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Review Paper

Nutritional Strategies for Type 2 Diabetes: A Comprehensive Review on Current Evidence and Future Perspectives

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Abstract: **Background:** Type 2 diabetes mellitus (T2DM) is a growing global public health challenge characterized by chronic hyperglycemia resulting from insulin resistance and progressive β-cell dysfunction. Nutritional therapy plays a central role in both the prevention and management of T2DM. **Objectives:** This review synthesizes evidence from clinical and epidemiological studies on the effectiveness of various dietary approaches in improving glycemic control, insulin sensitivity, and metabolic health in individuals with or at risk of T2DM. **Key Findings:** Low-carbohydrate diets demonstrate superior short-term reductions in HbA1c compared to low-fat diets, while Mediterranean diets are consistently associated with improved cardiovascular outcomes and moderate glycemic benefits. Plant based diets show promise in enhancing insulin sensitivity and weight management, particularly when rich in whole grains and legumes. Calorie-restricted diets are effective in promoting weight loss and glycemic control, although adherence varies. The review also highlights the potential of personalized nutrition, interventions based on genetic makeup, metabolic status, and gut Microbiome composition to optimize therapeutic outcomes. Functional foods containing bioactive compounds such as polyphenols, peptides, and omega-3 fatty acids have shown favorable effects on glucose metabolism in preclinical and clinical settings. However, challenges remain in personalization and long-term adherence to these strategies, especially in diverse populations and real-world settings. **Conclusion:** Dietary interventions, particularly when personalized and integrated with lifestyle changes, offer promising avenues for sustainable management and prevention of T2DM. Future research should address the long-term efficacy and feasibility of such approaches, considering individual variability and adherence barriers.

Keywords: Diabetes, Mediterranean diet, Personalized nutrition, Gut Microbiome, Nutritional therapy

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1. Introduction

The prevalence of type 2 diabetes represents a serious public health issue and this complex disease features ongoing hyperglycemia, caused by a multiple factors including insulin resistance or insulin deficiency (Alam *et al.,* 2021). Its clinical

expression the development of this condition is influenced by both inherited predispositions and lifestyle factors. A key explanation for its origins is the "thrifty genotype hypothesis," which suggests that genetic adaptations beneficial for survival during periods of food scarcity have become harmful in today's environment of abundance. Another perspective proposes that type 2 diabetes results from a metabolic adaptation in adulthood, triggered by inadequate fetal nutrition, emphasizing the impact of early-life factors on disease development (Wells, 2023).

Insulin resistance, a key characteristic of diabetes, is influenced by genetic and metabolic factors, with central obesity being the most common cause. Excess abdominal fat leads to metabolic disturbances, including glucose intolerance, hypertension, dyslipidemia, increased blood clot risk, and a higher likelihood of macro vascular disease. In many cases, beta cells fail to produce enough insulin to compensate for insulin resistance, resulting in persistent hyperglycemia. The complex nature of type 2 diabetes arises from the interplay of genetic, environmental, and lifestyle factors, contributing to its varied clinical presentations (Wondmkun, 2020).

Type 2 diabetes leads to serious complications, encompassing small vessel damage (retinopathy, nephropathy, neuropathy) and large vessel damage (cardiovascular disease, stroke). Clinical studies have shown that reducing chronic hyperglycemia and managing associated metabolic abnormalities are essential to minimizing these complications. Guidelines recommend achieving To effectively minimize health risks, maintain hemoglobin A1c below 7.0%, blood pressure under 130/80 mmHg, and LDL cholesterol below 2.6 mmol/L (100 mg/dL) (Faselis *et al.,* 2020).

Management of diabetes involves a progressive, stepwise approach. Oral antihyperglycemic agents are often used to address different aspects of the disease through strategies that enhance natural insulin release, combat insulin resistance, or manage post-meal glucose levels by slowing the breakdown of complex carbohydrates (Ali, Khan, et al., 2025). Over time, many individuals require combination therapy with oral agents and insulin to maintain glycemic control. Managing diabetes relies heavily on lifestyle adjustments, including weight reduction, increased physical activity, and dietary modifications (Schroeder, 2022).

Despite advancements in understanding type 2 diabetes, challenges remain in identifying precise biomarkers for its subtypes and addressing the global epidemic driven by lifestyle changes and obesity (Steyn *et al.,* 2004). The diabetes affected an estimate 462 million people worldwide, representing 6.28% of the global population. In 2017 alone, it caused over 1 million deaths, making it the ninth leading cause of mortality a significant increase from its eighteenth ranks in 1990. Additionally, diabetes ranks seventh in terms of disability-adjusted life years (DALYs), reflecting its substantial impact on human suffering (Pearson, 2019).

The prevalence of type 2 diabetes is closely linked to socioeconomic progress, with developed regions, particularly Western Europe, experiencing significantly high rates. Despite public health efforts, these rates continue to rise without signs of slowing. Pacific Island nations, including Fiji, Mauritius, American Samoa, and Kiribati, have the highest prevalence globally. In Southeast Asia, cases have surged in Indonesia, Malaysia, Thailand, and Vietnam over the past two decades. However, due to their large populations, China, India, and the United States have the highest absolute number of individuals with type 2 diabetes (El-Kebbi *et al.,* 2021).

It is stated that males exhibit slightly higher type 2 diabetes prevalence than females, the difference is statistically marginal. The age of diagnosis is also slightly earlier in males, with prevalence increasing with age and

incidence peaking between 55–59 years. The age distribution of the disease has remained relatively stable from 1990 to 2017 (Fernández *et al.,* 2024). Despite primarily affecting older individuals, diabetes is now the seventh leading cause of disability and lost years of life (DALYs), a significant rise from nineteenth in 1990, highlighting a shift towards non-communicable diseases globally. Statistical projections indicate a further increase in global diabetes prevalence to 7,079 per 100,000 by 2030 and 7,862 per 100,000 by 2040, with a potential range of 5,821 to 9,904 per 100,000. (Abdul Basith Khan *et al.,* 2020).

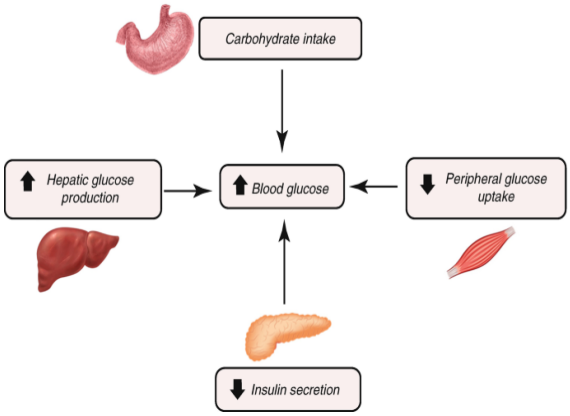

Figure 1. Dysregulation of blood glucose in type 2 diabetes mellitus: Increased carbohydrate intake raises blood glucose levels, which are further elevated by increased hepatic glucose production and reduced peripheral glucose uptake. Additionally, impaired insulin secretion from the pancreas contributes to persistent hyperglycemia, leading to metabolic disturbances (Kesavadev *et al.,* 2023).

In the 2017 IDF Diabetes Atlas, Pakistan is listed as the 10th country with the highest diabetes prevalence, out of 221 nations with diabetes affecting approximately 7.5 million individuals aged 20 to 79 (Khurshid *et al.,* 2022). Despite the alarming prevalence, the country lacks a comprehensive national diabetes strategy, including organizational frameworks, national recommendations, and a diabetes registry, as highlighted by the World Health Organization (WHO) in 2016. In Pakistan, 12% of the population is affected by type 2 diabetes mellitus (T2DM), leading to a significant risk of early death and serious complications involving both large and small blood vessels. Common small vessel complications include retinopathy (58.0%), neuropathy (39.5%), and nephropathy (61.4%) (Abdul Basit *et al.,* 2023).

The last national diabetes survey, conducted in 1999 and published in 2007, indicated an 11% prevalence of type 2 diabetes mellitus depend on oral glucose intake tolerance tests. However, subsequent findings have shown varied prevalence rates, ranging from 7.2% to 19.21% across different regions (Ranasinghe *et al.,* 2024). The IDF estimated a diabetes prevalence of 6.8% in its 5th edition, but healthcare professionals suspected this to be underestimated. A study in major cities revealed 6.4% of outpatients had undiagnosed diabetes, highlighting risk factors such as a BMI >23 kg/m², low physical activity, and a family history of diabetes. Newly diagnosed T2DM patients were advised on lifestyle modifications alongside oral anti-diabetic drugs (OADs), primarily Biguanides and Sulphonyl urea. Nearly 45.1% of patients started treatment with two OADs, while 9.5% began with insulin. Monitoring HbA1c and fasting blood glucose (FBG) levels over three months showed significant improvements, with a 1.6% reduction in HbA1c and a 41.9 mg/dL drop in FBG (Ogurtsova *et al.,* 2022).

A 2018 survey using glycated hemoglobin (HbA1c) screening confirmed a high prevalence of undiagnosed diabetes across all regions of Pakistan. Key contributors to complications include public unawareness, delayed diagnosis, inadequate treatment, and non-compliance with therapy. According to the IDF Diabetes Atlas 9th edition, diabetes prevalence in Pakistan surged to 17.1% in 2019, affecting nearly 19 million people, of whom 8.5 million remain undiagnosed and at risk of life-threatening complications. This highlights an urgent need for effective national strategies and public health interventions (Hasan & Siddiqui, 2024).

The effective nutritional management of Type 2 diabetes has shifted from general

low-fat recommendations to emphasizing macronutrient quality, dietary patterns, and avoidance of processed foods. Individualized dietary approaches focusing on high-quality carbohydrates, proteins, and fats are crucial, with adherence over time being key to success. Healthy patterns like a Mediterranean-style diet, featuring plenty of vegetables, fruits, whole grains, legumes, nuts, and fermented dairy improve glucose-insulin homeostasis and cardiovascular health, though debates about restricting fruits or grains in low-carb diets persist. Specific foods such as oily fish, yogurt, and extra virgin olive oil have demonstrated benefits, while processed meats, refined grains, sugary foods, and trans fats are discouraged. Weight management, through calorie restriction, portion control, and physical activity, plays a vital role, and sustained dietary changes may even lead to diabetes remission. Challenges remain in updating and tailoring dietary guidelines to individual needs, but ongoing research, including into the gut microbiome's role, aims to improve evidence-based dietary strategies for managing Type 2 diabetes effectively. (Forouhi *et al.,* 2018).

Engaging in physical activity significantly aids in the prevention and control of type 2 diabetes by enhancing cellular glucose absorption. Lowering blood glucose levels, and supporting weight loss. Regular exercise also improves cholesterol levels and blood pressure. Research indicates that increased physical activity correlates with a lower likelihood of developing type 2 diabetes, while a sedentary lifestyle elevates the risk. Exercise, combined with a healthy diet, is effective in improving blood glucose control. Moderate exercises, such as brisk walking, are especially beneficial, with current recommendations advising at least 2.5 hours of moderate aerobic activity per week (or 30 minutes daily for 5 days) to prevent diabetes. The intensity, duration, and frequency of exercise are key factors in reducing diabetes-related complications. Historically, walking served as a primary mode of transport in many cultures, offering natural protection against diabetes, but urbanization and Western influences have reduced physical activity levels. (Bekele *et al.,* 2020).

This review aims to provide updated information of nutritional strategies for managing and preventing type 2 diabetes mellitus (T2DM), with a particular focus on emerging approaches such as personalized nutrition, the gut Microbiome, and functional foods. Unlike previous reviews, this paper emphasizes recent advancements from the past three years and highlights region-specific challenges in low and middle income countries, especially Pakistan. The objective is to bridge current scientific evidence with practical applications, offering future directions for more targeted and effective dietary interventions in diverse populations.

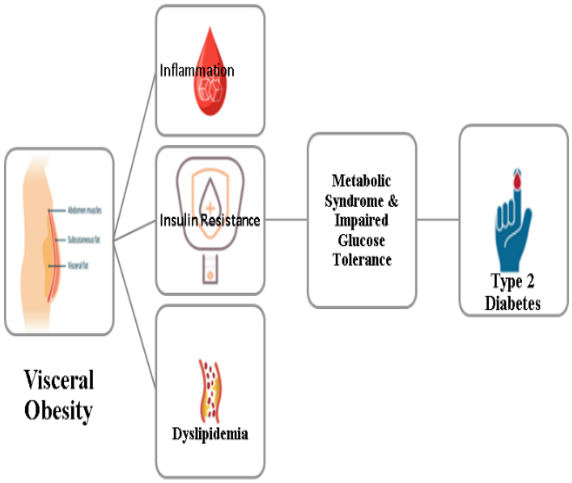

Figure 2. The diagram illustrates the progression from visceral obesity to type 2 diabetes mellitus (T2DM). It highlights how excess abdominal fat leads to insulin resistance, inflammation, and dyslipidemia that lead to oxidative stress, and β-cell dysfunction. The resulting persistent hyperglycemia accelerates the development of long-term complications, forming a destructive feedback loop that exacerbates disease progression.

Pathophysiology

A gradual and complex process involving insulin resistance (IR) and β-cell dysfunction leads to Type 2 Diabetes Mellitus (T2DM), characterized by long-term high blood glucose. Insulin resistance is when cells in tissues like muscle, liver,

and fat become less responsive to insulin (Figure 1). In a healthy state, insulin

Table 1: Evidence-Based Prevention Strategies for Type 2 Diabetes Management and Dietary Recommendations.

Strategy	Description	References
Dietary Fiber Intake	High fiber intake improves insulin sensitivity and glucose control.	(Mao *et al.,* 2021)
Low Glycemic Index Diet	Consuming low-GI foods reduces postprandial glucose spikes.	(Papakonstantinou *et al.,* 2022)
Mediterranean Diet	Rich in healthy fats, whole grains, and lean protein, lowering diabetes risk.	(Capurso, 2021)
Plant-Based Diet	Reduces inflammation and improves insulin sensitivity.	(Faselis *et al.,* 2020)
Intermittent Fasting	Enhances insulin sensitivity and lowers blood glucose levels.	(Yuan *et al.,* 2022))
Caloric Restriction	Reduces weight and improves metabolic markers.	(Kanikowska *et al.,* 2021)
Weight Loss	Losing 5-10% body weight prevents diabetes progression.	(Kucera, Marchewka, & Craib, 2021)
Regular Physical Activity	≥150 min/week of moderate exercise improves glucose metabolism.	(Ahmad & Ali, 2022)
Resistance Training	Enhances muscle glucose uptake and insulin function.	(Verbrugge *et al.,* 2022)
Reducing Sugary Beverages	Lowers diabetes risk by preventing insulin resistance.	(Tseng *et al.,* 2021)
Omega-3 Fatty Acids Intake	Improves lipid profile and reduces inflammation.	(Żebrowska *et al.,* 2021)
Vitamin D Supplementation	Supports insulin function and lowers diabetes risk.	(Rasouli *et al.,* 2022)
Mindfulness and Stress Management	Reduces cortisol levels, improving insulin response.	(Sayadi *et al.,* 2022)
Quality Sleep (7-9 hrs./night)	Improves glucose metabolism and insulin regulation.	(Coombe *et al.,* 2022)
Smoking Cessation	Reduces inflammation and insulin resistance.	(Cho *et al.,* 2022)
Moderate Alcohol Consumption	May improve insulin sensitivity if consumed responsibly.	(Llamosas-Falcón *et al.,* 2023)
Probiotic and Prebiotic Intake	Modulates gut microbiota to enhance glucose control.	(Wang *et al.,* 2022)

facilitates glucose uptake and storage in these tissues, as well as suppresses glucose production in the liver. However, in T2DM, these processes become impaired. The liver continues to produce glucose despite elevated insulin levels, and glucose uptake in muscle and adipose tissues decreases significantly. In response to this resistance, the pancreas attempts to compensate by increasing insulin secretion, a state known as hyperinsulinemia. During the early stages of T2DM, this compensatory mechanism is sufficient to maintain normal blood glucose levels. Over time, however, the β-cells in the pancreas begin to fail. Prolonged overproduction of insulin imposes stress on

these cells, leading to a decline in their functionality and a subsequent reduction in insulin secretion. This Visceral obesity plays a key role in the development of type 2 diabetes mellitus (Figure 2). Excess abdominal fat releases free fatty acids (FFAs) and inflammatory molecules, driving insulin resistance. Chronic inflammation, driven by cytokines like IL-6, TNF-α, and IL-1β, impairs insulin signaling and β-cell function. High-calorie diets further exacerbate oxidative stress, perpetuating insulin resistance and β-cell dysfunction. Persistent hyperglycemia promotes the formation of advanced glycation end products (AGEs), activating inflammatory and oxidative pathways that lead to complications like vascular damage. This creates a feedback loop that accelerates disease progression (Banday, Sameer, & Nissar, 2020).

Physical inactivity is another critical factor contributing to the progression of T2DM. Sedentary behavior worsens obesity and systemic inflammation, further aggravating insulin resistance. On the other hand, regular physical activity has protective effects, as it improves glucose uptake in muscle cells independently of insulin. Exercise also reduces inflammation by decreasing pro-inflammatory cytokines and enhancing the production of anti-inflammatory molecules. It increases the synthesis of antioxidants, countering oxidative stress, and promotes the release of beneficial compounds like irisin, which improves glucose tolerance and reduces cardiovascular risks associated with T2DM. T2DM is marked by a gradual progression from mild insulin resistance to significant β-cell dysfunction, leading to persistent hyperglycemia (Ali, Ayub, et al., 2025). The interplay of genetic predispositions, environmental influences such as diet and activity level, chronic inflammation, and oxidative stress creates a complex and self-perpetuating cycle. This complex pathophysiology highlights the need for multifaceted management approaches to prevent and treat T2DM, targeting not just blood glucose control but also the underlying factors such as obesity, inflammation, and physical inactivity (Alam, 2021).

2. Evidence-based prevention strategies for Type 2 Diabetes

To prevent Type 2 Diabetes (T2DM), evidence strongly supports lifestyle modifications focused on diet, physical activity, and weight loss. Trials like the Diabetes Prevention Program (DPP) and the Finnish Diabetes Prevention Study (DPS) demonstrate significant risk reductions, especially in those with impaired glucose tolerance (IGT). Modest weight loss (5-7% of body weight) improves insulin sensitivity, and in the DPP, each kilogram lost reduced diabetes incidence by 16%. Furthermore, independent of weight, 150 minutes of moderate-intensity exercise weekly reduces diabetes risk by up to 27% (Li *et al.,* 2023).

Nutritional strategies play a key role in reducing diabetes risk (Table 1). Diets rich in whole grains, dietary fiber, and low in saturated fat significantly lower diabetes incidence. Increasing fiber intake and consuming high-quality carbohydrates, such as those with a low glycemic index, have been shown to improve glucose metabolism and β-cell function. Limiting sugar-sweetened beverage intake also helps reduce risk, as excessive consumption is strongly linked to obesity and metabolic dysfunction (Adnan et al., 2025). Individualized dietary counseling, especially by registered dietitians, supports sustained behavior change and ensures dietary recommendations are culturally tailored and practically applicable (Minari *et al.,* 2023).

Behavioral counseling, coupled with regular follow-ups, is essential to help individuals adopt and sustain lifestyle changes. Evidence supports strategies such as setting specific goals, self-monitoring, empathy-driven counseling, and personalized recommendations. Community-based programs leveraging group settings or technology (e.g., apps or text messages)

have been effective in translating controlled trial successes into real-world contexts, achieving meaningful weight loss and glycemic improvements (Uusitupa *et al.,* 2019). Additionally, integrating preventive strategies into clinical practice—via structured counseling models like the 5-As (Assess, Advice, Agree, Assist, Arrange)—has shown promise. This approach systematically supports health care providers in guiding patients through lifestyle changes. Overall, a multi-pronged focus on weight management, physical activity, and dietary quality, supported by professional and community-driven initiatives, forms the backbone of evidence-based Type 2 Diabetes prevention (Galaviz *et al.,* 2018)

A case-control study was conducted in Karachi, Pakistan, from April 2020 to September 2021, with ethical approval (JSMU/IRB/456). Participants aged 18+ with or without Type 2 Diabetes Mellitus (T2DM) were selected using nonprobability convenience sampling. Individuals with hemoglobinopathies or those over 60 without prior diabetes screening were excluded. Informed consent was obtained, and questionnaires were distributed via social media due to COVID-19 restrictions. Out of 300 approached, 200 responded (66.67%), with 194 included in the final analysis (97 cases and 97 controls). Sociodemographic, diabetes, and comorbidity data were recorded and analyzed using SPSS, with significance tested by Chi-square ($p \leq 0.05$). The study population's average age was 26, with no significant demographic differences between groups. A significant portion had a family history of diabetes (61.90%), engaged in physical activity (66.50%), and followed a balanced diet (52.60%). Blood group B was significantly more prevalent in T2DM patients (p=0.006), while blood group O was less common (p=0.001). No significant associations were found with blood groups. (Sharjeel *et al.,* 2021).

Further analysis of diabetes-related demographics in a larger cohort of 1,839 patients indicated that the dominant age group was 40–50 years (60.1%), with females making up 52.2% of the sample. The majority were married (88.7%), and 31.1% had a college degree or higher. Unemployment was common (53.4%), with significant variation in household income. The most frequently reported diabetes duration was less than 5 years (69.3%), and the most preferred treatment approach was a combination of oral hypoglycemic agents and insulin (44.8%). The vast majority of patients (95.3%) were on oral antidiabetic drugs, while a smaller subset (12.0%) relied on insulin immunotherapy (Butt *et al.,* 2022).

An international study spanning 778 sites across 38 countries revealed that 50.5% of participating centers were primary care facilities, with 72.5% located in urban areas. The highest prevalence of primary care centers was observed in Europe and the Western Pacific, whereas specialized diabetes centers were more common in other regions. Most facilities were privately funded (61.8%), and the primary investigators were either endocrinologists/diabetologists (45.7%) or primary care physicians (33.7%). Regional variations indicated that primary care physicians were more prevalent in Africa and Europe, while specialists dominated in other areas. Urban centers were overrepresented, and patient self-referral was the most common mode of recruitment (65.0%). Additionally, most sites managed over 50 T2DM patients per month (59.3%), particularly in the Western Pacific (86.6%) and Eastern Mediterranean (78.4%). (Gomes *et al.,* 2019).

This study, involving 778 sites across multiple regions, revealed significant variations in site characteristics. Overall, primary care centers comprised 50.5% of the sites, but their prevalence ranged widely from 15.6% in Africa to 67.7% in Europe. Urban locations were dominant (72.5%),

with the Americas and Eastern Mediterranean showing nearly 100% urban sites. Funding was primarily private (61.8%), though public funding was more common in Europe (53.7%). The main investigators were mostly endocrinologists/diabetologists (45.7%) or primary care physicians (33.7%), with primary care physicians more common in Europe and Africa, while specialists dominated in other regions. Patient self-referral was the most common referral source (65.0%), especially in the Western Pacific (77.6%) and Europe (72.4%). The majority of sites reported managing over 50 T2DM patients per month (59.3%), with this being particularly prevalent in the Western Pacific (86.6%) and Eastern Mediterranean (78.4%).

3. Nutritional management of Type 2 Diabetes

Nutritional management of type 2 diabetes has shifted from low-fat diets to a focus on macronutrient quality, dietary patterns, and processed food avoidance (Table 2). Research supports personalized dietary approaches over fixed macronutrient ratios, with low-carbohydrate diets proving effective for weight loss and blood glucose control if they emphasize high-quality foods (Younas et al., 2024; Zia-ur-Rehman et al., 2025). The healthy dietary patterns like the Mediterranean diet, rich in vegetables, fruits, whole grains, legumes, nuts, and low-fat dairy, improve metabolic health and reduce cardiovascular risk (Saeed et al., 2025). While debates continue on fruit and whole-grain restrictions in low-carb diets, nuts and fermented dairy products show promise in diabetes prevention and management. Table 2 provides information about foods for the management of diabetes. Unhealthy foods like processed red meats, refined grains, sugary items, and Trans fats are discouraged, while whole grains and high-fiber foods are favored for better metabolic health. Sodium reduction is vital for cardiovascular health, especially in diabetes. Weight management through calorie control, portioning, and exercise may even lead to type 2 diabetes remission, though optimal strategies remain debated. The gut micro biome's role in diabetes is an emerging focus. However, dietary guidelines often lack relevance, quality, and accessibility. Greater transparency and research funding are needed to develop personalized, evidence-based nutrition plans for effective diabetes management and improved long-term outcomes (Forouhi *et al.,* 2018).

4. Emerging trends and future perspective of Type 2 diabetes

The rising global prevalence of type 2 diabetes mellitus (T2DM), driven by obesity and lifestyle changes, has led to a significant healthcare crisis. As a result, there is an increasing focus on personalized medicine that recognizes the diverse nature of T2DM, with variations in insulin deficiency, treatment needs, and prognosis. Understanding genetic predispositions and the underlying mechanisms, such as beta-cell dysfunction and insulin resistance, is crucial. This growing knowledge is fostering the development of therapies tailored to individual patient profiles. Advances in pharmacology, such as GLP-1 receptor agonists, represent an important shift, offering treatments that not only manage hyperglycemia but also promote weight loss, a key factor in reducing T2DM-related complications. Moreover, regenerative medicine, including stem cell therapy aimed at restoring or replacing beta cells, offers promising potential for addressing the progressive decline of beta-cell function in T2DM.

In addition to pharmacological advances, lifestyle interventions remain critical in managing T2DM, with growing interest in precision nutrition based on individual metabolic profiles. New technologies, such as continuous glucose monitoring and digital health tools, are transforming diabetes management by providing real-time monitoring and personalized feedback to patients. The gut microbiome's role in

glucose metabolism and insulin sensitivity is another emerging area of research, opening the door to probiotic and dietary interventions that could change how T2DM is understood and treated. Public health strategies are also shifting towards prevention, targeting environmental and societal factors that contribute to obesity and

Table 2: Specific Foods and Recommendations for Diabetes Management Based on Evidence-Based Strategies.

Food Category	Recommended Foods	Benefits for Diabetes	References
Whole Grains	Brown rice, Quinoa, Whole wheat	High fiber content helps regulate blood sugar levels	(Khan, Gul, & Liu, 2024)
	Oats, Barley, Buckwheat	Low glycemic index, improves insulin sensitivity	(Valenzuela Zamudio & Segura Campos, 2022)
Legumes	Lentils, Chickpeas, Black beans	Rich in fiber and protein, slows glucose absorption	(Lukus, Doma, & Duncan, 2020)
	Kidney beans, Peas, Soybeans	Enhances satiety and reduces diabetes risk	(Lukus, Doma, & Duncan, 2020)
Non-Starchy Vegetables	Spinach, Kale, Broccoli	Rich in fiber, vitamins, and antioxidants	(Singh, 2023)
	Bell peppers, Cauliflower	Low-calorie and supports blood sugar control	
	Zucchini, Eggplant, Cabbage	Contains polyphenols that may improve insulin sensitivity	
Fruits	Berries (Blueberries, Strawberries)	Antioxidant-rich, helps prevent blood sugar spikes	(Espe, 2019)
	Apples, Pears, Citrus fruits	High fiber, supports stable blood glucose levels	
	Cherries, Plums, Peaches	Contains anthocyanins, linked to lower diabetes risk	(Mallhi *et al.,* 2023)
Nuts and Seeds	Almonds, Walnuts, Pistachios	Provides healthy fats, improves lipid profile	(Gervasi *et al.,* 2021)
	Chia seeds, Flaxseeds, Sunflower seeds	Rich in omega-3s and fiber, reduces inflammation	
Dairy Products	Greek yogurt, Cottage cheese	Provides probiotics, supports gut health	(Abreu, Lima, & Rocha, 2023)
	Low-fat milk, Fortified soy milk	Contains calcium and protein for metabolic regulation	
Lean Proteins	Chicken breast, Turkey	Helps maintain muscle mass, promotes satiety	(Angwech, 2018)
	Fish (Salmon, Tuna, Mackerel)	High in omega-3 fatty acids, reduces inflammation	(Samanta *et al.,* 2022)
	Tofu, Tempeh, Seitan	Plant-based protein alternatives, low glycemic impact	(Bakhsh *et al.,* 2021)

Healthy Fats	Olive oil, Avocado	Supports heart health, reduces inflammation	(Pacheco *et al.,* 2022)
	Fatty fish (Sardines, Herring)	Improves insulin sensitivity and cardiovascular health	(Abachi *et al.,* 2023)
	Coconut oil (in moderation)	May support fat metabolism and energy balance	(Valente *et al.,* 2018)
Herbs and Spices	Cinnamon, Turmeric, Ginger	Anti-inflammatory, may improve insulin function	(Moosavi *et al.,* 2020)
	Garlic, Fenugreek, Cloves	Lowers cholesterol, enhances glucose metabolism	(Pradeep & Srinivasan, 2019)
Beverages	Green tea, Black coffee	Contains polyphenols that may enhance insulin sensitivity	(Williamson & Sheedy, 2020)
	Herbal teas (Chamomile, Peppermint)	Supports relaxation and reduces oxidative stress	(Poswal *et al.,* 2019)
	Lemon water, Infused water	Promotes hydration, aids digestion	(Maieves *et al.,* 2023)
Fermented Foods	Kimchi, Sauerkraut, Miso	Contains probiotics, improves gut microbiota	(Dimidi *et al.,* 2019)
	Kefir, Kombucha	Supports digestion and may enhance glucose metabolism	
Dark Chocolate	85% or higher cocoa content	Contains flavonoids, improves endothelial function	(Ebaditabar *et al.,* 2020)
Mushrooms	Shiitake, Reishi, Maitake	Boosts immunity, contains beta-glucans for blood sugar control	(Van Steenwijk, Bast, & De Boer, 2021)
Foods to Avoid	Sugary drinks, White bread, Pastries	High glycemic index, increases blood sugar levels	(Sjöblad, 2019)
	Processed snacks, French fries	High in trans fats, promotes insulin resistance	(Wells, 2023)
	Red meat, Processed meats	Linked to increased diabetes risk	(Qian *et al.,* 2020)

inactivity. Despite challenges such as ensuring equitable access to these new therapies and technologies, these emerging trends indicate a paradigm shift in T2DM management, promising improved outcomes and a reduced healthcare burden in the future. Additionally, the exploration of GLP-1 receptor agonists and stem cell therapy represents significant advancements, with potential applications extending beyond glycemic control to include cardiovascular and metabolic health benefits (Reed, Bain, & Kanamarlapudi, 2021).

5. Barriers to Implementation

The worldwide prevalence of type 2 diabetes (T2D) makes it a critical health problem, affecting countless people and posing an expanding public health challenge. Medical nutritional therapy (MNT) plays a critical role in managing T2D and is integral to a multidisciplinary approach. Lifestyle

changes associated with MNT can lead to reductions in A1C levels comparable to or exceeding those achieved through pharmacological treatments. MNT focuses on adopting healthy dietary patterns and making informed food choices, emphasizing its inclusion in diabetes self-care education programs. However, barriers to adherence to long-term nutritional plans can hinder success, and limited information exists regarding strategies to overcome these obstacles. Research aims to evaluate changes in barriers and outcomes, including dietary intake, anthropometric, and biochemical variables, following the implementation of tailored strategies over time. (Rushforth *et al.,* 2016)

The global incidence of T2D is on the rise, with approximately 463 million cases reported in 2019, and forecasts indicating a surge to 700 million by 2045. Lifestyle modifications, particularly addressing poor diet and sedentary habits, are crucial in preventing, slowing, and potentially reversing the disease. Multifactorial interventions, such as those integrating high exercise volumes and dietary counseling, have demonstrated positive outcomes in reducing glucose-lowering medications and achieving remission in some cases. Despite these successes, sustaining lifestyle changes remains a significant challenge, with positive outcomes often declining after interventions end. Adherence to prescribed treatments, emphasizing active patient involvement is key to long-term success. Research exploring motivational factors and barriers from patients' perspectives highlight the importance of understanding these dynamics to design effective and sustainable interventions. (Blasco-Blasco *et al.,* 2020)

The growing spread of diabetes, notably in low- and middle-income countries, emphasizes the necessity for enhanced prevention and management tactics. Factors such as unhealthy dietary habits, limited healthcare access, and sociocultural disparities contribute to higher rates of complications, including diabetic retinopathy. Strengthening primary care systems to focus on prevention and early detection is essential. However, the implementation of evidence-based strategies faces challenges, particularly in adapting recommendations to local contexts. Addressing barriers specific to these settings can enhance the effectiveness of interventions. Observational studies in Latin America and the Caribbean (LAC) emphasize the importance of understanding sociocultural and healthcare-related factors to improve diabetes management and reduce complications.

Diabetes poses substantial public health and economic burdens, with significant morbidity and mortality related to macro- and micro vascular complications. Despite evidence-based guidelines, many patients do not achieve recommended glycemic, cholesterol, and blood pressure targets. Primary care plays a central role in managing diabetes through structured reviews and shared care models. However, interventions to improve care have shown modest effects, highlighting the need to better understand clinician and organizational behavior. Research focusing on perceived barriers and enablers among primary care clinicians provides insights into improving adherence to best practices.

In the U.S., 13% of adults have diabetes, and an estimated 34.5% have prediabetes. To address this, the National Diabetes Prevention Program (NDPP), based on the Diabetes Prevention Program (DPP) trial, was launched in 2010 to implement evidence-based interventions nationwide for at-risk individuals, the NDPP promotes lifestyle changes to achieve weight loss and reduce diabetes incidence. Despite notable successes, challenges remain in extending the program's reach, maintaining effectiveness, and ensuring sustainability. Continued efforts to address these challenges are crucial for maximizing the program's long-term impact (Schmidt *et al.,* 2020).

6. Overcoming Challenges in Diabetes Prevention

Despite the National Diabetes Prevention Program's goal of reaching millions of U.S. adults with prediabetes, its impact remains limited due to low awareness levels, with only 15.3% recognizing their condition. While awareness has improved from 30% in 2011 to 45% in 2016, participation remains low, even though 71% of those aware take preventive actions. Although 90.2% of program sites use mass media for recruitment, its cost-effectiveness is uncertain. Expanding outreach through healthcare provider referrals, culturally tailored messaging, and targeted community engagement is essential to increasing participation and ensuring broader program reach. The National Diabetes Prevention Program, based on the Diabetes Prevention Program (DPP) clinical trial, has demonstrated success in reducing diabetes risk through lifestyle interventions, with participants achieving a 4.2% average weight loss in in-person sessions and 4.3% in virtual programs, nearing the program's ≥5% target. Older adults, particularly those over 60, experienced the highest weight loss (6.4%), and diverse populations, including women with a history of gestational diabetes, have benefited. However, retention remains a challenge, with 72% of participants failing to meet the weight loss goal and median attendance lasting only 134 days. Women, younger adults, racial minorities, and low-income individuals experience lower weight loss outcomes. Strategies such as motivational pre-sessions, provider referrals, culturally adapted interventions, and non-monetary incentives like gym memberships have improved retention, though monetary incentives show mixed results. While virtual programs address barriers like work, caregiving, and transportation, only 19% of participants remain engaged for nine months, and weight loss disparities persist. Hybrid models combining virtual and in-person coaching have been more effective, with a mean weight loss of 4.6%. Further research is needed to optimize digital interventions and enhance long-term program adherence.

7. Global Trends in Nutritional Strategies

Globally, the management of type 2 diabetes is shifting toward personalized, culturally sensitive, and evidence-based nutritional approaches. There is a growing emphasis on precision nutrition, which tailors dietary interventions based on genetics, metabolic biomarkers, and gut microbiome profiles (Saenz et al., 2025). The popularity of plant-based diets, low-carbohydrate patterns, and intermittent fasting has increased significantly, supported by clinical trials showing their effectiveness in improving glycemic control and weight management (Papamichou, Panagiotakos, & Itsiopoulos, 2019). Moreover, digital health technologies, such as mobile apps and continuous glucose monitors, are enhancing patient engagement and adherence to dietary plans. These trends reflect a move away from one-size-fits-all guidelines toward individualized care models that integrate lifestyle, behavior, and socio-economic factors (Richardson, 2024). This review addresses these developments and explores their implications for global and regional diabetes care.

8. Conclusion

The global rise in type 2 diabetes mellitus (T2DM), largely influenced by genetic and environmental factors, especially obesity, has resulted in severe complications and higher mortality rates. Pakistan ranks among the top 10 countries with high diabetes prevalence, yet lacks a cohesive national strategy, contributing to under diagnosis and poor treatment adherence. T2DM development is fueled by insulin resistance, β-cell dysfunction, chronic inflammation, and physical inactivity, making lifestyle interventions healthy diet, exercise, and weight management crucial for prevention and management. Behavioral counseling,

community programs, and technology-driven approaches can enhance adherence to these interventions. Advancements in personalized medicine, pharmacology, and emerging therapies, such as GLP-1 receptor agonists and gut microbiome research, provide promising treatment options, though accessibility remains a challenge. Addressing T2DM requires a comprehensive approach that includes public health initiatives, early detection, lifestyle modifications, and innovative treatments to reduce disease burden and improve global health outcomes.

Declarations

Authors Contribution: Design of the work, I.Y.M., M.K.U, A.N and S.Z. Drafting the work, I.Y.M.; M.K.U., S.N., S.H. and U.A; analysis, S.R. & Review, M.J.I; S.H.; S.N., and I.Y.M. All authors have read and agreed to the published version of the manuscript; All authors also agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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