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ROLE OF NUTRITION IN THE PREVENTION AND MANAGEMENT OF TYPE 2 DIABETES MELLITUS

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Abstract

Type 2 Diabetes Mellitus (T2DM) is a major and growing public health challenge globally. Nutrition plays a central role both in preventing the onset of T2DM and in managing its progression. Key nutritional strategies include maintaining healthy body weight, optimizing macronutrient composition (especially the quality of carbohydrates and dietary fats), increasing fiber intake, and aligning dietary patterns with individual preferences and metabolic goals. Diets that emphasize whole grains, legumes, fruits, vegetables, nuts, and unsaturated fats, while limiting refined carbohydrates, red and processed meat, sugar-sweetened beverages, and saturated or trans fats have demonstrated benefits in reducing risk of T2DM and improving glycemic control, lipids and other metabolic biomarkers. Emerging evidence also highlights the influence of vitamins, minerals, epigenetics, and gut microbiota in modulating individual responses to diet interventions. While there is no one-size-fits-all diet, dietary patterns such as the Mediterranean diet, low-glycemic index diets, vegetarian or plant-based diets, and modestly reduced-carbohydrate diets have shown consistent efficacy. Personalized nutrition, incorporating medical nutrition therapy as part of multidisciplinary care, can achieve meaningful reductions in HbA1c (often up to 2 %) and other risk factors over 3-6 months. In sum, nutritional interventions are foundational to both preventing T2DM and optimizing its management, acting synergistically with lifestyle modifications and, where needed, pharmacotherapy.

Key words: Nutritional therapy, Dietary habits, Fiber and Protein intake, Limiting intake saturated and trans fats, Healthy fats like omega-3, PUFA, Weight management, Micronutrient and vitamin balance, Insulin resistance improvement, Glucose control, Physical activity and lifestyle.

1. INTRODUCTION

1.1. Global and Regional Burden of Type 2 Diabetes Mellitus (T2DM)

Type 2 Diabetes Mellitus has emerged as one of the most significant global public health challenges of the 21st century. Characterized by insulin resistance and relative insulin deficiency, T2DM accounts for over 90% of all diabetes cases worldwide. The prevalence of T2DM has been steadily increasing, driven by factors such as aging populations, sedentary lifestyles, and rising rates of obesity. The disease burden of T2DM caused by high body mass index rank among all risk factors Fig. (1) illustrates. The International Diabetes Federation (IDF), approximately 537 million adults (20–79 years) were living with diabetes globally in 2021, and this number is projected to rise to 643 million by 2030 and 783 million by 2045 (IDF, 2021). The disease not only imposes a substantial health burden through its complications such as cardiovascular disease, kidney failure, and neuropathy but also contributes significantly to global healthcare costs and reduced productivity [1].

The International Diabetes Federation (IDF) reported that Europe has a significant T2DM burden, particularly in Southern and Eastern Europe. In countries like Greece, Italy, and Spain, T2DM prevalence is high due to dietary habits, aging populations, and lifestyle factors [2].

The United States has one of the highest rates of Type 2 Diabetes. According to the Centers for Disease Control and Prevention (CDC), nearly 1 in 10 Americans have diabetes, with about 90-

95% of those being Type 2 due to higher obesity rates, lower physical activity levels, and poor access to healthcare [3].

The American Diabetes Association (ADA) estimates that the total direct and indirect costs of diabetes in the U.S. are $327 billion annually [4].

In 2021, diabetes and kidney disease due to diabetes caused over 2 million deaths. In addition, around 11% of cardiovascular deaths were caused by high blood glucose.

More than half of people living with diabetes did not take medication for their diabetes in 2022. Diabetes treatment coverage was lowest in low- and middle-income countries [5].

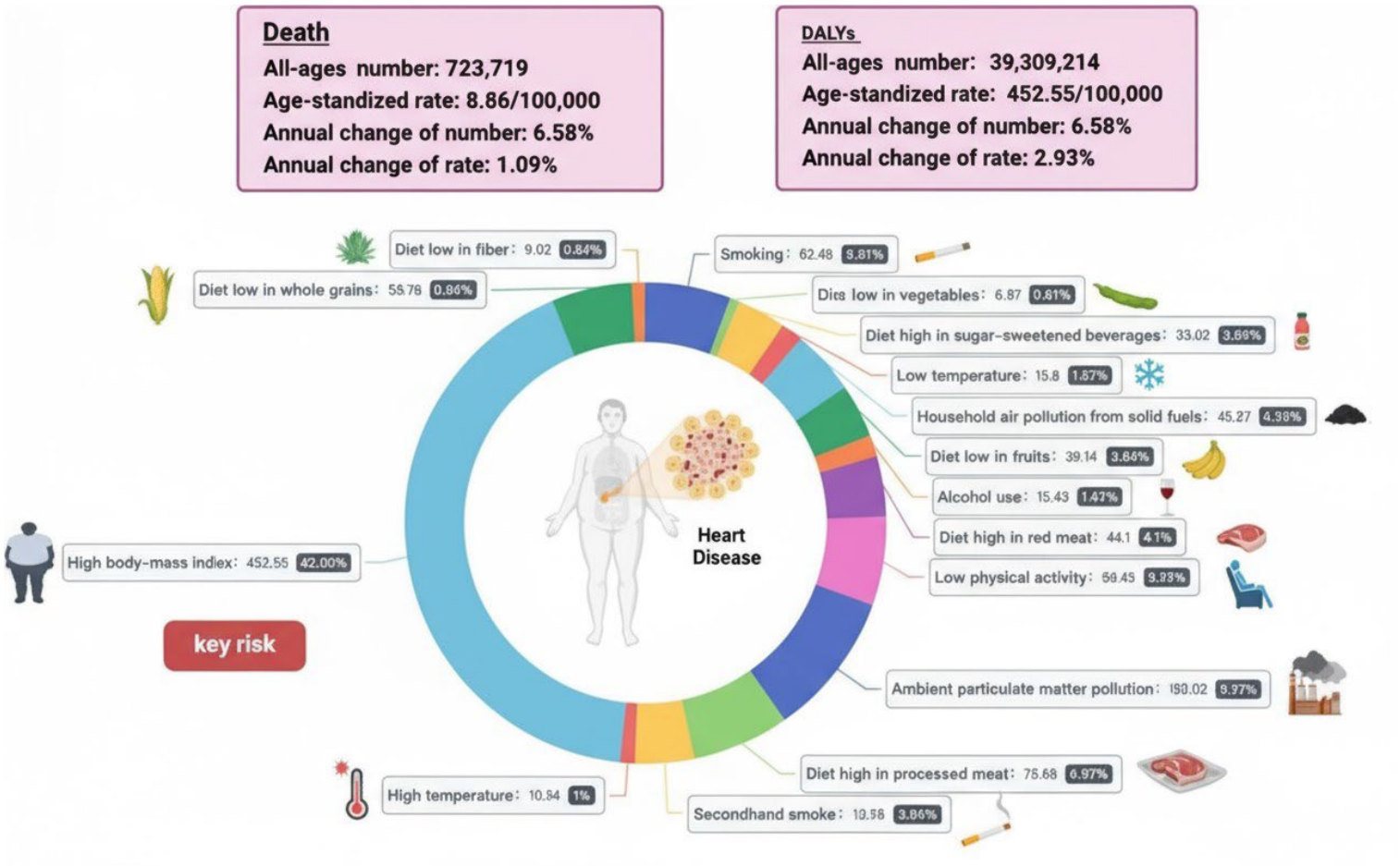

Fig. (1). Burden of T2DM caused by high body mass index rank among all risk factors

1.2. Pathophysiology of T2DM: Insulin Resistance and β-Cell Dysfunction

The pathophysiology of T2DM involves an interplay of genetic, environmental, and lifestyle factors that lead to alterations in glucose homeostasis, resulting in hyperglycemia and the associated long-term complications. Insulin resistance, a key feature of T2DM, refers to the reduced effectiveness of insulin in promoting glucose uptake into muscle, fat, and liver cells. As a result, there is an increased level of circulating glucose and insulin in the bloodstream. Initially, the pancreas compensates for this resistance by producing more insulin, a condition known as compensatory hyperinsulinemia. Over time, however, pancreatic β-cells become dysfunctional and their ability to secrete insulin declines, further exacerbating hyperglycemia Fig. (2) illustrates.

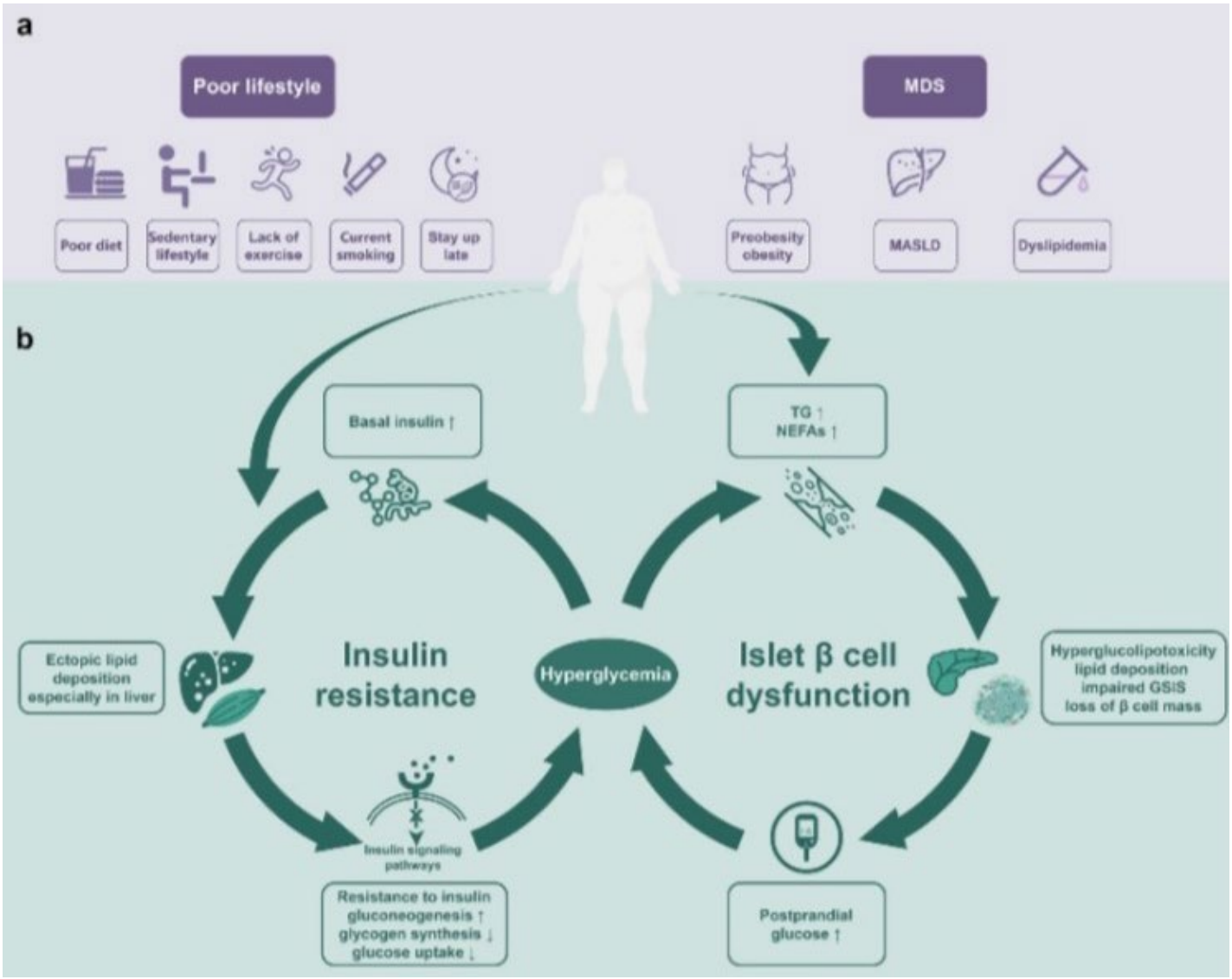

Fig. (2). Insulin Resistance and β-Cell Dysfunction

The molecular mechanisms behind insulin resistance [6,7] are multifactorial, involving disruptions in insulin signaling pathways, impaired glucose transporter function, and the presence of inflammatory mediators. Key factors contributing to insulin resistance include obesity.

Free fatty acids in Obesity and dietary factors (like high-fat or high-sugar diets) contribute to the accumulation of lipids and glucose in β-cells, exacerbating dysfunction. The Development of insulin resistance and β-Cell Dysfunction [8].

The management of metabolic syndrome in people with T2DM focuses on improving insulin sensitivity, reducing obesity, and managing cardiovascular risk factors. Lifestyle modifications-Diet, exercise (aerobic and resistance training), and weight loss. Medications: Metformin is commonly used to improve insulin sensitivity in T2DM. Monitoring: Regular monitoring of glucose levels, blood pressure [9].

Central to the pathogenesis is insulin resistance, which leads to:

- Increased free fatty acids, which contribute to inflammation and insulin resistance.
- Impaired glucose metabolism, leading to higher blood glucose levels.
- Dysfunctional lipid metabolism, which increases the risk of atherosclerosis.

1.3. Importance of Nutrition in the Etiopathogenesis and Management of T2DM

Nutrition plays a central role in the etiopathogenesis (the cause and development) of many diseases. The body ability to maintain health and prevent or combat disease is heavily influenced by dietary patterns, nutrient intake, and overall nutritional status. A lack of essential nutrients, such as vitamins, minerals, or amino acids, can result in specific diseases. A lack of essential nutrients, such as vitamins, minerals, or amino acids, can result in specific diseases. Micronutrients like zinc, selenium, and vitamins A, C, and E are essential for the proper functioning of immune cells and the prevention of infections and autoimmune diseases [10,11].

Nutrition is central to managing blood glucose levels in people with T2DM. Diets rich in low-glycemic index (GI) foods, such as whole grains, legumes, and vegetables, have been shown to help stabilize blood sugar levels. The glycemic index refers to how quickly a carbohydrate-containing food raises blood glucose levels. Foods with a low GI cause slower, more gradual

increases in blood glucose, whereas high-GI foods lead to rapid spikes in blood sugar levels [12,13].

Obesity is a significant risk factor for the development and progression of T2DM. In many cases, weight loss (even modest weight reduction) has been shown to improve insulin sensitivity, reduce blood glucose levels, and in some cases, lead to remission of T2DM. A well-balanced, calorie-controlled diet that includes nutrient-dense foods can help individuals with T2DM achieve and maintain a healthy weight [14].

Nutrients like fiber, healthy fats (e.g., omega-3 fatty acids), and lean proteins are essential in improving insulin sensitivity. A diet rich in fiber, especially soluble fiber, has been shown to help manage insulin resistance, which is a hallmark of T2DM. Omega-3 fatty acids from sources like fatty fish (e.g., salmon, mackerel) and walnuts have anti-inflammatory effects that help enhance insulin sensitivity and reduce the risk of cardiovascular disease in diabetic patients [15].

Individuals with T2DM are at increased risk for complications such as cardiovascular disease, nephropathy, retinopathy, and neuropathy. A healthy diet can help mitigate these risks. For instance, reducing intake of saturated and trans fats can lower the risk of cardiovascular disease, while an adequate intake of vitamins and minerals, such as vitamin D and magnesium, supports the prevention of diabetic neuropathy [16].

Carbohydrate intake and manage blood glucose level. Originally designed for hypertension, the Dietary Approaches to Stop Hypertension (DASH) diet emphasizes low-fat dairy, fruits, vegetables, and whole grains, which can also support blood sugar management. The intermittent fasting may improve insulin sensitivity and aid in weight management in individuals with T2DM [17]. *Chromium:* May improve insulin sensitivity. *Magnesium:* Low levels of magnesium have been linked with increased insulin resistance. *Vitamin D:* Insulin resistance is commonly associated with vitamin D deficiency, so maintaining adequate levels may improve insulin sensitivity [18].

2. Dietary Regulation of Adiponectin in Type 2 Diabetes

2.1. Role of Adiponectin in Glucose Homeostasis and Lipid Metabolism

Adiponectin is an adipocyte-derived hormone that plays a crucial role in regulating glucose levels and lipid metabolism. It enhances insulin sensitivity by promoting glucose uptake in skeletal muscle and inhibiting hepatic gluconeogenesis. Additionally, adiponectin facilitates fatty acid oxidation and reduces triglyceride content in muscle and liver, contributing to improved lipid profiles. Low levels of adiponectin are associated with insulin resistance, type 2 diabetes, obesity, and cardiovascular disease.

Adiponectin exerts its effects primarily through activation of AMP-activated protein kinase (AMPK) and peroxisome proliferator-activated receptor alpha (PPAR-α) pathways, which regulate energy balance and lipid catabolism [19-22].

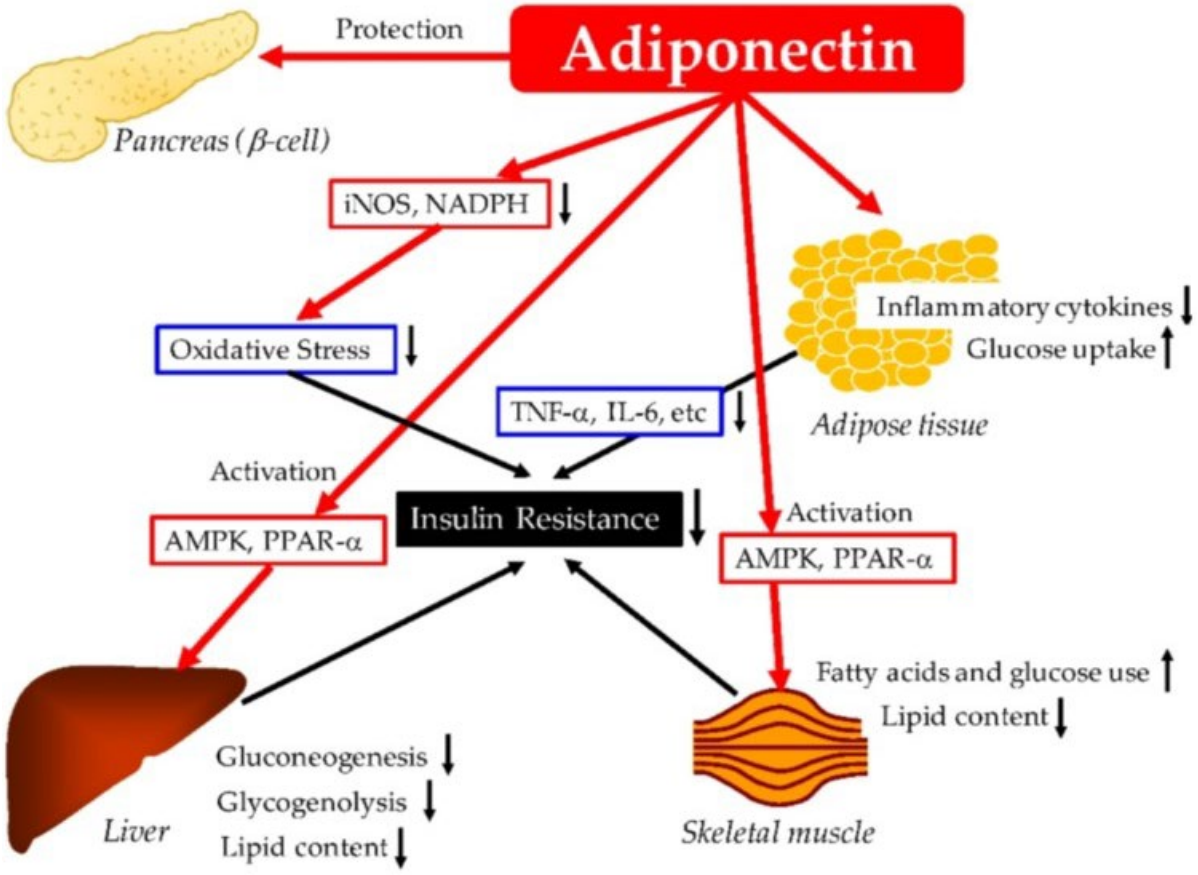

Fig. (3). Dietary Regulation of Adiponectin in Type 2 Diabetes

2.2. Adiponectin Signaling Pathways and Insulin Sensitivity

Adiponectin is an adipokine secreted predominantly by adipose tissue and plays a crucial role in regulating glucose levels and lipid metabolism. It enhances insulin sensitivity through multiple signaling pathways, primarily involving AMP-activated protein kinase (AMPK), peroxisome proliferator-activated receptor-α (PPAR-α), and p38 MAPK. Fig. (3). illustrates.

Upon binding to its receptors (AdipoR1 and AdipoR2), adiponectin activates AMPK, which in turn promotes glucose uptake and fatty acid oxidation in skeletal muscle and liver, thereby improving insulin sensitivity. In the liver, activation of PPAR-α by adiponectin enhances fatty acid combustion and decreases gluconeogenesis. These pathways collectively counteract insulin resistance, often observed in obesity and type 2 diabetes [23-26].

2.3. Influence of Nutritional Patterns on Adiponectin Secretion

Nutritional patterns significantly influence adiponectin secretion, thereby affecting metabolic health and insulin sensitivity. Diets rich in monounsaturated fats, omega-3 fatty acids, fiber, and polyphenols such as those found in the Mediterranean diet have been shown to increase adiponectin levels. In contrast, high intake of saturated fats, refined carbohydrates, and excessive calories typical of Western dietary patterns tends to lower adiponectin secretion and contribute to insulin resistance.

Caloric restriction and weight loss, regardless of diet type, are also associated with increased adiponectin levels, particularly the high-molecular-weight form that is most active in enhancing insulin sensitivity [27].

3. Nutritional Approaches in the Prevention of Type 2 Diabetes

3.1. Adiponectin-Rich Dietary Patterns

Adiponectin is an adipokine (a hormone secreted by fat cells) that plays a crucial role in regulating glucose levels and fatty acid oxidation. Fig. (4). and Table 1 illustrates higher levels of adiponectin are associated with reduced risk of insulin resistance, type 2 diabetes, cardiovascular disease and obesity [28-30].

Table. 1. The difference between high and low intake of Foods.

High intake	Low intake
Fruits and vegetables	Refined carbohydrates
Whole grains	Added sugars
Legumes	Saturated fats and trans fats
Nuts and seeds oil	Processed meats

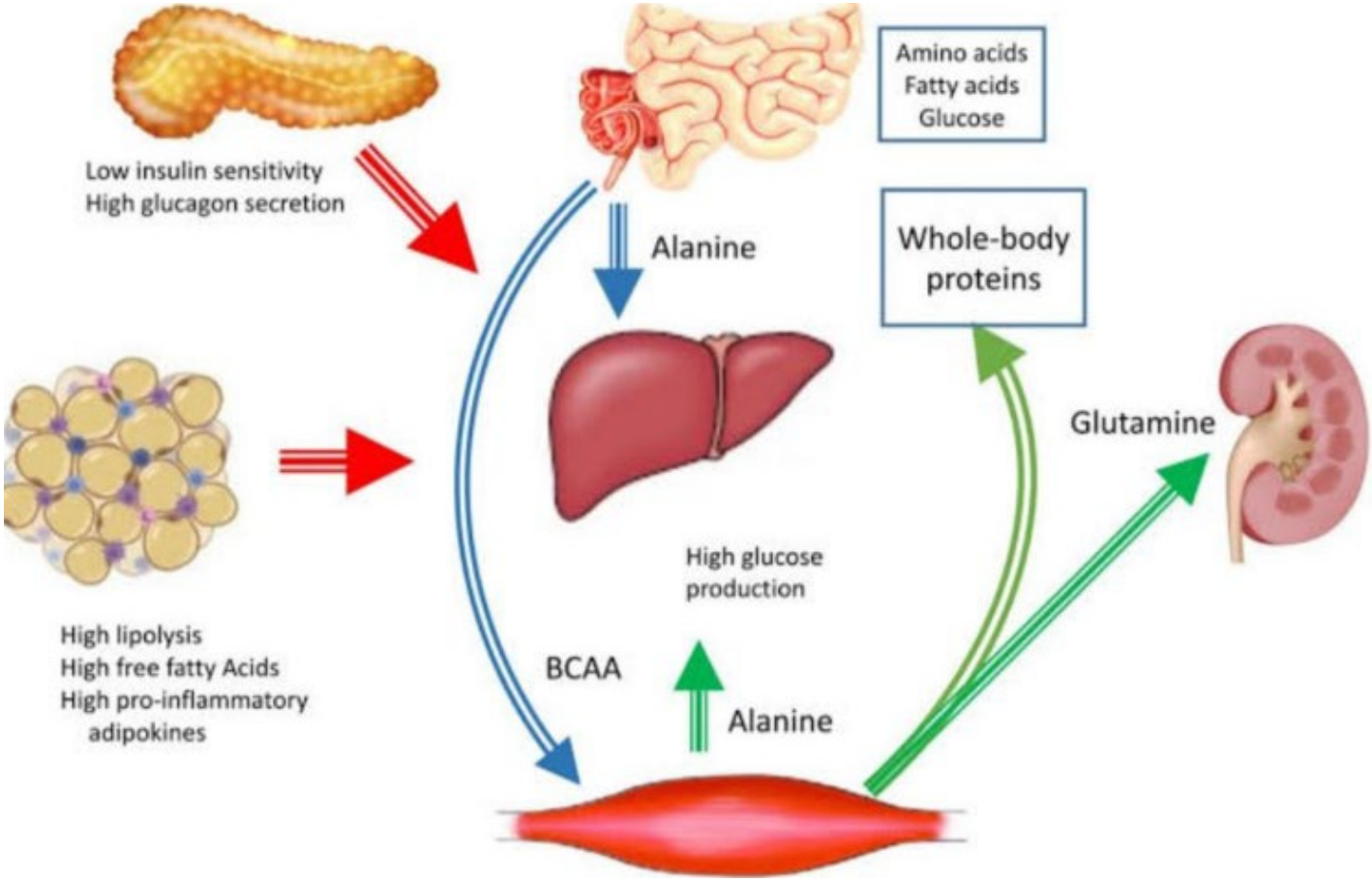

Fig. (4). T2DM Approaches

3.2. Plant-Based and Vegetarian Diets

Plant-based and vegetarian diets emphasize the consumption of foods derived primarily from plants, including fruits, vegetables, whole grains, legumes, nuts, and seeds. Vegetarian diets exclude meat, and may or may not include animal products like dairy and eggs, while plant-based

diets focus more on whole, minimally processed plant foods and often reduce or eliminate all animal products [31-33].

These diets are associated with numerous health benefits, including:

- Lower risk of cardiovascular disease
- Reduced incidence of type 2 diabetes

3.3. Mediterranean Diet and Its Protective Role

The Mediterranean diet is a traditional dietary pattern originating from countries bordering the Mediterranean Sea [34-36]. Protective roles include:

- Reduced risk of cardiovascular disease
- Improved blood lipid profiles and insulin sensitivity
- Lower incidence of type 2 diabetes and metabolic syndrome
- The Mediterranean diet is also associated with longer life expectancy and better overall quality of life.

3.4. Low-Glycemic Index and High-Fiber Foods

T2DM, managing blood glucose levels is critical. Low-glycemic index (GI) foods, which are digested and absorbed more slowly, help prevent sharp spikes in blood glucose. These foods such as whole grains, legumes, vegetables, and certain fruits improve glycemic control and insulin sensitivity.

High-fiber foods, particularly those rich in soluble fiber, also benefit people with T2DM. Dietary fiber slows glucose absorption, improves postprandial blood sugar levels, and enhances satiety, which can support weight management an important aspect of diabetes care. Combining low-GI and high-fiber diets has been shown to reduce HbA1c levels and cardiovascular risk factors in diabetic patients [37].

3.5. Limiting Ultra-Processed and High-Fat Foods

Limiting ultra-processed and high-fat foods is crucial for managing Type 2 Diabetes (T2D), as these foods can negatively impact blood glucose control, insulin sensitivity, and overall metabolic health. Ultra-processed foods, often high in added sugars, unhealthy fats, and refined carbohydrates, contribute to weight gain, insulin resistance, and inflammation, all of which exacerbate T2D symptoms. Additionally, high-fat foods, particularly those rich in trans fats and saturated fats, can impair insulin function and increase the risk of cardiovascular complications, which are common among individuals with T2D [38,39].

4. Nutritional Interventions in the Management of Established Type 2 Diabetes

4.1. Macronutrient Composition and Glycemic Control

The table 2 below summarizes the effects of various macronutrient distributions on glycemic control and provides contextual insights relevant to dietary planning for T2DM management [40].

Table 2. Macronutrient composition and its impact on glycemic control in T2DM

Macronutrient Composition (% of total energy)	Effect of Glycemic Control in DM2	Comments
Carbohydrates 45-60%	Moderate carbohydrate intake generally recommended.	Carbohydrates primarily influence postprandial blood glucose; sources and quality matter.
Protein 15-20%	Higher protein intake improves glycemic control	Protein reduces post-meal glucose spikes and supports insulin secretion.
Fat 20-35%	Mixed effects; MUFA and PUFA fats beneficial, saturated fats limited.	Fat delays gastric emptying, modulates glucose response; fat source impacts lipids and glycemia.
Low-Carbohydrate, High-Fat (Ketogenic) Diet	May improve glycemic control, reduce glucose spikes.	Carbohydrates restricted to ~10%, protein ~20%, fat ~70%;

		promotes lipid metabolism over glucose.
Protein and Fat combined with Carbohydrates	Protein + fat with carbs reduces postprandial glucose peaks.	Combining protein with carbs lowers glycemic response compared to carbs alone
Higher Carbohydrate (>54%) with lower protein/fat	Less favorable for glycemic control in T2D remission/prevention.	Suggested for normoglycemia or prevention groups, but reduction in carbs better for remission.

4.2. Micronutrients and Bioactive Compounds in Diabetes Modulation

Micronutrients and bioactive compounds play an important role in modulating diabetes risk and managing T2D through their antioxidant, anti-inflammatory, and insulin-sensitizing effects. Key micronutrients such as magnesium, chromium, zinc, and vitamins like D and C have been shown to improve insulin sensitivity and reduce oxidative stress, which is a contributor to T2DM pathogenesis. Magnesium, for instance, has been associated with better glycemic control and lower insulin resistance (Barbagallo & Dominguez, 2010). Similarly, vitamin D deficiency is linked to impaired insulin secretion and resistance, and supplementation may help improve blood sugar regulation .Bioactive compounds from food sources like polyphenols (found in fruits, vegetables, and tea) and flavonoids can further enhance insulin sensitivity and protect against diabetic complications .Incorporating a diet rich in these micronutrients and bioactive compounds through whole foods like leafy greens, nuts, seeds, and berries can help manage blood sugar levels and improve long-term health outcomes in individuals with T2DM [41-43].

4.3. Functional Foods and Phytochemicals: Antioxidant and Anti-Inflammatory Roles

Functional foods and phytochemicals bioactive compounds found in plant-based foods play a significant role in managing T2D by acting as antioxidants and anti-inflammatory agents. Chronic inflammation and oxidative stress are key contributors to insulin resistance and β-cell dysfunction in T2DM. Phytochemicals such as polyphenols, flavonoids, and carotenoids possess antioxidant properties that help neutralize free radicals, thereby reducing oxidative stress and protecting against cellular damage in individuals with T2DM. Compounds like curcumin (from turmeric), resveratrol (from grapes), and anthocyanins (from berries) have shown anti-inflammatory effects,

which can improve insulin sensitivity, reduce blood glucose levels, and prevent complications such as cardiovascular disease [44,45].

4.4. Role of Probiotics and Gut Microbiota in Glycemic Regulation

Probiotics and gut microbiota play a significant role in the regulation of glycemic control in T2DM. The gut microbiota, a complex community of microorganisms residing in the intestines, can influence metabolic processes, including glucose homeostasis. Dysbiosis (an imbalance in gut microbiota) is often observed in T2DM patients, which is linked to insulin resistance, impaired glucose metabolism, and inflammation.

Probiotics, live microorganisms that confer health benefits to the host, can help restore microbial balance and improve gut health. By modulating the gut microbiota, probiotics can enhance insulin sensitivity, reduce inflammation, and improve the integrity of the gut barrier. Some studies have shown that probiotic supplementation can lead to lower fasting blood glucose levels, reduced HbA1c, and better postprandial glucose control [46,47].

5. Mechanistic Insights: Linking Diet, Adiponectin, and Insulin Sensitivity

5.1. Nutritional Modulation of Adiponectin Expression

Adiponectin is a key adipokine secreted by adipose tissue that plays a critical role in regulating glucose metabolism, insulin sensitivity, and fatty acid oxidation. In T2DM adiponectin levels are often reduced, contributing to insulin resistance, inflammation, and metabolic dysregulation. Nutritional interventions have emerged as a promising strategy to modulate adiponectin expression, thereby improving glycemic control and insulin sensitivity in individuals with T2DM [48,49]. Adiponectin secretion:

- Dietary Fat: Monounsaturated Fats, Omega-3 Fatty Acids.
- Dietary Fiber
- Low Glycemic Index (GI) Foods
- Caloric Restriction

- Polyphenols: Flavonoids and Resveratrol

5.2. Impact on Insulin Signaling and β-Cell Preservation

Insulin resistance is primarily driven by factors such as obesity, inflammation, and elevated free fatty acids, which interfere with insulin receptor signaling pathways. Key proteins involved in this process include IRS (Insulin Receptor Substrate), PI3K (Phosphoinositide 3-kinase), and AKT (Protein Kinase B). In T2DM, these pathways are often disrupted, leading to decreased glucose uptake and metabolic dysfunction [50-52].

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5.3. Reduction of Oxidative Stress and Inflammatory Pathways

Inflammatory pathways are also activated in T2DM, often due to the dysregulation of immune responses in adipose tissue and other organs. Increased levels of pro-inflammatory cytokines like TNF-α, IL-6, and IL-1β contribute to insulin resistance and exacerbate metabolic abnormalities [55]. The pathophysiology of T2DM, focusing on the role of insulin resistance, oxidative stress, and inflammation in the development of the disease [56]. Oxidative stress mechanisms in T2DM and their implications on disease progression [57], inflammatory cytokines and insulin resistance highlighting the critical pathways involved in T2DM [58]. Table 3 illustrates the role of chronic low-grade inflammation in the pathogenesis of T2DM and highlights the key components targeted by various therapeutic strategies [59-62].

Table 3. Antioxidant, anti-inflammatory with the Mechanism and Key components.

Nutritional class	**Key components**
Antioxidant Nutrients	Vit C, E, Polyphenols
Phytochemicals	Curcumin, Resveratrol, Anthocyanin
Omega 3 Fatty Acids	Fish oil, Walnuts

Rich Polyphenols	Cocoa, Olive oil, green Tea
Natural Supplements	Vit D, Curcumin, Resveratrol, Omega 3

Approaches to Reduction

- **Antioxidants**: A diet rich in antioxidants (vitamin C, E, and polyphenols) has shown potential in reducing oxidative stress. These compounds neutralize free radicals, thereby protecting cells from oxidative damage.
- **Anti-inflammatory Agents**: Drugs such as metformin and thiazolidinediones (TZDs) have anti-inflammatory effects. Metformin, for instance, reduces the production of ROS and modulates inflammatory cytokines.
- **Lifestyle Modifications**: Regular physical activity and weight loss can significantly lower both oxidative stress and inflammatory markers in T2DM patients.
- **Natural Supplements**: Compounds like curcumin, resveratrol, and omega-3 fatty acids have demonstrated the ability to reduce inflammation and oxidative stress, offering additional therapeutic options.

6. Lifestyle and Nutritional Integration for Diabetes Reversal

6.1. Combined Effect of Diet, Exercise, and Weight Management

Recent narrative reviews in the Malaysian population demonstrate that fasting modalities such as intermittent fasting (IF), time-restricted eating (TRE), and fasting-mimicking diets (FMD) significantly complement dietary interventions in achieving T2DM remission. Fasting boosts insulin sensitivity, enhances β-cell regeneration, and reduces hepatic fat accumulation. In addition, combining fasting with plant-based and Mediterranean diets amplifies adiponectin secretion and promotes metabolic flexibility mechanisms that are central to long-term diabetes reversal. A balanced and individualized diet, focusing on nutrient-rich foods and maintaining healthy blood sugar levels, is key for managing T2DM [63-67]. The combined effect of diet on T2DM involves several factors:

Carbohydrate Quality and Quantity: Emphasis on low glycemic index (GI) foods, such as whole grains, legumes, and non-starchy vegetables, helps stabilize blood sugar levels.

Dietary Fiber: High fiber intake from sources like fruits, vegetables, and whole grains has been shown to improve insulin sensitivity and regulate blood sugar levels by slowing down carbohydrate digestion and absorption.

Healthy Fats: Consuming unsaturated fats from sources like olive oil, nuts, and fatty fish can help reduce inflammation and improve insulin sensitivity.

Protein Intake: Adequate protein intake supports muscle mass and helps control appetite.

Weight Management: Diets aimed at achieving or maintaining a healthy weight, such as those with moderate caloric restriction, have shown to improve insulin sensitivity and reduce the risk of complications associated with T2DM. Improved blood glucose control, reduced need for medications, and lower risk of cardiovascular diseases.

Meal Timing and Frequency: Regular meal patterns with balanced macronutrients can help in better glucose control. Some research suggests that smaller, more frequent meals can prevent large fluctuations in blood glucose.

Exercise Frequency: At least 150 minutes of moderate-intensity aerobic exercise or 75 minutes of vigorous exercise per week, combined with strength training exercises at least twice a week.

6.2. Behavioral and Cultural Influences on Dietary Adherence

Islamic fasting practices, including Ramadan fasting and voluntary puasa sunat, are deeply rooted in Malaysia cultural and spiritual traditions. Integrating these practices within diabetes nutritional therapy has demonstrated improved adherence and patient satisfaction. Aligning dietary recommendations with religious fasting cycles and Malay health philosophies (seimbang and berpantang) enhances long-term compliance and holistic well-being.

Knowledge and Education: Lack of knowledge about nutrition and the impact of certain foods on blood sugar levels can impede adherence. Education programs that focus on practical, easy-to-understand information are crucial for improving dietary compliance [68].

Social Support: In some cultures, family plays a significant role in food preparation and eating. Positive family support can reinforce adherence to healthy eating patterns, whereas family traditions and pressure to maintain cultural eating habits may undermine adherence [69].

Asian cultural traditions impact dietary choices and the challenges faced by Asian communities in adhering to Western dietary guidelines for diabetes management. It provides culturally appropriate strategies for improving adherence [70]. The influence of food preferences, family traditions, and community practices in managing T2DM in various cultural groups. It offers insights into integrating cultural values into diabetes care and dietary [71]. The effectiveness of different behavioral interventions, such as cognitive-behavioral therapy and self-monitoring, in improving dietary adherence in individuals with T2D [72].

6.3. Personalized Nutrition and Nutrigenomic Perspectives

Personalized fasting protocols tailored through nutrigenomic profiling could optimize outcomes among obese diabetics. Studies highlight that TRE or IF regimens adapted to individual circadian rhythms and genetic predispositions yield better glycemic and lipid control compared to uniform caloric restriction models. The integration of fasting-responsive genes such as AMPK and SIRT1 may open new frontiers in precision nutritional medicine for T2DM management.

A growing body of research suggests that by combining genetic information with dietary interventions, healthcare professionals can provide more effective, individualized treatment plans for managing T2DM [73-81]. Precision nutrition in T2DM, therefore, holds promise in helping to prevent the onset of diabetes or delay its progression, improve patient adherence to dietary regimens, and enhance metabolic health.

7. Public Health Implications and Preventive Strategies

From a public health perspective, structured fasting interventions should be recognized as viable adjuncts to nutrition-based preventive programs. National diabetes guidelines in Malaysia could include physician-supervised TRE and Ramadan-based fasting education, emphasizing safe fasting for stable T2DM patients. Culturally grounded health literacy campaigns, integrating

Islamic and biomedical narratives, have shown improved engagement and metabolic results, suggesting strong potential for policy inclusion. The condition is associated with significant morbidity and mortality, contributing to an increased risk of heart disease, kidney failure, stroke, and neuropathy [82-86].

- Lifestyle Modification
- Screening and Early Detection
- Community-Based Programs
- Pharmacological Interventions
- Environmental Changes

7.1. Community-Based Nutritional Education

Community-based nutritional education plays a pivotal role in the prevention and management of T2DM. It involves structured interventions delivered within community settings such as schools, workplaces, community centers, and primary healthcare facilities to promote healthier eating habits and improve diabetes-related outcomes. Nutrition education provides the following key benefits for individuals with or at risk of T2DM, contributing to improved metabolic outcomes and sustainable lifestyle changes:

Improved Glycemic Control: Nutritional education helps individuals with T2DM understand carbohydrate counting, portion control, and the glycemic index, leading to better blood glucose regulation [87].

Increased Awareness: It raises awareness about diabetes-friendly diets and debunks common dietary myths prevalent in local communities.

Cost-Effectiveness: Such interventions are relatively low-cost and can be scaled to reach large populations, especially in resource-limited settings [88].

Cultural Relevance: Community-based programs can be tailored to cultural food practices and literacy levels, increasing acceptance and long-term adherence [89].

The Diabetes Prevention Program (DPP) in the U.S. showed that lifestyle changes, including dietary education, reduced T2DM incidence by 58% in high-risk individuals [90].

The FINDRISC-based intervention in Finland successfully used community settings to reduce risk factors for T2DM through lifestyle changes, including nutrition education [91].

7.2. Policy and Dietary Guidelines for Diabetes Prevention

Malaysia dietary and fasting practices offer a culturally congruent model for integrating religious, behavioral, and nutritional strategies in national diabetes policy frameworks. This dual approach supports WHO directive on culturally adaptive health interventions and aligns with public health sustainability objectives by reducing pharmacotherapy burden and improving life quality.

7.2.1. Health Promotion Policies

Health promotion policies play a pivotal role in shaping population-level behaviors and environments conducive to the prevention of T2DM

- Policies that focus on reducing the intake of unhealthy foods, especially sugar-sweetened beverages and high-fat foods, can have a significant impact on T2DM prevention.
- Taxation on sugary drinks and junk food, as seen in countries like Mexico and Hungary, has been linked to reduced consumption and improved public health outcomes [92].
- Urban planning policies that promote physical activity, such as the development of pedestrian-friendly environments and public spaces, are critical in preventing T2DM [93].

7.2.2. Food Labeling and Regulation

Clear nutritional labeling and regulation of food marketing especially to children help consumers make informed decisions about their diets. The implementation of front-of-package labeling in countries like Chile and the U.K. has shown positive effects on reducing unhealthy eating habits [94].

7.2.3. Subsidies for Healthy Foods

Government subsidies for fruits, vegetables, and whole grains can help lower the price of nutritious food and increase accessibility, especially for low-income populations [95].

7.2.4. Dietary Guidelines for Diabetes Prevention

Dietary modification remains a cornerstone strategy in the prevention of T2DM, as it directly influences glucose metabolism, insulin sensitivity, and overall metabolic health.

Balanced Diet: A diet rich in whole grains, vegetables, fruits, lean proteins, and healthy fats (like those from nuts and olive oil) is key in preventing T2DM. The Mediterranean diet has been particularly recommended for its positive effects on blood glucose regulation and weight management [96].

Limiting Refined Carbohydrates and Sugars: Reducing intake of refined sugars, sugary beverages, and foods with high glycemic indices helps maintain stable blood glucose levels and reduces insulin resistance [97].

Portion Control and Caloric Intake: Maintaining a healthy weight through portion control and managing caloric intake is essential. Guidelines recommend reducing overall calorie consumption for individuals at risk for T2DM [98].

Regular Meals and Balanced Macronutrients: Encouraging regular meal patterns (e.g., three balanced meals and healthy snacks) helps manage blood sugar levels and prevent overeating.

7.2.5. Global and National Guidelines

Several international and national health authorities have established dietary guidelines aimed at reducing the global burden of T2DM.

World Health Organization (WHO): The WHO recommends a healthy diet for the prevention of T2DM that includes high fiber foods, reduced intake of free sugars, and limited consumption of fats (WHO, 2020).

American Diabetes Association (ADA): The ADA emphasizes a healthy eating plan that includes whole grains, low-fat dairy, lean meats, and a variety of vegetables. The ADA also advocates for

portion control and mindful eating as strategies for managing weight and preventing T2DM (ADA, 2020).

European Food Safety Authority (EFSA): EFSA guidelines emphasize the need for reducing sugar and fat intake, advocating for diets that promote a healthy weight and improve insulin sensitivity (EFSA, 2010).

7.2.6. Effectiveness of Policies and Guidelines

Evidence suggests that policies aimed at improving food environments and promoting healthier diets can lead to reduced T2DM risk in the population. For instance, the **Finland Diabetes Prevention Program (DPS)**, which incorporated both dietary changes and physical activity, showed a 58% reduction in the incidence of T2DM among participants at high risk [99].

Government-led policies, including the introduction of "sugar taxes" and nutritional education, have been effective in lowering the consumption of unhealthy foods and reducing obesity, a key risk factor for T2DM (Cawley & Frisvold, 2015).

7.3. Future Directions in Nutrition-Based Diabetes Management

The management of diabetes through nutrition is evolving rapidly, as emerging research highlights the importance of individualized dietary interventions. Future directions in nutrition-based diabetes management focus on precision nutrition, novel dietary patterns, and advanced technologies for personalized care.

Personalized Nutrition: Advances in genomics and metabolomics are paving the way for tailored dietary strategies based on genetic, microbiome, and metabolic profiles. Precision nutrition aims to optimize glycemic control by identifying how individuals respond to different foods [100].

Plant-Based Diets: The growing body of evidence suggests that plant-based diets, rich in fiber, antioxidants, and low in saturated fats, can improve insulin sensitivity and reduce inflammation, making them a promising strategy for managing diabetes [101].

Low-Carb and Ketogenic Diets: These diets have gained attention for their potential to improve blood glucose control and weight loss in Type 2 diabetes. Research suggests that lower carbohydrate intake may help reduce reliance on medications [102].

Gut Microbiome and Diet: Increasing attention is being paid to the role of the gut microbiome in diabetes. Studies suggest that gut health plays a critical role in blood sugar regulation, and dietary interventions may help modulate the microbiome to improve outcomes in diabetes [103].

Use of Digital Health Tools: Mobile apps, wearable devices, and continuous glucose monitoring (CGM) systems allow for real-time tracking of blood glucose levels and food intake. These technologies help patients make data-driven decisions to manage diabetes more effectively [104].

Intermittent Fasting and Time-Restricted Eating: Emerging research shows that intermittent fasting and time-restricted eating may improve insulin sensitivity and promote weight loss, offering new avenues for diabetes management [105].

8. Conclusion

Nutrition plays an indispensable role in both the prevention and management of T2DM. A carefully planned, balanced diet, rich in whole foods and focused on managing carbohydrate intake, fiber, and healthy fats, is essential in regulating blood glucose levels, enhancing insulin sensitivity, and preventing complications associated with the disease.

In particular, diets emphasizing whole grains, high-fiber foods, plant-based options, and healthy fats contribute to improved metabolic health and better long-term diabetes control. Alongside weight management, a tailored approach to meal timing and nutrient intake offers additional benefits in controlling insulin resistance. The growing evidence supporting dietary strategies such as low glycemic index foods, plant-based eating, and intermittent fasting demonstrates the potential for nutrition to not only prevent the onset of T2DM but also significantly improve the outcomes for those already diagnosed.

As research continues to evolve, personalized nutrition approaches considering factors like genetics, gut microbiome, and individual preferences will play an increasingly important role in

optimizing diabetes management. By prioritizing nutrition as part of a comprehensive lifestyle intervention, individuals with or at risk for T2D can achieve better health outcomes, reduce medication reliance, and improve overall quality of life.

In conclusion, nutrition is a cornerstone in both preventing and managing Type 2 diabetes, offering an effective, sustainable, and cost-efficient strategy for combating one of the most prevalent chronic conditions of our time.

Reference

1. Kumar, Arvind, et al. "Prevalence of Diabetes in India: A Review of IDF Diabetes Atlas 10th Edition." *Current Diabetes Reviews*, vol. 19, no. 10.2174/1573399819666230413094200, 13 Apr. 2023, https://doi.org/10.2174/1573399819666230413094200.
2. Europe PMC. "Europe PMC." *Europepmc.org*, 2016, europepmc.org/article/nbk/nbk581934?utm_medium=email&utm_source=transaction&client=bot.
3. Henley, S, et al. "Centers for Disease Control & Prevention (CDC) Vital Signs." *Mortality Weekly Report*, vol. 65, no. 44, 2016, pp. 1212–1218,
4. Parker, Emily D, et al. "Economic Costs of Diabetes in the U.S. In 2022." *Diabetes Care*, vol. 47, no. 1, 1 Nov. 2023, diabetesjournals.org/care/article/47/1/26/153797/Economic-Costs-of-Diabetes-in-the-U-S-in-2022, https://doi.org/10.2337/dci23-0085.
5. Saeedi, Pouya, et al. "Global and Regional Diabetes Prevalence Estimates for 2019 and Projections for 2030 and 2045: Results from the International Diabetes Federation Diabetes Atlas, 9th Edition." *Diabetes Research and Clinical Practice*, vol. 157, no. 157, 10 Sept. 2019, p. 107843, https://doi.org/10.1016/j.diabres.2019.107843.
6. DeFronzo, R. A., and D. Tripathy. "Skeletal Muscle Insulin Resistance Is the Primary Defect in Type 2 Diabetes." *Diabetes Care*, vol. 32, no. suppl_2, 29 Oct. 2009, pp. S157–S163, https://doi.org/10.2337/dc09-s302.
7. Freeman, Andrew M, and Nicholas Pennings. "Insulin Resistance." *Nih.gov*, StatPearls Publishing, 17 Aug. 2023, www.ncbi.nlm.nih.gov/books/NBK507839/.

8. Boden, G., and G. I. Shulman. "Free Fatty Acids in Obesity and Type 2 Diabetes: Defining Their Role in the Development of Insulin Resistance and β-Cell Dysfunction." *European Journal of Clinical Investigation*, vol. 32, no. 3, 16 May 2002, pp. 14–23, https://doi.org/10.1046/j.1365-2362.32.s3.3.x.
9. Grundy, Scott M., et al. "Diagnosis and Management of the Metabolic Syndrome." *Circulation*, vol. 112, no. 17, 25 Oct. 2005, pp. 2735–2752, https://doi.org/10.1161/circulationaha.105.169404.
10. Calder, Philip C. "Functional Roles of Fatty Acids and Their Effects on Human Health." *JPEN. Journal of Parenteral and Enteral Nutrition*, vol. 39, no. 1 Suppl, 2015, pp. 18S32S, https://doi.org/10.1177/0148607115595980.
11. Byers, Tim. "The Role of Nutrition and Nutrients in the Prevention of Chronic Diseases." *Primary Care: Clinics in Office Practice*, vol. 29, no. 3, Sept. 2002, pp. 615–627, https://doi.org/10.1016/s0095-4543(02)00007-6.
12. Byrd-Bredbenner, Carol, et al. "Satisfying America's Fruit Gap: Summary of an Expert Roundtable on the Role of 100% Fruit Juice." *Journal of Food Science*, vol. 82, no. 7, 6 June 2017, pp. 1523–1534, https://doi.org/10.1111/1750-3841.13754. Accessed 29 May 2019.
13. Brand-Miller, J., et al. "Low-Glycemic index Index Diets in the Management of Diabetes: A Meta-Analysis of Randomized Controlled Trials." *Diabetes Care*, vol. 26, no. 8, 25 July 2003, pp. 2261–2267, diabetesjournals.org/care/article/26/8/2261/22776/Low-Glycemic index-Index-Diets-in-the-Management-of, https://doi.org/10.2337/diacare.26.8.2261.
14. Berger, Samantha E., et al. "Change in Cardiometabolic Risk Factors Associated with Magnitude of Weight Regain 3 Years after a 1-Year Intensive Lifestyle Intervention in Type 2 Diabetes Mellitus: The Look AHEAD Trial." *Journal of the American Heart Association*, vol. 8, no. 20, 15 Oct. 2019, https://doi.org/10.1161/jaha.118.010951.
15. Miller, Michael, et al. "Triglycerides and Cardiovascular Disease: A Scientific Statement from the American Heart Association." *Circulation*, vol. 123, no. 20, 2011, pp. 2292–333, www.ncbi.nlm.nih.gov/pubmed/21502576, https://doi.org/10.1161/CIR.0b013e3182160726.
16. Siam, Nawfal Hasan, et al. "Diabetes Mellitus and Cardiovascular Disease: Exploring Epidemiology, Pathophysiology, and Treatment Strategies." *Reviews in Cardiovascular Medicine*, vol. 25, no. 12, 11 Dec. 2024, https://doi.org/10.31083/j.rcm2512436.

17. Shai, Iris, et al. "Weight Loss with a Low-Carbohydrate, Mediterranean, or Low-Fat Diet." *The New England Journal of Medicine*, vol. 359, no. 3, 17 July 2008, pp. 229–41, www.ncbi.nlm.nih.gov/pubmed/18635428, https://doi.org/10.1056/NEJMoa0708681.
18. Barbagallo, Mario, et al. "Magnesium in Aging, Health and Diseases." *Nutrients*, vol. 13, no. 2, 30 Jan. 2021, p. 463, https://doi.org/10.3390/nu13020463.
19. Yamauchi, T., et al. "Adiponectin Stimulates Glucose Utilization and Fatty-Acid Oxidation by Activating AMP-Activated Protein Kinase." *Nature Medicine*, vol. 8, no. 11, 7 Oct. 2002, pp. 1288–1295, https://doi.org/10.1038/nm788.
20. Fruebis, J., et al. "Proteolytic Cleavage Product of 30-KDa Adipocyte Complement-Related Protein Increases Fatty Acid Oxidation in Muscle and Causes Weight Loss in Mice." *Proceedings of the National Academy of Sciences*, vol. 98, no. 4, 13 Feb. 2001, pp. 2005–2010, https://doi.org/10.1073/pnas.98.4.2005.
21. Abu-Elheiga, L. "Continuous Fatty Acid Oxidation and Reduced Fat Storage in Mice Lacking Acetyl-CoA Carboxylase 2." *Science*, vol. 291, no. 5513, 30 Mar. 2001, pp. 2613–2616, https://doi.org/10.1126/science.1056843. Accessed 8 May 2020.
22. Miyamoto, Licht. "Significance of 5'AMP-Activated Protein Kinase in Metabolomic Regulation by Skeletal Muscle Contraction." *The Journal of Physical Fitness and Sports Medicine*, vol. 4, no. 1, 2015, pp. 93–102, https://doi.org/10.7600/jpfsm.4.93. Accessed 19 Nov. 2019.
23. Wu, Xiang-Dong, et al. "Involvement of AMP-Activated Protein Kinase in Glucose Uptake Stimulated by the Globular Domain of Adiponectin in Primary Rat Adipocytes." *Diabetes*, vol. 52, no. 6, 1 June 2003, pp. 1355–1363, https://doi.org/10.2337/diabetes.52.6.1355. Accessed 2 May 2023.
24. Arita, Y, et al. "Paradoxical Decrease of an Adipose-Specific Protein, Adiponectin, in Obesity." *Biochemical and Biophysical Research Communications*, vol. 257, no. 1, 1999, pp. 79–83, www.ncbi.nlm.nih.gov/pubmed/10092513, https://doi.org/10.1006/bbrc.1999.0255.
25. Maeda, Kazuhisa, et al. "Adipocyte/Macrophage Fatty Acid Binding Proteins Control Integrated Metabolic Responses in Obesity and Diabetes." *Cell Metabolism*, vol. 1, no. 2, Feb. 2005, pp. 107–119, https://doi.org/10.1016/j.cmet.2004.12.008. Accessed 24 Jan. 2020.

26. Hardie, D. Grahame, et al. "THE AMP-ACTIVATED/SNF1 PROTEIN KINASE SUBFAMILY: Metabolic Sensors of the Eukaryotic Cell?" *Annual Review of Biochemistry*, vol. 67, no. 1, June 1998, pp. 821–855, https://doi.org/10.1146/annurev.biochem.67.1.821. Accessed 7 Feb. 2022.
27. Matsuzawa, Yuji. "Adiponectin: A Key Player in Obesity Related Disorders." *Current Pharmaceutical Design*, vol. 16, no. 17, 1 June 2010, pp. 1896–1901, https://doi.org/10.2174/138161210791208893. Accessed 5 Dec. 2019.
28. Han, Seung Hwan, et al. "Adiponectin and Cardiovascular Disease." *Journal of the American College of Cardiology*, vol. 49, no. 5, Feb. 2007, pp. 531–538, www.sciencedirect.com/science/article/pii/S0735109706028622, https://doi.org/10.1016/j.jacc.2006.08.061. Accessed 21 Jan. 2020.
29. Fragopoulou, Elizabeth, et al. "The Association between Adherence to the Mediterranean Diet and Adiponectin Levels among Healthy Adults: The ATTICA Study." *The Journal of Nutritional Biochemistry*, vol. 21, no. 4, Apr. 2010, pp. 285–289, https://doi.org/10.1016/j.jnutbio.2008.12.013. Accessed 22 Oct. 2020.
30. Esposito, Katherine, et al. "Effect of a Mediterranean-Style Diet on Endothelial Dysfunction and Markers of Vascular Inflammation in the Metabolic Syndrome." *JAMA*, vol. 292, no. 12, 22 Sept. 2004, p. 1440, jamanetwork.com/journals/jama/fullarticle/199488, https://doi.org/10.1001/jama.292.12.1440.
31. Satija, Ambika, and Frank B. Hu. "Plant-Based Diets and Cardiovascular Health." *Trends in Cardiovascular Medicine*, vol. 28, no. 7, Oct. 2018, pp. 437–441, www.sciencedirect.com/science/article/pii/S1050173818300240?via%3Dihub, https://doi.org/10.1016/j.tcm.2018.02.004.
32. Dinu, Monica, et al. "Vegetarian, Vegan Diets and Multiple Health Outcomes: A Systematic Review with Meta-Analysis of Observational Studies." *Critical Reviews in Food Science and Nutrition*, vol. 57, no. 17, 6 Feb. 2016, pp. 3640–3649, www.tandfonline.com/doi/full/10.1080/10408398.2016.1138447, https://doi.org/10.1080/10408398.2016.1138447.

33. Tuso, Philip, et al. "Nutritional Update for Physicians: Plant-Based Diets." *The Permanente Journal*, vol. 17, no. 2, 2013, pp. 61–66. *NCBI*, www.ncbi.nlm.nih.gov/pmc/articles/PMC3662288/, https://doi.org/10.7812/tpp/12-085.

34. Estruch, Ramón, et al. "Primary Prevention of Cardiovascular Disease with a Mediterranean Diet Supplemented with Extra-Virgin Olive Oil or Nuts." *New England Journal of Medicine*, vol. 378, no. 25, 21 June 2018, p. e34, www.nejm.org/doi/10.1056/NEJMoa1800389?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%20%200www.ncbi.nlm.nih.gov, https://doi.org/10.1056/NEJMoa1800389.

35. F, Sofi, et al. "Adherence to Mediterranean Diet and Health Status: Meta-Analysis." *BMJ (Clinical Research Ed.)*, 11 Sept. 2008, pubmed.ncbi.nlm.nih.gov/18786971/.

36. Sd, Petersson, and Philippou E. "Mediterranean Diet, Cognitive Function, and Dementia: A Systematic Review of the Evidence." *Advances in Nutrition (Bethesda, Md.)*, 15 Sept. 2016, pubmed.ncbi.nlm.nih.gov/27633105/.

37. Jenkins, David J. A., et al. "Effect of a Low–Glycemic index Index or a High–Cereal Fiber Diet on Type 2 Diabetes." *JAMA*, vol. 300, no. 23, 17 Dec. 2008, p. 2742, https://doi.org/10.1001/jama.2008.808.

38. Micha, Renata, et al. "Association between Dietary Factors and Mortality from Heart Disease, Stroke, and Type 2 Diabetes in the United States." *JAMA*, vol. 317, no. 9, 7 Mar. 2017, p. 912, jamanetwork.com/journals/jama/fullarticle/2608221, https://doi.org/10.1001/jama.2017.0947.

39. Rice Bradley, Beth H. "Dietary Fat and Risk for Type 2 Diabetes: A Review of Recent Research." *Current Nutrition Reports*, vol. 7, no. 4, 2018, pp. 214–226, www.ncbi.nlm.nih.gov/pmc/articles/PMC6244743/, https://doi.org/10.1007/s13668-018-0244-z.

40. Evert, Alison B., et al. "Nutrition Therapy for Adults with Diabetes or Prediabetes: A Consensus Report." *Diabetes Care*, vol. 42, no. 5, 15 Apr. 2019, pp. 731–754, care.diabetesjournals.org/content/42/5/731, https://doi.org/10.2337/dci19-0014.

41. Basu, Arpita, et al. "Blueberries Decrease Cardiovascular Risk Factors in Obese Men and Women with Metabolic Syndrome." *The Journal of Nutrition*, vol. 140, no. 9, 21 July 2010, pp. 1582–1587, https://doi.org/10.3945/jn.110.124701.

42. Barbagallo, Mario. "Magnesium and Type 2 Diabetes." *World Journal of Diabetes*, vol. 6, no. 10, 2015, p. 1152, www.ncbi.nlm.nih.gov/pmc/articles/PMC4549665/, https://doi.org/10.4239/wjd.v6.i10.1152.
43. Palomer, X., et al. "Role of Vitamin D in the Pathogenesis of Type 2 Diabetes Mellitus." *Diabetes, Obesity and Metabolism*, vol. 10, no. 3, Mar. 2008, pp. 185–197, https://doi.org/10.1111/j.1463-1326.2007.00710.x.
44. Gantenbein, Katherina V., and Christina Kanaka-Gantenbein. "Mediterranean Diet as an Antioxidant: The Impact on Metabolic Health and Overall Wellbeing." *Nutrients*, vol. 13, no. 6, 6 June 2021, p. 1951, https://doi.org/10.3390/nu13061951.
45. Clemente-Suárez, Vicente Javier, et al. "Functional and Therapeutic Roles of Plant-Derived Antioxidants in Type 2 Diabetes Mellitus: Mechanisms, Challenges, and Considerations for Special Populations." *Antioxidants*, vol. 14, no. 6, 13 June 2025, p. 725, www.mdpi.com/2076-3921/14/6/725, https://doi.org/10.3390/antiox14060725. Accessed 15 Oct. 2025.
46. Ayesha, Ismat E, et al. "Probiotics and Their Role in the Management of Type 2 Diabetes Mellitus (Short-Term versus Long-Term Effect): A Systematic Review and Meta-Analysis." *Cureus*, vol. 15, no. 10, 9 Oct. 2023, www.ncbi.nlm.nih.gov/pmc/articles/PMC10631563/, https://doi.org/10.7759/cureus.46741.
47. Craciun, Cristian-Ioan, et al. "The Relationships between Gut Microbiota and Diabetes Mellitus, and Treatments for Diabetes Mellitus." *Biomedicines*, vol. 10, no. 2, 28 Jan. 2022, p. 308, https://doi.org/10.3390/biomedicines10020308.
48. Nguyen, Thi Mong Diep. "Adiponectin: Role in Physiology and Pathophysiology." *International Journal of Preventive Medicine*, vol. 11, no. 1, 3 Sept. 2020, www.ncbi.nlm.nih.gov/pmc/articles/PMC7554603/#:~:text=Adiponectin%2C%20an%20adipokine%20secreted%20by, https://doi.org/10.4103/ijpvm.IJPVM_193_20.
49. Baldelli, Sara, et al. "The Role of Adipose Tissue and Nutrition in the Regulation of Adiponectin." *Nutrients*, vol. 16, no. 15, 26 July 2024, pp. 2436–2436, www.mdpi.com/2072-6643/16/15/2436, https://doi.org/10.3390/nu16152436.
50. LeRoith, Derek. "β-Cell Dysfunction and Insulin Resistance in Type 2 Diabetes: Role of Metabolic and Genetic Abnormalities." *The American Journal of Medicine*, vol. 113, no. 6, Oct. 2002, pp. 3–11, https://doi.org/10.1016/s0002-9343(02)01276-7.

51. Li, Leah, et al. "Body Mass Index throughout the Life-Course and Blood Pressure in Mid-Adult Life: A Birth Cohort Study." *Journal of Hypertension*, vol. 25, no. 6, June 2007, pp. 1215–1223, https://doi.org/10.1097/hjh.0b013e3280f3c01a. Accessed 8 Nov. 2019.
52. Torloni, M. R., et al. "Prepregnancy BMI and the Risk of Gestational Diabetes: A Systematic Review of the Literature with Meta-Analysis." *Obesity Reviews*, vol. 10, no. 2, Mar. 2009, pp. 194–203, https://doi.org/10.1111/j.1467-789x.2008.00541.x.
53. Reas, Deborah L, et al. "Changes in Body Mass Index by Age, Gender, and Socio-Economic Status among a Cohort of Norwegian Men and Women (1990–2001)." *BMC Public Health*, vol. 7, no. 1, 30 Sept. 2007, bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-7-269, https://doi.org/10.1186/1471-2458-7-269. Accessed 25 Oct. 2019.
54. Mishra, Gita D., et al. "Short-Term Weight Change and the Incidence of Diabetes in Midlife." *Diabetes Care*, vol. 30, no. 6, 1 June 2007, pp. 1418–1424, https://doi.org/10.2337/dc06-2187. Accessed 6 June 2022.
55. Maritim, A. C., et al. "Diabetes, Oxidative Stress, and Antioxidants: A Review." *Journal of Biochemical and Molecular Toxicology*, vol. 17, no. 1, 2003, pp. 24–38, onlinelibrary.wiley.com/doi/abs/10.1002/jbt.10058, https://doi.org/10.1002/jbt.10058.
56. Kahn, Steven E, et al. "Pathophysiology and Treatment of Type 2 Diabetes: Perspectives on the Past, Present, and Future." *The Lancet*, vol. 383, no. 9922, Mar. 2014, pp. 1068–1083, pubmed.ncbi.nlm.nih.gov/24315620/, https://doi.org/10.1016/s0140-6736(13)62154-6.
57. Wright, E., et al. "Oxidative Stress in Type 2 Diabetes: The Role of Fasting and Postprandial Glycaemia." *International Journal of Clinical Practice*, vol. 60, no. 3, 22 Feb. 2006, pp. 308–314, www.ncbi.nlm.nih.gov/pmc/articles/PMC1448694/, https://doi.org/10.1111/j.1368-5031.2006.00825.x.
58. Al-Mansoori, Layla, et al. "Role of Inflammatory Cytokines, Growth Factors and Adipokines in Adipogenesis and Insulin Resistance." *Inflammation*, vol. 45, no. 1, 18 Sept. 2021, https://doi.org/10.1007/s10753-021-01559-z.
59. Pillarisetti, Sivaram, and Uday Saxena. "Role of Oxidative Stress and Inflammation in the Origin of Type 2 Diabetes – a Paradigm Shift." *Expert Opinion on Therapeutic Targets*, vol. 8, no. 5, Oct. 2004, pp. 401–408, https://doi.org/10.1517/14728222.8.5.401. Accessed 13 Sept. 2021.

60. Fatima, Munazza Tamkeen, et al. "The Role of Dietary Antioxidants in Type 2 Diabetes and Neurodegenerative Disorders: An Assessment of the Benefit Profile." *Heliyon*, vol. 9, no. 1, Jan. 2023, p. e12698, https://doi.org/10.1016/j.heliyon.2022.e12698.
61. Shoelson, S. E. "Inflammation and Insulin Resistance." *Journal of Clinical Investigation*, vol. 116, no. 7, 3 July 2006, pp. 1793–1801, www.ncbi.nlm.nih.gov/pmc/articles/PMC1483173/, https://doi.org/10.1172/jci29069.
62. Sibony, Roni Weinberg, et al. "Overview of Oxidative Stress and Inflammation in Diabetes." *Journal of Diabetes*, vol. 16, no. 10, 1 Oct. 2024, https://doi.org/10.1111/1753-0407.70014.
63. ElSayed, Nuha A., et al. "Classification and Diagnosis of Diabetes: Standards of Care in Diabetes." *Diabetes Care*, vol. 46, no. Supplement_1, 2022, pp. S19–S40, pubmed.ncbi.nlm.nih.gov/36507649/, https://doi.org/10.2337/dc23-s002.
64. Franz, Marion J., et al. "Academy of Nutrition and Dietetics Nutrition Practice Guideline for Type 1 and Type 2 Diabetes in Adults: Systematic Review of Evidence for Medical Nutrition Therapy Effectiveness and Recommendations for Integration into the Nutrition Care Process." *Journal of the Academy of Nutrition and Dietetics*, vol. 117, no. 10, Oct. 2017, pp. 1659–1679, https://doi.org/10.1016/j.jand.2017.03.022.
65. Hosseini, Fatemeh, et al. "Dietary Carbohydrate and the Risk of Type 2 Diabetes: An Updated Systematic Review and Dose–Response Meta-Analysis of Prospective Cohort Studies." *Scientific Reports*, vol. 12, no. 1, 15 Feb. 2022, https://doi.org/10.1038/s41598-022-06212-9.
66. Colberg, Sheri R., et al. "Physical Activity/Exercise and Diabetes: A Position Statement of the American Diabetes Association." *Diabetes Care*, vol. 39, no. 11, 2016, pp. 2065–2079, diabetesjournals.org/care/article/39/11/2065/37249/Physical-Activity-Exercise-and-Diabetes-A-Position, https://doi.org/10.2337/dc16-1728.
67. Amato, Angelica Amorim, et al. "Obesity and Endocrine Disrupting Chemicals." *Endocrine Connections*, vol. 10, no. 2, Jan. 2021, https://doi.org/10.1530/ec-20-0578.
68. American Diabetes Association. "Standards of Care in Diabetes—2023 Abridged for Primary Care Providers." *Clinical Diabetes*, vol. 41, no. 1, 2023, pp. 4–31, diabetesjournals.org/clinical/article/41/1/4/148029/Standards-of-Care-in-Diabetes-2023-Abridged-for, https://doi.org/10.2337/cd23-as01.

69. Li-Geng, Tony, et al. "Cultural Influences on Dietary Self-Management of Type 2 Diabetes in East Asian Americans: A Mixed-Methods Systematic Review." *Health Equity*, vol. 4, no. 1, 1 Mar. 2020, pp. 31–42, https://doi.org/10.1089/heq.2019.0087.

70. Glanz, Karen, and Donald B. Bishop. "The Role of Behavioral Science Theory in Development and Implementation of Public Health Interventions." *Annual Review of Public Health*, vol. 31, no. 1, Mar. 2010, pp. 399–418, www.annualreviews.org/content/journals/10.1146/annurev.publhealth.012809.103604, https://doi.org/10.1146/annurev.publhealth.012809.103604.

71. Iqbal, Sobia. "Cultural Factors Influencing the Eating Behaviours of Type 2 Diabetes in the British South-Asian Population: A Scoping Review of the Literature." *Journal of Global Health Reports*, vol. 7, no. 7, 27 July 2023, www.joghr.org/article/84191-cultural-factors-influencing-the-eating-behaviours-of-type-2-diabetes-in-the-british-south-asian-population-a-scoping-review-of-the-literature, https://doi.org/10.29392/001c.84191.

72. Rebolledo, Julio A., and Regina Arellano. "Cultural Differences and Considerations When Initiating Insulin." *Diabetes Spectrum*, vol. 29, no. 3, Aug. 2016, pp. 185–190, www.ncbi.nlm.nih.gov/pmc/articles/PMC5001223/, https://doi.org/10.2337/diaspect.29.3.185.

73. Kapellou, Angeliki, et al. "Gene–Diet Interactions in Diabetes Mellitus: Current Insights and the Potential of Personalized Nutrition." *Genes*, vol. 16, no. 5, 14 May 2025, p. 578, www.mdpi.com/2073-4425/16/5/578#B14-genes-16-00578, https://doi.org/10.3390/genes16050578.

74. Kassem, Neemat M, et al. "Nutrigenomics and Microbes Shaping the Future of Personalized Medicine: A Review Article." *Journal of Genetic Engineering and Biotechnology*, vol. 21, no. 1, 1 Dec. 2023, pp. 134–134, https://doi.org/10.1186/s43141-023-00599-2.

75. Dedoussis, George V.Z., et al. "Genes, Diet and Type 2 Diabetes Mellitus: A Review." *The Review of Diabetic Studies*, vol. 4, no. 1, 2007, pp. 13–13, https://doi.org/10.1900/rds.2007.4.13.

76. Mphasha, Mabitsela, and Tebogo Mothiba. "Personalised Nutrition Approaches in the Prevention and Management of Type 2 Diabetes: A Narrative Review of Evidence and Practice." *International Journal of Environmental Research and Public Health*, vol. 22, no. 7, 30 June 2025, p. 1047, https://doi.org/10.3390/ijerph22071047.

77. Nino-Fong, R., et al. "Nutrigenomics, β-Cell Function and Type 2 Diabetes." *Current Genomics*, vol. 8, no. 1, 1 Mar. 2007, pp. 29–42, pmc.ncbi.nlm.nih.gov/articles/PMC2474685/, https://doi.org/10.2174/138920207780076947. Accessed 21 Oct. 2025.

78. Kaput, Jim, et al. "Application of Nutrigenomic Concepts to Type 2 Diabetes Mellitus." *Nutrition, Metabolism and Cardiovascular Diseases*, vol. 17, no. 2, Feb. 2007, pp. 89–103, https://doi.org/10.1016/j.numecd.2006.11.006. Accessed 17 May 2021.

79. Arshad, Muhammad Tayyab, et al. "Personalized Nutrition in the Era of Digital Health: A New Frontier for Managing Diabetes and Obesity." *Food Science & Nutrition*, vol. 13, no. 10, 26 Sept. 2025, https://doi.org/10.1002/fsn3.71006.

80. Hu, Frank B., and Kothandaraman Narasimhan. "Nutritional Genomics and Metabolomics in Obesity and Type 2 Diabetes." *BMC Genomics*, vol. 15, no. S2, Apr. 2014, https://doi.org/10.1186/1471-2164-15-s2-o10. Accessed 10 Mar. 2019.

81. Guo, Yajie, et al. "The Role of Nutrition in the Prevention and Intervention of Type 2 Diabetes." *Frontiers in Bioengineering and Biotechnology*, vol. 8, no. 1, 15 Sept. 2020, www.ncbi.nlm.nih.gov/pmc/articles/PMC7523408/, https://doi.org/10.3389/fbioe.2020.575442.

82. American Diabetes Association. "Classification and Diagnosis of Diabetes: Standards of Medical Care in Diabetes—2022." *Diabetes Care*, vol. 45, no. Supplement_1, 2022, pp. S17–S38, diabetesjournals.org/care/article/45/Supplement_1/S17/138925/2-Classification-and-Diagnosis-of-Diabetes, https://doi.org/10.2337/dc22-s002.

83. Gyawali, Bishal, et al. "Community-Based Interventions for Prevention of Type 2 Diabetes in Low- and Middle-Income Countries: A Systematic Review." *Health Promotion International*, vol. 34, no. 6, 16 Oct. 2018, https://doi.org/10.1093/heapro/day081.

84. CDC. "National Diabetes Statistics Report, 2020 : Estimates of Diabetes and Its Burden in the United States." *Stacks.cdc.gov*, 2020, stacks.cdc.gov/view/cdc/85309.

85. Knowler, William C, et al. "Reduction in the Incidence of Type 2 Diabetes with Lifestyle Intervention or Metformin." *The New England Journal of Medicine*, vol. 346, no. 6, 7 Feb. 2002, pp. 393–403, https://doi.org/10.1056/NEJMoa012512.

86. World Health Organization. "Global Report on Diabetes." *Www.who.int*, 2016, www.who.int/publications/i/item/9789241565257.

87. Chrvala, Carole A., et al. "Diabetes Self-Management Education for Adults with Type 2 Diabetes Mellitus: A Systematic Review of the Effect on Glycemic index Control." *Patient Education and Counseling*, vol. 99, no. 6, June 2016, pp. 926–943, www.sciencedirect.com/science/article/pii/S0738399115301166, https://doi.org/10.1016/j.pec.2015.11.003.

88. Ali, Mohammed K., et al. "Diabetes: An Update on the Pandemic and Potential Solutions." *PubMed*, The International Bank for Reconstruction and Development / The World Bank, 2017, www.ncbi.nlm.nih.gov/books/NBK525150/.

89. Ruggiero, Laurie, et al. "Community-Based Translation of the Diabetes Prevention Program's Lifestyle Intervention in an Underserved Latino Population." *The Diabetes Educator*, vol. 37, no. 4, 20 June 2011, pp. 564–572, https://doi.org/10.1177/0145721711411107.

90. Herman, William H, et al. "The Cost-Effectiveness of Lifestyle Modification or Metformin in Preventing Type 2 Diabetes in Adults with Impaired Glucose Tolerance." *Annals of Internal Medicine*, vol. 142, no. 5, 2005, pp. 323–32, www.ncbi.nlm.nih.gov/pubmed/15738451, https://doi.org/10.7326/0003-4819-142-5-200503010-00007.

91. Lindstrom, J., et al. "The Finnish Diabetes Prevention Study (DPS): Lifestyle Intervention and 3-Year Results on Diet and Physical Activity." *Diabetes Care*, vol. 26, no. 12, 21 Nov. 2003, pp. 3230–3236, diabetesjournals.org/care/article/26/12/3230/21849/The-Finnish-Diabetes-Prevention-Study-DPS, https://doi.org/10.2337/diacare.26.12.3230.

92. Cawley, John, et al. "The Impact of Sugar-Sweetened Beverage Taxes on Purchases: Evidence from Four City-Level Taxes in the United States." *Health Economics*, vol. 29, no. 10, 28 July 2020, pp. 1289–1306, https://doi.org/10.1002/hec.4141.

93. Hyseni, Lirije, et al. "Systematic Review of Dietary Salt Reduction Policies: Evidence for an Effectiveness Hierarchy?" *PLOS ONE*, vol. 12, no. 5, 18 May 2017, p. e0177535, https://doi.org/10.1371/journal.pone.0177535.

94. Sun, Hong, et al. "IDF Diabetes Atlas: Global, Regional and Country-Level Diabetes Prevalence Estimates for 2021 and Projections for 2045." *Diabetes Research and Clinical Practice*, vol. 183, no. 109119, 2021, https://doi.org/10.1016/j.diabres.2021.109119.

95. Afshin, Ashkan, et al. "Health Effects of Dietary Risks in 195 Countries, 1990–2017: A Systematic Analysis for the Global Burden of Disease Study 2017." *The Lancet*, vol. 393, no.

10184, 3 Apr. 2019, pp. 1958–1972, www.thelancet.com/journals/lancet/article/PIIS0140-6736(19)30041-8/fulltext, https://doi.org/10.1016/s0140-6736(19)30041-8.

96. R, Estruch, et al. "Primary Prevention of Cardiovascular Disease with a Mediterranean Diet." *The New England Journal of Medicine*, 4 Apr. 2013, pubmed.ncbi.nlm.nih.gov/23432189/.

97. Barclay, Alan W, et al. "Glycemic index Index, Glycemic index Load, and Chronic Disease Risk—a Meta-Analysis of Observational Studies." *The American Journal of Clinical Nutrition*, vol. 87, no. 3, 1 Mar. 2008, pp. 627–637, academic.oup.com/ajcn/article/87/3/627/4633329, https://doi.org/10.1093/ajcn/87.3.627.

98. "Understanding Diabetes Diagnosis." *American Diabetes Association*, American Diabetes Association, 2023, diabetes.org/about-diabetes/diagnosis.

99. Uusitupa, Matti, et al. "The Finnish Diabetes Prevention Study." *British Journal of Nutrition*, vol. 83, no. S1, June 2000, pp. S137–S142, https://doi.org/10.1017/s0007114500001070.

100. de Toro-Martín, Juan, et al. "Precision Nutrition: A Review of Personalized Nutritional Approaches for the Prevention and Management of Metabolic Syndrome." *Nutrients*, vol. 9, no. 8, 22 Aug. 2017, p. 913, www.ncbi.nlm.nih.gov/pmc/articles/PMC5579706/, https://doi.org/10.3390/nu9080913.

101. Wang, Yeli, et al. "Associations between Plant-Based Dietary Patterns and Risks of Type 2 Diabetes, Cardiovascular Disease, Cancer, and Mortality - a Systematic Review and Meta-Analysis." *Nutrition Journal*, vol. 22, no. 1, 4 Oct. 2023, p. 46, pubmed.ncbi.nlm.nih.gov/37789346/, https://doi.org/10.1186/s12937-023-00877-2.

102. Wheatley, Sean D., et al. "Low Carbohydrate Dietary Approaches for People with Type 2 Diabetes—a Narrative Review." *Frontiers in Nutrition*, vol. 8, no. 8, 15 July 2021, www.ncbi.nlm.nih.gov/pmc/articles/PMC8319397/, https://doi.org/10.3389/fnut.2021.687658.

103. Hills, Ronald D., et al. "Gut Microbes: Profound Implications for Diet and Disease." *Nutrients*, vol. 11, no. 7, 16 July 2019, p. 1613, www.ncbi.nlm.nih.gov/pmc/articles/PMC6682904/, https://doi.org/10.3390/nu11071613.

104. Cahn, Avivit, et al. "Digital Health Technology and Diabetes Management." *Journal of Diabetes*, vol. 10, no. 1, 6 Nov. 2017, pp. 10–17, onlinelibrary.wiley.com/doi/full/10.1111/1753-0407.12606, https://doi.org/10.1111/1753-0407.12606.

105.Longo, Valter D, and Satchidananda Panda. "Fasting, Circadian Rhythms, and Time-Restricted Feeding in Healthy Lifespan." *Cell Metabolism*, vol. 23, no. 6, 2016, pp. 1048–1059, https://doi.org/10.1016/j.cmet.2016.06.001.