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EFFECTIVENESS OF LIFESTYLE INTERVENTIONS BASED ON DIET, PHYSICAL ACTIVITY, AND DIGITAL TECHNOLOGY IN THE PREVENTION AND MANAGEMENT OF TYPE 2 DIABETES COMPLICATIONS: A SYSTEMATIC REVIEW

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ABSTRACT
Type 2 Diabetes Mellitus (T2DM) requires comprehensive lifestyle management to prevent life-threatening microvascular and macrovascular complications. Although diet and physical activity are the main pillars, the integration of digital technology offers new potential for improving compliance and clinical outcomes. Objective: This systematic review aims to synthesize evidence on the effectiveness of multidomain lifestyle interventions (diet, physical activity, digital technology) on glycemic control, cardiovascular complication risk, and quality of life in T2DM patients. A systematic literature search was conducted in PubMed, Scopus, and SAGE Journals databases for English and Indonesian articles published between 2020 and 2025. Study selection followed the PRISMA 2020 guidelines, using the Search String pumped ("Diabetes Mellitus, Type 2"[MeSH] OR "T2DM" OR "prediabetes") AND ("Life Style"[MeSH] OR "diet" OR "physical activity" OR "exercise") AND ("Telemedicine"[MeSH] OR "mobile app" OR "digital health") AND ("Randomized Controlled Trial" OR "Cohort Study". Search String Scopus TITLE-ABS-KEY(("Diabetes Mellitus, Type 2" OR "T2DM") AND ("Life Style" OR "diet" OR "exercise") AND ("digital health" OR "mobile app") AND ("RCT" OR "Cohort")). Search String sage journal ("Type 2 Diabetes" OR "T2DM") AND ("Lifestyle" OR "Diet" OR "Physical Activity") AND ("Digital Health" OR "App). Methodological quality was assessed using the Joanna Briggs Institute (JBI) instrument. Due to high clinical heterogeneity, data were synthesized narratively. A total of 20 studies (17 RCTs and 3 Prospective Cohort Studies; N > 50,000) met the inclusion criteria. Low-carbohydrate and plant-based dietary interventions significantly reduced HbA1c with Mean Differences (MD) ranging from -0.5% to -1.3% and supported diabetes remission (NNT=5.3). The combination of aerobic and resistance physical activity reduced inflammatory markers and improved insulin sensitivity. Digital technology-based interventions (apps/CGM) recorded an average HbA1c reduction of -0.4% to -1.8% ($p<0.01$) and increased Time-in-Range (+31 minutes/day). Long-term evidence shows that combined lifestyle interventions reduce cardiovascular mortality (Hazard Ratio [HR] 0.54; 95% CI 0.3–0.9) and diabetes incidence (HR 0.76) over a 20–30-year follow-up period. The combination of dietary modification, structured physical activity, and digital technology provides superior clinical effectiveness compared to single interventions. Despite limitations such as heterogeneity in intervention duration, the evidence supports the integration of hybrid (digital-physical) care models into standard nursing practice for the prevention of long-term complications.

Keywords: cardiovascular disease; digital health technology; HbA1c; lifestyle intervention; type 2 diabetes mellitus

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INTRODUCTION

Type 2 diabetes mellitus (T2DM) is one of the most prevalent chronic metabolic diseases worldwide. Based on the latest data from the 11th edition of the IDF Diabetes Atlas, it is estimated that 589 million adults (aged 20–79 years) will be living with diabetes in 2024, equivalent to a global prevalence of 11.1% or 1 in 9 adults. This number is predicted to increase to 853 million by 2050 (IDF Diabetes, 2025) . Data from The Lancet and WHO show that the global prevalence of diabetes in adults increased from 7% to 14% between 1990 and 2022, with 80% of people with

diabetes living in low- and middle-income countries ((NCD-RisC), 2024; WHO, 2024) . In Indonesia alone, 20.4 million adults were living with diabetes in 2024, making it the country with the fifth-highest number of people with diabetes in the world (IDF Diabetes, 2025) .

T2DM is characterized by insulin resistance and relative insulin secretion deficiency, which causes chronic hyperglycemia. Prolonged hyperglycemia contributes to significant microvascular (retinopathy, nephropathy, neuropathy) and macrovascular (coronary heart disease, stroke, peripheral artery disease) complications that reduce quality of life and increase mortality (Goyal et al., 2023) . Diabetes caused 3.4 million deaths in 2024, or 1 death every 9 seconds, and accounted for global health expenditures of USD 1.015 trillion, an increase of 338% over the past 17 years (IDF Diabetes, 2025) . The disease burden of T2DM in terms of Disability-Adjusted Life Years (DALYs) continues to increase, especially in regions with low and medium Socio-Demographic Index (SDI), driven by population growth, urbanization, shifts in dietary patterns toward processed and calorie-dense foods, and decreased physical activity (He et al., 2024) .

Lifestyle modifications, including dietary changes, increased physical activity, and weight management, are the main pillars of preventing the onset of T2DM and managing patients who have already been diagnosed. Various international clinical guidelines, including those from the American Diabetes Association (ADA) and the International Diabetes Federation (IDF), recommend lifestyle interventions as the first line of therapy, either as monotherapy or in combination with pharmacology (Balapattabi et al., 2025) . Landmark studies such as the Diabetes Prevention Program (DPP) in the United States have demonstrated that lifestyle interventions can prevent the progression of prediabetes to T2DM by 51–58% over 3–6 years (Crandall, Dabelea, Knowler, Nathan, Hivert, et al., 2025) .

The importance of an integrated approach is becoming increasingly clear from the latest scientific evidence. Interventions that combine diet, physical activity, and digital technology simultaneously show superior synergistic effects compared to single-component interventions. The PREDIMED-Plus study (2025) demonstrated that combining a low-calorie Mediterranean diet with an intensive physical activity program reduced the risk of new-onset diabetes by 31% compared to the Mediterranean diet alone, after 6 years of follow-up (Ruiz-Canela et al., 2025) . A recent meta-analysis by (Wang et al., 2025) shows that blended interventions (a combination of face-to-face and digital) resulted in a 37% reduction in the risk of T2DM (RR 0.63; 95% CI 0.49–0.81) and an 87% increase in reversal to normoglycemia (RR 1.87; 95% CI 1.30–2.69). (found that a combined program of physical activity and therapeutic diet resulted in significant improvements in body composition, glycemic control (decrease in HbA1c), lipid profile, and insulin resistance, with more substantial improvements compared to diet or physical activity interventions alone. This synergistic mechanism can be explained through: (1) physical activity enhances insulin sensitivity and glucose uptake via an insulin-independent AMPK pathway, (2) a healthy diet regulates blood glucose levels and supports weight loss, and (3) digital technology facilitates real-time monitoring, personalized feedback, and improved patient adherence (Lee et al., 2023; Tesfa et al., 2025) .

Although evidence of the effectiveness of interventions for T2DM continues to grow, several critical gaps remain to be addressed: First, existing studies tend to be fragmented and focus on a single component—diet alone, physical activity alone, or digital technology alone—without a systematic evaluation of the combined effects of the three components in an integrated manner. There is no comprehensive synthesis analyzing how the optimal combination of these three modalities can maximize clinical outcomes (Duong et al., 2025; Wang et al., 2025) . Second, the rapid development of digital health technology post-COVID-19 pandemic has not been systematically evaluated. The COVID-19 pandemic has dramatically accelerated the adoption of telehealth and digital interventions in diabetes management (Hartmann-Boyce et al., 2024; Stevens et al., 2022) . However, existing systematic reviews mostly cover literature from before or early in

the pandemic, thus failing to integrate the latest evidence from rapidly evolving digital health innovations over the past 3–5 years. A systematic review by (Duong et al., 2025) found that the effects of digital health interventions on T2DM prevention have not been fully evaluated based on the quadruple aims (population health, consumer experience, healthcare provider experience, and healthcare costs). Third, there is high heterogeneity in the methods, duration, intensity of interventions, and clinical outcomes measured across studies, necessitating systematic evaluation to understand real-world effectiveness, identify success moderators, and provide evidence-based recommendations applicable in clinical practice (Kerr et al., 2024; Wang et al., 2025) . Fourth, most of the evidence comes from high-income countries (HICs), while 80% of people with diabetes live in low- and middle-income countries (LMICs) with different socioeconomic contexts, access to health services, and digital infrastructure (Sagastume et al., 2022) .

Given these disparities, this systematic review aims to synthesize the latest evidence (2020–2025) on the effectiveness of integrated lifestyle interventions combining dietary modification, physical activity, and digital technology support on glycemic control, complication risk, and quality of life in T2DM patients and high-risk individuals (prediabetes). The 2020–2025 period was specifically chosen to capture post-COVID-19 pandemic developments in digital health technology that have not been extensively covered in previous systematic reviews. Type 2 diabetes mellitus (T2DM) is a global health challenge that requires holistic management strategies. Although pharmacological therapy has advanced, lifestyle interventions remain the foundation of cost-effective and sustainable management. However, there is still a gap in the literature regarding the comparative effectiveness of various lifestyle intervention strategies on clinical outcomes and the risk of long-term complications.

This study seeks to answer the following critical questions: (1) How effective is a low-carbohydrate diet in lowering HbA1c and metabolic profile? (2) How does structured physical activity (aerobic, resistance, or combination) affect glucose control? (3) Do digital technologies (mobile apps, telecoaching, glucose sensors) provide superior effectiveness compared to conventional interventions? (4) What are the long- cts of intensive lifestyle interventions on reducing the risk of cardiovascular and microvascular complications?

The objective of this study is to evaluate the effectiveness of various lifestyle intervention modalities on primary clinical outcomes (HbA1c, lipid profile, blood pressure, body weight), analyze the impact on complication risk, and identify the most effective intervention strategies based on current evidence (2020–2025). The study results are expected to provide evidence-based recommendations for clinical implementation and public health policy development.

METHOD

Research Design

This systematic review was conducted using the PRISMA 2020 (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) guidelines to ensure transparency, replicability, and methodological quality.

Literature Search Strategy

Literature searches were conducted in three major electronic databases: PubMed Scopus, SAGE Journals published between 2020 and 2025, with the last search conducted on October 25, 2025. To minimize publication bias, the search also included *grey literature* through Google Scholar to identify relevant studies that may not be indexed in the main databases. The search strategy used a combination of *Medical Subject Headings* (MeSH) terms and free keywords with Boolean operators (AND, OR). The search was limited to articles in English and Indonesian published within the last 5 years (January 2020 – December 2025).

Search String pumped *("Diabetes Mellitus, Type 2"[MeSH] OR "T2DM" OR "prediabetes") AND ("Life Style"[MeSH] OR "diet" OR "physical activity" OR "exercise") AND ("Telemedicine"[MeSH] OR "mobile app" OR "digital health") AND ("Randomized Controlled Trial" OR "Cohort Studies"* Search String Scopus *TITLE-ABS-KEY(("Diabetes Mellitus, Type 2" OR "T2DM") AND ("Life Style" OR "diet" OR "exercise") AND ("digital health" OR "mobile app") AND ("RCT" OR "Cohort"))* Search String sage journal *("Type 2 Diabetes" OR "T2DM") AND ("Lifestyle" OR "Diet" OR "Physical Activity") AND ("Digital Health" OR "App"*

Data extraction and quality assessment

Data were extracted from selected studies related to study design, sample size, type of intervention, and outcomes. The Joanna Briggs Institute (JBI) critical appraisal tool was used to assess study quality. The Joanna Briggs Institute (JBI) critical appraisal tool was chosen because of its robust framework for assessing the methodological quality of intervention studies. This tool provides a comprehensive and standardized approach to evaluate various study designs, ensuring reliability and consistency in assessing risk of bias and validity. Findings. This tool is well suited for systematic reviews that aim to synthesize evidence from diverse study designs, such as randomized controlled trials (RCTs) and cohort studies.

PICOS Table: Inclusion and Exclusion Criteria

Study eligibility criteria are established based on the PICOS framework (*Population, Intervention, Comparator, Outcome, Study Design*) as detailed in

Table 1.
Inclusion and exclusion criteria

PICOS	Inclusion Criteria	Exclusion Criteria
Population (P)	Patients with type 2 diabetes or prediabetes; Age ≥ 18 years	Patients with type 1 diabetes; Patients with gestational diabetes; Age < 18 years
Intervention (I)	Structured diet; Physical activity; Digital technology; Combination of several intervention components Minimum intervention duration of 12 weeks	Pharmacological intervention as the sole component; Unstructured or unclear intervention Intervention duration < 12 weeks
Comparator (C)	Control group or comparator (non-intervention group or standard intervention)	Studies without a control or comparison group; case series studies or observational studies without a comparison group
Outcome (O)	HbA1c; Fasting blood glucose; Lipid profile; Blood pressure; BMI; Risk of complications; Quality of life	Studies with only secondary outcomes without primary clinical data; Incomplete outcome data
Study Design (S)	Randomized Controlled Trials (RCT); Prospective cohort	Systematic review; Meta-analysis; Narrative review; Case report; Case series; Cross-sectional study
Language	English, Indonesian	Other than English, Indonesian
Publication Year	2020-2025	<2020->2025

RESULT

Study Selection (PRISMA 2020)

The study selection process followed the PRISMA 2020 diagram. The initial search identified a total of 500 articles from selected databases. After removing duplicates using reference management software (n=80), 420 articles were screened based on their titles and abstracts. At the initial screening stage (title and abstract), 320 articles were excluded because they were irrelevant to the topic or had an inappropriate study design (containing: *review articles*, animal studies), leaving 100 articles for *full-text review*. Of these 100 articles, 80 were excluded for reasons including: inappropriate population (n=20), non-digital-based intervention (n=20), and incomplete data outcomes (n=40). A total of 20 studies were ultimately included in the qualitative synthesis.

Two reviewers independently assessed the methodological quality of the included studies using the *Joanna Briggs Institute* (JBI) *Critical Appraisal Checklist*, adapted for RCTs and cohort studies. The assessment focused on internal validity, including randomization, allocation *concealment*, blinding, and *intention-to-treat* analysis. Assessment results were categorized into three levels of risk of bias: (1) *Low* Risk: Meets >75% of JBI criteria, (2) *Moderate Risk*: Meets 50-75% of criteria, (3) *High Risk*: Meets <50% of criteria. Studies with high risk of bias were not excluded but were interpreted with caution in the synthesis of results to avoid *overestimating* the effectiveness of the intervention.

Search and selection results in this systematic review: Studies originated from various countries: United States (6), Germany (3), Australia (1), Japan (1), China (2), Vietnam (1), Indonesia (1), European Multinational (1), France (1), Spain (1), Uzbekistan (1), Marshall Islands (1). Randomized Controlled Trials (RCT): (17). Prospective Cohort (3). Data were extracted using a standardized form covering: author/year, study design, sample size, details of the digital intervention, duration, and clinical outcomes. Given the substantial heterogeneity between studies in terms of the type of technology used (application vs. teleconsultation), intervention duration (12 weeks to >1 year), and population characteristics, meta-analysis was not possible. Therefore, data synthesis was performed narratively. Findings were grouped based on the mode of technological intervention to provide a comprehensive overview of the effectiveness of each approach.

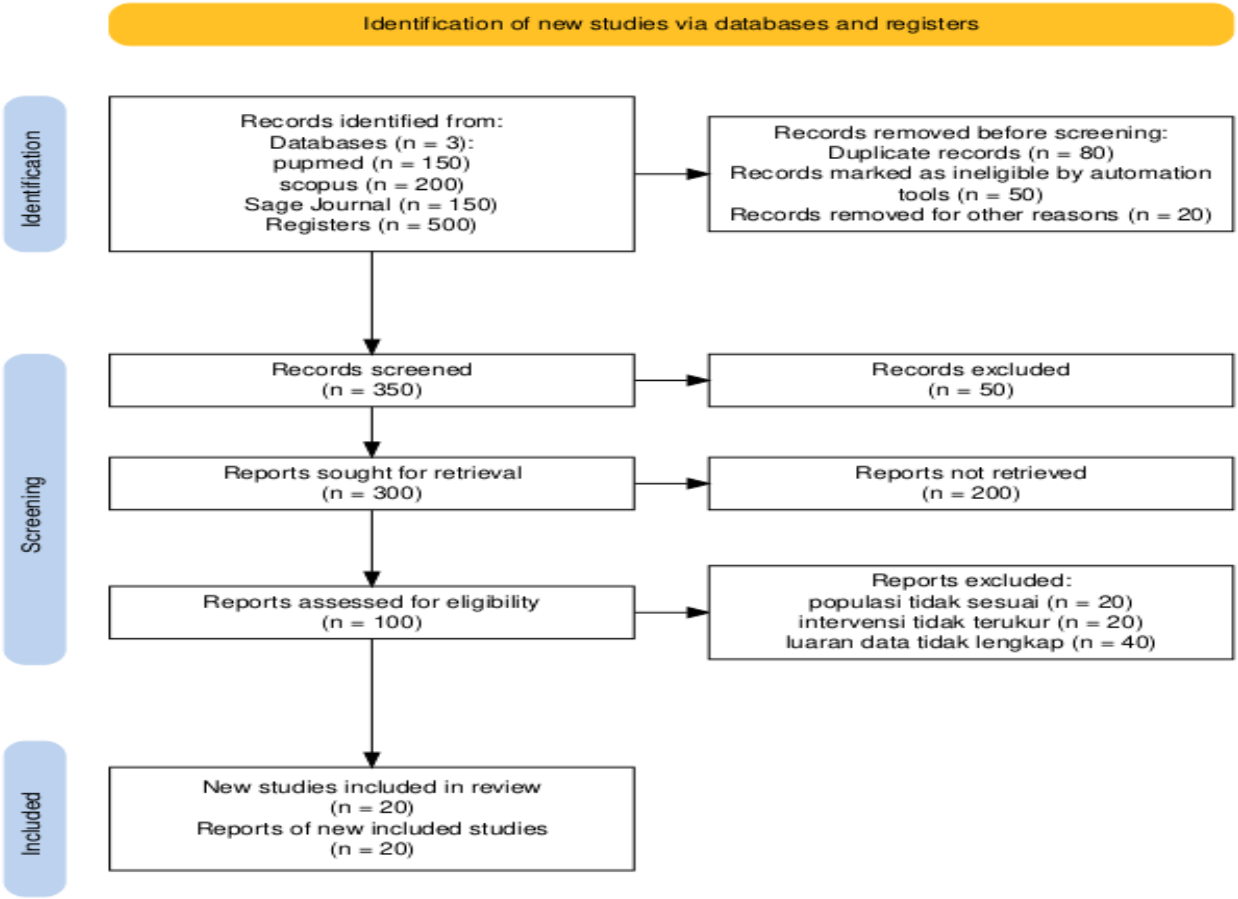

Table 1.
Respondent characteristics

No	Author	Study Design	Sample	Type of Intervention	Outcome Measure	JBI Score RCT (13) Cohort (11)
1.	(Hanick et al., 2025)	RCT	169	WFPB diet + exercise	HbA1c, medication use, remission	JBI RCT 11/13 (85%) *Low* Risk
2.	(Röhling, Kempf, Banzer, Braumann, Führer-sakel, et al., 2022)	RCT	463	Diet formula + lifestyle	SBP, DBP, HR, PWV	JBI RCT 11/13 (85%) *Low* Risk
3.	(Pamungkas, Usman, Chamroonsawasdi, et al., 2022)	RCT	60	Smartphone app coaching	DSM practice, HbA1c	JBI RCT 12/13 (92%) *Low* Risk
4.	(Röhling et al., 2020)	RCT	141	Diet formula (prediabetes)	Normoglycemia conversion	JBI RCT 11/13 (85%) *Low* Risk
5.	(Thanh & Tien, 2021a)	RCT	364	Group education (3 months)	Glucose, knowledge	JBI RCT 10/13 (77%) *Low* Risk
6.	(Michaud et al., 2023a)	RCT	599	Digital DPP (CVD focus)	CV risk reduction	JBI RCT 11/13 (85%) *Low* Risk
7.	(Crandall, Dabelea, Knowler, Nathan, & Temprosa, 2025b)	RCT	3234	DPP lifestyle + metformin	T2DM incidence, complications	JBI RCT 12/13 (92%) *Low* Risk
8.	(Mamun et al., 2020)	RCT	221	Community-based CBPR	Metabolic syndrome	JBI RCT 10/13 (77%) *Low* Risk
9.	(Su et al., 2022)	RCT	30	Aerobic exercise + resistance training (AE+RT)	FBG, 2hPG, inflammatory markers, HRV	JBI RCT: 10/13 (77%) *Low* Risk
10.	(Johnson et al., 2023a)	RCT	808	Intensive Lifestyle Intervention (ILI) vs DSE	Bone mineral density (BMD), fracture	JBI RCT: 11/13 (85%) *Low* Risk
11.	(Evans et al., 2023)	RCT	5145	Multidomain Intensive Lifestyle Intervention (ILI)	Frailty index (FI-E), aging biomarkers	JBI RCT: 12/13 (92%) *Low* Risk
12.	(Montemayor et al., 2022b)	RCT	155	Mediterranean diet (3 variants) + lifestyle	NAFLD reduction, lipids, glucose	JBI RCT: 11/13 (85%) *Low* Risk
13.	(Shalaeva et al., 2023a)	Prospective Cohort	782	Medication adherence + lifestyle compliance evaluation	MACE, all-cause mortality, events	JBI COHORT: 9/11 (82%) *Low* Risk
14.	(Dening et al., 2023)	RCT	87	Web-based low carbohydrate diet (LCD) education	HbA1c, weight, BMI, medication	JBI RCT: 11/13 (85%) *Low* Risk
15.	(Kitazawa et al., 2024)	RCT	168	Smartphone app + isCGM glucose monitoring	Time in range glucose, BMI, carbs	JBI RCT: 11/13 (85%) *Low* Risk
16.	(Kempf et al., 2023)	RCT	817	Telemedical Lifestyle Intervention (TeLIPro) coaching	HbA1c, weight, QoL, eating behavior	JBI RCT: 11/13 (85%) *Low* Risk
17.	(Bétry et al., 2023)	RCT	54	Dietary + physical activity intervention (insulin pump)	Weight gain, HbA1c, lipids	JBI RCT: 10/13 (77%) *Low* Risk

No	Author	Study Design	Sample	Type of Intervention	Outcome Measure	JBI Score RCT (13) Cohort (11)
18.	(Zhou et al., 2025)	Prospective Cohort	8,736	Independent & combined PA domains (Work/Walk-bicycle/Recreational MVPA) + Inflammatory Diet Index (DII)	T2DM risk, PA domains effect, DII effect	JBI COHORT: 9/11 (82%) *Low* Risk
19.	(Dicken et al., 2024)	Prospective Cohort	311,892	Degree of food processing (NOVA classification): MPF vs PCI vs PF vs UPF	T2DM incidence, degree of processing risk	JBI COHORT: 10/11 (91%) *Low* Risk
20.	(Yu et al., 2024a)	RCT	540	Diet-only: calorie-adjusted (25-30 kcal/kg/day); carbohydrates 55–65%, protein 10–15%, fat 25–30% — Exercise-only: increase in recreational activity by at least 1 unit/day (~30 minutes of light or 20 minutes of moderate activity) — Diet+Exercise: combination of both	All-cause mortality (HR 0.77 on diet and 0.64 on diet+exercise) - Cardiovascular death (HR 0.67 and 0.54) - CVD events (HR 0.72 and 0.68) - Microvascular complications (HR 0.48 only on combination)	JBI RCT 11/13 *Low* Risk

Table 2.
Study Characteristics Included

No	Author (Year) & Country	Design & Sample	Intervention & Duration	Key Findings & Effect Size
A. Diet & Nutrition Intervention				
1	(Hanick et al., 2025) , Marshall Islands	RCT (n=169)	*Whole-food Plant-based* (WFPB) Diet + Exercise (24 mg)	HbA1c: Significant decrease in the intervention group (-22 mmol/mol) vs control group (-7 mmol/mol), p<0.0001. Diabetes remission: 8% in the intervention group vs 0% in the control group (p=0.02).
2	Röhling et al., 2022) Germany	RCT (n=463)	High-Protein Formula Diet + Lifestyle (12 months)	Blood Pressure (SBP): -7.3 mmHg (Intervention) vs -3.3 mmHg (Control), p=0.049. Body Weight: Significant correlation between weight loss and hemodynamic improvement.
3	(Röhling et al., 2020) Germany	RCT (n=141)	Low-Carb Diet Formula (Prediabetes) (52 mg)	Conversion to Normoglycemia: 50% (Intervention) vs 31% (Control) returned to normal, p<0.05. NNT (Number Needed to Treat): 5.3 patients for 1 cure.
4	Montemayor et al., 2022) Spain	RCT (n=155)	Mediterranean Diet + Physical Exercise (12 months)	NAFLD (Fatty Liver Disease): Significant improvement in liver fat levels and ALT enzyme levels. BMI: Reduction of -1.6 to -2.6 kg/m² across all intervention groups.
5	Dicken et al., 2024) Europe (EPIC)	Cohort (n=311,892)	Analysis of *Ultra-Processed Food* (UPF) Intake (10.9 years)	Risk of T2DM Incidence: Increased by +17% for every 10% increase in UPF consumption (HR 1.17, p<0.001). Replacing UPF with minimally processed foods reduces risk.
6	(Dening et al., 2023) Australia	RCT (n=87)	Web-Based Low-Carbohydrate Diet (LCD) (16 mg)	HbA1c: Significant decrease of -0.65% (p<0.0001). Body Weight: -3.26 kg lower than the control group.

No	Author (Year) & Country	Design & Sample	Intervention & Duration	Key Findings & Effect Size
7	(Bétry et al., 2023) France	RCT (n=54)	Adaptive Diet During Insulin Pump Initiation (6 months)	Body Weight: Increase of 3.9 kg (Intervention) vs 3.2 kg (Control), p=0.56 (Not Significant). A 6-month lifestyle intervention was insufficient to prevent weight gain due to insulin therapy.
B. Physical Activity Intervention				
8	(Su et al., 2022) China	RCT (n=30)	Aerobic + *Resistance Training* (AE+RT) (12 mg)	Blood Sugar & Inflammation: Significant reduction in FBG, IL-6, and TNF-α ($p<0.05$) compared to control group ( ). HRV: Improved cardiac autonomic nervous system function.
9	Zhou et al., 2025) USA	Cohort (n=8,736)	Physical Activity (MVPA) + Anti-inflammatory Diet	Risk of T2DM: The combination of high physical activity and an anti-inflammatory diet resulted in the greatest reduction in T2DM risk ($p<0.05$).
10	(Johnson et al., 2023) USA	RCT (n=808)	*Look AHEAD Study* (Intensive Intervention) (8 years)	Bone Mineral Density (BMD): Greater hip bone mass loss in the intensive weight loss intervention group (p=0.012), particularly in men.
C. Digital Technology-Based Intervention				
11	(Pamungkas et al., 2022) Indonesia	RCT (n=60)	*Smartphone App Coaching* (Education, Mindfulness) (12 mg)	HbA1c: 6.44% (Intervention) vs 8.24% (Control); Mean difference -1.8%, p=0.001. Medication Adherence: Score significantly increased (4.97 vs 3.10).
12	(Kitazawa et al., 2024) Japan	RCT (n=168)	App + *isCGM* (Continuous Glucose Monitoring) (12 mg)	Time in Range (TIR): Increased time in normal blood glucose range (+31.5 minutes) in the CGM+App group, p=0.03. Hypoglycemia: Significant reduction.
13	(Kempf et al., 2023) Germany	RCT (n=817)	*Telemedical Coaching* (TeLIPro) (12 months)	HbA1c: Average decrease of -0.4% ($p<0.001$); greater effect (-0.5%) in long-term DM patients (>5 years).
14	(Michaud et al., 2023) , USA	RCT (n=599)	Digital Diabetes Prevention Program (d-DPP) (12 months)	Cardiovascular Risk (ASCVD): Risk reduction of -0.96% at month 4 (95% CI -1.58, -0.34). Effect diminished at month 12 without maintenance.
D. Combination Intervention & Education				
15	(Crandall, Dabelea, Knowler, Nathan, & Temprosa, 2025) USA	RCT (n=3,234)	DPPOS: Lifestyle vs Metformin (21-year follow-up)	Incidence of T2DM: Lifestyle reduces risk by 24% vs Metformin 17% (vs Placebo). Survival: Diabetes-free for 3.5 years longer in the lifestyle group.
16	Yu et al., 2024) China	RCT (n=540)	Da Qing Study (Diet vs Exercise vs Combination) (30 years)	CVD Mortality: 46% risk reduction (HR 0.54, p=0.038) in the Combination group. Overall Mortality: HR 0.64 (p=0.002) in the Combination group.
17	(Thanh & Tien, 2021) Vietnam	RCT (n=364)	Structured Group Education (3 months)	Knowledge (MDKT): Pass rate 81.3% (Int) vs 51.7% (Ctrl). HbA1c: Decrease of -0.54% (p=0.012).
18	(Evans et al., 2023 USA	RCT (n=5,145)	Multidomain Lifestyle Intervention (18-year follow-up)	Frailty Index (Frailty): Frailty scores were consistently lower in the lifestyle group over 8–18 years of follow-up.
19	(Michaud et al., 2023) USA	RCT (n=221)	Community/Church-Based Intervention (10 months)	Metabolic Syndrome: The odds ratio (OR) for metabolic syndrome was 2.14 times higher in the intervention group (p=0.02).
20	(Shalaeva et al., 2023) Uzbekistan	Cohort (n=782)	Medication Adherence & Lifestyle (1 year)	MACE (Major Adverse Cardiac Events): 9.66 times higher risk in patients with poor medication and lifestyle adherence (HR 9.66).

Based on 20 analyzed studies, structured lifestyle interventions consistently improved metabolic control. Most diet and digital intervention studies reported reductions in HbA1c with Effect Sizes ranging from 0.4% to 1.8%. Combined diet and physical activity interventions showed the strongest long-term impact on mortality reduction (HR 0.64) and diabetes incidence (24% risk reduction), although single interventions such as physical activity alone provided more moderate effects. However, effects were more stable in intensive digital interventions lasting >6 months.

DISCUSSION

Overall, findings from the 20 analyzed journals consistently indicate that multifaceted lifestyle interventions integrating diet, physical activity, and digital technology utilization provide the most significant impact in managing T2DM. Although each modality has its strengths, comprehensive combined diet and physical activity interventions, in particular, demonstrate superior effectiveness in reducing the risk of long-term mortality and vascular complications in individuals with glucose intolerance (Yu et al., 2024)

In terms of the effectiveness of dietary interventions, low-carbohydrate diets and whole-food plant-based diets have been shown to be highly effective in lowering HbA1c and body weight (Hanick et al., 2025) (Dening et al., 2023) . The study by Hanick et al. (Hanick et al., 2025) reported a significant reduction in HbA1c (-22 mmol/mol) and an average weight loss of 2.7 kg with a whole-food plant-based diet over 24 weeks, which also allowed for a reduction in medication. Röhling et al. (Röhling et al., 2020) demonstrated that a low-carbohydrate, energy-deficient formula diet superiorly converted 50% of prediabetic patients to normoglycemic status, showing significant improvements in HbA1c, BMI, waist circumference, fat mass, fasting blood glucose, systolic and diastolic blood pressure, and lipid profile (Röhling et al., 2022) (Röhling et al., 2020) . Group diet education was also effective in increasing diabetes knowledge by 81.3% and glycemic control in T2DM patients (Thanh & Tien, 2021) .In addition, reducing total calorie, fat, and sodium intake accompanied by education was shown to reduce metabolic risk by 25.81% in African-American women (Mamun et al., 2020)

The biological mechanisms behind the effectiveness of dietary interventions include improved insulin sensitivity. Low-carbohydrate diets contribute to increased insulin sensitivity by reducing the glycemic load and potentially through the induction of mild ketogenesis, which increases fatty acid oxidation (Dening et al., 2023) .The use of high-protein, low-glycemic formula diets has been shown to significantly reduce HbA1c and improve insulin sensitivity (Röhling et al., 2022). Nutritional quality, such as avoiding ultra-processed foods and adopting a Mediterranean diet, also plays an important role in reducing systemic inflammation and the risk of non-alcoholic fatty liver disease, a condition closely associated with insulin resistance (Montemayor et al., 2022) .Physical activity, both aerobic and resistance, enhances muscle glucose uptake through the upregulation of glucose transporter type 4 translocation, primarily via the activation of the AMP-activated protein kinase pathway, which is an insulin-independent mechanism (Su et al., 2022). This leads to improved insulin sensitivity and better glycemic control. Although physical activity may not directly prevent weight gain after insulin therapy in some cases (Bétry et al., 2023) , it significantly reduces microvascular complications by 40% (Crandall, Dabelea, Knowler, Nathan, & Temprosa, 2025) The use of digital technology does not work at the biological level directly, but rather psychologically and behaviorally, by increasing patient compliance and self-efficacy (Pamungkas et al., 2022) . Smartphone applications and telecoaching provide real-time feedback, reminders, and personalized targets, which motivate patients to maintain lifestyle changes (Pamungkas et al., 2022) (Kitazawa et al., 2024) (Kempf et al., 2023) . Digital interventions, such as those using Continuous Glucose Monitoring (isCGM), can increase the average daily Time-in-Range glucose by 31 minutes and reduce BMI by 0.26 points in individuals at high risk for T2DM (Kitazawa et al., 2024).

Comparison with the latest guidelines shows strong consistency. Many of the studies reviewed refer to the recommendations of the American Diabetes Association (Crandall, Dabelea, Knowler, Nathan, & Temprosa, 2025) . For example, the standard of care in a group education study in Vietnam is consistent with the ADA guidelines (Thanh & Tien, 2021) . The Diabetes Prevention Program, which forms the basis for many lifestyle interventions, is recommended by the ADA, International Diabetes Federation, and European Association for the Study of Diabetes for populations at high risk for T2DM (Crandall, Dabelea, Knowler, Nathan, & Temprosa, 2025) . The DPP demonstrated that intensive lifestyle interventions, including increased physical activity and weight loss, significantly delay or prevent the onset of diabetes (Crandall, Dabelea, Knowler, Nathan, & Temprosa, 2025) . Meal replacement therapy has also been included in national and international diabetes association guidelines as a primary treatment option for T2DM (Kempf et al., 2023) . Digital diabetes prevention programs can also reduce the proportion of individuals with hyperlipidemia and physical inactivity (Michaud et al., 2023) . However, specific comparisons with the guidelines of the International Working Group on the Diabetic Foot were not explicitly found in the reviewed articles.

The clinical implications of these findings for medical-surgical nursing practice are significant. Nurses can serve as facilitators of digital health literacy and case managers who monitor patient data remotely, particularly through telemedicine platforms (Kempf et al., 2023) . It is important for nurses to promote personalized nutrition education, such as whole-food plant-based or low-carbohydrate diets, and encourage active participation in structured physical activity programs (Hanick et al., 2025)) . The use of smartphone applications and continuous glucose monitoring systems can provide real-time feedback that improves patient engagement and self-management (Pamungkas et al., 2022) (Kitazawa et al., 2024) . Long-term effects show that adherence to a healthy lifestyle and therapy can reduce one-year mortality by up to 70% and major cardiovascular events (Shalaeva et al., 2023) . Multidomain lifestyle interventions can also slow biological aging (Montemayor et al., 2022) . Nurses also need to be aware of potential risks, such as decreased bone density in older men undergoing intensive weight loss ((Johnson et al., 2023) . Therefore, fracture prevention strategies should be integrated into care plans.

This review, however, has several limitations. The high heterogeneity in the type and duration of interventions (ranging from a few weeks to over 20 years), variations in sample size (some studies had small samples), and differences in the cultural and geographical backgrounds of the study populations may affect the generalizability of the results (Su et al., 2022) ((Bétry et al., 2023) Another limitation is the potential for performance bias, as lifestyle interventions often involve active patient participation and self-reporting, which are prone to recall bias or selection bias (Kitazawa et al., 2024) (Zhou et al., 2025) . Nevertheless, the consistency of positive effects in most studies reinforces the validity of findings that lifestyle interventions are a key pillar in the prevention and management of T2DM.

CONCLUSION

Based on an analysis of 20 selected articles with moderate- to high-quality evidence, it was concluded that a combination of multidomain lifestyle interventions is the most effective strategy in the management of Type 2 Diabetes Mellitus (T2DM). Approaches that integrate a low-carbohydrate or plant-based diet, combined physical exercise (aerobic and resistance training), and digital technology support, such as apps or Continuous Glucose Monitoring (CGM), provide the most consistent results in reducing HbA1c levels (in the range of 0.5–1.8%) and patient weight. The greatest impact of these interventions occurs when implemented for at least 6 months, supported by structured behavioral education and ongoing digital monitoring. In addition to short-term metabolic improvements, these interventions have also been shown to reduce the risk of major cardiovascular complications (MACE), slow biological aging (frailty), and reduce long-term mortality by up to 46%. Based on these findings, it is recommended that diabetes management protocols in healthcare

facilities adopt a hybrid approach, combining standard clinical care with the use of digital health tools, to achieve optimal patient outcomes.

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