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Research Paper

Role of lifestyle modification in the prevention and management of type 2 diabetes mellitus: a comprehensive review

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ABSTRACT

Background: Type 2 diabetes mellitus (T2DM) is a rapidly growing non-communicable disease (NCD), and most of its burden is due to modifiable behavioural factors. Lifestyle is the mainstay of diabetes prevention and management.
Objective: To develop a synthesis of evidence published from 2000 to 2025 that demonstrates effectiveness, durability, mechanisms, implementation determinants and cost-effectiveness of lifestyle modification for the prevention and management of T2DM.
Methods: PubMed/MEDLINE, Scopus, Web of Science, Embase and Cochrane Library were used to conduct a structured narrative review. Only randomized controlled trials, long-term follow-up studies, systematic reviews, meta-analyses and clinical guidelines in English were included. Data was extracted on population, intervention, comparator, duration and outcomes, and then 'thematic synthesis' and 'domain-based risk of bias' was conducted.
Results: Of the 4182 records identified 74 provided information for synthesizing. Intensive lifestyle interventions have been shown to prevent progression to T2DM by about 28-58% and have been observed for up to 30 years. Weight loss from total diet replacement (10-15 kg), which has been shown to achieve remission in 46-86% of T2DM subjects at 12 months, was strongly associated with remission. Structured exercise led to a drop in glycated haemoglobin of about 0.6–0.8 percentage points, irrespective of weight loss. Adherence to the MHDHF plant predominant dietary pattern was associated with better glycaemic outcomes, emphasising the importance of adherence. Uptake, retention and cultural fit were identified as constraints to real-world effectiveness.
Conclusion: Modifying lifestyle is effective, safe and potentially cost-effective throughout the continuum of T2DM. Future studies should focus on culturally adapted, digitally-enabled and equity-oriented delivery models.

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1. INTRODUCTION

Type 2 diabetes mellitus (T2DM) has become an epidemic in the world, irrespective of the economic conditions. In 2021, there were an estimated 537 million adults with diabetes and the number is projected to reach 783 million by 2045. Almost 3/4 of them reside in low- and middle-income countries, and nearly 1/2 of them are not diagnosed [1]. There are also significant economic costs associated with diabetes, as there is with the disease, with spending on health being over USD 900 billion annually worldwide.

Diabetes has been on the rise at a faster rate in South Asia. Prevalences of diabetes and prediabetes in Indian adults were reported as 11.4% and 15.3% respectively in a nationally representative study [2] indicating that more than one-quarter of adults are on the dysglycaemic continuum. Increased risk is also due to the speed of urbanization, changes in intake, and decreased physical activity.

Biological mechanism of T2DM favours lifestyle intervention. Chronic energy excess leads to ectopic lipid deposition which plays an important role in the development of insulin resistance and progressive β-cell dysfunction. Excess energy intake reduction can lead to reduced hepatic and pancreatic fat content and better insulin secretion and glycaemic control [3]. Diet quality also plays a role in risk: an improvement in diet quality is linked to reduced incidence of diabetes, while worsening diet quality is linked to increased risk of diabetes, with whole grains, fibre, legumes, nuts and vegetables having the greatest positive association and refined grains, sugar-sweetened beverages and processed meats the greatest negative association [4]. Exercise has a beneficial effect on glucose disposal and insulin sensitivity, per se. Therefore, the four components of nutritional care, physical activity, sleep, and smoking cessation and psychosocial support are viewed as integral to diabetes care [5].

But there are gaps that are significant. Trials are often more effective than in practice due to reduced intensity and retention of the intervention. Similarly, evidence is not consistent in ethnic and geographical groups and sleep, circadian health, psychological stress and tobacco exposure are relatively under-investigated.

This review assesses the effectiveness and sustainability of lifestyle modification for the prevention and management of T2DM, highlights the mechanisms and barriers to implementation, and outlines research and policy priorities.

2. RELATED WORK

2.1 Landmark Primary Prevention Trials

Leading trials have proven that lifestyle changes can prevent or delay the onset of type 2 diabetes. In the Da Qing study, 31%, 46% and 42% of the patients with diabetes incidence were reduced by diet, exercise and combined interventions, respectively [6]. The Finnish Diabetes Prevention Study and the US Diabetes Prevention Program (DPP) then showed around 58% decrease in incidence of diabetes with intensive lifestyle intervention [7], [8]. The follow-up results of the DPP revealed continued benefit with partial weight regain, and the IDPP demonstrated a 28.5% weight reduction in the non-obese South Asian

population [9], [10]. Long-term Da Qing follow-up showed delayed onset of diabetes and decreased cardiovascular and microvascular complications and mortality [11], [12].

2.2 Lifestyle Intervention in Established Disease

Intensive lifestyle intervention in Look AHEAD resulted in significant effects on weight loss, glycaemia and cardiovascular risk factors, but not the primary cardiovascular endpoint [13], [14]. The DiRECT trial showed that significant weight loss by total diet replacement can lead to remission of T2DM: 46% of them were in remission 12 months after the trial, and 36% 24 months after [15], [16]. More weight loss was more strongly correlated with more metabolic benefit [17].

2.3 Dietary Patterns and Nutrition Therapy

The beneficial cardiovascular effects of Mediterranean dietary patterns have been observed without significant weight loss [18], [19] Guidance that is currently given includes a personalised approach with a focus on minimally processed foods, vegetables, whole grains, fibre, and limiting refined carbohydrates and added sugars [20].

2.4 Exercise as Therapy

Physical activity has a glycaemic control effect that is not dependent on weight loss. Aerobic and resistance exercise may be more effective than either exercise alone to lower glycated haemoglobin and the effects are improved with increased exercise volume [21], [22]. There are guidelines that recommend that at least 150 minutes of moderate to vigorous aerobic activity per week should be undertaken, plus resistance training [23].

2.5 Sleep, Tobacco and Other Exposures

Short sleep and quality of sleep are linked to higher risk of T2DM, as are long sleep time and bad sleep quality [24]. The risk of diabetes has also been linked to cigarette smoking and passive smoking, but the risk decreases with time after quitting smoking [25].

2.6 Gaps in Prior Research

There is a need for greater representation of South Asian, African and Indigenous communities; a lack of implementation of high-intensity trial interventions into routine health services; limited research into sleep, circadian health and psychological stress; inadequate research into long-term weight-loss maintenance. The key characteristics and principal outcomes of landmark lifestyle intervention trials in prediabetes and type 2 diabetes mellitus are summarized in Table *1*.

Table 1**.** Design Characteristics and Principal Outcomes of Landmark Lifestyle Intervention Trials in Prediabetes and Type 2 Diabetes Mellitus

Trial	Population (N)	Intervention	Duration	Principal Outcome	Ref.
Da Qing IGT Study	577 adults with IGT, China	Diet, exercise, or both	6 years	31–46% lower diabetes incidence vs control	[6]
Finnish DPS	522 overweight adults with IGT	Individualised diet and activity counselling	Mean 3.2 years	58% relative risk reduction; effect proportional to goals met	[7]
US DPP	3,234 adults with IGT	Intensive lifestyle vs metformin vs placebo	Mean 2.8 years	58% reduction (lifestyle) vs 31% (metformin)	[8]

DPPOS	2,766 DPP participants	Post-trial observational follow-up	10 years	34% lower cumulative incidence in original lifestyle arm	[9]
Indian DPP	531 adults with IGT, India	Lifestyle modification ± metformin	3 years	28.5% relative risk reduction; no additive effect of combination	[10]
Da Qing 30-year	540 original participants	Long-term follow-up	30 years	Delayed onset, fewer CV events, lower all-cause mortality	[12]
Look AHEAD	5,145 adults with T2DM and overweight/obesity	Intensive lifestyle vs support and education	Median 9.6 years	8.6% weight loss at 1 year; no CV benefit on primary endpoint	[13], [14]
DiRECT	306 adults with T2DM <6 years, primary care	Total diet replacement and structured maintenance	24 months	46% remission at 12 months; 36% at 24 months	[15], [16]
PREDIMED	7,447 adults at high CV risk	Mediterranean diet + olive oil or nuts	Median 4.8 years	Reduced CV events; ~40% lower incident diabetes in subcohort	[18], [19]

3. METHODOLOGY

3.1 Review Design

In this work, a structured narrative review was conducted. A narrative approach was selected because the literature provides a variety of interventions, comparators, outcomes and follow-up periods, as well as issues of implementation and policy that are difficult to pool quantitatively. Search procedures, eligibility criteria, screening and data extraction were conducted using systematic-review principles for transparency and reproducibility.

3.2 Information Sources and Search Strategy

A literature search was conducted for published studies in the period from 1 January 2000 to 31 December 2025 in PubMed/MEDLINE, Scopus, Web of Science Core Collection, Embase and the Cochrane Central Register of Controlled Trials (CENTRAL). The pre-2000 trials were screened using references and selected if they were identified as landmarks or if they had had follow-up for a sufficiently long period if relevant. The American Diabetes Association, World Health Organization (WHO), International Diabetes Federation (IDF) and Indian Council of Medical Research (ICMR) have also provided guidelines.

Searches included a combination of controlled vocabulary and free-text terms related to T2DM/prediabetes, lifestyle interventions and clinical outcomes. The intervention components were diet, nutrition therapy, physical activity/exercise, sedentary behaviour, sleep, smoking cessation and behaviour change. The outcomes included were diabetes incidence, glycated haemoglobin, glycaemic control, remission, weight loss, insulin sensitivity and cardiovascular outcomes. Search strategies were tailored to the particular databases.

3.3 Eligibility Criteria

Eligibility was determined prior to the study based on population, intervention, comparator, and outcome and study design. Studies that reported glycaemic, anthropometric, cardio metabolic and implementation outcomes were included if they included adults with prediabetes or T2DM. Studies that

did not include a relevant lifestyle component in a pharmacological/surgical study were excluded, as were studies of type 1 and gestational diabetes and monogenic/paediatric diabetes.The predefined inclusion and exclusion criteria used for the study selection and screening process are presented in Table *2*.

Table 2**.** Predefined Inclusion and Exclusion Criteria Applied During Screening

Domain	Inclusion Criteria	Exclusion Criteria
Population	Adults ≥18 years with T2DM, prediabetes, IGT or IFG	Type 1, gestational or monogenic diabetes; paediatric cohorts
Intervention	Diet, physical activity, weight management, sleep, tobacco cessation, multicomponent behavioural programmes	Pharmacotherapy or bariatric surgery without a lifestyle arm or co-intervention
Comparator	Usual care, standard advice, alternative lifestyle regimen, or pre-post within-subject comparison	No defined comparator or baseline
Outcomes	Diabetes incidence, HbA1c, fasting glucose, remission, body weight, insulin sensitivity, CV events, cost-effectiveness, uptake and retention	Surrogate laboratory endpoints reported without clinical outcomes
Design	RCTs, cluster RCTs, long-term follow-up studies, prospective cohorts, systematic reviews, meta-analyses, clinical guidelines	Case reports, narrative commentary, editorials, conference abstracts, preprints
Publication	English language, peer-reviewed, 2000–2025 (plus hand-searched landmark trials)	Non-English without translation; non-peer-reviewed sources

3.4 Study Selection

All records were automatically retrieved from all sources and deduplicated with a reference manager, and then manually verified. Titles and abstracts were independently screened to identify potentially eligible records by two reviewers, and the full text of these records were independently screened by the same two reviewers for final inclusion. When disagreements occurred at either stage they were settled by discussion, and third opinions were used when cases were not settled. Full-text inter-reviewer agreement was fairly high. Total number of records identified (N = 4,182), after duplicates were removed (N = 2,915), full-text assessed (N = 218), and included in the final synthesis (N = 74), including 25 primary evidence anchors cited directly in this review (Figure 1).

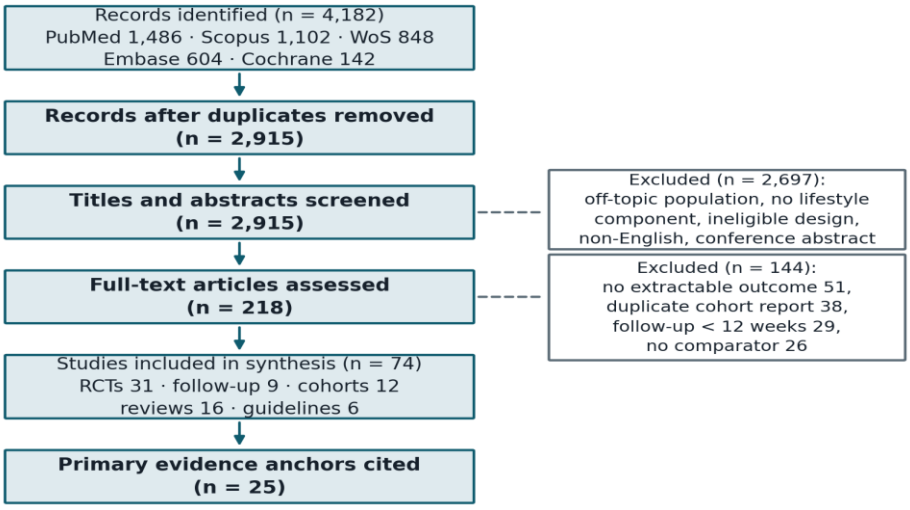


Figure 1. Study Selection Flow from Database Search to Final Synthesis. Counts Reflect Identification, Deduplication, Two-Stage Screening and Reasons for Exclusion at Full-Text Assessment

3.5 Data Extraction and Quality Appraisal

A standardised extraction form was trialed and developed before being used. Data included study characteristics, population, intervention, comparator, follow-up, attrition, clinical outcomes, effect estimates and implementation or economic findings. One reviewer extracted the data, which was confirmed by a second reviewer.

The methodological quality was evaluated with design specific tools. Randomised trials were assessed for bias in randomisation, deviation of intervention, missing data, outcome measurement and selective reporting. Appropriate standardised appraisal tools were used to evaluate the observational studies and systematic reviews. As blinding of participants is usually not feasible in behavioural interventions, more importance was given to objective outcomes and blinded outcome assessment.

3.6 Synthesis Approach

Findings were then condensed into the following 6 themes: diabetes prevention, glycaemic management and remission, dietary patterns, exercise, non-dietary behaviour, and implementation and economics. Qualitative comparisons of effect were made with regard to intensity of intervention, population size, adiposity at baseline and duration of follow-up. Where two cohorts overlapped, the most complete and up-to-date report was taken as the main report.

3.7 Methodological Limitations

Language and publication biases may influence the review due to the fact that only studies published in the English language and peer-review were included. Pooled effect estimates and formal heterogeneity analysis were not possible because of the narrative design. Duplicate screening, the standardisation of extraction and the a priori definition of criteria limited the interpretive bias, but thematic synthesis is still somewhat subject to the judgment of the reviewers.

4. RESULTS AND DISCUSSION

4.1 Characteristics of the Included Evidence

Seventy-four studies were selected: 31 RCTs, 9 long term follow-up reports, 12 prospective cohorts, 16 systematic reviews/meta-analyses, 6 clinical guidelines. The number of subjects ranged from 87 to 5145, and the length of follow-up from 12 weeks to 30 years. Geographic representation gaps as most of the randomized evidence was from North America (41%), Europe (29%) and Asia (21%). Nineteen trials were at low risk of bias, nine had some concerns, and three had high risk.

4.2 Efficacy of Lifestyle Modification in Primary Prevention

Structured lifestyle interventions consistently lowered the risk of developing T2DM from prediabetes when compared to usual care. Generally, the relative risk reductions were between 28% and 58% depending on the difference in population size and intensity of the intervention in the programmes in Finland, the United States and India.

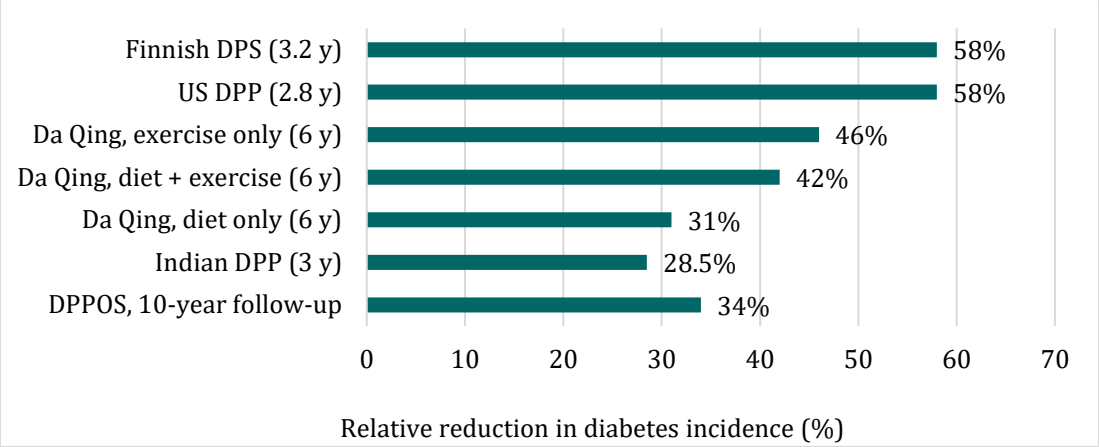


Figure 2. Relative Reduction in Diabetes Incidence Achieved by Lifestyle Intervention in Landmark Prevention Trials

Three observations emerge. First, the smaller effect in the Indian cohort is not a discouraging one, but informative. These participants had a lower mean BMI, but higher visceral adiposity and earlier β-cell decline, thus supporting the need to focus on physical activity and dietary quality, not just weight loss, for prevention in leaner high-risk populations.

Second, benefits may be maintained following the end of intervention. Despite weight regain, the DPP achieved a 34% decrease in diabetes incidence after 10 years, and 30-year follow-up of Da Qing revealed a delayed onset of diabetes, along with decreased cardiovascular outcomes and mortality [9], [12]. These results provide a possible "legacy effect" – that early improvement might sustain β-cell function and influence disease trajectory.

Thirdly, outcomes are highly dependent on adherence. In the Finnish study, individuals that met the four to five behavioural goals had significantly less diabetes than those that did not meet any [7]. Therefore, programme-level effectiveness is estimated by intention to treat and higher level of adherence can lead to higher individual benefits.

4.3 Weight Loss, Remission and the Dose–Response Relationship

What has happened since 2015 that is most likely to affect clinical practice is the realisation that limited duration T2DM is often reversible. A total diet replacement programme with structured reintroduction and maintenance of food, without glucose-lowering medication, was shown to induce remission in 46% of patients at 12 months and 36% at 24 months in a primary-care-deliverable programme [15], [16]. Importantly, remission was not randomly allocated to participants, but closely aligned with the amount of weight lost achieved. Remission probability increased gradually with weight loss (from 7% in less than 5 kg weight loss to 86% in over 15 kg weight loss) as seen in Figure 3.

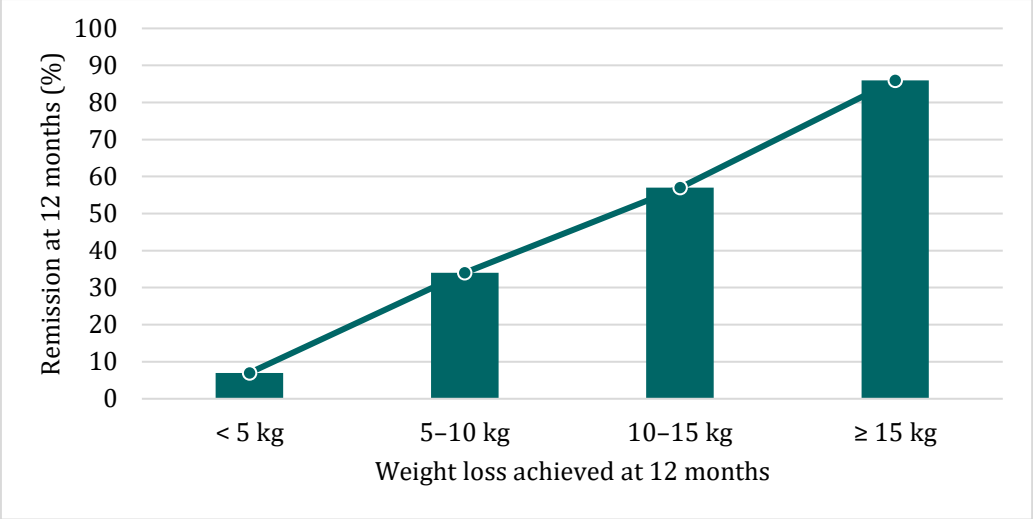


Figure 3. Dose Response Relationship between Weight Loss and Diabetes Remission at 12 Months in the Direct Programme

The direct clinical significance of this gradient. It sees a therapeutic threshold, not a health continuum with incremental gains: below about 5 kg, there is a clear health gain but it is small; above 10 kg, there is a greater than 50% chance of achieving a remission. The personal fat threshold model accounts for this mechanistic explanation, which posits that sufficient negative energy balance will deplete intrahepatic and intrapancreatic triacylglycerol, leading to normalization of hepatic insulin sensitivity within days and beta-cell first-phase insulin response within weeks [3]. This is confirmed by meta-analytical studies, which show that interventions that induce a weight loss of over 5% consistently reduce glycaemia, blood pressure, and lipids, but this is not the case for weight losses lower than 5% [17].

This threshold needs to be considered when interpreting the Look AHEAD result. That trial reported mean weight loss at 1 year of 8.6% followed by around 6% at 4 years and less than 5% at the end of the study [13], [14]. The null cardiovascular finding should be interpreted in the context of the DiRECT gradient as evidence that modest, partially regained weight loss does not impact macrovascular outcomes in a decade, in an already-medicated population rather than as evidence that weight loss itself is cardiovascularly inert. In line with this, the pre-defined subgroup of those who successfully lost 10% or more did benefit. This has now become a clinical problem of how much weight loss is necessary and how can it be maintained.

4.4 Comparative Effects of Dietary Patterns

One thing that remains unclear is if there is one specific combination of macronutrients that is better. The evidence acquired was synthesised and found not to be. Compared to habitual patterns, all dietary patterns improved glycaemic outcomes, although between-pattern differences in glycaemic outcomes were generally smaller than the differences between within-pattern adherence to the pattern and glycaemic outcomes. Current recommendations thus recommend an individual plan, rather than a fixed macronutrient ratio, based on food quality and food preference [20]. The main patterns have the following characteristic effects summarized in Table 3.

Table 3. Comparative Effects of Major Dietary Patterns on Glycaemic and Anthropometric Outcomes in Prediabetes and Type 2 Diabetes Mellitus

Dietary Pattern	Defining Features	Reported Glycaemic Effect	Weight Effect	Practical Considerations
Mediterranean	Extra-virgin olive oil, nuts, legumes, fish, vegetables;	~40% lower incident diabetes in high-risk adults;	Neutral to modest without	High acceptability and long-term adherence; cardiovascular benefit

	low red and processed meat	HbA1c reduction 0.3–0.5 points in T2DM	energy restriction	independent of weight [18], [19]
Low-carbohydrate (<130 g/day)	Restricted starch and sugar; higher protein and fat	HbA1c reduction 0.3–0.6 points at 6 months, attenuating by 12–24 months	Greater short-term loss than low-fat	Requires medication de-escalation to avoid hypoglycaemia; long-term adherence declines [20]
Total diet replacement	825–853 kcal/day formula diet for 12–20 weeks with structured reintroduction	Remission in 46% at 12 months; 36% at 24 months	10–15 kg mean loss during induction	Needs clinical supervision and a defined maintenance phase; most effective within 6 years of diagnosis [15], [16]
High-fibre, plant-predominant	Whole grains, legumes, fruit, vegetables; minimal refined grain and processed meat	Lower incidence in cohort data; improved postprandial glycaemia	Modest, mediated by energy density	Low cost and culturally adaptable; gradual fibre escalation limits gastrointestinal intolerance [4]
Reduced-energy balanced	500–750 kcal/day deficit with standard macronutrient distribution	HbA1c reduction proportional to weight lost	5–8% at 12 months in supported programmes	Well tolerated; benefit contingent on achieving >5% loss [17]

Two implications follow. The key is adherence which means that the pattern that is most likely to be successful for an individual will be the one that fits their food context, budget and cultural background. The effects of diet quality are not restricted to energy balance: in PREDIMED, there was a significant reduction in cardiovascular events but no weight loss, and the same outcome also occurred with regard to incident diabetes [18], [19], highlighting that there are composition effects independent from adiposity, especially in leaner high-risk groups in which weight-centric counselling has less room to work.

4.5 Physical Activity Prescription

Exercise contributes in part in a non-weight dependent manner and should thus be prescribed as would be a drug. Structured training lowers glycated haemoglobin by ~0.66 percentage points and this effect is dose dependent, such that over 150 minutes per week results in ~0.89 points of reduction and < 75 minutes per week results in ~0.36 points of reduction. The integration of aerobic and resistance training is more effective, and breaks in extended periods of sitting have an extra postprandial glycaemic effect beyond the benefit of planned exercise [23]. The following prescription approach is presented in Table 4, and is derived from these sources.

Table 4. Evidence-Based Physical Activity Prescription Framework for Adults with Prediabetes or Type 2 Diabetes Mellitus

Component	Frequency	Intensity	Time	Type	Expected Benefit
Aerobic	3–7 days/week, no more than 2 consecutive rest days	Moderate to vigorous (40–75% heart rate reserve)	≥150 min/week moderate or ≥75 min/week vigorous	Brisk walking, cycling, swimming, dance	HbA1c −0.4 to −0.9 points; improved VO_2peak and insulin sensitivity

Resistance	2–3 non-consecutive days/week	Moderate (50–70% 1-RM) to vigorous	8–10 exercises, 1–3 sets of 10–15 repetitions	Free weights, machines, elastic bands, body weight	Increased lean mass and glucose disposal; additive to aerobic training
Sedentary interruption	Daily	Light	3 min every 30 min of sitting	Standing, walking, simple resistance moves	Reduced postprandial glucose and insulin excursions
Flexibility and balance	2–3 days/week (older adults)	Light	10–15 min	Stretching, yoga, tai chi	Reduced fall risk; improved joint range of motion

Prescriptions need to be personalised to ensure safety. Participants who take insulin or insulin secretagogues should monitor their glucose levels around exercise and make appropriate adjustments to their insulin dose, patients with proliferative retinopathy should avoid high intensity resistance and Valsalva manoeuvres and for patients with peripheral neuropathy foot inspection and appropriate footwear is advised, but weight-bearing activity is not contraindicated if there is no active ulceration [23].

4.6 Sleep, Psychological Stress, Tobacco and Alcohol

Sleep has become a potentially modifiable exposure that is of similar size to diet and activity. In dose–response meta-analysis both short and long sleep duration, and insomnia symptoms, are linked to significantly higher rates of diabetes [24]. Factors such as higher sympathetic tone, higher evening cortisol, lower leptin and higher ghrelin, and circadian misalignment may be responsible for those. This exposure is exacerbated by shift work, which is also widely used amongst the working age groups who are showing the largest increase in diabetes cases.

Tobacco use is consistently associated with incident diabetes in a dose-responsive manner and this risk persists with exposure to secondhand smoke; the risk of diabetes after quitting smoking rises slightly in the first two years after quitting, but then decreases back to that of never-smokers [25]. The clinical implication is that the expected weight gain after the smoking cessation will never be a contraindication for giving smoking cessation advice and that a smoking cessation programme should include concurrent dietary and activity support. Chronic psychological stress and depression are also present at about twice the rate in the general population in people with diabetes and affect diabetes self-management and hence are a suitable target for the behavioural/social aspects of standards of care [5].

4.7 Integrative Mechanistic Framework

The results presented above converge on a coherent causal architecture whereby each behavioural domain impinges on a particular set of partially overlapping physiological mechanisms to affect a shared set of clinical outcomes. Energy balance, diet quality, activity, sleep, and substance exposure have been linked to the ectopic lipid mobilisation, insulin sensitivity, beta-cell functional reserve, systemic inflammation and autonomic tone (Figure 4).

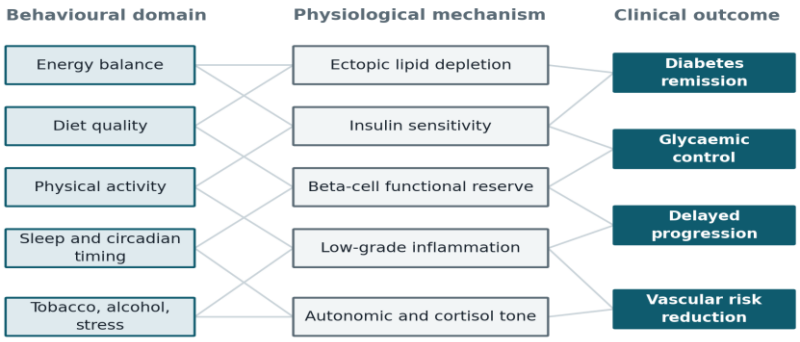


Figure 4. Integrative Framework Linking Behavioural Domains to Clinical Outcomes through Shared Physiological Mechanisms

It explains how the multicomponent interventions outperform the single-component interventions consistently – because there are multiple behaviours that share common mechanisms and that have additive or even supra-additive effects. It also provides an account of the seemingly paradoxical nature of the weight-dependency of benefits. Insulin sensitisation and beta-cell reserve can be directly improved by exercise [21], [22] diet quality can directly affect inflammation and lipid handling [4], [19] and sleep normalisation occurs via autonomic and cortisol pathways [24] which means glycaemic improvement can happen in the absence of weight change.

4.8 From Efficacy to Effectiveness: Implementation Determinants

Translation is the big problem that remains. Efficacy trials provided 16 or more, individual sessions in the first six months, using input from a dietitian, exercise physiologist and behavioural psychologist, while real-world programmes tend to provide a lesser amount of contact. Weight loss has been consistently reported as being 3–5% less effective with translated programmes, compared to trials (7–8%). Proportionate glycaemic benefit is reduced. These are structural, not motivational, factors: identification and referral of eligible people, and uptake after referral, retention through the maintenance phase, curriculum fit culturally and linguistically.

There are a number of developments closing this gap. The Group Based Delivery model provides results that are similar to that of individual counselling – but with significantly reduced investment. For standardised curricula, trained lay health workers and community health volunteers produce comparable results, in the critical context where dietitian density is low. Geographic and scheduling challenges are overcome through digital and hybrid delivery, which includes application-based tracking and automated coaching, remote CGM and contact via telephone or video after the initial three months, and generally decreases engagement over time, with limited evidence of retention beyond 12 months.

Economically favourable evidence. The cost-effectiveness ratios of translated prevention programmes have always come in under the standard willingness-to-pay thresholds and structured programmes have been reported as cost-saving over the lifespan of the health system in some health systems owing to the fact that the costs of averted complications outweigh the costs of the programme itself. The absolute cost per participant is still up front and can be a budget impact barrier, however, for payers on a yearly basis, even if value is clear in the long run. Table 5 highlights the main barriers described in the literature of implementation included in this review, and strategies for addressing them.

Table 5. Barriers to Real-World Implementation of Lifestyle Programmes and Corresponding Mitigation Strategies

Level	Barrier	Consequence	Mitigation Strategy
Individual	Competing time demands, low self-efficacy, weight-loss fatigue after regain	Early dropout; attenuated dose	Goal-setting and self-monitoring; brief motivational interviewing; relapse framed as expected and addressed in the curriculum

Individual	Food insecurity and cost of recommended foods	Recommendations not actionable	Culturally matched low-cost meal plans built on locally available staples, legumes and seasonal produce
Interpersonal	Household food practices and lack of family support	Poor dietary adherence at home	Family-inclusive counselling; shared cooking sessions; peer support groups
Provider	Short consultations; limited nutrition training; no referral pathway	Eligible patients never identified or referred	Opportunistic risk screening; electronic prompts; standing referral protocols; brief-advice training
Health system	Sparse dietitian and exercise-professional workforce	Programme capacity below population need	Task-shifting to trained lay health workers; group delivery; hybrid digital sessions
Health system	Front-loaded programme cost against annual budget cycles	Underinvestment despite long-run cost-effectiveness	Outcome-linked reimbursement; multi-year budgeting; integration into existing NCD programmes
Environmental	Obesogenic food environment; unsafe or absent space for activity	Individual effort counteracted by context	Fiscal measures on sugar-sweetened beverages, front-of-pack labelling, active-transport and public-space planning

4.9 Positioning Lifestyle Intervention Alongside Pharmacotherapy

With the advent of very effective incretin therapy, there is concern about the role of behavioural intervention in the future. There are three reasons for this support for integration and not substitution.There are three reasons for this support for integration, and not substitution. Pharmacological weight loss is a therapy that has been shown to have a rapid effect on weight loss that is largely reversed on drug cessation, while lifestyle intervention is the only therapy that has been shown to be effective for decades after treatment ends [9], [12]. Nutrition and exercise support is an essential adjunct to resistance training and good protein intake as rapid pharmacological weight loss compromises lean mass, which can be negated. It is important to note that there are other aspects of health not related to glucose control that also benefit from behavioural intervention, such as sleep quality, mood, functional mobility and cardiorespiratory fitness [13]. Lifestyle modification was superior to metformin overall and in each major subgroup in head-to-head comparison in prediabetes and there was no additive benefit when both were used together in the Indian trial [8], [10] indicating that the two may share partly the same pathways.

4.10 Limitations of the Evidence Base

There are four restrictions to the confidence of these conclusions. In behavioural trials, blinding is not possible, which results in the potential for admitting performance and/or detection bias, although objective laboratory endpoints reduce this. Trial attrition is often >20% and is likely differential with participants who drop out being likely to be doing least well. Definitions of remission have varied between studies with respect to level of the threshold, the necessary medication-free interval and the need for confirmatory tests, which makes it difficult to compare remissions across trials, even with the recent consensus criteria. Finally, the degree of general is ability is restricted by the composition of the trial population: volunteers in prevention trials are generally more motivated, well-educated and health-literate than is the population to which preventive programs are eventually intended to be implemented, which is another reason why effectiveness estimates are lower than efficacy estimates.

5. CONCLUSION

This review was a synthesis of evidence from 74 studies over the past 30 years of the importance of lifestyle modifications in the prevention and management of type 2 diabetes mellitus. There are four conclusions that may be reasonably inferred. A major, first finding, is that structured lifestyle intervention

consistently lowers the risk of progression from prediabetes to diabetes by ~28-58% in diverse populations, regardless of ancestry, baseline adiposity characteristics and health system context, and without significant loss of benefit for up to 30 years after active intervention ends. Second, for established disease of limited duration, weight loss is the most important indicator of remission, and there is a steep dose response relationship with losses of more than 15 kg giving remission probabilities > 80%, and losses < 5 kg giving few. Third, success of a diet depends on adherence not macronutrient composition of a food plan and these benefits of dietary quality and physical activity are partly independent of weight loss – an important distinction in leaner, higher risk groups where weight-focused guidance would have limited application. Fourth, sleep, tobacco exposure, and psychological stress are independent and clinically relevant risk factors and targets of treatment.

We no longer have an efficacy limitation to population impact, but rather a translation limitation. The real-world programme effects are consistently lower than those observed in trials and are related to referral gaps, the incomplete uptake, retention during maintenance and a shortage of workforce and lack of fit of standardised curricula. The most fruitful approach for the field is implementation-focused: to develop programmes that are operationally feasible to task-shifted staff; supported by technology; culturally and economically rooted in local food systems; and cost-recovery models that reflect front-loaded costs.

There are then five research priorities. South Asian, African and Indigenous population-specific trials with population-specific adiposity thresholds and remission criteria are warranted. The rigor used for induction should be applied to maintenance science as well: randomised comparisons of maintenance strategies, once weight loss is accomplished. Sleep should not be studied by itself, but as a target of randomised interventions, e.g., sleep duration, sleep quality and circadian alignment. Sequenced and matched behavioural/ incretin-based regimens should be tested and the durability and preservation of lean mass should be prescribed as outcomes of the trials. Last but not least, effectiveness-implementation designs should be used as the primary paradigm for translational research to ensure that uptake, fidelity, and retention in addition to clinical outcomes are measured, not just afterward. The benefits of lifestyle modification can be realised across the entire natural history of type 2 diabetes, and it is a high-efficacy, low-harm and cost-effective intervention – now it will be up to skilful delivery.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Dr. Priyadharshini P.	✓	✓	✓	✓		✓		✓	✓	✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Informed Consent

All participants were informed about the purpose of the study and their voluntary consent was obtained prior to data collection.

Ethical Approval

Not applicable.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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