [60,63]. The findings from the systematic review showed that the Da Qing follow-up study conducted in China demonstrated a significant reduction in CVD events [44]. However, CVD events were not reduced in two other studies [62,64]. CVD events were assessed through a review of

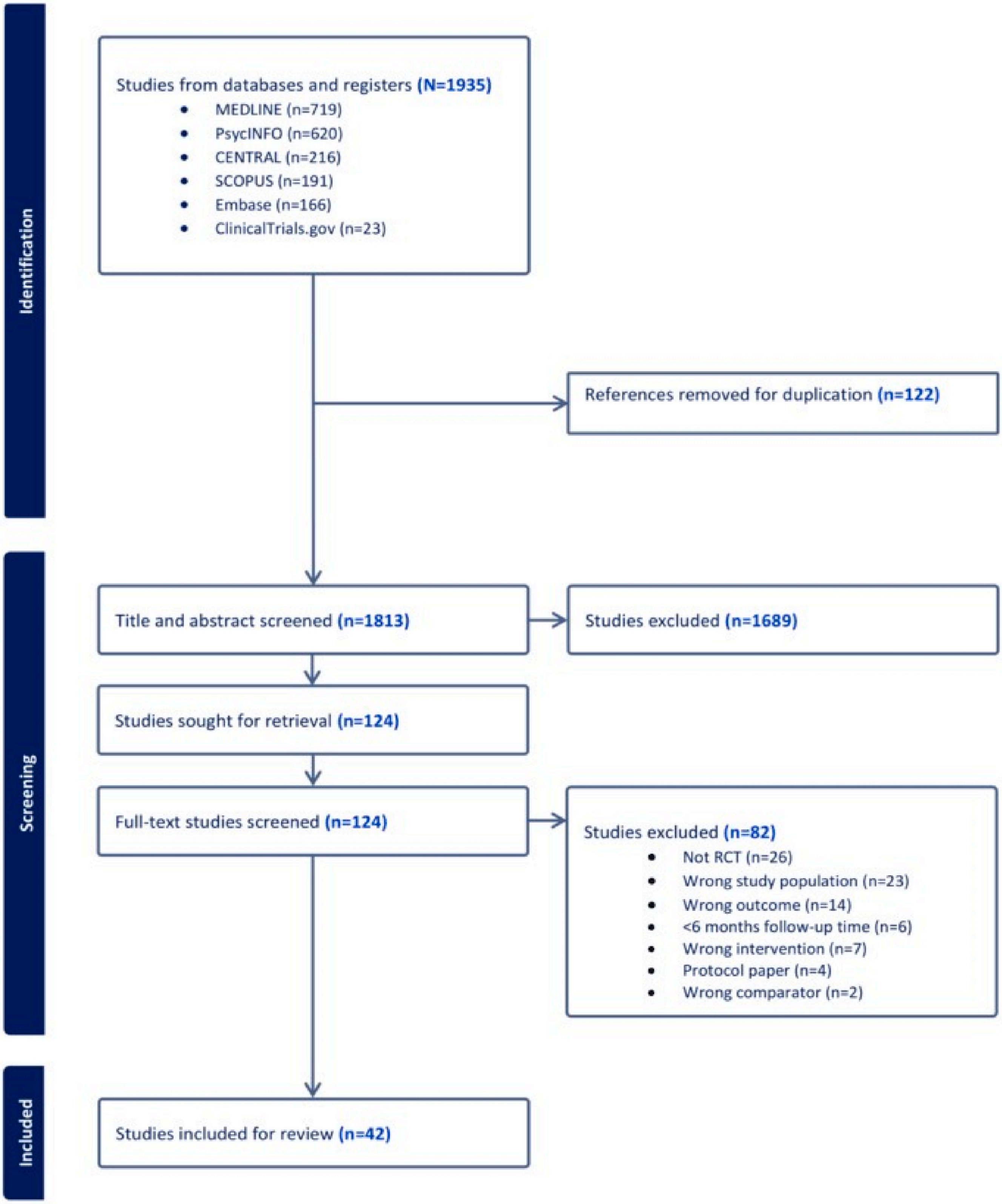

Fig. 1. PRISMA flowchart of the study selection.

medical records and death certificates [44,59].

3.3.2. Secondary outcomes (CVD risk factors)

Individuals with prediabetes who participated in lifestyle interventions had an average 25 % lower risk of progressing to type 2 diabetes compared to those who received usual care or minimal intervention (RR=0.75; 95 % CI: 0.67, 0.84; P<0.001). Our meta-analysis also indicated that lifestyle interventions positively affected various

Table 1
Characteristics of the included studies (n=42).

Studies	Country	Setting	Sample size (Control/ Intervention)	Duration of follow-up (years)	Age (mean) in years	Male, n (%)	Intervention components	Characteristics of the Lifestyle Interventions
Aekplakorn et al, 2019	Thailand	Primary care units	1903 (873/ 1030)	2	50.8	1195 (62.8)	Diet, physical activity, and motivational skills	Participants in the intervention group attended a workshop for three days, followed by monthly sessions for six months, then bimonthly sessions for eighteen months, and quarterly sessions for the final six months
[a]Davies et al, 2016	UK	Primary care setting	880 (433/447)	3	63.9	560 (63.6)	Diet and physical activity	The intervention group participated in a 3-h refresher session at 12 and 24 months, along with a 15-min call every 3 months.
Diabetes Prevention Program (DPP) Research Group, 2002	US	Clinic centres	2161 (1082/ 1079)	2.8	51	680 (31.5)	Diet and physical activity	A 16-lesson behavior modification curriculum was delivered one-on-one over 24 weeks, followed by monthly individual and group sessions to reinforce changes. The program was flexible, personalized, and culturally sensitive.
[a]Dunbar et al., 2015	Australia	Community setting	342 (165/177)	1	65	129 (37.7)	Diet and physical activity	30-45 minute individual sessions, followed by five 90-min group sessions on motivation and risk perception
Gong et al., 2019	China	clinics	540 (135/405)	30	71	312 (54.2)	Diet and physical activity	Weekly individual and small group sessions for one month, followed by monthly sessions for three months, and then once every three months for the remainder of the first study.
Hu.,et al 2017	China	Community setting	434 (220/214)	1	69.5	180 (41.5)	Diet and physical activity	Lifestyle interventions and training on fasting glucose measurement were provided for three months
Katula et al., 2022	UK	Medical Centre	599 (300/299)	1	55.4	231 (38.6)	Diet and physical activity	An initial 16-week digital intensive curriculum focusing on weight loss followed by a 36-week curriculum on weight maintenance
Kosaka et al., 2005	Japan	Hospital	458 (356/102)	4	–	458 (100)	Diet and physical activity	Individual lifestyle counseling was given at hospital visits every 3–4 months for four years
DPP Research Group, 2005	US	Clinic centres	2161 (1082/ 1079)	3.2	54	680 (31.5)	Diet and physical activity	A 16-lesson behavior modification curriculum was delivered one-on-one over 24 weeks, followed by monthly individual and group sessions to reinforce changes. The program was flexible, personalized, and culturally sensitive.
Li et al., 2019	China	clinics	576 (138/438)	20	–	312 (54.2)	Diet and physical activity	Weekly individual and small group sessions for one month, followed by monthly sessions for three months, and then once every three months for the remainder of the first study.
Lindström et al., 2006, Diabetes Prevention Study (DPS)	Finland	Clinics	522 (257/265)	7	55	172 (32.9)	Diet and physical activity	Lifestyle advice was provided every three months. Each member of the intervention group attended seven sessions in the first year, followed by one session every three months afterward.
[a]Lotfaliany et al., 2020	India	Community-based	1007 (507/ 500)	2	46	532 (52.8)	Diet, physical activity, tobacco cessation, and reducing alcohol consumption and ensuring adequate sleep	The intervention consisted of 15 group sessions over 12 months. After an introductory session led by the research team, local experts facilitated two half-day sessions on diabetes prevention and management, while trained peer leaders conducted monthly follow-up sessions.

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Table 1 (*continued*)

Studies	Country	Setting	Sample size (Control/ Intervention)	Duration of follow-up (years)	Age (mean) in years	Male, n (%)	Intervention components	Characteristics of the Lifestyle Interventions
Goldberg et al., 2022	US	Clinic centres	2152 (1073/ 1079)	21	72	680 (31.5)	Diet and physical activity	A 16-lesson behavior modification curriculum was delivered one-on-one over 24 weeks, followed by monthly individual and group sessions to reinforce changes. The program was flexible, personalized, and culturally sensitive.
Lindstrom et al, 2003 (DPS)	Finland	Clinics	522 (257/265)	4	55	172 (32.9)	Diet and physical activity	Lifestyle advice was provided every three months. Each member of the intervention group attended seven sessions in the first year, followed by one session every three months afterward.
[a]Michaud et al., 2023	US	Clinics	599 (300/299)	1	55	231 (38.5)	Diet and physical activity	A 16-week intensive curriculum on weight loss with weekly interactive behavioral change lessons followed by a 36-week curriculum focusing on weight maintenance.
Oldroyd et al., 2001	UK	Hospital	67 (32/35)	6 months	–	29 (43.2)	Diet and physical activity	Counseling given based on the stages of change model
Pan et al., 1997	China	Health care clinics	576 (138/438)	6	45	312 (54.2)	Diet and physical activity	Weekly individual and small group sessions for one month, followed by monthly sessions for three months, and then once every three months for the remainder of the first study.
Penn et al., 2009	UK	Clinics	102 (51/51)	5	57	41 (40.2)	Diet and physical activity	individual motivational interviewing aimed at lifestyle modification for up to 5 years
Ramachandran et al., 2006	India	Workplace	269(136/133)	3	46	208 (77.3)	Diet and physical activity	Monthly phone calls provided ongoing motivation, and personal sessions were held every 6 months
Ramachandran et al., 2013	India	Workplace	537 (271/266)	2	46	537 (100)	Diet and physical activity	The mobile phone message was delivered based on the transtheoretical model of behavioral change
DPP Research Group, 2009	US	Clinic centres	2161 (1082/ 1079)	10	55.3	680 (31.5)	Diet and physical activity	A 16-lesson behavior modification curriculum was delivered one-on-one over 24 weeks, followed by monthly individual and group sessions to reinforce changes. The program was flexible, personalized, and culturally sensitive..
Roumen et al., 2008	Netherland	Community	147 (73/74)	3	54	28 (53.8)	Diet and physical activity	Every three months, a skilled dietitian provided individualized dietary and physical activity advice during a 1-h counseling session, following a review of a three-day food diary
Saito et al., 2011	Japan	Hospitals	641 (330/341)	3.2	50	143 (22.3)	Diet and physical activity	lifestyle modification from the medical staff 9 times for 36 months
Lindstrom et al, 2013 (DPS)	Finland	Clinics	522 (257/265)	3	–	172 (32.9)	Diet and physical activity	Lifestyle advice was provided every three months. Each member of the intervention group attended seven sessions in the first year, followed by one session every three months afterward.
Sakane et al., 2011	Japan	Primary health care	304 (152/152)	3	51	150 (49.3)	Diet and physical activity	In the initial six months, four group sessions were held, utilizing slides, videotapes, and a booklet, each lasting two to 3 h. Additionally, individual sessions were conducted biannually over the three years, lasting 20 to 40 minutes
Sampson et al., 2021	UK	Primary health care	1028 (178/ 424/426)	4	65	645 (62.7)	Diet and physical activity	A theory-based lifestyle intervention with 6 core and up

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Table 1 (*continued*)

Studies	Country	Setting	Sample size (Control/ Intervention)	Duration of follow-up (years)	Age (mean) in years	Male, n (%)	Intervention components	Characteristics of the Lifestyle Interventions
								to 15 maintenance sessions was given
Tuomilehto et al., 2001 (DPS)	Finland	Clinics	522 (257/265)	4	55	172 (32.9)	Diet and physical activity	Lifestyle advice was provided every three months. Each member of the intervention group attended seven sessions in the first year, followed by one session every three months afterward.
Fottrell et al., 2023	Bangladesh	Community	2470(832/ 841/797)	5	–	–	Diet and physical activity	Voice messages about health behavior and awareness were delivered twice a week for 14 months. The intervention included monthly community meetings focused on participatory learning and action.
Uusitupa et al., 2009 (DPS)	Finland	Clinics	522 (257/265)	10	55	172 (32.9)	Diet and physical activity	Lifestyle advice was provided every three months. Each member of the intervention group attended seven sessions in the first year, followed by one session every three months afterward..
Vermunt et al., 2012	Netherland	Primary care setting	925 (446/479)	2.5	–	–	Diet and physical activity	11 individual consultations of 20 min and group sessions were scheduled over 2.5 years
Yeh et al., 2016	US	Hospital	60(30/30)	1	57	26 (43.3)	Diet and Physical activity	12 bi-weekly core sessions and six monthly follow-up sessions with trained lifestyle coaches at a community site
Yin et al., 2018	China	Hospital and community centre	184(75/109)	1	52	0	Diet and physical activity	12 large-group health education and 10 small-group sessions for goal setting and evaluation, counseling, and social support
Youngwanichsetha et al., 2015	Thailand	Hospital	170(85/85)	6 months	34	0	Diet and physical activity	Advised to follow Southern Thai foods and daily 30-min brisk walking, and encouraged to follow the healthy eating manual at least twice a day and 5 days a week for 24 weeks
[a]Chen et al., 2021	China	Hospital	165 (82/83)	2	60.7	57 (34.5)	Physical activity alone	60-min aerobic training sessions were held three times per week. The intervention lasted for two years
Dai et al., 2019	China	Health service centres	172(45/127)	2	59	45 (26.2)	Physical activity alone	Supervised exercise programs were completed for 60 minutes per day, three non-consecutive days per week for 24 months.
Pimentel et al., 2010	Brazil	Community	67(43/24)	1	52	25 (37.3)	Diet alone	Participants in the intervention group received individual and group counseling to improve diet quality by increasing their intake of vegetables, fruits, and whole grains, and reducing saturated fats
Fottrell et al., 2019	Bangladesh	Community	2470(832/ 841/797)	2	–	–	Diet and physical activity	Voice messages about health behavior and awareness were delivered twice a week for 14 months. The intervention included monthly community meetings focused on participatory learning and action.
Thankappan et al., 2018	India	Community	1007 (507/ 500)	2	46	475 (47.2)	Lifestyle modification	The intervention consisted of 15 group sessions over 12 months. After an introductory session led by the research team, local experts facilitated two half-day sessions on diabetes prevention and management, while trained peer leaders conducted monthly follow-up sessions.
Kawahara et al., 2008	Japan	Health centres/ Hospitals	426(142/143/ 141)	3	51.4	199 (46.7)	Diet, physical activity, and behavior modification	The short-term hospitalization group received a nine-lesson curriculum on behavior

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Table 1 (*continued*)

Studies	Country	Setting	Sample size (Control/ Intervention)	Duration of follow-up (years)	Age (mean) in years	Male, n (%)	Intervention components	Characteristics of the Lifestyle Interventions
								modification. The diabetes education and support group received written information and periodic 20- to 30-min individual sessions.
[a]Lipscomb et al., 2009	India	Health facilities	92 (46/46)	1	56.7	40 (44)	Diet and physical activity	16 classroom meetings focused on goal setting, self-monitoring, and problem-solving were conducted. Each session lasted between 60 and 90 minutes and was delivered over a span of 16 to 20 weeks.
Xu et al., 2013	China	Community centre	88 (42/46)	1	58	42 (47.7)	Diet and physical activity	A daily meal replacement and intensive lifestyle intervention were provided during the first 3 months, followed by monthly follow-up sessions
Wong et al., 2013	China	–	104 (50/54)	2	55	97 (93.2)	Diet and Physical activity	In the first 3 months, text messages were sent three times per week; in the next 3 months, once per week; and in the following 6 and 12 months, once per month

[a] Studies include CVD risk as an outcome.

clinical and biochemical secondary outcomes. The details of the meta-analysis results for the secondary outcomes are presented in Table 2, with corresponding forest plots available in Supplementary File 2.

3.3.2.1. Behavioral and psychosocial risk factors. In this systematic review, we found that six studies [45,59,65-68] showed a significant increase in physical activity among the intervention groups compared to the control groups, while two studies reported a non-significant increase [53,59]. Six studies [15,59,60,65,67,68] reported that a decrease in the intake of saturated fats and high-calorie consumption in the intervention groups, while five studies [15,26,43,48,51] reported an increase in the consumption of fruits, vegetables, and fiber. Three studies [43,51,68] highlighted a reduction in alcohol consumption among the intervention groups. Although two studies [46,49] reported on smoking, neither study found a significant difference between the treatment groups. Lastly, only one study [60] reported on psychosocial risk factors, reporting a reduction in both depression and anxiety in the intervention group; however, a reduction in depression was not statistically significant.

3.3.2.2. Comparing the effects of the interventions based on follow-up time. In studies that reported CVD risk as an outcome, all were categorized as having short- to mid-term follow-ups. A significant reduction in CVD risk, up to 2.23 %, was observed in the intervention groups in four of the studies [26,41,49,50] while no significant effect was found in the remaining two studies [60,63]. Additionally, the incidence of type 2 diabetes decreased significantly in studies with short and medium-term follow-ups, with reductions of up to 58 % reported in trials such as the US DPP and the Finnish DPS [14,16]. However, the effectiveness of the intervention declined in long-term follow-ups compared to the short- and medium-term follow-ups. A similar trend was observed for clinical outcomes such as weight, waist circumference, and blood pressure, as well as biochemical markers like glycemic control and lipid profiles. Furthermore, behavioral outcomes, including diet, physical activity, smoking cessation, and alcohol consumption, showed greater improvements in studies with short- and medium-term follow-ups compared to those with long-term follow-ups.

3.3.2.3. Comparison of digital interventions and health practitioner-delivered interventions. Out of 42 studies, a total of five studies reported using digital interventions [46,53,56,63,69]. Among the six studies that reported CVD risk as an outcome, five studies delivered their intervention through health practitioners. Of these, three studies reported a reduction in CVD risk, while only one study that employed a digital intervention did not achieve a reduction in CVD risk [63]. Additionally, of the four digital interventional studies that evaluated the incidence of type 2 diabetes, only one study showed a reduction in the incidence of this condition [53]. Most effective diabetes prevention programs, including the US DPP and the Finnish DPS, primarily utilized face-to-face interactions or health practitioner-led approaches to successfully reduce the incidence of type 2 diabetes and other cardiometabolic risk factors.

3.3.2.4. Quality of the studies. The assessment using the ROB2 tool revealed that 62 % of the included studies were classified as low risk, 24 % had some concerns, and 14 % were categorized as high risk. A summary of the risk of bias for the included studies is presented in Fig. 2.

3.4. Certainty of the evidence

The GRADE assessment results indicated that most of the included studies (73 %) presented evidence with either very low or low certainty regarding the analyzed outcomes. Fig. 3 shows the summary of the GRADE assessment for the outcomes of this review.

3.5. Publication bias

Publication bias was evaluated for the outcomes included in this review that had more than 10 studies. Evidence of publication bias was found for the outcome of incidence of type 2 diabetes, as indicated by an asymmetrical funnel plot, which was supported by Egger's test ($P = 0.001$) (Supplementary file 3). In contrast, no signs of publication bias were detected for the other outcomes (weight, BMI, 2-h plasma glucose, and fasting plasma glucose), based on the funnel plots and their corresponding results from Egger's test (Supplementary file 3).

4. Discussion

In this systematic review and meta-analysis of 42 studies, we found that lifestyle interventions significantly reduced the 10-year predicted

Table 2
Results of meta-analysis for the secondary outcomes.

SN	Outcomes	Number of studies included	Effect measure	Estimate (SMD/RR (95 % CI)	I^2 (%)	P value
1	Incidence of type 2 diabetes	18	RR	0.75 (0.67, 0.84)	71.9	<0.001[a]
2	Weight (kg)	20	SMD	−0.38 (-0.54, -0.22)	91.4	<0.001[a]
3	BMI	12	SMD	−0.08 (-0.31, 0.14)	93.9	0.480
4	Waist circumference (cm)	8	SMD	−0.35 (-0.53, -0.17)	86.3	<0.001[a]
5	2hr plasma glucose	11	SMD	−0.22 (-0.36, -0.09)	71.2	<0.001[a]
6	Fasting plasma glucose	16	SMD	−0.12 (-0.48, -0.23)	97.6	0.490
7	HbA1c	6	SMD	−0.49 (-0.88, -0.10)	91.9	0.010[a]
8	Systolic blood pressure (mmHg)	8	SMD	−0.13 (-0.2, -0.06)	45.9	<0.001[a]
9	Diastolic blood pressure (mmHg)	8	SMD	−0.14 (-0.2, -0.07)	22.9	<0.001[a]
10	Total cholesterol	8	SMD	−0.06 (-0.18, -0.07)	63.4	0.370
11	HDL-cholesterol	5	SMD	0.16 (0.05, 0.28)	0.0	<0.001[a]
12	LDL-cholesterol	7	SMD	−0.05 (-0.17, 0.07)	53.1	0.370
13	Triglycerides	8	SMD	−0.26 (-0.45, -0.07)	89.0	0.010[a]

[a] Statistically significant (P<0.05) SMD- Standardized Mean Difference, RR-Relative Risk, HDL- High-Density Lipoprotein, LDL- Low-Density Lipoprotein, HbA1c- Hemoglobin A1c.

CVD risk and improved associated risk factors. These risk factors included the incidence of type 2 diabetes, anthropometric indices (weight and waist circumference), glycaemic control (2-hr plasma glucose and HbA1c), blood pressure, triglycerides, and HDL-cholesterol. These benefits were primarily observed during the short and mid-term follow-up periods, compared to the long-term follow-up periods. However, it is important to interpret these results with caution due to the high level of heterogeneity among the studies. For this analysis, we included all the eligible studies, but the heterogeneity that we found in our analysis may be due to the inclusion of studies that used either the WHO or the ADA criteria, with different cut-off points used to identify individuals with prediabetes.

The reduction in absolute CVD risk with lifestyle interventions among individuals with prediabetes in this review aligns with findings from previous systematic reviews and meta-analyses conducted among individuals at risk of CVD or those without CVD at baseline in other study populations [70,71]. Lifestyle changes, including increased physical activity and dietary adjustments, improve insulin sensitivity and help reduce chronic hyperglycemia, a risk factor for atherosclerosis, CVD, and prediabetes [72]. Moreover, lifestyle interventions effectively lower CVD risk by addressing multiple behavioral factors [73]. For example, reducing saturated fat intake decreases LDL cholesterol levels, whereas limiting alcohol consumption helps regulate blood pressure and maintain a healthy heart rhythm [74]. Furthermore, increasing physical activity improves cardiac function, circulation, and metabolism, which in turn lowers the risk of obesity and type 2 diabetes [75]. A diet rich in fruits and vegetables provides essential nutrients and antioxidants that combat inflammation and improve vascular health [76]. Collectively, these changes contribute to lowering modifiable CVD risk factors such as hypertension, hyperlipidemia, and insulin resistance, establishing lifestyle interventions as a fundamental aspect of CVD prevention and risk reduction [77,78].

Our meta-analysis demonstrates that lifestyle intervention in the intervention groups reduced the progression to type 2 diabetes by 25 %. Additionally, these interventions led to improvements in various cardiometabolic indicators, including reductions in weight and waist circumference, better glycaemic control (2-hr plasma glucose and HbA1c), lowered blood pressure, reduced triglycerides, and increased HDL-cholesterol. These findings are consistent with findings from a previous systematic review and meta-analysis [79]. Landmark studies, such as the US DPP, Finnish DPS, and the Da Qing study in China, confirm that key interventions, including dietary changes, increased physical activity, and behavioral counseling, not only delay the onset of diabetes but also improve weight management and overall cardiometabolic health [14,16,80].

Our findings indicate that the effectiveness of lifestyle interventions tends to decrease over time. Most significant benefits are seen in short- and medium-term follow-ups compared to long-term follow-ups. This trend is evident across various cardiometabolic outcomes, including the reduction of CVD risk, the incidence of type 2 diabetes, and clinical measures such as weight, waist circumference, and blood pressure. Additionally, biochemical markers like glycemic control and lipid profiles, as well as behavioral factors including diet, physical activity, smoking cessation, and alcohol reduction, also show this trend. Established diabetes prevention programs, such as the US DPP and Finnish DPS, have demonstrated that intensive intervention efforts lead to considerable early benefits [14,16]. The lack of sustained improvements in long-term follow-ups highlights the challenge of maintaining the effects of lifestyle interventions over extended periods. These findings emphasize the importance of ongoing support strategies, including reinforcement programs and behavioral maintenance interventions, to enhance long-term adherence and sustain health benefits.

Due to a limited number of studies (three) and differences in measurement methods, we did not conduct a meta-analysis to assess the effects of lifestyle interventions on CVD events and behavioral CVD risk factors. However, our narrative synthesis in this systematic review indicates uncertainty regarding the effectiveness of lifestyle interventions in reducing CVD events among individuals with prediabetes. One of the included studies, the Da Qing study in China, reported a 6.1 % reduction in CVD events in the intervention group [44], suggesting a potential protective effect of lifestyle modifications on the reduction of CVD events. In contrast, other significant follow-up studies, such as the US DPP (2022) and the Finnish DPS (2021), found no significant difference in CVD event rates between the intervention and control groups [62,64]. The inconsistency in findings may be attributed to variations in participant characteristics, adherence to interventions, differences in intervention approaches, and healthcare settings. Additionally, while lifestyle interventions are well-established for improving cardiometabolic risk factors such as weight, blood glucose, and lipid profiles, their effectiveness in reducing CVD events remains unclear possibly due to the multifactorial nature of CVD development or because the risk factor changes observed in studies of short and medium duration are not sustained in the long term [81,82].

Our systematic review narrative synthesis also revealed that lifestyle interventions positively impacted behavioral CVD risk factors. These interventions reduced saturated fat intake and alcohol consumption while promoting increased physical activity and higher consumption of fruits and vegetables among the participants. This finding aligns with results from other systematic reviews [18,19]. Lifestyle interventions employ diverse strategies to effectively modify behavioral CVD risk

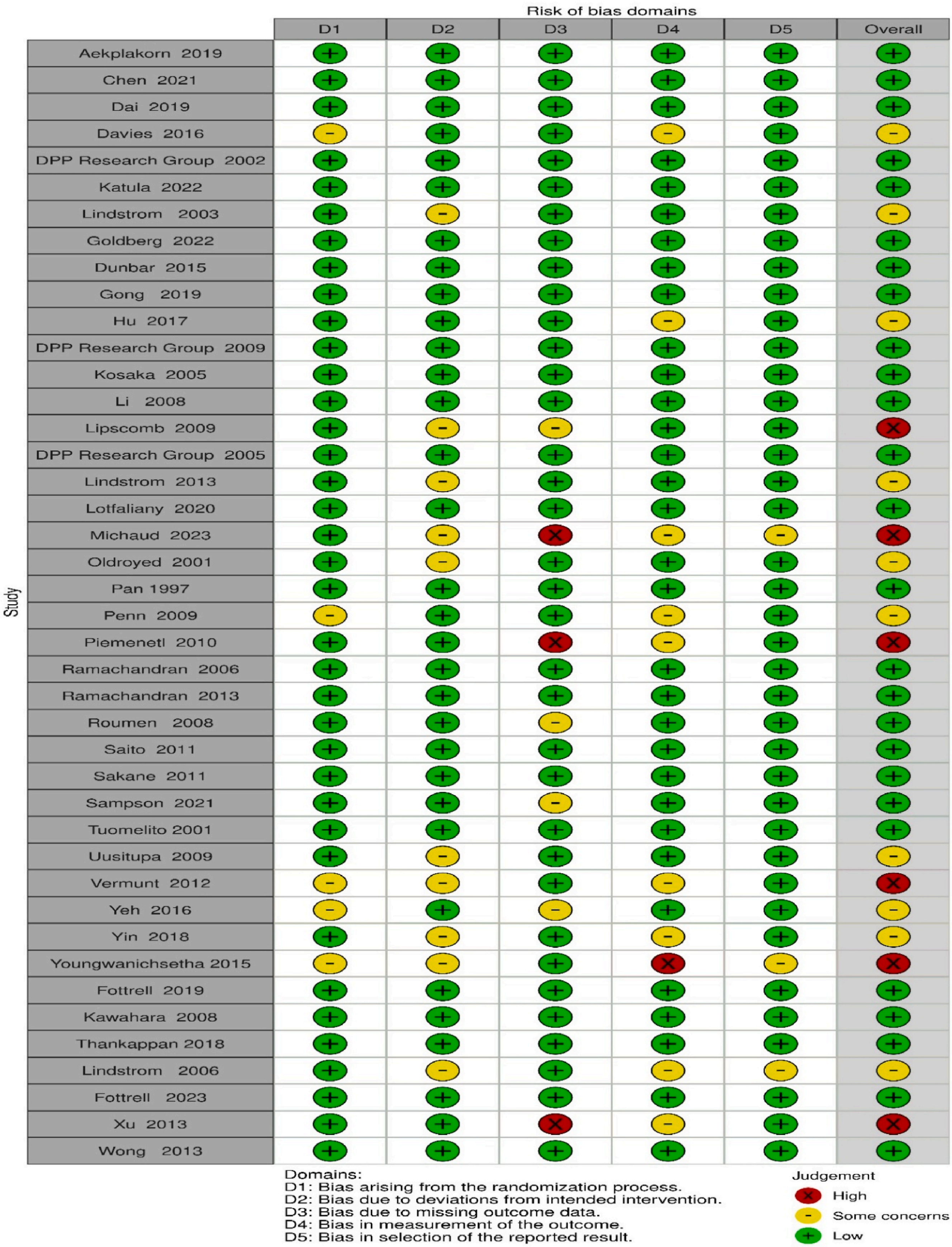

Fig. 2. Summary of risk of bias: Review authors' judgments for included studies.

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	№ of participants (studies)	Certainty of the evidence (GRADE)
	Risk with usual care	Risk with intervention			
Change in CVD risk	The mean CVD risk change was 0.75	SMD 1.91 lower (2.89 lower to 0.93 lower)	-	3052 (6 RCTs)	⊕◯◯◯ Very low
Change in CVD events	205 per 1,000	159 per 1,000	-	3197 (3 RCTs)	⊕◯◯◯ Very low
Incidence of type2 Diabetes	336 per 1,000	252 per 1,000 (225 to 282)	RR 0.75 (0.67 to 0.84)	11796 (18 RCTs)	⊕⊕◯◯ Low
Weight change	The mean weight change was -0.52	SMD 0.38 lower (0.54 lower to 0.22 lower)	-	8739 (20 RCTs)	⊕◯◯◯ Very low
BMI change	The mean body Mass Index change was -0.63	SMD 0.08 lower (0.31 lower to 0.14 higher)	-	5724 (12 RCTs)	⊕◯◯◯ Very low
Waist circumference change	The mean waist circumference change was -0.60	SMD 0.35 lower (0.53 lower to 0.17 lower)	-	4004 (8 RCTs)	⊕◯◯◯ Very low
2 hr plasma glucose change	The mean 2 hr plasma glucose change was 0.62	SMD 0.22 lower (0.36 lower to 0.09 lower)	-	3747 (11 RCTs)	⊕⊕◯◯ Low
HbA1c change	The mean hbA1c change was 0.64	SMD 0.49 lower (0.88 lower to 0.1 lower)	-	1933 (6 RCTs)	⊕◯◯◯ Very low
Systolic blood pressure change	The mean systolic blood pressure change was -0.64	SMD 0.13 lower (0.2 lower to 0.06 lower)	-	6507 (8 RCTs)	⊕⊕⊕◯ Moderate
Diastolic blood pressure change	The mean diastolic blood pressure change was -1.91	SMD 0.14 lower (0.2 lower to 0.07 lower)	-	5621 (8 RCTs)	⊕⊕⊕◯ Moderate
Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	№ of participants (studies)	Certainty of the evidence (GRADE)
	Risk with usual care	Risk with intervention			
Total cholesterol change	The mean total cholesterol change was -2.11	SMD 0.06 lower (0.18 lower to 0.07 lower)	-	3432 (8 RCTs)	⊕◯◯◯ Very low
HDL-cholesterol change	The mean HDL-cholesterol change was 0.05	SMD 0.16 higher (0.05 higher to 0.28 higher)	-	1208 (5 RCTs)	⊕⊕⊕◯ Moderate
LDL-cholesterol change	The mean LDL-cholesterol change was -4.48	SMD 0.05 lower (0.17 lower to 0.07 higher)	-	3836 (7 RCTs)	⊕⊕◯◯ Low
Triglycerides change	The mean triglyceride change was -3.16	SMD 0.26 lower (0.45 lower to 0.07 lower)	-	5022 (8 RCTs)	⊕◯◯◯ Very low

Fig. 3. Summary of GRADE for the outcomes of the included studies.

factors [83]. Nutritional interventions, such as dietary counseling, healthy meal planning, and portion control, help participants reduce their saturated fat intake and increase their consumption of fruits and vegetables [83]. Additionally, promoting physical activity through structured exercise programs, community-based activities, and reducing sedentary behavior improves cardiovascular fitness, circulation, and weight management [84]. Furthermore, awareness campaigns, peer-led support programs, motivational interviewing, and behavioral and psychological support reinforce long-term adherence to these lifestyle changes [85-87].

4.1. Implications of the study

The findings from this systematic review and meta-analysis emphasize the importance of prioritizing lifestyle interventions, such as a healthy diet and increased physical activity, to reduce CVD risk and CVD risk factors in individuals with prediabetes. However, there is still uncertainty regarding the effectiveness of these interventions in lowering the incidence of CVD events within this population. Additionally, the GRADE assessment indicates that more well-designed and rigorous research is needed to enhance the reliability of the evidence and reach a more definitive conclusion. Therefore, further evaluation through extended follow-up studies is essential to assess the impact of lifestyle interventions on CVD events and risk factors among individuals with prediabetes.

4.2. Strengths and limitations

To the best of our knowledge, this review is the most comprehensive examination of how lifestyle interventions impact CVD risk and CVD risk factors among individuals with prediabetes. As such, it can provide valuable insights for policy changes, particularly in LMICs. A notable strength of this study is its focus on RCTs, which enhances the reliability of the intervention programs' effectiveness. However, there are still some limitations to consider. Firstly, our search was confined to studies published in English, which may have led us to overlook relevant studies available in other languages. As meta-analysis was not conducted for CVD event outcomes due to the limited number of eligible studies, and for behavioral risk factors due to variations in outcome definitions and measurement methods, the conclusions of the meta-analysis and the overall generalizability of our findings may have been affected.

5. Conclusion

This systematic review and meta-analysis demonstrate that lifestyle interventions can effectively reduce the risk of CVD and related factors in individuals with prediabetes. However, the long-term effectiveness of these interventions in decreasing the incidence of type 2 diabetes may diminish over time, and their impact on reducing CVD events remains uncertain.

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Declaration of competing interest

The authors declare that they have no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.numecd.2025.104130.

References

[1] Cheng YJ, et al. Association of A1C and fasting plasma glucose levels with diabetic retinopathy prevalence in the US population: implications for diabetes diagnostic thresholds. Diabetes Care 2009;32(11):2027–32.
[2] Ford ES, Zhao G, Li C. Pre-diabetes and the risk for cardiovascular disease: a systematic review of the evidence. J Am Coll Cardiol 2010;55(13):1310–7.
[3] Khan RMM, et al. From pre-diabetes to diabetes: diagnosis, treatments and translational research. Medicina 2019;55(9):546.
[4] Rooney MR, et al. Global prevalence of prediabetes. Diabetes Care 2023;46(7):1388–94.
[5] Amelia R, et al. Risk of cardiovascular complication among type 2 diabetes mellitus patients in medan, Indonesia. A cross-sectional study. Med Arch 2022;76(5):324.
[6] Hostalek U. Global epidemiology of prediabetes-present and future perspectives. Clinical diabetes and endocrinology 2019;5(1):5.
[7] DeFronzo RA. Pathogenesis of type 2 diabetes mellitus. Medical clinics 2004;88(4):787–835.
[8] Huang Y, et al. Association between prediabetes and risk of cardiovascular disease and all cause mortality: systematic review and meta-analysis. Bmj 2016;355:i5953.
[9] Brannick B, Dagogo-Jack S. Prediabetes and cardiovascular disease: pathophysiology and interventions for prevention and risk reduction. Endocrinol Metab Clin North Am 2018;47(1):33–50.
[10] American Diabetes Association. Standards of medical care in diabetes—2014. Diabetes Care 2014;37(Supplement_1):S14–80.
[11] Colberg SR, et al. Physical activity/exercise and diabetes: a position statement of the American Diabetes Association. Diabetes Care 2016;39(11):2065.
[12] Newman JD, et al. Primary prevention of cardiovascular disease in diabetes mellitus. J Am Coll Cardiol 2017;70(7):883–93.
[13] Franquesa M, et al. Mediterranean diet and cardiodiabesity: a systematic review through evidence-based answers to key clinical questions. Nutrients 2019;11(3).
[14] Tuomilehto J, et al. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. N Engl J Med 2001;344(18):1343–50.
[15] Lindström J, et al. Sustained reduction in the incidence of type 2 diabetes by lifestyle intervention: follow-up of the Finnish Diabetes Prevention Study. Lancet 2006;368(9548):1673–9.
[16] The Diabetes Prevention Program (DPP) Research Group. Description of lifestyle intervention. Diabetes Care 2002;25(12):2165–71.
[17] Li G, et al. The long-term effect of lifestyle interventions to prevent diabetes in the China Da Qing Diabetes Prevention Study: a 20-year follow-up study. Lancet 2008;371(9626):1783–9.
[18] Limbachia J, et al. Effects of lifestyle interventions on cardiovascular risk factors in South Asians: a systematic review and meta-analysis. BMJ Open 2022;12(12):e059666.
[19] Zhang X, et al. Effect of lifestyle interventions on cardiovascular risk factors among adults without impaired glucose tolerance or diabetes: a systematic review and meta-analysis. PLoS One 2017;12(5):e0176436.
[20] Shirinzadeh M, et al. The effect of community-based programs on diabetes prevention in low-and middle-income countries: a systematic review and meta-analysis. Glob Health 2019;15(1):1–13.
[21] Moher D, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Annals of internal medicine 2009;151(4):264–9.
[22] Demissie GD, et al. Effects of lifestyle interventions on cardiovascular disease risk and risk factors among individuals at high risk for type 2 diabetes: protocol for a systematic review and meta-analysis of randomized controlled trials. JMIR Research Protocols 2024;13(1):e53517.
[23] ElSayed NA, et al. Addendum. 2. Classification and diagnosis of diabetes: standards of care in diabetes—2023. Diabetes care 2023; 46 (suppl. 1): S19–S40. Diabetes Care 2023;46(9):1715. 1715.
[24] World Health Organization. Definition and diagnosis of diabetes mellitus and intermediate hyperglycaemia: report of a WHO/IDF consultation. 2006.
[25] American Diabetes Association. Classification and diagnosis of diabetes: standards of medical care in diabetes-2021. Diabetes Care 2021;44(Suppl 1):S15–s33.
[26] Dunbar JA, et al. Challenges of diabetes prevention in the real world: results and lessons from the Melbourne Diabetes Prevention Study. BMJ Open Diabetes Res Care 2015;3(1):e000131.
[27] ovidence systematic review software, Veritas Health Innovation, Melbourne, Australia. Availableat.www.covidence.org.
[28] World Health Organization. Global action plan for the prevention and control of noncommunicable diseases 2013-2020. 2013.
[29] Sterne JA, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. bmj 2019:366.

[30] McGuinness LA, Higgins JP. Risk-of-bias VISualization (robvis): an R package and Shiny web app for visualizing risk-of-bias assessments. Res Synth Methods 2021;12 (1):55–61.
[31] Guyatt GH, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. Bmj 2008;336(7650):924–6.
[32] DerSimonian R, Laird N. Meta-analysis in clinical trials revisited. Contemp Clin Trials 2015;45(Pt A):139–45.
[33] Borenstein M, et al. Introduction to meta-analysis. John wiley & sons; 2021.
[34] Chang Y, et al. The 5 min meta-analysis: understanding how to read and interpret a forest plot. Eye 2022;36(4):673–5.
[35] Deeks JJ, et al. Analysing data and undertaking meta-analyses. Cochrane handbook for systematic reviews of interventions 2019:241–84.
[36] Lin L, Chu H. Quantifying publication bias in meta-analysis. Biometrics 2018;74 (3):785–94.
[37] Egger M, et al. Bias in meta-analysis detected by a simple, graphical test. bmj 1997; 315(7109):629–34.
[38] StataCorp LLC. Stata statistical software: release 18. College station, TX. 2023. 2023.
[39] Cooper H, Hedges LV, Valentine JC. The handbook of research synthesis and meta-analysis. Russell Sage Foundation; 2019.
[40] Higgins J, et al. Cochrane handbook for systematic reviews of interventions version 6.2 (updated February 2021). Cochrane, www.training.cochrane.org/handbook. [Accessed 3 June 2021]. 2021.
[41] Chen X, et al. Effects of aerobic training and resistance training in reducing cardiovascular disease risk for patients with prediabetes: a multi-center randomized controlled trial. Prim Care Diabetes 2021;15(6):1063–70.
[42] Dai X, et al. Two-year-supervised resistance training prevented diabetes incidence in people with prediabetes: a randomised control trial. Diabetes/metabolism research and reviews 2019;35(5):e3143.
[43] Hu Z, Qin L, Xu H. One-year results of a synthetic intervention model for the primary prevention of T2D among elderly individuals with prediabetes in rural China. Int J Environ Res Publ Health 2017;14(4):417.
[44] Gong Q, et al. Morbidity and mortality after lifestyle intervention for people with impaired glucose tolerance: 30-year results of the Da Qing Diabetes Prevention Outcome Study. Lancet Diabetes Endocrinol 2019;7(6):452–61.
[45] Yin Z, et al. Cultural adaptation of an evidence-based lifestyle intervention for diabetes prevention in Chinese women at risk for diabetes: results of a randomized trial. International health 2018;10(5):391–400.
[46] Wong CK, et al. A short message service (SMS) intervention to prevent diabetes in Chinese professional drivers with pre-diabetes: a pilot single-blinded randomized controlled trial. Diabetes Res Clin Pract 2013;102(3):158–66.
[47] Xu D-F, et al. Effects of lifestyle intervention and meal replacement on glycaemic and body-weight control in Chinese subjects with impaired glucose regulation: a 1-year randomised controlled trial. British journal of nutrition 2013;109(3):487–92.
[48] Pan X-R, et al. Effects of diet and exercise in preventing NIDDM in people with impaired glucose tolerance: the Da Qing IGT and Diabetes Study. Diabetes Care 1997;20(4):537–44.
[49] Lotfaliany M, et al. Effects of a lifestyle intervention on cardiovascular risk among high-risk individuals for diabetes in a low-and middle-income setting: secondary analysis of the Kerala Diabetes Prevention Program. Prev Med 2020;139:106068.
[50] Lipscomb ER, et al. Reduced 10-year risk of coronary heart disease in patients who participated in a community-based diabetes prevention program: the DEPLOY pilot study. Diabetes Care 2009;32(3):394–6.
[51] Thankappan KR, et al. A peer-support lifestyle intervention for preventing type 2 diabetes in India: a cluster-randomized controlled trial of the Kerala Diabetes Prevention Program. PLoS Med 2018;15(6):e1002575.
[52] Ramachandran A, et al. The Indian Diabetes Prevention Programme shows that lifestyle modification and metformin prevent type 2 diabetes in Asian Indian subjects with impaired glucose tolerance (IDPP-1). Diabetologia 2006;49:289–97.
[53] Ramachandran A, et al. Effectiveness of mobile phone messaging in prevention of type 2 diabetes by lifestyle modification in men in India: a prospective, parallel-group, randomised controlled trial. Lancet Diabetes Endocrinol 2013;1(3):191–8.
[54] Aekplakorn W, et al. Evaluation of a community-based diabetes prevention program in Thailand: a cluster randomized controlled trial. Journal of primary care & community health 2019;10:2150132719847374.
[55] Youngwanichsetha S, Phumdoung S, Cersosimo E. Effects of a metabolic syndrome self-management programme for women with pre-diabetes. Focus Alternative Compl Ther 2015;20(2):74–80.
[56] Fottrell E, et al. Community groups or mobile phone messaging to prevent and control type 2 diabetes and intermediate hyperglycaemia in Bangladesh (DMagic): a cluster-randomised controlled trial. Lancet Diabetes Endocrinol 2019;7(3): 200–12.
[57] Fottrell E, et al. Intermediate hyperglycaemia, diabetes and blood pressure in rural Bangladesh: five-year post-randomisation follow-up of the DMagic cluster-randomised controlled trial. The Lancet Regional Health-Southeast Asia 2023;10: 100122.
[58] Pimentel GD, et al. Long-term nutrition education reduces several risk factors for type 2 diabetes mellitus in Brazilians with impaired glucose tolerance. Nutr Res (NY) 2010;30(3):186–90.
[59] Lindström J, et al. Improved lifestyle and decreased diabetes risk over 13 years: long-term follow-up of the randomised Finnish Diabetes Prevention Study (DPS). Diabetologia 2013;56:284–93.
[60] Davies MJ, et al. A community based primary prevention programme for type 2 diabetes integrating identification and lifestyle intervention for prevention: the Let's Prevent Diabetes cluster randomised controlled trial. Prev Med 2016;84: 48–56.
[61] Kosaka K, Noda M, Kuzuya T. Prevention of type 2 diabetes by lifestyle intervention: a Japanese trial in IGT males. Diabetes Res Clin Pract 2005;67(2): 152–62.
[62] Goldberg RB, et al. Effects of long-term metformin and lifestyle interventions on cardiovascular events in the diabetes prevention program and its outcome study. Circulation 2022;145(22):1632–41.
[63] Michaud TL, et al. Effects of a digital diabetes prevention program on cardiovascular risk among individuals with prediabetes. Primary Care Diabetes 2023;17(2):148–54.
[64] Uusitupa M, et al. Ten-year mortality and cardiovascular morbidity in the Finnish Diabetes Prevention Study–secondary analysis of the randomized trial. PLoS One 2009;4(5):e5656.
[65] Lindstrom J, Tuomilehto J. The diabetes risk score: a practical tool to predict type 2 diabetes risk. Diabetes Care 2003;26(3):725–31.
[66] Oldroyd JC, et al. Randomised controlled trial evaluating the effectiveness of behavioural interventions to modify cardiovascular risk factors in men and women with impaired glucose tolerance: outcomes at 6 months. Diabetes Res Clin Pract 2001;52(1):29–43.
[67] Roumen C, et al. Impact of 3-year lifestyle intervention on postprandial glucose metabolism: the SLIM study. Diabet Med 2008;25(5):597–605.
[68] Saito T, et al. Lifestyle modification and prevention of type 2 diabetes in overweight Japanese with impaired fasting glucose levels: a randomized controlled trial. Arch Intern Med 2011;171(15):1352–60.
[69] Katula JA, et al. Effects of a digital diabetes prevention program: an RCT. Am J Prev Med 2022;62(4):567–77.
[70] Kariuki JK, et al. Impact of lifestyle-based interventions on absolute cardiovascular disease risk: a systematic review and meta-analysis. JBI evidence synthesis 2024;22 (1):4–65.
[71] Goyer L, et al. Randomized controlled trial on the long-term efficacy of a multifaceted, interdisciplinary lifestyle intervention in reducing cardiovascular risk and improving lifestyle in patients at risk of cardiovascular disease. J Behav Med 2013;36:212–24.
[72] Knowler WC, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med 2002;346(6):393–403.
[73] Rippe JM. Lifestyle strategies for risk factor reduction, prevention, and treatment of cardiovascular disease. Am J Lifestyle Med 2019;13(2):204–12.
[74] Roerecke M, et al. The effect of a reduction in alcohol consumption on blood pressure: a systematic review and meta-analysis. Lancet Public Health 2017;2(2): e108–20.
[75] Pinckard K, Baskin KK, Stanford KI. Effects of exercise to improve cardiovascular health. Front Cardiovasc Med 2019;6:69.
[76] Holt EM, et al. Fruit and vegetable consumption and its relation to markers of inflammation and oxidative stress in adolescents. J Am Diet Assoc 2009;109(3): 414–21.
[77] Ghodeshwar GK, Dube A, Khobragade D. Impact of lifestyle modifications on cardiovascular health: a narrative review. Cureus 2023;15(7):e42616.
[78] Look AHEAD Research Group. Long-term effects of a lifestyle intervention on weight and cardiovascular risk factors in individuals with type 2 diabetes mellitus: four-year results of the Look AHEAD trial. Arch Intern Med 2010;170(17):1566–75.
[79] Walker KZ, et al. Diet and exercise in the prevention of diabetes. J Hum Nutr Diet 2010;23(4):344–52.
[80] Uusitupa M, et al. Prevention of type 2 diabetes by lifestyle changes: a systematic review and meta-analysis. Nutrients 2019;11(11):2611.
[81] Ebrahim S, et al. Multiple risk factor interventions for primary prevention of coronary heart disease. Cochrane Database Syst Rev 2011;(1).
[82] Patnode CD, et al. Behavioral counseling to promote a healthful diet and physical activity for cardiovascular disease prevention in adults without known cardiovascular disease risk factors: updated systematic review for the U.S. Preventive services Task force. Rockville (MD): Agency for Healthcare Research and Quality (US); 2017.
[83] Salvia MG, Quatromoni PA. Behavioral approaches to nutrition and eating patterns for managing type 2 diabetes: a review. American Journal of Medicine Open 2023; 9:100034.
[84] Fletcher GF, et al. Promoting physical activity and exercise: JACC health promotion Series. J Am Coll Cardiol 2018;72(14):1622–39.
[85] Castelnuovo G, et al. Cognitive behavioral therapy to aid weight loss in obese patients: current perspectives. Psychol Res Behav Manag 2017;10:165–73.
[86] Barrett S, et al. Integrated motivational interviewing and cognitive behaviour therapy for lifestyle mediators of overweight and obesity in community-dwelling adults: a systematic review and meta-analyses. BMC Public Health 2018;18(1): 1160.
[87] Cook JA, et al. Whole health action management: a randomized controlled trial of a peer-led health promotion intervention. Psychiatr Serv 2020;71(10):1039–46.