

RESEARCH PAPER

Lifestyle Modification As Foundational Therapy In Diabetes: Reclaiming Its Role in the Era of New Pharmacotherapy.

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ABSTRACT

Background:

Type 2 Diabetes mellitus (T2D) represents one of the most significant global health challenges, with rapidly rising prevalence particularly in low- and middle-income countries. India is at the epicentre of this epidemic, with over 101 million adults currently living with diabetes. Accumulating evidence suggests that lifestyle factors—including diet, physical inactivity, obesity, sleep disruption, psychosocial stress, and addictive behaviors—play a central role in the development and progression of T2D. Despite advances in pharmacotherapy, lifestyle modification remains the most fundamental and cost-effective strategy for both prevention and management of diabetes.

Objective:

This narrative review aims to comprehensively evaluate the role of lifestyle modification in the prevention and management of T2D, integrating evidence across multiple domains including nutrition, physical activity, weight management, sleep and circadian health, stress and mental health, addictive behaviors, and emerging digital lifestyle tools.

Methods:

A narrative review of contemporary literature, including randomized controlled trials, observational studies, meta-analyses, and international guideline recommendations, was conducted to synthesize current evidence on lifestyle interventions influencing glycaemic control and cardiometabolic outcomes.

Results:

Evidence consistently demonstrates that structured lifestyle interventions significantly reduce the incidence of T2D and improve metabolic outcomes. Dietary approaches such as Mediterranean, vegetarian, and DASH diets improve glycaemic control, insulin sensitivity, and cardiovascular risk markers, whereas Western and ultra-processed food-rich diets increase diabetes risk. Regular physical activity—including aerobic, resistance, and high-intensity interval training—enhances insulin sensitivity and reduces HbA1c levels. Weight reduction of 5–10% through caloric restriction and behavioral support produces meaningful improvements in glycaemia and cardiometabolic health. Emerging therapies such as GLP-1-based pharmacotherapy, digital therapeutics, and microbiome interventions complement lifestyle interventions. Additionally, adequate sleep, circadian alignment, stress reduction strategies such as yoga and mindfulness, and avoidance of tobacco, alcohol, and substance abuse contribute to improved metabolic regulation and diabetes outcomes.

Conclusion:

Lifestyle modification remains the cornerstone of diabetes prevention and management, offering

multifaceted metabolic benefits that extend beyond glycaemic control. Integrated care models that combine structured lifestyle interventions with pharmacological therapy and digital health tools represent a promising strategy for addressing the growing diabetes burden, particularly in resource-constrained settings such as India.

Keywords: Type 2 Diabetes mellitus; lifestyle modification; diet; physical activity; obesity; sleep; stress; digital health; prevention.

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INTRODUCTION

Diabetes mellitus is one of the most significant global health challenges of the 21st century. An estimated 537 million adults were living with diabetes in 2021, a figure projected to rise to 643 million by 2030 and 783 million by 2045, with Type 2 Diabetes mellitus (T2D) accounting for over 90% of cases [1]. The Global Burden of Disease (GBD) 2021 study further highlights diabetes as a leading contributor to disability-adjusted life years (DALYs), mortality, and healthcare expenditure worldwide, particularly in low- and middle-income countries undergoing rapid urbanization and lifestyle transitions [2].

India represents a major epicentre of the diabetes epidemic, with over 101 million adults affected and an additional 136 million individuals living with prediabetes [3]. South Asians are especially susceptible due to higher visceral adiposity, greater insulin resistance, and earlier β -cell dysfunction, resulting in earlier onset and accelerated progression of T2D [3]. The disease imposes a substantial burden through its association with cardiovascular disease, chronic kidney disease, neuropathy, and retinopathy [2].

Lifestyle factors are central to the development of T2D. Suboptimal dietary intake alone has been estimated to account for more than 14 million new diabetes cases globally, particularly through low whole-grain consumption and excess intake of refined grains and processed meats [4]. Evidence from randomized controlled trials and meta-analyses demonstrates that comprehensive lifestyle modification (LSM), incorporating dietary changes, physical activity, and behavioral support, can reduce diabetes incidence by 40–60% among high-risk individuals and may even induce remission in early T2D [5–7]. Consequently, despite advances in pharmacotherapy, lifestyle modification remains the cornerstone of diabetes

prevention and management, addressing the fundamental drivers of the disease [5–7]. Recent large-scale trials and real-world studies show highly encouraging success rates:

The DIADEM-I Trial: Demonstrated a remarkable 61% remission rate at one year using intensive lifestyle interventions in early-stage, younger adults.

The DiRECT Study Extension: Maintained a 46% remission rate at 12 months following a structured weight management and low-calorie diet.

Lean vs. Obese Phenotypes: Emerging data challenges the idea that remission is only for the severely overweight. A landmark prospective study showed that 60.64% of lean T2D subjects achieved remission compared to 64.52% of obese subjects through structured lifestyle modifications.

Long-Term Complication Reductions: Achieving lifestyle-based remission cuts the risk of cardiovascular disease (CVD) by 40% and chronic kidney disease (CKD) by 33%.

The Pillars of Precision Lifestyle Medicine: The American College of Lifestyle Medicine (ACLM) defines remission as maintaining an $HbA1c < 6.5\%$ for at least 3 months without any active glucose-lowering medications or surgical interventions. Precision medicine delivers this through six main pillars. Low-Carbohydrate Profiles, substantially cutting sugar and refined carbohydrates to lower the pancreatic insulin demand. Diets rich in high-fiber, nutrient-dense, plant-based whole foods restore insulin sensitivity and repair pancreatic morphology. Using precise, short-term hypocaloric regimens (~800-850 kcal/day) to shed visceral organ fat rapidly. The 10-10-10 Rule, actively prescribing three 10-minute walks immediately after main

meals to blunt postprandial glucose spikes by utilizing active muscle glucose uptake without requiring excess insulin. Tailoring resistance exercises to specific baseline muscle mass metrics to enhance peripheral insulin sensitivity. Poor sleep duration or quality alters cortisol profiles and exacerbates night time insulin resistance. Precision protocols map sleep hygiene to individual chronotypes to stabilize fasting blood glucose levels

Diet

Dietary patterns are fundamental to the prevention and management of T2D, influencing glycemic control, insulin sensitivity, HbA1c, and cardio-metabolic risk factors [8]. Healthy dietary patterns, including vegetarian, Mediterranean, and DASH diets, are associated with improved metabolic outcomes and reduced T2D risk, whereas Western dietary patterns and ultra-processed foods (UPFs) increase the risk of obesity, insulin resistance, and T2D [8–11]. Diets emphasizing carbohydrate moderation and higher fiber intake have been linked to better glycemic control and cardiovascular health [12,13].

Dietary Patterns and Type 2 diabetes Mellitus Risk

Plant-based diets: Vegetarian diets, rich in fiber and low in saturated fat, are associated with improved weight management, insulin sensitivity, glycemic control, and reduced T2D risk [14–19]. In individuals with T2D, these diets can lower HbA1c, BMI, and the need for glucose-lowering medications [17].

Omnivorous diets: While omnivorous diets remain the most common globally, higher consumption of animal-derived foods, particularly those rich in saturated fats and low in fiber, has been associated with poorer weight control, insulin resistance, chronic inflammation, and increased T2D risk [20–22].

Western diets: Western dietary patterns, characterized by high intakes of UPFs, sugary beverages, refined grains, red and processed meats, and fried foods, are strongly associated with obesity and T2D [23]. Meta-analyses indicate that frequent consumption of these foods increases T2D risk by 12–30% and is also linked to cardiovascular disease and other adverse health outcomes [24,25].

Low-carbohydrate diets: Low-carbohydrate diets (LCDs), including ketogenic diets, can improve glycemic control and promote weight loss in T2D [26,27]. Very low-carbohydrate ketogenic diets have demonstrated short-term reductions in HbA1c of approximately 0.6% [28]. However, their long-term effectiveness may be limited by challenges in adherence and sustainability [29].

Prudent Dietary Patterns

The Mediterranean diet, emphasizing vegetables, fruits, whole grains, legumes, nuts, and olive oil, is consistently associated with lower T2D risk and improved metabolic health [30,31]. Greater adherence is linked to lower HbA1c, BMI, and prevalence of metabolic syndrome, with additional benefits observed when combined with regular physical activity [32]. DASH diet, originally developed for hypertension management, the DASH diet promotes fruits, vegetables, whole grains, and low-fat dairy while limiting saturated fat and added sugars [33]. DASH-style dietary interventions improve blood pressure, HbA1c, fasting glucose, and LDL cholesterol in individuals with T2D [34,35]. Emerging evidence suggests that moderate carbohydrate restriction within a DASH framework may further enhance long-term glycemic outcomes [35]. Overall, dietary patterns rich in plant-based, minimally processed foods and dietary fiber are associated with improved glycemic control and reduced T2D risk, whereas Westernized dietary habits and UPFs contribute significantly to the diabetes epidemic [8,35]. Adhering to strict lifestyle diets—such as those recommended for T2D or weight management—is notoriously difficult. A recent cross-sectional study cited that over 90% of individuals struggled to maintain regimens during social gatherings or work-related events. Because Indians eat roughly 95% of their meals at home, adherence strongly depends on the whole family's eating habits. Moreover, easy access to fast food and ultra-processed options often derails long-term compliance.

Exercise Type and Intensity in Diabetes

Physical activity (PA), defined by the World Health Organization (WHO) as any bodily movement produced by skeletal muscles that requires energy expenditure, is a cornerstone of diabetes prevention and management (36,37). Regular PA improves cardiovascular fitness, insulin sensitivity, glycaemic control, and overall metabolic health.

Exercise is broadly categorized into aerobic, resistance, flexibility, and balance training. Aerobic activities such as walking, cycling, and swimming improve cardiorespiratory fitness and glycaemic control, while resistance training increases muscle strength and insulin sensitivity (38,39). Flexibility exercises enhance joint mobility, and balance training helps prevent falls, particularly in older adults with diabetes (39,40). High-intensity interval training (HIIT) has also emerged as a time-efficient approach to improving insulin sensitivity and metabolic outcomes (41).

Evidence from clinical trials and meta-analyses demonstrates that structured exercise programs reduce HbA1c, improve lipid profiles, enhance glucose uptake, and lower the risk of developing T2D (38–42). Exercise intensity influences these benefits, with moderate-intensity activity (50–70% of maximal heart rate) being practical and sustainable for most individuals, while vigorous-intensity exercise may confer greater cardiovascular benefits (43).

The American Diabetes Association (ADA) recommends at least 150 minutes of moderate-to-vigorous aerobic activity per week, or 75 minutes of vigorous activity, combined with 2–3 sessions of resistance training weekly, alongside flexibility and balance exercises (44). Similarly, WHO guidelines advise 150–300 minutes of moderate-intensity or 75–150 minutes of vigorous-intensity activity per week for adults, and at least 60 minutes of daily moderate-to-vigorous activity for children and adolescents (37). Both organizations emphasize minimizing sedentary behavior and regularly interrupting prolonged sitting (37,44). Spread sessions over ≥ 3 days/week, with no more than 2 consecutive days without activity to prevent insulin resistance reversibility. Perform 2 to 3 sessions per week on non-consecutive days. Incorporate 2 to 3 sessions of yoga per week, especially for older adults. Break up prolonged sitting by getting up every 30 minutes for brief bouts of activity.

Safety & Glycemic Management: For those on insulin therapy, monitor glucose levels before and after activity to avoid dangerous drops. Avoid exercising if hyperglycemia and elevated blood ketones are present. Individuals with severe foot injuries/ulcers should avoid weight-bearing physical activity. Those with autonomic neuropathy should undergo cardiovascular screening before increasing exercise intensity. [1, 2, 3, 4]

In summary, combining aerobic, resistance, flexibility, and balance exercises according to ADA and WHO recommendations improves glycaemic control, cardiovascular health, and overall well-being. Individualized exercise prescriptions based on age, fitness level, and comorbidities are essential for maximizing long-term adherence and benefits (37, 44).

Obesity and Weight Management Strategies

Obesity (BMI ≥ 30 kg/m²) is a chronic, progressive, and relapsing disease affecting over one billion people worldwide and is a major risk factor for T2D, cardiovascular disease, and premature mortality [45]. In older adults, obesity frequently coexists with sarcopenia, resulting in sarcopenic obesity, a phenotype associated with increased frailty, disability, and mortality [45]. Effective management requires a lifelong, multidisciplinary approach integrating lifestyle modification, pharmacotherapy, and procedural interventions.

Lifestyle Interventions

Lifestyle modification remains the cornerstone of obesity management. Calorie restriction, healthy dietary patterns, regular physical activity, and behavioral support can achieve clinically meaningful weight loss and improve cardiometabolic outcomes [46]. Combined aerobic and resistance exercise helps preserve lean mass, improve insulin sensitivity, and support long-term weight maintenance. Behavioral interventions such as counseling, self-monitoring, and cognitive behavioral strategies further enhance adherence and outcomes [47].

Pharmacotherapy

Anti-obesity medications are recommended for individuals who do not achieve adequate weight loss with lifestyle interventions alone. Recent advances in incretin-based therapies, including GLP-1 receptor agonists and dual GIP/GLP-1 receptor agonists, have demonstrated substantial and sustained weight reduction along with improvements in glycemic and cardiometabolic outcomes [48]. Retatrutide, a novel triple agonist targeting GLP-1, GIP, and glucagon receptors, has shown promising results, achieving weight loss exceeding 20% in clinical trials and representing a potential future option for obesity and T2D management [49].

Strong overview of GLP-1 and incretin therapies: GLP-1 and incretin therapies are a class of medications that mimic natural gut hormones to regulate blood sugar, increase satiety, and promote weight loss. They have transformed the treatment of T2D and obesity, while offering significant cardiovascular and renal protective benefits. Incretins are metabolic hormones—primarily GLP-1 (Glucagon-Like Peptide-1) and GIP (Glucose-Dependent Insulinotropic Polypeptide)—released by the gut after eating. They naturally signal the pancreas to release insulin, suppress the liver's production of glucagon (which raises blood sugar), and slow gastric emptying so you feel full longer. The most common side effects are gastrointestinal in nature, including nausea, vomiting, diarrhea, and constipation. These are typically most pronounced when first starting the medication or increasing the dose.

Lean mass preservation

During pharmacologically induced weight loss with GLP-1 and incretin therapies, approximately 15% to 39% of total weight lost can be lean soft tissue. This requires active mitigation through progressive resistance training and adequate dietary protein intake (>1 g/kg of body weight/day) to prevent functional decline or sarcopenia. While DEXA scans often register this reduction as muscle loss, body composition data can be deceiving. DEXA measures all non-fat and non-bone tissue—including glycogen, water, and intramuscular fat—as lean mass. Advanced MRI studies demonstrate that incretins significantly reduce unhealthy ectopic intramuscular fat, meaning that some of the "lost" lean mass is actually metabolically favourable. Furthermore, clinical trials such as the SELECT and SURPASS-3 studies have shown that patients maintain or even improve overall muscle strength and functional mobility despite the absolute reduction in mass. To optimize body composition, global consensus guidelines emphasize the integration of lifestyle modifications with pharmacotherapy. The most effective strategies for preserving skeletal muscle integrity include:

- **Progressive Resistance Training:** Engaging in resistance exercise 3 to 5 days per week to stimulate muscle hypertrophy and counteract the catabolic effects of a caloric deficit.
- **Nutritional Optimization:** Consuming daily protein targets of 1.6 to 2.3 g/kg of fat-free mass, distributed evenly across all meals.

- **Targeted Supplementation:** Utilizing amino acid, vitamin, and mineral supplementation to prevent nutritional inadequacies common with delayed gastric emptying

Procedural Interventions

For individuals with severe obesity or obesity-related complications, metabolic-bariatric surgery remains the most effective and durable treatment, producing substantial and sustained weight loss while improving or inducing remission of obesity-related comorbidities, including T2D [50].

Emerging Therapies

Digital therapeutics, including smartphone-based behavioral coaching and monitoring platforms, have emerged as valuable adjuncts to conventional obesity treatment by improving adherence and self-management [51]. Microbiome-targeted interventions, such as probiotics, prebiotics, and synbiotics, have demonstrated potential benefits in reducing body weight, improving insulin sensitivity, and lowering systemic inflammation, although further research is needed before routine clinical implementation [52].

Optimizing Sleep and Circadian Health

Sleep and circadian health are now recognised as cornerstones of metabolic and cardiovascular wellbeing, yet modern lifestyles especially shift work routinely disrupt both sleep - duration and timing. As a practising diabetologist, I have closely observed how disrupted sleep rhythms can fuel metabolic chaos and lead to the insulin resistance and obesity. Not many people are aware that sleep and circadian health form the backbone of metabolic Wellness, it influences glucose Homeostasis, and inflammation.

Short sleep, usually less than six hours, disturb cortisol and Ghrelin and harms by elevating diabetes risk by 9 to 28% as per meta-analysis. (53, 54). Ideal adequate Sleep duration is 7 to 9 hours. Long sleep >9 hours signal Underlying issues like sleep apnoea and compounding cardiovascular threats in diabetics.

Obstructive Sleep Apnea (OSA) and T2D have a strong bidirectional link. OSA causes oxygen drops and fragmented sleep, triggering insulin resistance and higher blood sugar. Conversely, diabetes can impair nerve signals to airway

muscles, worsening OSA. Managing both requires lifestyle changes and CPAP therapy. An estimated 30% to 50% of people with T2D also suffer from OSA.

In obese individuals with T2D, the prevalence of OSA can be as high as 86%. Every time breathing stops, the body undergoes intermittent hypoxia (low oxygen) and sleep fragmentation. This stress response elevates cortisol, triggers systemic inflammation, and stimulates the sympathetic nervous system, directly decreasing insulin sensitivity and raising blood glucose levels. Untreated OSA is linked to poor metabolic control and elevated HbA1c levels, making blood sugar much harder to manage even with diet, exercise, or medication. High overnight fasting blood sugar that persists into the morning can be an early indicator of OSA. Treating OSA with Continuous Positive Airway Pressure (CPAP) therapy, alongside weight loss, can help stabilize glucose metabolism and improve insulin sensitivity.

Including Healthcare sector in many professionals shift work is prevalent. Shift work, particularly night or rotating shifts, forces sleep-wake and eating-fasting cycles to occur at biologically inappropriate times, leading to circadian misalignment and it de-synchronises suprachiasmatic nucleus mimicking jetlag.

Night Shifts impair melatonin levels, spikes sympathetic activity and raise T2D odds by 40% via blunted insulin secretion (55). Such patients often face heightened risks of Hypoglycaemia during misaligned wakefulness.

Chrono-nutrition which broadly means timing your meals to circadian cues. It also depends on frequency and composition of meals. This can be managed by eating within a 10–12-hour window, loading calories early enhances fat oxidation and better glycaemic control.

Late night feasts disrupt peripheral clock in liver and pancreas worsening HbA1c levels (56).

Studies have shown that time restricted eating reduces fasting glucose levels by 3 to 5% in shift workers. (57)

Practical strategies that can be adopted to overcome these issues Prioritise 7 to 9 hours sleep, and prioritise consistent sleep-wake cycles. Align eating with your biological day earlier, regular meals and no large meals 2–3 hours before bed, especially if you work night

shifts. (Need individual alignment as per Personal chronotype). In shift workers, better chrono-nutrition (regular, structured meals timed to their work-sleep schedule) and sleep with blackout curtains and nap strategically pre-shift is associated with better subjective sleep, less fatigue and may help to preserve circadian integrity and long-term health.

STRESS, DEPRESSION, YOGA, MINDFULNESS IN MANAGEMENT OF DIABETES MELLITUS

Daily life stress can directly elevate glucose levels in individuals at high metabolic risk, indicating stress as a modifiable risk factor for progression to T2D [58]. Psychological and physical stress contributes to the initiation and progression of T2D at the neuroendocrine and cellular levels.

Stress triggers activation of the hypothalamic-pituitary-adrenal (HPA) axis and sympathetic nervous system, leading to elevated cortisol and catecholamine release. These hormones increase hepatic glucose output, induce insulin resistance, and impair glucose uptake in peripheral tissues. Chronic stress also elevates pro-inflammatory cytokines and disrupts insulin signalling pathways. Over time, these integrated mechanisms promote persistent hyperglycemia and metabolic dysfunction, key features of diabetes onset and progression [59].

Person living with diabetes have a higher prevalence of depression, and depressive symptoms are consistently linked with poorer glycemic control and greater diabetes complications. The relationship between depression and glycemic status is complex and often mediated by psychosocial and behavioral factors such as self-efficacy (confidence in managing diabetes), social support, and diabetes-related distress. Lower self-efficacy and limited support are key pathways through which depression worsens self-management behaviors (e.g., diet adherence, medication compliance), which in turn deteriorate glycemic outcome [60].

Integrating Structured yoga practice with standard diabetes care significantly improved glycemic outcomes (FBS, PPBS, HbA1c, HOMA-IR) and reduced oxidative stress markers, while also enhancing psychological well-being in individuals with or at risk of T2D [61]. 12-week yoga intervention significantly lowered HbA1c and average glucose and improved quality of life and psychological

measures in adolescents with T1DM, supporting yoga's utility across diabetes types [62].

Mindfulness-based interventions like Mindfulness-Based Stress Reduction (MBSR) and Mindfulness-Based Cognitive Therapy (MBCT), appear to modestly improve glycemic control (HbA1c) and significantly benefit psychological well-being (stress, anxiety, depression) in people with diabetes. Mindfulness may improve diabetes outcomes by enhancing self-regulation, emotion control, and stress-reduction, which in turn can support self-care behaviors and metabolic regulation[63].

Tobacco, Alcohol, and Substance Use

Lifestyle modification (LSM) should include assessment and management of tobacco, alcohol, and substance use, as these behaviors adversely affect glycemic control and cardiometabolic health. Tobacco use is an independent risk factor for insulin resistance and T2D, contributing to hyperglycemia, endothelial dysfunction, systemic inflammation, and accelerated microvascular and macrovascular complications. Smoking cessation improves insulin sensitivity and reduces cardiovascular risk [64, 65, 66].

Vaping and e-cigarettes are widely marketed as safer alternatives to combustible smoking, but they pose unique, often hidden risks for people managing—or at risk of developing—diabetes and obesity. Because e-cigarettes typically contain nicotine, their metabolic effects can mirror those of traditional cigarettes, complicating blood sugar control and weight management. Nicotine alters glucose metabolism, making your cells less responsive to insulin. It triggers the release of stress hormones (like cortisol and epinephrine) which block insulin from doing its job, leading to elevated blood sugar. Nicotine acts as a central nervous system appetite suppressant. While some individuals may use this to curb eating, bypassing meals can lead to severe hypoglycemia (dangerously low blood sugar) if diabetes medications are not adjusted. Large-scale public health data links e-cigarette use alone to an increased risk of developing prediabetes, often stemming from short-term insulin function impairment and weight fluctuations. Nicotine exposure triggers your body to produce more triglycerides, a type of fat linked to insulin resistance, metabolic syndrome, and abdominal obesity.

Alcohol exerts dose-dependent metabolic effects. While acute intake may increase the risk

of hypoglycemia by suppressing hepatic gluconeogenesis, chronic heavy consumption promotes insulin resistance, central obesity, dyslipidemia, and poor glycemic control [67, 68]. Given the risks of hypoglycemia, dependency, and hepatic dysfunction, alcohol intake should be discouraged or carefully moderated based on individual risk assessment [69].

Substance abuse further compromises metabolic control. Stimulants, opioids, and cannabis can impair glucose regulation, treatment adherence, and self-care behaviors, leading to poorer diabetes outcomes. Routine screening, behavioral counselling, pharmacological support for cessation, and referral to de-addiction services should be integrated into comprehensive diabetes care to improve metabolic and cardiovascular outcomes.

The Vaping and Obesity Connection

Research consistently shows that combining vaping with traditional combustible cigarettes (dual use) compounds the health risks, causing the highest risk factors for prediabetes and diabetes. The "Quitting" Weight Dilemma, while vaping is sometimes used to transition away from smoking, the ultimate goal should be complete nicotine cessation. Quitting all nicotine products can sometimes lead to weight gain—a common side effect as appetite normalizes. However, the cardiovascular and metabolic benefits of quitting nicotine far outweigh the risks of weight gain.

Digital Lifestyle Tools for Diabetes: Apps, Wearable's, and CGM-Guided Lifestyle Changes

Digital health technologies have transformed diabetes management by enabling real-time monitoring, personalized feedback, and data-driven lifestyle interventions. Mobile health (mHealth) applications support blood glucose tracking, dietary monitoring, medication reminders, and diabetes education. Evidence suggests that apps incorporating behavior change techniques such as goal setting, self-monitoring, and feedback can improve glycemic control and promote healthier behaviors [72]. Digital lifestyle programs that combine app-based monitoring with coaching and personalized feedback have also been shown to reduce HbA1c and improve quality of life in individuals with T2D [73].

Wearable devices, including fitness trackers and smart watches, complement mobile applications by objectively monitoring physical activity, heart rate, and sleep. Integration of wearable data into digital platforms enhances patient engagement and supports sustained improvements in physical activity, weight management, and metabolic health [74].

Continuous glucose monitoring (CGM) has emerged as a powerful lifestyle management tool by providing real-time glucose feedback. CGM-guided nutritional and lifestyle interventions have been associated with reductions in HbA1c, body weight, and glucose variability in adults with T2D [75]. Real-time visualization of glucose responses to meals and physical activity promotes self-awareness and facilitates healthier behavioral choices [76].

Emerging applications of artificial intelligence and machine learning combined with CGM data offer opportunities for precision lifestyle medicine. These technologies can identify individual metabolic patterns and predict personalized glycemic responses, enabling tailored dietary and behavioral recommendations [77].

Integrated Models of Care, Indian Context, Gaps, and Future Research

Integrated diabetes care has evolved toward person-centred models in which lifestyle modification (LSM) is a core therapeutic intervention alongside pharmacotherapy and behavioral support [78,79]. Intensive lifestyle programs combining dietary modification, physical activity, and counselling improve HbA1c, weight, and cardiometabolic risk factors, with benefits often comparable to early pharmacotherapy escalation [80]. Multidisciplinary approaches involving dietitians, diabetes educators, exercise specialists, and mental health professionals consistently achieve better outcomes than medication-focused care alone [81,82].

The relevance of LSM is particularly important in India, where T2D develops at younger ages and lower BMI levels, driven by visceral adiposity, insulin resistance, physical inactivity, and dietary transitions [84,85]. The Indian Diabetes Prevention Programme demonstrated that lifestyle intervention alone reduced diabetes progression by nearly 30%, highlighting its therapeutic potential in the Indian population [86]. Real-world Indian programs have similarly shown improvements in glycemic control,

weight, and treatment adherence through structured lifestyle support [87].

Despite strong evidence, implementation remains inadequate. Lifestyle advice is often unstructured, while healthcare systems remain largely pharmacocentric with limited resources for behavioral counselling and long-term support [85,88]. Psychosocial factors, including stress, depression, sleep disturbances, and socioeconomic barriers, are also insufficiently addressed despite their impact on diabetes outcomes [89].

Future research should evaluate lifestyle modification as a primary treatment strategy rather than background care. Priority areas include pragmatic trials comparing intensive lifestyle intervention with pharmacotherapy, studies on diabetes remission and cardiovascular outcomes, and implementation research focused on scalable, cost-effective models using digital platforms, community health workers, and multidisciplinary teams [83, 90]. Integrating psychosocial care, sleep optimization, and culturally tailored interventions such as yoga may further enhance long-term diabetes management [91].

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