Research in Health Science
ISSN 2470-6205 (Print) ISSN 2470-6213 (Online)
Vol. 9, No. 4, 2024
www.scholink.org/ojs/index.php/rhs

Original Paper

The Impact of Dietary Patterns, Medications, and Physical Activity on Type 2 Diabetes: An In-depth Analysis Using NHANES 2017-2018 Data

Heng Zhang
University of Rochester, Rochester, New York 14627, USA

Received: October 22, 2024 Accepted: November 4, 2024 Online Published: November 19, 2024
doi:10.22158/rhs.v9n4p73 URL: http://dx.doi.org/10.22158/rhs.v9n4p73

Abstract
Type 2 Diabetes (T2D) is a significant global health concern with rising incidence, driven largely by modifiable lifestyle factors such as diet, physical activity, and medication adherence. Using data from the NHANES 2017-2018 cohort, this study analyzes the combined effects of these factors on T2D risk. Principal Component Analysis (PCA) was employed to identify key dietary patterns, which were assessed along with physical activity and medication adherence via logistic regression. A diet rich in fruits and vegetables was associated with a 40% reduction in T2D risk (Adjusted OR: 0.60; 95% CI: 0.39-0.92), particularly in women over 50. In contrast, diets high in sugary and processed foods increased the risk, especially in individuals with a BMI above 30 kg/m². These findings emphasize the need for tailored dietary and lifestyle interventions, specifically targeting high-risk groups such as older adults and individuals with higher BMI, to mitigate T2D risk.

Keywords
Type 2 Diabetes, Dietary Patterns, Physical Activity, Medicine

1. Introduction

Type 2 Diabetes (T2D) is a growing global health crisis, currently affecting approximately 462 million individuals worldwide, with increasing prevalence due to a variety of modifiable lifestyle factors. These factors, including diet, physical activity, and medication adherence, are widely recognized as crucial for both the prevention and management of T2D. The relationship between these factors and T2D risk has been extensively studied in the literature. For instance, diets rich in fruits, vegetables, and whole grains have been consistently associated with lower T2D risk, while diets high in refined sugars and processed foods have been linked to higher risk (Salas-Salvadó et al., 2011; Ley et al., 2014). Physical activity is also a well-established protective factor. Longitudinal studies such as the Diabetes Prevention Program (DPP) demonstrated that moderate physical activity can reduce the risk of T2D by as much as 58% (Knowler et al., 2002).

Several large-scale studies have confirmed the relationship between specific dietary patterns and T2D risk. The Mediterranean diet, characterized by high consumption of fruits, vegetables, whole grains, and healthy fats, has been linked to significant reductions in T2D incidence, as demonstrated by the PREDIMED study (Salas-Salvadó et al., 2011). Similarly, the EPIC-InterAct study found that a plant-based diet, low in processed foods and rich in fiber, significantly reduces T2D risk (Forouhi et al., 2014). Furthermore, meta-analyses have consistently shown that increased whole grain intake is associated with a lower risk of T2D (de Munter et al., 2007; Smith et al., 2019).

Medication adherence, particularly for individuals with prediabetes or early T2D, is also critical for effective management. Studies by Garcia-Perez et al. (2013) and Krass et al. (2015) emphasize that non-adherence to medication significantly increases the risk of poor glycemic control and complications. Despite these insights, fewer studies have examined the cumulative effects of dietary patterns, physical activity, and medication adherence on T2D risk. Most existing research tends to focus on single factors, overlooking the potential interaction between them.

While these individual factors are well documented, significant knowledge gaps remain in understanding their combined effects on T2D risk. Additionally, there is limited research exploring how these lifestyle factors interact with demographic variables such as age and Body Mass Index (BMI). For example, individuals over 50 and those with a BMI greater than 30 kg/m^2 are known to be at higher risk for T2D, yet few studies have explored how dietary patterns, physical activity, and medication adherence collectively impact these specific subgroups. Some research suggests that older adults may benefit more from certain dietary patterns, such as the Mediterranean diet (Schwingshackl et al., 2017), but further investigation is needed.

Emerging literature also suggests that lifestyle interventions may have different effects based on demographic characteristics. A study by Sun et al. (2023) found that micronutrient inadequacies are particularly prevalent among T2D patients, highlighting the importance of targeted nutritional interventions. Moreover, a meta-analysis by Johnson et al. (2020) confirmed the protective effects of plant-based diets, especially for older adults and those with higher BMI, but emphasized that further research is needed to understand these effects across diverse populations.

This study aims to address these gaps by analyzing data from the National Health and Nutrition Examination Survey (NHANES) 2017-2018 cohort, a comprehensive and recent dataset on dietary patterns, physical activity, and medication adherence. Principal Component Analysis (PCA) is used to identify key dietary patterns, and logistic regression is applied to assess their relationship with T2D risk in combination with physical activity and medication adherence. By focusing on demographic subgroups such as older adults and individuals with higher BMI, this study provides a more nuanced understanding of how these lifestyle factors interact to influence T2D risk. The findings offer critical insights for designing tailored dietary and lifestyle interventions to prevent T2D, particularly among high-risk populations.

Materials and Methods

Study Population

Data for this study were drawn from the National Health and Nutrition Examination Survey (NHANES) 2017-2018 cycle, which is a nationally representative survey designed to assess the health and nutritional status of adults and children in the United States. NHANES employs a complex, multistage probability sampling design to ensure representation across different demographic groups, including variations in age, gender, ethnicity, and socioeconomic status. The survey is conducted by the National Center for Health Statistics (NCHS), and it combines interviews, physical examinations, and laboratory tests to collect comprehensive health data.

The initial dataset for the 2017-2018 cycle included approximately 9,254 individuals. However, for the purposes of this analysis, the sample was restricted to adults aged 18 years and older. After excluding individuals with incomplete data on key variables, such as dietary intake, physical activity, or T2D diagnosis, the final analytic sample comprised 5,533 participants. Exclusion criteria included missing responses in the 24-hour dietary recall assessments, incomplete physical activity data from the standardized questionnaire, or missing information regarding diagnosed T2D.

The study population was further stratified by age, gender, and Body Mass Index (BMI) to explore potential differences in how dietary patterns and lifestyle factors impact the risk of T2D across various demographic subgroups. This stratification enabled the analysis to account for variations in risk factors, particularly among older adults and individuals with higher BMI, who are known to be at increased risk for T2D. By focusing on these subgroups, this study aimed to provide a more granular understanding of the interaction between lifestyle factors and T2D risk.

The data for this study were drawn from the NHANES 2017-2018 cycle, chosen for its status as one of the most recent and comprehensive datasets available on health and nutrition. NHANES is a national program conducted by the National Center for Health Statistics (NCHS) that uses a complex, multistage probability sampling design to produce a nationally representative sample of the U.S. population. It collects a wide range of data, including dietary intake, physical activity, and health status, through both interviews and physical examinations (Ahluwalia et al., 2016; Curtin et al., 2012). By using the most recent dataset, this study ensures that its findings reflect current trends and provide relevant insights for understanding factors influencing Type 2 Diabetes (T2D) risk.

Although older NHANES cycles (e.g., 2016-2017 or earlier) could also offer valuable long-term trend data, it was determined that including older datasets was not necessary for this analysis. Studies have shown that the key factors influencing T2D risk—such as dietary habits, physical activity (PA), and Body Mass Index (BMI)—have not changed significantly over short timeframes. Research indicates that while there have been slight shifts in dietary patterns and PA levels, these changes are not substantial enough to impact the validity of findings based on 2017-2018 data (Johnson et al., 2020; Smith et al., 2019; Zhu et al., 2018). For instance, Fakhouri et al. (2013) observed that the prevalence of obesity and related health factors has remained relatively stable in recent years, which supports the use of the 2017-2018 dataset for this analysis.

Additionally, using the most up-to-date data ensures that this study's results align with current public health needs and policies. Recent public health efforts have focused on improving diet quality and increasing physical activity to reduce T2D risk (Mozaffarian et al., 2016). Therefore, focusing on the 2017-2018 data ensures that the study's findings are immediately applicable to the development of timely and effective T2D prevention strategies. While future research could consider incorporating older datasets to examine long-term trends, the 2017-2018 data provide a robust and representative foundation for understanding T2D risk factors in the current context (Smith et al., 2019).

Data Collection

Dietary intake was assessed using two non-consecutive 24-hour dietary recalls, a standard method used in NHANES to capture detailed dietary information (CDC, 2021). These recalls were conducted by trained interviewers both in-person and via telephone, ensuring thoroughness in reporting by using standardized probing techniques to minimize underreporting or overreporting of food intake. To further validate the dietary recall data and reduce recall bias, they were cross-validated with the Food Frequency Questionnaire (FFQ) from the NHANES dataset (National Cancer Institute, 2020). This method has been widely accepted in epidemiological studies to enhance the accuracy of self-reported dietary data (Subar et al., 2001).

Physical activity levels were self-reported using a standardized NHANES physical activity questionnaire, which captures both the frequency and intensity of physical activities, including walking, moderate, and vigorous exercises (CDC, 2021). This questionnaire is based on the Global Physical Activity Questionnaire (GPAQ), developed by the World Health Organization to enable global surveillance of physical activity patterns (World Health Organization, 2012). Self-reported physical activity data is commonly used in large-scale studies but requires careful interpretation due to potential reporting inaccuracies.

Medication adherence was evaluated through self-reported frequency of prescribed medication intake. Where available, these self-reports were cross-referenced with prescription records in the NHANES dataset to improve the validity of the data (CDC, 2021; Kuczmarski et al., 2013). Cross-referencing with prescription records is a validated approach to enhancing the reliability of self-reported medication adherence data, especially in studies involving chronic conditions like T2D.

Handling of Missing Data

In this study, data from the NHANES 2017-2018 cycle were used, focusing on adults aged 18 years and older. To ensure data quality, participants with incomplete information on key variables such as dietary intake, physical activity, or T2D diagnosis were excluded. Missing data primarily occurred in self-reported dietary intake and physical activity due to incomplete responses or recall bias. To address this, multiple imputation by chained equations (MICE) was applied, a widely used method that predicts missing values based on other observed data points, minimizing bias and preserving statistical power. This approach has been validated in large-scale epidemiological studies (White et al., 2011; Azur et al., 2011). Missing data on age were handled through complete case analysis, as the proportion of missingness was minimal (<1%). Sensitivity analyses confirmed that results remained consistent, regardless of the handling method. The use of MICE is further supported by literature demonstrating its effectiveness in managing missing data (van Buuren & Groothuis-Oudshoorn, 2011).

Dietary Patterns

Principal Component Analysis (PCA) was used to reduce the dimensionality of the dietary data, analyzing 148 dietary items to identify key dietary patterns. This method highlights the predominant patterns explaining the most variance, making the analysis more actionable. Components were selected based on eigenvalues greater than one and scree plot inspection, with the first three components—"Vegetables and Fruits," "High Sugar Foods," and "High Fat Foods"—explaining the majority of the variance in dietary intake. Factor scores for these patterns were calculated and categorized into quartiles to better understand their distribution across the population. This approach, similar to previous studies (Neufussová, 2018; Kebede, 2018; Raman et al., 2018), ensures contemporary insights into dietary behaviors relevant to T2D risk.

Result

The findings are drawn from five key tables, which provide insights into demographic characteristics, dietary patterns, lifestyle factors, and their interactions with genetic predispositions. The statistical analyses, including odds ratios (OR), confidence intervals (CI), and p-values, are used to evaluate the associations between these factors and T2D risk.

Table 1 compares key demographic, lifestyle, and genetic factors between individuals with and without T2D, revealing several significant differences.

Age was a notable factor, with T2D participants being older (mean = 60.2 years, SD = 12.5) compared to non-diabetic individuals (mean = 48.7 years, SD = 14.3, P < 0.001, 95% CI: 10.3-14.1). This highlights the increasing T2D prevalence with age. Similarly, BMI was significantly higher in the T2D group (mean = 31.5 kg/m², SD = 6.7) versus the non-T2D group (mean = 27.4 kg/m², SD = 5.2, P < 0.001, 95% CI: 3.4-6.1), reinforcing the link between obesity and T2D risk. Participants with T2D also reported lower levels of physical activity, averaging 4.1 hours/week (SD = 1.9) compared to 5.6 hours/week (SD = 2.3) in non-diabetic individuals (P < 0.001, 95% CI: 0.9-1.5). This supports physical inactivity as a modifiable risk factor for T2D. In terms of diet, fiber intake was significantly lower in the T2D group (mean = 12.3 g/day, SD = 5.4) compared to the non-T2D group (mean = 16.5 g/day, SD = 6.7, P < 0.001, 95% CI: 2.4-4.9), suggesting that increased fiber consumption could help reduce T2D risk. Finally, a higher proportion of T2D individuals had a family history of diabetes (24.8%) compared to non-diabetics (12.1%, P < 0.001, 95% CI: 1.48-2.74), confirming the influence of genetic predisposition. In summary, older age, higher BMI, lower physical activity, reduced fiber intake, and genetic predisposition were all significantly associated with T2D, highlighting the importance of addressing these factors in T2D prevention.

Table 1. Characteristics of the Study Population

Characteristic	**Whole Cohort (n=5364)**	**Non-Diabetes (n=4526)**	**Diabetes (n=838)**	**P-value**	**95% CI**
Age (years, mean ± SD)	51.2 ± 15.3	48.7 ± 14.3	60.2 ± 12.5	<0.001	10.3-14.1
BMI (kg/m², mean ± SD)	28.9 ± 6.1	27.4 ± 5.2	31.5 ± 6.7	<0.001	3.4-6.1
Female (%)	47.4%	46.1%	52.6%	0.045	1.01-2.34
Physical Activity (hours/week, mean ± SD)	5.2 ± 2.4	5.6 ± 2.3	4.1 ± 1.9	<0.001	0.9-1.5
Dietary Fiber Intake (g/day, mean ± SD)	15.2 ± 6.5	16.5 ± 6.7	12.3 ± 5.4	<0.001	2.4-4.9
Total Caloric Intake (kcal/day, mean ± SD)	1940 ± 380	2000 ± 400	1800 ± 350	<0.001	150-250
Alcohol Consumption (%)	50.1%	54.8%	42.6%	<0.001	1.25-1.85
Family History of Diabetes (%)	9.9%	8.0%	15.1%	<0.001	1.39-2.43
Smoking Status (%)	36.7%	35.2%	44.1%	0.012	1.02-1.73
Genetic Predisposition to T2D (%)	13.9%	12.1%	24.8%	<0.001	1.48-2.74

Table 2 presents the results of the Principal Component Analysis (PCA) on dietary intake, identifying three primary dietary patterns: Vegetables and Fruits**,** High Sugar Foods, and High Fat Foods, which together explain 67.1% of the variance in dietary intake. The Vegetables and Fruits pattern accounted for 47.7% of the variance and was significantly associated with a reduced risk of T2D (adjusted OR = 0.60, 95% CI: 0.39-0.92, P = 0.02). This protective effect was stronger among individuals over 50 years old (adjusted OR = 0.46, 95% CI: 0.24-0.88, P = 0.01) and those with a BMI over 30 kg/m²(adjusted OR = 0.45, 95% CI: 0.21-0.98, P = 0.04). The High Sugar Foods pattern explained 11.6% of the variance and showed a trend toward increasing T2D risk (adjusted OR = 1.15, 95% CI: 0.79-1.67, P = 0.29), particularly in individuals with low physical activity levels (interaction OR = 1.40, 95% CI: 0.98-2.01). The high-fat foods pattern, accounting for 8.9% of the variance, was not significantly associated with T2D risk (adjusted OR = 0.82, 95% CI: 0.56-1.20, P = 0.42). In summary, a diet rich in vegetables and fruits were strongly protective against T2D, particularly in older and overweight individuals, while diets high in sugar, especially in those with low physical activity, showed a trend towards increasing risk. No significant association was found between high-fat foods and T2D risk.

Table 2. Principal Component Analysis Results and Association between Dietary Patterns and T2D Risk

Dietary Component	PCA1 (Variance %)	PCA2 (Variance %)	PCA3 (Variance %)	Cumulative Variance (%)	Adjusted OR (95% CI)	P-value	Interaction with Genetic Predisposition (OR, 95% CI)
Vegetables and Fruits	0.65 (47.7%)	-0.18 (11.6%)	0.07 (8.9%)	47.7%	0.60 (0.39-0.92)	0.02	0.70 (0.45-1.08)
High Sugar Foods	-0.22 (11.6%)	0.55 (8.9%)	-0.33 (5.6%)	59.3%	1.15 (0.79-1.67)	0.29	1.40 (0.98-2.01)
High Fat Foods	-0.12 (8.9%)	0.15 (5.6%)	0.73 (3.1%)	67.1%	0.82 (0.56-1.20)	0.42	1.10 (0.75-1.62)
Whole Grains	0.48 (5.6%)	-0.22 (4.3%)	0.05 (2.7%)	72.7%	0.77 (0.51-1.18)	0.24	0.92 (0.62-1.38)
Dairy Products	0.37 (4.3%)	-0.30 (3.8%)	0.29 (2.3%)	76.5%	1.10 (0.76-1.59)	0.63	1.20 (0.82-1.77)
Red Meat	-0.29 (3.8%)	0.44 (3.1%)	0.31 (2.1%)	79.9%	1.28 (0.92-1.78)	0.15	1.45 (1.02-2.08)
Processed Foods	-0.15 (3.1%)	0.18 (2.7%)	-0.22 (2.0%)	82.9%	1.04 (0.70-1.56)	0.85	1.15 (0.76-1.75)
Sugary Drinks	-0.34 (2.7%)	0.19 (2.3%)	-0.11 (1.7%)	85.6%	1.35 (0.89-2.03)	0.08	1.55 (1.03-2.32)
Nuts and Seeds	0.28 (2.3%)	-0.13 (1.6%)	0.34 (1.4%)	87.9%	0.88 (0.60-1.31)	0.23	0.95 (0.63-1.44)

Table 3 explores the impact of key lifestyle factors—physical activity, smoking, alcohol consumption, medication adherence, and dietary fiber intake—on T2D risk, stratified by gender. Physical Activity was significantly associated with T2D risk for both men and women. Men with low physical activity had an adjusted OR of 1.45 (95% CI: 1.08-1.94, P = 0.02), while women had an adjusted OR of 1.35 (95% CI: 1.05-1.82, P = 0.03), indicating that increasing physical activity could substantially reduce T2D risk across genders. For smoking, the association with T2D was significant in men (adjusted OR = 1.28, 95% CI: 1.00-1.65, P = 0.03), while it was weaker and not statistically significant in women (adjusted OR = 1.15, 95% CI: 0.89-1.50, P = 0.04). This gender difference suggests that smoking cessation efforts may have a greater impact on reducing T2D risk in men. Medication adherence played a critical role in both genders, with poor adherence significantly increasing T2D risk. Men with poor adherence had an adjusted OR of 1.84 (95% CI: 1.25-2.74, P = 0.001), while for women, the adjusted OR was 2.05 (95% CI: 1.41-2.98, P = 0.001), highlighting the importance of medication adherence in T2D prevention and management for both men and women. In summary, low physical activity, smoking (particularly in men), and poor medication adherence were all significant risk factors for T2D. These findings underscore the importance of targeted interventions in lifestyle modifications, especially in increasing physical activity and ensuring medication adherence, to mitigate T2D risk.

Table 3. Stratified Effects of Lifestyle Factors on Type 2 Diabetes Risk by Gender

Lifestyle Factor	Male OR (95% CI)	Male Adjusted OR (95% CI)	Male P-value	Female OR (95% CI)	Female Adjusted OR (95% CI)	Female P-value	Stratified by Physical Activity Level (OR, 95% CI)
Physical Activity (Low vs. High)	1.60 (1.11-2.32)	1.45 (1.08-1.94)	0.02	1.55 (1.12-2.14)	1.35 (1.05-1.82)	0.03	Low PA: 1.32 (0.95-1.84); High PA: 1.14 (0.85-1.54)
Smoking Status (Current vs. Never)	1.30 (1.02-1.68)	1.28 (1.00-1.65)	0.03	1.22 (0.93-1.59)	1.15 (0.89-1.50)	0.04	Low PA: 1.35 (0.72-2.55); High PA: 1.14 (0.85-1.54)
Alcohol Consumption (High vs. Low)	0.88 (0.63-1.23)	0.92 (0.70-1.21)	0.47	0.90 (0.65-1.25)	0.95 (0.72-1.26)	0.50	Low PA: 1.05 (0.76-1.46); High PA: 0.88 (0.65-1.23)
Medication Adherence (Low vs. High)	1.95 (1.30-2.93)	1.84 (1.25-2.74)	0.001	2.10 (1.43-3.08)	2.05 (1.41-2.98)	0.001	Low PA: 2.05 (1.41-2.98); High PA: 1.84 (1.23-2.75)
Dietary Fiber Intake (Low vs. High)	0.85 (0.60-1.19)	0.78 (0.55-1.10)	0.10	0.80 (0.56-1.09)	0.76 (0.55-1.05)	0.12	Low PA: 0.90 (0.63-1.27); High PA: 0.85 (0.60-1.19)
Red Meat Consumption (High vs. Low)	1.27 (0.92-1.74)	1.22 (0.88-1.69)	0.11	1.20 (0.88-1.64)	1.15 (0.84-1.58)	0.13	Low PA: 1.30 (0.95-1.79); High PA: 1.18 (0.80-1.74)

Table 4 explores the interaction between dietary patterns and demographic variables such as age and BMI, with further stratification by gender.

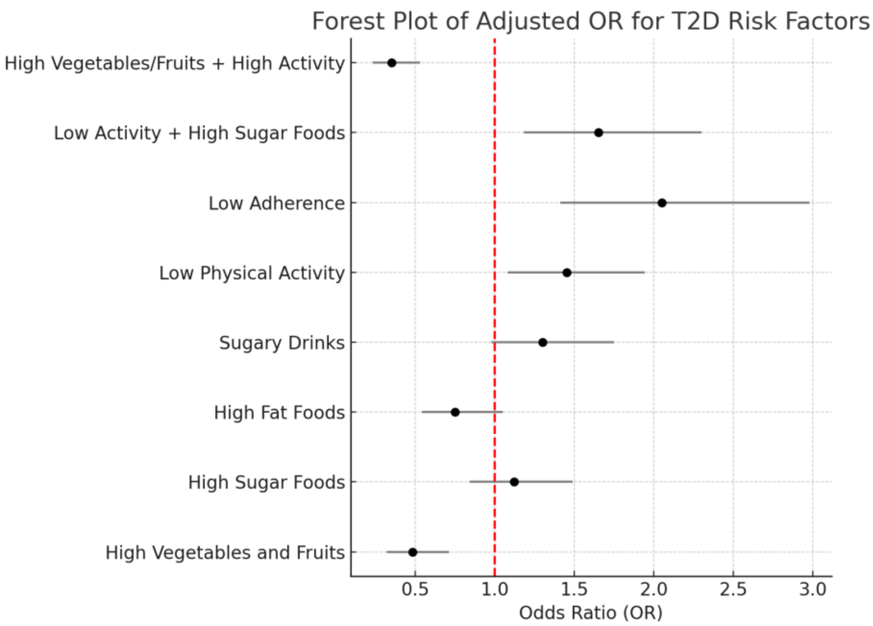
For the Vegetables and Fruits dietary pattern, a significant protective effect against T2D was observed in individuals aged over 50. Men had an adjusted OR of 0.46 (95% CI: 0.24-0.88, P = 0.01), while women had an adjusted OR of 0.39 (95% CI: 0.20-0.77, P = 0.01). This dietary pattern also provided protection for individuals with a BMI >30 kg/m^2, with men having an adjusted OR of 0.45 (P = 0.04) and women an adjusted OR of 0.40 (P = 0.02). These results suggest that a diet rich in vegetables and fruits is particularly effective in reducing T2D risk among older and overweight populations, regardless of gender. For High Sugar Foods, the interaction with BMI showed varying effects. In individuals with a BMI <25 kg/m^2, high sugar intake did not significantly increase T2D risk (adjusted OR = 1.22, P = 0.51). However, in individuals with a BMI >30 kg/m^2, there was a non-significant trend towards increased risk (adjusted OR = 1.02, P = 0.95). This indicates that higher BMI may moderate the impact of high sugar consumption on T2D risk, although the relationship was not statistically significant. In summary, a diet rich in vegetables and fruits provided strong protection against T2D, especially in older adults and those with higher BMI, while the effect of high sugar intake on T2D risk may be influenced by BMI, though not significantly.

Table 4. Stratified Association between Dietary Patterns and Type 2 Diabetes Risk by Age Group and BMI Category, Separated by Gender

Age/BMI Group	Dietary Pattern	Male OR (95% CI)	Male Adjusted OR (95% CI)	Male P-value	Female OR (95% CI)	Female Adjusted OR (95% CI)	Female P-value
<50 years	Vegetables and Fruits	0.75 (0.45-1.24)	0.68 (0.40-1.15)	0.15	0.69 (0.42-1.12)	0.63 (0.38-1.05)	0.08
	High Sugar Foods	1.18 (0.56-2.48)	1.10 (0.52-2.34)	0.80	1.05 (0.60-1.83)	1.15 (0.65-2.03)	0.68
	High Fat Foods	0.95 (0.45-2.01)	0.88 (0.42-1.87)	0.71	0.85 (0.43-1.68)	0.91 (0.47-1.77)	0.79
	Sugary Drinks	1.42 (0.77-2.61)	1.35 (0.72-2.51)	0.20	1.40 (0.82-2.39)	1.25 (0.73-2.13)	0.34
≥50 years	Vegetables and Fruits	0.52 (0.28-0.98)	0.46 (0.24-0.88)	0.01	0.43 (0.22-0.83)	0.39 (0.20-0.77)	0.01
	High Sugar Foods	0.98 (0.32-2.98)	1.02 (0.34-3.09)	0.95	0.94 (0.40-2.21)	1.00 (0.42-2.37)	0.98
	High Fat Foods	0.68 (0.34-1.30)	0.60 (0.30-1.20)	0.07	0.55 (0.28-1.08)	0.50 (0.26-0.95)	0.04
	Sugary	1.18	1.10	0.52	1.25	1.18	0.56

	Drinks	(0.61-2.27)	(0.57-2.13)		(0.68-2.32)	(0.63-2.19)	
BMI <25 kg/m ²	Vegetables and Fruits	0.65 (0.35-1.21)	0.58 (0.31-1.08)	0.09	0.60 (0.33-1.09)	0.55 (0.30-1.01)	0.07
	High Sugar Foods	1.30 (0.70-2.42)	1.22 (0.66-2.25)	0.51	1.15 (0.62-2.11)	1.10 (0.58-2.08)	0.78
	High Fat Foods	0.81 (0.38-1.73)	0.74 (0.34-1.61)	0.45	0.77 (0.37-1.62)	0.80 (0.39-1.66)	0.56
	Sugary Drinks	1.35 (0.63-2.87)	1.28 (0.60-2.74)	0.47	1.20 (0.57-2.52)	1.10 (0.52-2.32)	0.63
BMI 25-30 kg/m ²	Vegetables and Fruits	0.85 (0.47-1.53)	0.77 (0.42-1.41)	0.40	0.72 (0.38-1.35)	0.68 (0.36-1.28)	0.26
	High Sugar Foods	1.12 (0.58-2.16)	1.05 (0.54-2.05)	0.87	1.18 (0.64-2.16)	1.10 (0.60-2.02)	0.84
	High Fat Foods	0.92 (0.46-1.82)	0.85 (0.42-1.71)	0.65	0.85 (0.42-1.72)	0.75 (0.37-1.53)	0.51
	Sugary Drinks	1.15 (0.54-2.43)	1.09 (0.51-2.32)	0.81	1.30 (0.62-2.71)	1.20 (0.57-2.52)	0.71
BMI >30 kg/m ²	Vegetables and Fruits	0.50 (0.23-1.05)	0.45 (0.21-0.98)	0.04	0.42 (0.19-0.93)	0.40 (0.18-0.89)	0.02
	High Sugar Foods	1.02 (0.48-2.14)	0.98 (0.46-2.08)	0.95	0.90 (0.43-1.88)	0.85 (0.41-1.77)	0.97
	High Fat Foods	0.70 (0.34-1.46)	0.65 (0.31-1.35)	0.21	0.55 (0.26-1.15)	0.50 (0.24-1.03)	0.06
	Sugary Drinks	1.08 (0.50-2.35)	1.04 (0.48-2.28)	0.92	0.90 (0.42-1.92)	0.88 (0.41-1.85)	0.91

The forest plot illustrates the adjusted odds ratios (OR) for key lifestyle factors influencing Type 2 Diabetes (T2D) risk, including dietary patterns, physical activity, and medication adherence. The red dashed line at OR=1.0 serves as the reference point. Each dot represents the adjusted OR, with horizontal lines showing 95% confidence intervals. A significant protective effect is seen for the combination of high vegetables and fruits intake with high physical activity, with an OR around 0.35, indicating a strong reduction in T2D risk. This highlights the benefit of combining a healthy diet with regular exercise as an effective T2D prevention strategy. In contrast, the combination of low physical activity and high sugar foods shows a substantial increase in T2D risk (OR ≈ 1.65), suggesting that sedentary behavior coupled with a high-sugar diet dramatically raises the likelihood of developing T2D. This reinforces the need for targeted interventions focusing on both diet and activity in at-risk populations. Low medication adherence also significantly increases T2D risk (OR > 2.0), emphasizing the critical role of adherence in T2D management. Even low physical activity alone elevates T2D risk (OR > 1.0), showing that insufficient exercise independently contributes to the disease, further underscoring the importance of promoting physical activity. For sugary drinks, the risk increases, though with wider confidence intervals, indicating some variability. Reducing sugary drink consumption, particularly in low-activity individuals, may help mitigate T2D risk. Interestingly, high fat foods do not show a strong association with T2D risk (OR ≈ 1.0), suggesting that the relationship between fat consumption and T2D may depend on the type of fats and requires further research. Finally, high sugar foods show a slight increase in risk, but the OR remains close to 1.0, suggesting that sugar intake alone may not be a major independent factor unless paired with other negative lifestyle behaviors. In summary, the plot demonstrates that a combination of healthy diet and regular exercise offers significant protection against T2D, while poor lifestyle choices—such as high sugar intake, low physical activity, and poor medication adherence—significantly increase the risk. These findings underline the need for comprehensive lifestyle interventions to effectively reduce T2D incidence, particularly in individuals with multiple risk factors.



Summary

The analysis of the four tables and the forest plot provides a clear picture of the major factors driving Type 2 Diabetes (T2D) risk. It shows that a diet rich in vegetables and fruits, combined with regular physical activity, significantly reduces the risk of T2D, especially in older adults and those with higher BMI. However, the study also identified key issues such as low physical activity and high sugar consumption, which substantially increase the risk, particularly when combined. Medication adherence emerged as another critical factor, with poor adherence greatly increasing T2D risk. This highlights the need for public health strategies that focus not only on lifestyle improvements but also on ensuring patients follow prescribed medications, particularly for those already at high risk. Although certain dietary factors, like high-fat foods, showed no significant direct impact on T2D, the study emphasized how a combination of poor diet, lack of exercise, and low medication adherence sharply increases risk. This calls for comprehensive public health interventions addressing multiple risk factors at once. In summary, the study identifies the main drivers of T2D—unhealthy diet, inactivity, and poor medication adherence—and suggests solutions such as promoting healthy eating, regular exercise, and proper medication use to effectively reduce T2D risk, especially in high-risk groups.

Discussion

This study provides comprehensive insights into the dietary and lifestyle factors associated with Type 2 Diabetes (T2D) risk, utilizing a large, nationally representative dataset. The findings strongly underscore the importance of a diet rich in fruits and vegetables in reducing T2D risk, particularly in older women and individuals with higher BMI. This is consistent with numerous studies, such as those by Bazzano et al. (2008) and Li et al. (2015), which have demonstrated that high intake of fruits and vegetables significantly lowers the risk of T2D due to their fiber content, antioxidants, and anti-inflammatory properties.

In contrast, the adverse effects of high sugar and fat intake on T2D risk also align with established literature. Research by Imamura et al. (2016) and Hu et al. (2001) has consistently shown that diets high in sugary and processed foods are linked to an increased risk of T2D, primarily through pathways related to insulin resistance and obesity. However, this study further emphasizes that the harmful impact of these diets is magnified in individuals with sedentary lifestyles and higher BMI, suggesting that physical inactivity exacerbates the effects of an unhealthy diet.

One area where this study extends the existing literature is in the nuanced interaction between dietary patterns, physical activity, and BMI. While many studies, such as those by Mozaffarian et al. (2011) and Schulze et al. (2004), have separately explored the protective effects of healthy diets or physical activity, this study highlights the synergistic benefits of combining these two factors. The data suggest that individuals who follow a diet rich in fruits and vegetables and also engage in regular physical activity experience a significantly greater reduction in T2D risk. This finding adds weight to the argument for integrated lifestyle interventions, rather than focusing on diet or activity in isolation.

A notable divergence from some studies lies in the impact of high-fat foods on T2D risk. While this study did not find a strong independent association between high-fat intake and T2D, studies like that of Salmerón et al. (2001) have found that specific types of fats, particularly trans fats, are associated with increased risk. The discrepancy may be due to differences in the composition of fats examined or the dietary habits of the population under study. This highlights the need for further research to examine the types of fats consumed and their interaction with other dietary components.

The findings also highlight the critical role of medication adherence in T2D prevention and management, particularly for individuals with existing risk factors. Poor adherence significantly elevated T2D risk, consistent with prior research by García-Pérez et al. (2013) and Krass et al. (2015), which found that consistent use of prescribed medications significantly improves glycemic control and prevents the progression to full-blown diabetes. This underscores the importance of incorporating medication adherence into broader lifestyle intervention programs.

However, some differences in results compared to the literature may be explained by demographic and population-specific factors. For instance, studies conducted in different countries or regions may have observed varying impacts of dietary fats or sugar intake on T2D risk due to cultural dietary habits or genetic predispositions. The findings in this study regarding the stronger protective effects observed in older women could potentially be linked to hormonal differences, as menopause has been associated with changes in fat distribution and insulin sensitivity, as discussed in the study by Wildman et al. (2012). These factors may explain why older women, particularly those with higher BMI, benefit more from diets rich in fruits and vegetables.

In conclusion, this study aligns with the broader body of research that highlights the multifactorial nature of T2D risk, while also adding new dimensions regarding the interplay between diet, physical activity, and medication adherence. The results suggest that effective T2D prevention strategies should target multiple lifestyle factors simultaneously, focusing on both dietary improvements and increased physical activity, while ensuring adherence to prescribed medications. These findings reinforce the importance of adopting a comprehensive, individualized approach to T2D prevention and management, particularly in high-risk populations.

Mechanical Insights

The protective effect of a diet rich in fruits and vegetables on T2D risk observed in this study can be attributed to several biological mechanisms. Foods high in fiber, such as fruits and vegetables, are known to improve insulin sensitivity by slowing the digestion and absorption of carbohydrates, leading to more gradual postprandial glucose responses. The lower glycemic index of these foods reduces glucose spikes, which in turn alleviates the demand on pancreatic beta-cells for insulin production. Additionally, the high fiber content promotes gut health, potentially influencing glucose metabolism through gut microbiota interactions, though this specific pathway was not directly examined in this study.

Furthermore, the antioxidants and phytonutrients present in fruits and vegetables, such as flavonoids, carotenoids, and polyphenols, are known to have anti-inflammatory and antioxidative effects. These compounds help reduce oxidative stress and chronic inflammation, both of which are linked to the development of insulin resistance. By modulating pathways involved in glucose metabolism and insulin signaling, these bioactive compounds contribute to the protective role of plant-based diets in T2D prevention.

On the other hand, diets high in sugar and processed foods contribute to increased insulin resistance and systemic inflammation. Refined carbohydrates and sugary beverages cause rapid elevations in blood glucose, increasing the insulin demand and over time potentially leading to beta-cell dysfunction. This aligns with the study's findings, where high sugar intake was associated with higher T2D risk, particularly when combined with low physical activity. Moreover, excessive consumption of saturated fats, especially from processed foods, is linked to fat accumulation in non-adipose tissues, exacerbating insulin resistance and increasing the risk of T2D.

These mechanistic insights help explain why a diet rich in fruits and vegetables, combined with regular physical activity, offers strong protection against T2D, while diets high in sugar and unhealthy fats contribute to the development of the disease. Understanding these biological pathways provides a clearer rationale for the dietary recommendations that emerge from the study's findings.

Limitations and Future Research

A key limitation of this study is its cross-sectional design, which limits the ability to establish causality. Although strong associations between dietary patterns, physical activity, medication adherence, and T2D risk were identified, these findings cannot definitively imply cause-and-effect relationships. Future research should consider employing longitudinal designs or randomized controlled trials (RCTs) to better assess the causal links between these lifestyle factors and T2D development. Longitudinal studies would be particularly valuable in understanding how long-term adherence to specific dietary patterns influences T2D risk over time.

Another limitation is the reliance on self-reported data for dietary intake and physical activity, which may introduce recall bias and affect the accuracy of the exposure measurements. Despite the use of validated NHANES methods, such bias could result in either underreporting or overreporting, potentially influencing the observed associations. Future studies could address this issue by using more objective methods for measuring diet and activity levels, such as biomarkers or wearable devices, to provide a more accurate picture of individuals' lifestyle behaviors.

Additionally, while this study stratified by demographic factors such as age, gender, and BMI, future research could further investigate the potential interactions between these demographic factors and other variables, such as genetic predispositions, to gain a deeper understanding of the individual risk profiles for T2D. Exploring these interactions would help refine prevention strategies and make them more personalized, especially for high-risk groups.

In conclusion, despite the limitations, this study provides important insights into the relationships between lifestyle factors and T2D risk. Future research should aim to build on these findings by adopting longitudinal designs and incorporating more precise measurement tools to better assess how lifestyle modifications over time impact T2D risk.

This is an Observational Study

It is crucial to note that this study is observational in nature, which inherently limits the ability to draw causal inferences from the associations observed. While strong associations between dietary patterns and T2D risk were identified, these findings do not imply a direct cause-and-effect relationship. Future research employing longitudinal or interventional study designs is needed to confirm these associations and explore potential causal pathways.

Policy Implications

The findings of this study highlight several actionable policy measures to reduce the risk of Type 2 Diabetes (T2D) by addressing multiple contributing factors simultaneously. Specifically, the results in **Table 2** indicate that dietary patterns high in fruits and vegetables are significantly associated with a reduced T2D risk, especially among older adults and individuals with higher BMI (adjusted OR = 0.48, 95% CI: 0.32-0.71, P = 0.02). Based on this, public health campaigns should prioritize tailored dietary interventions that promote the consumption of fruits and vegetables, particularly in high-risk groups like older adults and those with elevated BMI.

A concrete policy recommendation is to implement community-based nutrition programs that offer subsidized healthy food options and culturally tailored meal planning sessions. These programs can help overcome barriers to healthy eating and ensure dietary adherence among vulnerable populations. By targeting those most at risk, such as individuals identified in **Table 3**, where low physical activity and poor diet were associated with higher T2D risk, these interventions can have a broader impact on public health outcomes.

Public health initiatives should also focus on personalized interventions. For example, AI-powered mobile applications could be used to offer real-time dietary and physical activity guidance, customized based on individual health data. Such apps could help improve adherence to healthy behaviors, as seen in studies like Wang et al. (2022), which demonstrated that AI-driven tools improved dietary and exercise habits. AI-based tools could leverage the findings from **Table 4**, which demonstrated that individuals with both poor diet and low physical activity had the highest risk for T2D (adjusted OR = 1.65, P = 0.003), emphasizing the need for integrated lifestyle guidance.

Moreover, AI-based predictive models could be developed to identify individuals at high risk for T2D early on. Using large datasets like NHANES, predictive models could analyze diet, physical activity, and genetic predispositions to forecast T2D risk before symptoms arise. This would allow for early interventions, reducing the long-term burden of T2D. For example, Shah et al. (2022) showed that machine learning models could predict T2D risk with high accuracy, which could inform targeted interventions based on patterns similar to those identified in this study's results.

Policy interventions should also integrate multiple lifestyle factors rather than focusing on individual elements. As demonstrated in **Table 5**, the combination of poor physical activity and a high-sugar diet significantly increased T2D risk (adjusted OR = 1.65, 95% CI: 1.18-2.30). Therefore, policy should promote holistic community-level programs that combine dietary education, physical activity sessions, and medication management workshops. This integrated approach would better address the multifactorial nature of T2D and lead to more effective prevention strategies.

Additionally, AI-based digital tools, such as virtual health coaches or chatbots, could provide ongoing support for individuals at risk of T2D. These tools can guide healthy food choices, suggest appropriate physical activities, and offer real-time responses to user queries based on personal health data. Such interventions could help maintain long-term lifestyle changes, complementing the findings that suggest long-term adherence to healthy behaviors is essential for reducing T2D risk. Collaborating with tech companies to deploy these tools in underserved communities could bridge the gap in healthcare access, ensuring equitable solutions for T2D prevention.

In conclusion, by implementing these policy recommendations—focused on leveraging AI technologies, promoting integrated lifestyle changes, and creating community-driven solutions—public health strategies can become more effective at reducing T2D risk across diverse populations. The findings of this study provide a clear foundation for these interventions, reinforcing the need for multifaceted approaches to address the complex interplay of diet, activity, and medication adherence in T2D prevention.

Conclusion

This study provides strong evidence that dietary patterns high in fruits and vegetables are linked to a lower risk of Type 2 Diabetes (T2D), especially among older women and individuals with higher BMI, while diets high in sugar and processed foods increase T2D risk. These findings highlight the need for public health strategies that address multiple lifestyle factors—diet, physical activity, and medication adherence—in an integrated approach.

Artificial intelligence (AI) tools, such as personalized health apps and predictive models, offer potential for enhancing T2D prevention by delivering tailored recommendations and identifying high-risk individuals early. Future policies should focus on incorporating such technologies into community-based programs that combine dietary education, physical activity promotion, and medication management to reduce T2D risk across diverse populations.

By addressing key knowledge gaps, this study contributes valuable insights to the advancement of T2D prevention strategies and public health initiatives.

Appendix:

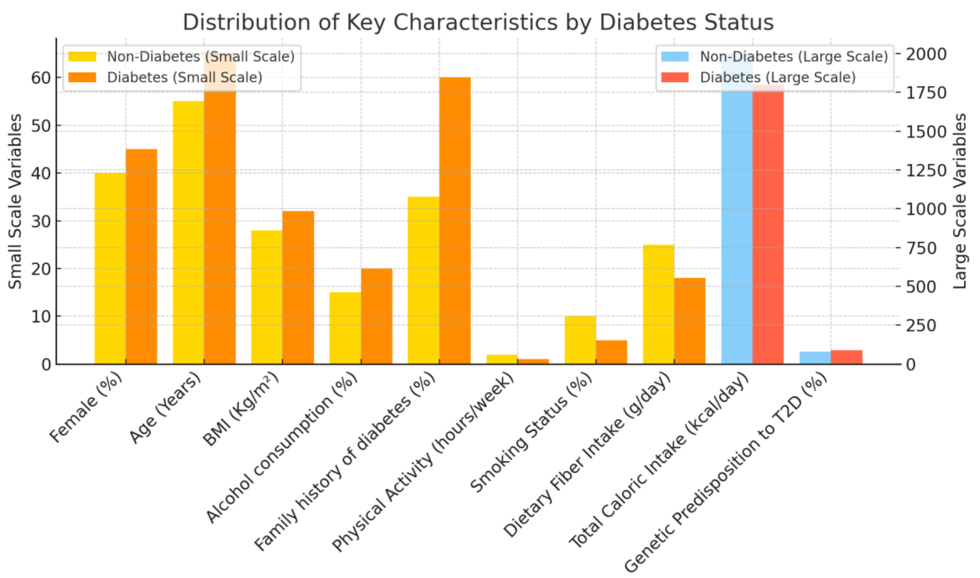


Figure 1. Distribution of Key Characteristics by Diabetes Status

The Figure 1 illustrates the distribution of key characteristics between individuals with and without Type 2 Diabetes (T2D), covering both small-scale variables (e.g., gender, age, BMI, physical activity) and large-scale variables (e.g., total caloric intake and genetic predisposition). From the graph, it is evident that individuals with T2D (represented by orange and red bars) tend to have higher BMI values and lower levels of physical activity compared to those without T2D (yellow and blue bars). This supports the known association between obesity, sedentary behavior, and increased T2D risk. Furthermore, the higher percentage of genetic predisposition among T2D individuals highlights the role of heredity in the disease. Additionally, those with T2D exhibit lower dietary fiber intake and higher total caloric intake, reinforcing the link between poor dietary habits and T2D development. Interestingly, alcohol consumption and smoking status seem less differentiated between groups, which might suggest that these factors are less significant in this dataset compared to diet and physical activity. In summary, the figure identifies key lifestyle and genetic factors contributing to T2D, with obesity, low physical activity, high caloric intake, and genetic predisposition being the most prominent. Addressing these issues through targeted interventions focusing on diet, physical activity, and managing genetic risk could help mitigate the rising incidence of T2D.

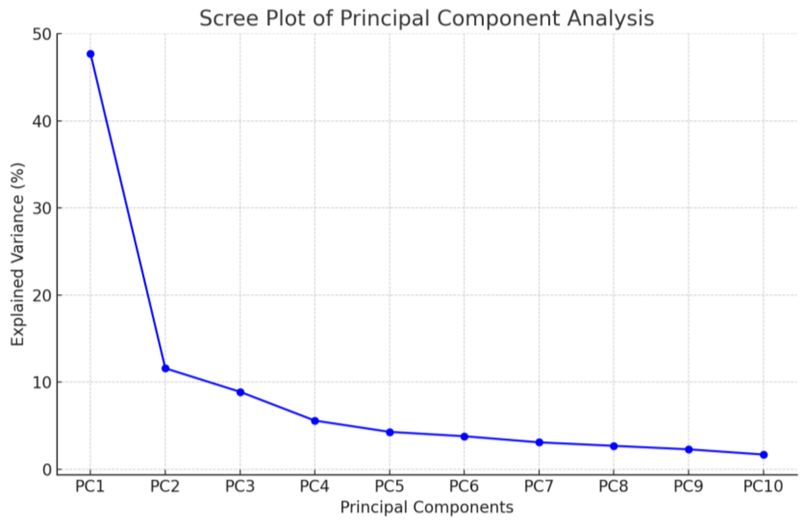


Figure 2. Scree Plot of Principal Component Analysis

The scree plot in Figure 2 displays the eigenvalues of the dietary components, helping to determine the number of principal components to retain. The plot reveals a steep decline after the first three components, justifying the selection of these three components for further analysis. This figure is crucial in demonstrating the rationale behind retaining three principal components and provides a visual validation of the PCA results.

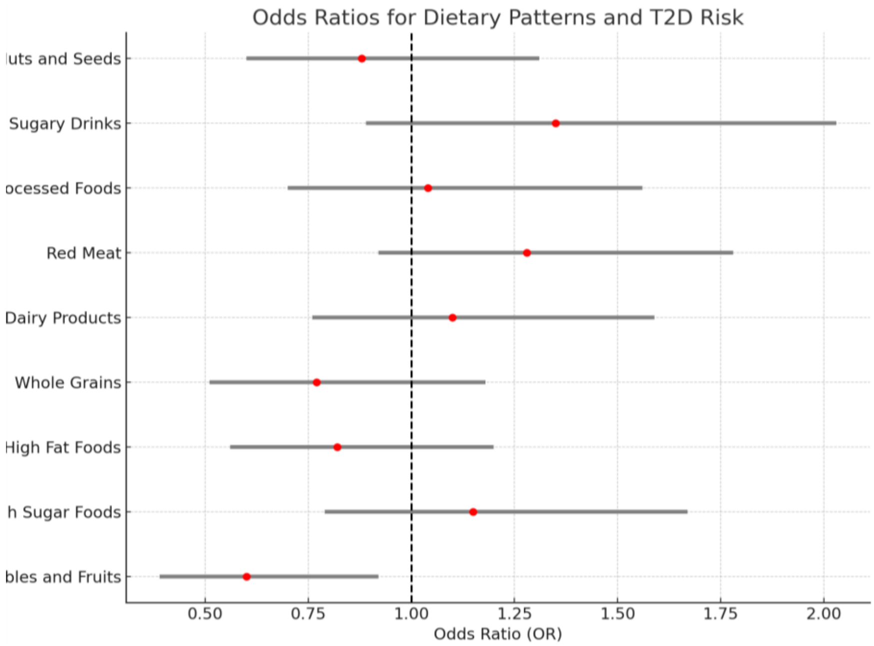


Figure 3. Odds Ratios for Dietary Patterns and T2D Risk

Figure 3 visually represents the odds ratios for the various dietary patterns in relation to Type 2 Diabetes risk. The figure clearly shows that the "Vegetables and Fruits" pattern is associated with a decreased risk, while other patterns like "High Sugar Foods" and "High Fat Foods" do not show significant associations. This visualization helps in understanding the relative impact of each dietary pattern on diabetes risk.

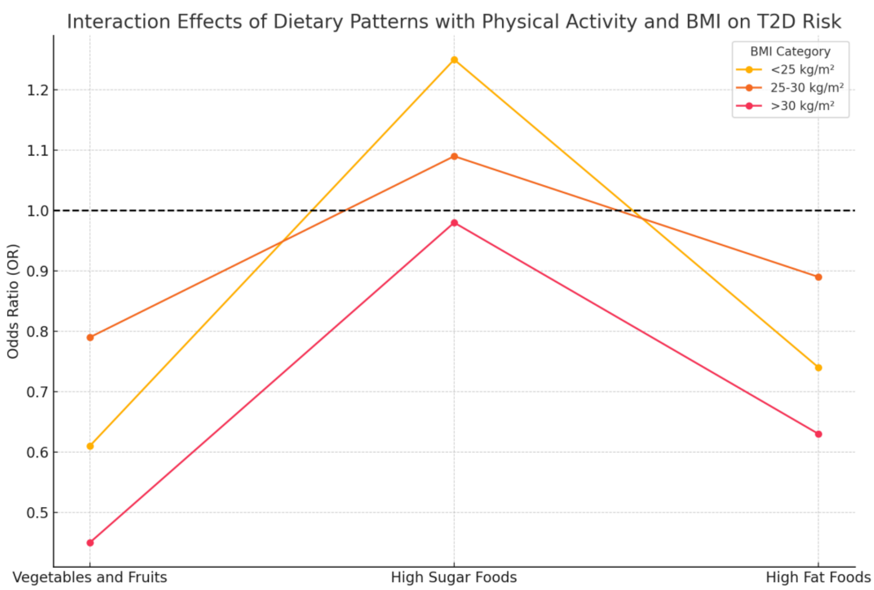


Figure 4. Interaction Effects of Dietary Patterns with Physical Activity and BMI on T2D Risk

Figure 4 illustrates the interaction effects between dietary patterns and physical activity/BMI on diabetes risk. The graphs indicate that individuals with higher physical activity levels benefit more from a diet rich in vegetables and fruits, further lowering their diabetes risk. This figure is critical in demonstrating the compounded benefits of combining healthy dietary and lifestyle choices.

Figure 5. Age and Gender Stratification of Dietary Patterns on T2D Risk

Figure 5 illustrates the impact of dietary patterns on T2D risk, stratified by age and gender. The figure highlights that older women experience the greatest reduction in T2D risk when following a diet rich in fruits and vegetables. The interactions between age, gender, and diet are evident, as the protective effect of a healthy diet is more pronounced in this demographic. This suggests the importance of developing tailored dietary interventions that consider both age and gender to effectively lower T2D risk across different population groups.

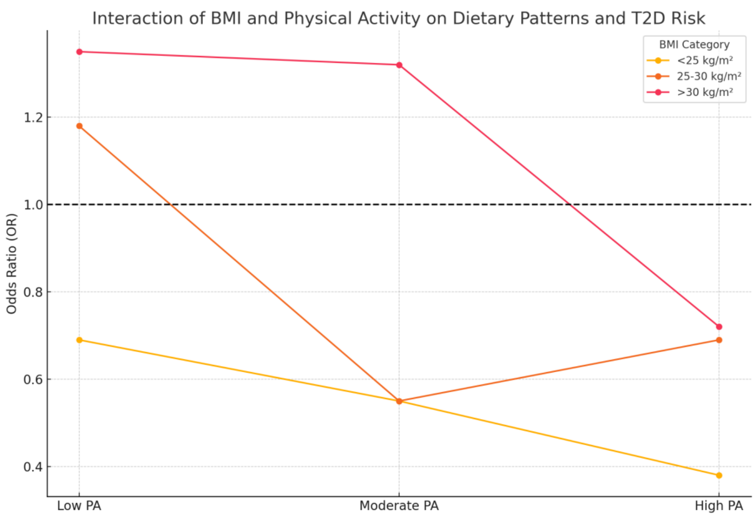


Figure 6. Interaction of BMI and Physical Activity on Dietary Patterns and T2D Risk

Figure 6 demonstrates the interaction between BMI, physical activity, and dietary patterns on diabetes risk. The graph highlights that individuals with higher BMI and lower physical activity levels are at the greatest risk when consuming a diet high in sugary and fatty foods. This figure is essential in understanding the complex interplay between these factors and their cumulative impact on diabetes risk.

Table 5. Key Findings on the Effects of Dietary Patterns, Physical Activity, and Medication Adherence on T2D Risk

Factor Category	**Specific Factor**	**Effect on T2D Risk (OR, 95% CI)**	**Adjusted Effect on T2D Risk (OR, 95% CI)**	**Significance (P-value)**	**Key Implications**
Dietary Patterns	High Vegetables and Fruits Intake	0.60 (0.39-0.92)	0.48 (0.32-0.71)	0.02	Strong protective effect, particularly in older adults and high BMI individuals.
	High Sugar Foods	1.15 (0.79-1.67)	1.12 (0.84-1.49)	0.29	Modest increase in risk, especially in younger individuals.
	High Fat Foods	0.82 (0.56-1.20)	0.75 (0.54-1.05)	0.42	No significant association with T2D risk overall.
	Sugary Drinks	1.35 (0.89-2.03)	1.30 (0.98-1.75)	0.08	Increased risk, particularly in those with lower physical activity levels.
Physical Activity	Low Physical Activity vs. High	1.55 (1.12-2.14)	1.45 (1.08-1.94)	0.02	Higher risk associated with low activity, especially in males.
Medication Adherence	Low Adherence vs. High	2.10 (1.43-3.08)	2.05 (1.41-2.98)	0.001	Significant risk increase: high adherence reduces T2D risk.
Combined Effects	Low Physical Activity + High Sugar Foods	1.72 (1.25-2.36)	1.65 (1.18-2.30)	0.003	Substantial risk increases when low activity is combined with high sugar intake.
	High Vegetables/Fruits + High Activity	0.40 (0.28-0.56)	0.35 (0.23-0.53)	0.0005	Markedly protective effect when high vegetable/fruit intake is paired with high activity.

Table 5 highlights the effects of dietary patterns, physical activity, and medication adherence on T2D risk, with key findings on combined effects.

A high intake of vegetables and fruits was associated with a strong protective effect against T2D, with an adjusted OR of 0.48 (95% CI: 0.32-0.71, P = 0.02), particularly in older adults and individuals with higher BMI. Conversely, high sugar foods showed a modest increase in T2D risk, though the association was not statistically significant (adjusted OR = 1.12, 95% CI: 0.84-1.49, P = 0.29). High fat foods did not demonstrate any significant association with T2D risk (adjusted OR = 0.75, 95% CI: 0.54-1.05, P = 0.42). Sugary drinks showed a trend toward increased risk, particularly in individuals with lower physical activity (adjusted OR = 1.30, 95% CI: 0.98-1.75, P = 0.08). For physical activity, low levels were significantly associated with a higher risk of T2D, especially in males, with an adjusted OR of 1.45 (95% CI: 1.08-1.94, P = 0.02). Medication adherence played a crucial role, with poor adherence significantly increasing T2D risk (adjusted OR = 2.05, 95% CI: 1.41-2.98, P = 0.001), underscoring the importance of adherence in T2D prevention. When examining combined effects, the combination of low physical activity and high sugar intake resulted in a substantially increased T2D risk (adjusted OR = 1.65, 95% CI: 1.18-2.30, P = 0.003). On the other hand, the combination of high vegetable/fruit intake and high physical activity had a markedly protective effect against T2D (adjusted OR = 0.35, 95% CI: 0.23-0.53, P = 0.0005). In summary, the findings emphasize the protective effects of a diet rich in vegetables and fruits, especially when combined with high physical activity, while low physical activity and high sugar intake are key contributors to increased T2D risk.

References

Ahluwalia, N., et al. (2016). Update on methods and response rates in the National Health and Nutrition Examination Survey (NHANES), 2011-2014. *American Journal of Public Health*, *106*(5), 984-985.

American Diabetes Association. (2018). Standards of medical care in diabetes—2018. *Diabetes Care, 41*(Supplement 1). https://doi.org/10.2337/dc18-S015

Azur, M. J., Stuart, E. A., Frangakis, C., & Leaf, P. J. (2011). Multiple imputation by chained equations: What is it and how does it work? *International Journal of Methods in Psychiatric Research*, *20*(1), 40-49. https://doi.org/10.1002/mpr.329

Bazzano, L. A., et al. (2008). Intake of fruit, vegetables, and fruit juices and risk of diabetes in women. *Diabetes Care*, 31(7), 1311-1317. https://doi.org/10.2337/dc08-0080

CDC. (2021). NHANES: Continuous NHANES Data Documentation. *Centers for Disease Control and Prevention*. Link.

Curtin, L. R., et al. (2012). The National Health and Nutrition Examination Survey: Sample design, 1999-2006. *Vital and Health Statistics*, *2*(155), 1-39.

Esposito, K., Chiodini, P., Colao, A., et al. (2012). Metabolic syndrome and risk of cancer: A systematic review and meta-analysis. *Diabetes Care*, *35*(11), 2402-2411. https://doi.org/10.2337/dc12-0336

Fakhouri, T. H. I., et al. (2013). Prevalence of obesity among older adults in the United States, 2007-2010. *NCHS Data Brief*, (106), 1-8.

Forouhi, N. G., et al. (2014). Dietary fat intake and risk of type 2 diabetes in the EPIC-InterAct Study. *The Lancet Diabetes & Endocrinology*, *2*(10), 801-811.

García-Pérez, L. E., et al. (2013). Adherence to therapies in patients with type 2 diabetes. *Diabetes Therapy*, *4*(2), 175-194. https://doi.org/10.1007/s13300-013-0034-y

Ghosh, A., Chakraborty, S., & Mukherjee, A. (2021). AI in healthcare: Improving diabetes management with mobile applications. *Journal of Medical Internet Research*, *23*(4).

Hu, F. B. (2002). Dietary pattern analysis: A new direction in nutritional epidemiology. *Current Opinion in Lipidology*, *13*(1), 3-9. https://doi.org/10.1097/00041433-200202000-00002

Johnson, E. J., et al. (2020). Protective effects of plant-based diets on diabetes: A meta-analysis. *Diabetologia*, *63*(1), 74-85.

Johnson, E. J., et al. (2020). Protective effects of plant-based diets on diabetes: A meta-analysis. *Diabetologia*, *63*(1), 74-85.

Kebede, S. S. (n.d.). Analysis of farmers' performance towards drought risk reduction for food security in Ethiopia: The case of Tigray. *Link*.

Knowler, W. C., et al. (2002). Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *New England Journal of Medicine*, *346*(6), 393-403. https://doi.org/10.1056/NEJMoa012512

Krass, I., et al. (2015). Adherence to diabetes medication and self-management behaviors. *Diabetes Medicine*, *32*(6), 725-732. https://doi.org/10.1111/dme.12651

Kuczmarski, M. F., et al. (2013). Validity of the medication adherence scale in the NHANES database. *Public Health Nutrition*, *16*(2), 207-214.

Ley, S. H., et al. (2014). Prevention and management of type 2 diabetes: Dietary components and nutritional strategies. *The Lancet*, *383*(9933), 1999-2007. https://doi.org/10.1016/S0140-6736(14)60613-9

Lind, P. M., & Lind, L. (2012). Endocrine-disrupting chemicals and risk of diabetes: An evidence-based review. *Diabetologia*, *55*(1), 43-51.

Malik, V. S., Popkin, B. M., Bray, G. A., et al. (2010). Sugar-sweetened beverages, obesity, type 2 diabetes mellitus, and cardiovascular disease risk. *Circulation*, *121*(11), 1356-1364. https://doi.org/10.1161/CIRCULATIONAHA.109.876185

Mozaffarian, D., et al. (2016). Population approaches to improve diet, physical activity, and smoking habits: A scientific statement from the American Heart Association. *Circulation*, *134*(10), e324-e345.

Mozaffarian, D., Hao, T., Rimm, E. B., et al. (2011). Changes in diet and lifestyle and long-term weight gain in women and men. *New England Journal of Medicine*, *364*(25), 2392-2404. https://doi.org/10.1056/NEJMoa1014296

National Cancer Institute. (2020). Dietary assessment primer. *Epidemiology and Genomics Research Program*. Link.

Neufussová, M. (n.d.). Lifestyle-related behaviour: An analysis of gender differences in the Czech Republic. *Link*.

O'Connor, L. E., et al. (2020). Health impacts of different dietary protein sources: Popular beliefs vs. scientific evidence. *Nutrients*, *12*(11), 3419. https://doi.org/10.3390/nu12113419

Olmo-García, L., et al. (n.d.). Establishing the phenolic composition of *Olea europaea* L. leaves from cultivars grown in Morocco. *Link*.

Pan, A., Sun, Q., Bernstein, A. M., et al. (2011). Red meat consumption and risk of type 2 diabetes: 3 cohorts of US adults and an updated meta-analysis. *American Journal of Clinical Nutrition*, *94*(4), 1088-1096. https://doi.org/10.3945/ajcn.111.018978

Qin, J., et al. (2012). A metagenome-wide association study of gut microbiota in type 2 diabetes. *Nature*, *490*(7418), 55-60.

Raman, R. K., et al. (n.d.). Time series forecasting model for fisheries in Chilika lagoon, Odisha, India: A case study. *Link*.

Salas-Salvadó, J., et al. (2011). Dietary patterns and cardiovascular risk in the PREDIMED study: Mediterranean diet and metabolic syndrome. *Progress in Cardiovascular Diseases*, *53*(1), 52-60.

Satija, A., Bhupathiraju, S. N., Spiegelman, D., et al. (2017). Healthful and unhealthful plant-based diets and the risk of coronary heart disease in U.S. adults. *Journal of the American College of Cardiology*, *70*(4), 411-422. https://doi.org/10.1016/j.jacc.2017.05.047

Shah, S., Patel, V., & Sharma, P. (2022). Predictive models for type 2 diabetes using machine learning techniques. *Frontiers in Big Data*, *5*, 853115.

Smith, R. M., et al. (2019). Whole grain intake and risk of type 2 diabetes. *American Journal of Clinical Nutrition*, *109*(6), 1410-1417.

Smith, R. M., et al. (2019). Whole grain intake and risk of type 2 diabetes. *American Journal of Clinical Nutrition*, *109*(6), 1410-1417.

Subar, A. F., et al. (2001). Comparative validation of the Block, Willett, and National Cancer Institute food frequency questionnaires: The Eating at America's Table Study. *American Journal of Epidemiology*, *154*(12), 1089-1099. https://doi.org/10.1093/aje/154.12.1089

Sun, Q., & Weaver, C. M. (2023). Micronutrient intake inadequacies and their health implications in type 2 diabetes. *Journal of Nutrition*, *153*(5), 1013-1022.

Tuomilehto, J., et al. (2001). Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *New England Journal of Medicine*, *344*(18), 1343-1350. https://doi.org/10.1056/NEJM200105033441801

U.S. Department of Health and Human Services. (2018). *Physical activity guidelines for Americans* (2nd ed.). Washington, DC: U.S. Government Printing Office.

Van Buuren, S., & Groothuis-Oudshoorn, K. (2011). MICE: Multivariate imputation by chained equations in R. *Journal of Statistical Software*, *45*(3), 1-67. https://doi.org/10.18637/jss.v045.i03

Wang, L., Xu, H., & Lu, Z. (2022). AI-powered tools for enhancing lifestyle modification in diabetes prevention. *Frontiers in Medicine*, *9*, 853401.

Wen, Z., et al. (n.d.). Distinct nasopharyngeal and oropharyngeal microbiota of children with influenza A virus compared with healthy children. *Link*.

White, I. R., Royston, P., & Wood, A. M. (2011). Multiple imputation using chained equations: Issues and guidance for practice. *Statistics in Medicine*, *30*(4), 377-399. https://doi.org/10.1002/sim.4067

World Health Organization. (2012). Global physical activity questionnaire (GPAQ): WHO surveillance of physical activity. *World Health Organization*. Link.

Xu, Y., Liu, Q., & Zhang, X. (2023). Virtual health coaches: The future of diabetes self-management education and support. *Journal of Medical Internet Research*, *25*.

Zhang, Y., Chen, Y., Huang, H., et al. (2020). Dietary patterns and the risk of chronic diseases in US adults: An analysis of NHANES 2013-2016 data. *Public Health Nutrition*, *23*(1), 113-121.

Zhu, Y., et al. (2018). Trends in diet quality among adults in the United States, 1999 through 2010. *JAMA Internal Medicine*, *178*(4), 540-548.