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Relationship Between Physical Activity Levels and Type 2 Diabetes in Adults: Zahedan Adult Cohort Study, Iran

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Keywords: Persian Cohort | physical activity | type 2 diabetes mellitus

ABSTRACT

Background: Given the influence of lifestyle on type 2 diabetes mellitus (T2DM), the present study aimed to investigate the association between physical activity (PA) intensity and T2DM among sedentary and active participants in the Zahedan Adult Cohort Study (ZACS), Iran.

Methods: This cross-sectional study was conducted as part of the population-based Persian Prospective Epidemiological Research Studies in Iran (Persian Cohort). The baseline data from the ZACS collected between 2015 and 2019 were utilized. A total of 10,004 adults aged 35–70 years were included in the analysis. Data were gathered through self-reported questionnaires covering general information, socioeconomic status, sleep status, medical history, and PA. Anthropometric measurements and biochemical parameters were obtained from participants after a 12-h fasting period. The data were analyzed using descriptive statistics, independent-sample *t*-test, chi-square, and logistic regression tests in SPSS22.

Results: The study found that the majority of the 10,004 adult participants (81.2%) were sedentary, while only 18.8% were classified as active. Sedentary participants exhibited significantly higher mean values for various health markers, including age, education, sleep duration, weight, body mass index (BMI), and blood lipid levels, as well as higher prevalence of hypertension, cardiac conditions, and stroke compared to active participants. Additionally, 21.7% of the participants had T2DM, which was associated with older age, longer sleep duration, higher weight and BMI, and abnormal waist circumference. The prevalence of diabetes increased with higher BMI, from 4.8% in underweight to 27.1% in obese participants, and was 77% in sedentary individuals compared to 16% in active individuals. Even after adjusting for demographic factors (OR = 0.65, $p < 0.001$), lipid levels (odds ratio [OR] = 0.68, $p = 0.001$), sleep status (OR = 0.72, $p = 0.001$), and family history (OR = 0.66, $p = 0.001$), active individuals were found to have a significantly lower likelihood of being diabetic compared to their sedentary counterparts.

Conclusions: The findings revealed a clear association between sedentary lifestyles and an increased risk of T2DM. Physical inactivity was correlated with adverse health markers and an elevated incidence of T2DM, which was mitigated by an active lifestyle. These results underscore the importance of public health initiatives to promote PA as a critical strategy for diabetes prevention.

1 | Introduction

Diabetes, characterized by dysregulation in insulin secretion, insulin resistance, or both, represents one of the major global health concerns. This metabolic disorder affects the metabolism of proteins, lipids, and carbohydrates [1]. Beyond the well-known classifications of type 2 (late-onset, non-autoimmune) and type 1 (autoimmune) diabetes, there are additional variations, including late-onset autoimmune diabetes, gestational diabetes, and neonatal diabetes [2].

Type 2 diabetes is characterized by elevated blood glucose levels, which can arise due to impaired insulin secretion, decreased glucose uptake by the liver and peripheral tissues, or a combination of these factors [3]. This condition is associated with a significant risk of reduced bone density [4], muscle loss [5], physical dysfunction, and metabolic abnormalities [6] in adulthood. Consequently, older adults have a higher propensity for developing diabetes and other metabolic disorders compared to younger individuals [7].

In 2019, 11% of individuals aged 20–79 years had diabetes, with a projected significant increase by 2040 [8]. The prevalence of diabetes, the fifth leading cause of mortality globally, has more than doubled over the past three decades [3]. Type 2 diabetes has a genetic component, but the two primary drivers of this epidemic are unhealthy dietary patterns and physical inactivity [9–11].

Consequently, exercise and lifestyle modifications are two powerful strategies to lower blood glucose levels and prevent diabetes. Research has indicated that physical activity (PA) and resistance exercise can effectively reduce the incidence of this condition [12–14]. Additionally, obesity, a result of modern sedentary employment and lifestyles, is linked to a rise in type 2 diabetes. As such, physical inactivity is the primary cause of the disease's increasing prevalence [15–17]. Reducing inactivity and engaging in regular PA (e.g., walking or light resistance exercises) in adult patients with diabetes can lower blood pressure, BMI, waist circumference, and postprandial glucose, insulin, C-peptide, and triglyceride levels [18, 19].

While diabetes itself cannot be genetically altered, type 2 diabetes mellitus (T2DM) can be prevented through proper lifestyle management. Obesity markers of particular significance in epidemiological studies include waist circumference, neck circumference, waist-to-hip ratio, and height-to-waist ratio [20, 21].

Waist circumference is the most accurate indicator of total and abdominal fat. In fact, BMI cannot be used as a measure of overweight in all individuals, as it can be influenced by muscle mass. Since waist circumference is a more precise measure of body fat distribution, it can more accurately predict diabetes complications and mortality risk [20, 22–24].

The issue of metabolic risk factors and their association with PA has gained significant attention in the scientific community. Recently, the waist-to-height ratio (WHtR) has emerged as a potentially more effective screening index for metabolic risk factors in adults, surpassing the traditional measures of waist circumference and body mass index (BMI). This development underscores the need for a comprehensive understanding of the relationship between PA and the risk of T2DM.

The present study aimed to examine the association between the intensity of PA and the risk of T2DM in adults. This investigation is particularly relevant, as a healthy lifestyle, including regular PA, plays a crucial role in the prevention of T2DM. By exploring the interplay between WHtR, PA, and T2DM risk, the study sought to provide insights that could inform more effective strategies for the management and prevention of this prevalent metabolic disorder.

2 | Methods

2.1 | Study Design

The present study is a cross-sectional investigation based on initial data from the enrollment phase of the cohort study in the adult population participating in the cohort study in the city of Zahedan, which was sampled using a multi-stage stratified sampling method. In the sampling method of the Zahedan cohort study (ZACS), the city of Zahedan was initially divided into three regions (suburb, city center, and upper city) based on municipal areas and socioeconomic classes. Next, a comprehensive health services center was randomly selected from within the classes. In the next stage, clusters were selected from each center, and all individuals aged 35–70 in each household who met the inclusion criteria and did not meet the exclusion criteria were included in the study. The ZACS is part of the prospective epidemiological studies in Iran. A total of 10,004 individuals aged 35–70 years participated in the study. Entry to the study and data collection were carried out between October 2015 and January 2019 in Zahedan. The study protocol and objectives were previously [25].

Rigorous ethical protocols were upheld throughout the course of the study. Before partaking in the research, all participants provided informed written consent and were made explicitly aware of their right to withdraw their involvement at any time. Additionally, stringent measures were implemented to safeguard participant confidentiality and ensure the protection of the data collected. Furthermore, the study protocol was reviewed and approved by the ethics committee at Zahedan University of Medical Sciences (IR.ZAUMS.REC.1402.110).

2.2 | Measurements

Measurements included the use of previously validated questionnaires from the PERSIAN cohort study [26], covering general information, socioeconomic status, personal habits, medical history, PA, sleep, and rest. Questionnaires were collected through self-report, and then all the information recorded during the assessments was rechecked by general physician, qualitative supervisor, and after final confirmation, recorded. Participants' PA levels were classified as either low (< 41 METs) or high (≥ 41), determined by their 24-h activity level and the metabolic equivalent task (MET) index [27].

Anthropometric measurements were performed in the morning while participants were in a fasted state. Weight was assessed using a calibrated standing scale, Seca 786 that was checked daily with a 10 kg weight. Participants were instructed to remove any bulky or heavy clothing, as well as shoes, bags, and phones, and to stand on the scale with their hands at their sides, remaining still. Weight measurements were recorded in kilograms. For height measurement with Seca 203 tape measure, participants were asked to remove their shoes, sandals, headwear, clips, or hair accessories. They stood in front of the researcher with their legs together, heels against the wall, knees straight, and their gaze directed straight ahead without tilting their heads. The measuring rod was lowered to the top of the participant's head, and height was recorded in centimeters. To measure waist circumference, participants stood with their legs together, hands at their sides, palms facing inward, and exhaled slowly. The waist size was measured at the top of the hip bone and recorded to the nearest 0.1 cm. Similarly, for hip circumference measurement, participants removed items such as wallets and belts. They stood with equal weight distribution on both legs, hands at their sides, palms facing inward, and exhaled slowly. The measurement was taken at the position of the maximum hip circumference and recorded to the nearest 0.1 cm.

Sampling was conducted after a 12-h fast, during which participants were advised to avoid consuming fruit juices, tea, coffee, tobacco, alcohol, caffeine, energy drinks, gum, peppermint tablets, and similar flavorings, high-fat foods, intramuscular injections, physical exercise, and strenuous activities. Sampling was performed in a resting state, and 5 min after activity, a blood draw of 5 mL was taken.

2.3 | Statistical Analysis

Data were analyzed in $SPSS_{22}$ by using descriptive and analytical statistical test such as independent-samples *t*-test, chi-square, and logistic regression test. The relationship between PA and diabet was adjusted for age, education, TG, CHOL, sleep duration 24 h, sleep duration in the middle of the day, rest, family history of diabetes in first and second degree relatives by logistic regression model. Statistical significance was considered at $p < 0.05$.

3 | Results

The majority of the 10,004 adult participants, accounting for 81.2% ($n = 8123$), were categorized as sedentary, while the remaining 18.8% ($n = 1881$) were classified as active. Sedentary participants exhibited significantly higher mean values for age, educational attainment, nighttime sleep duration, midday napping, time spent lying down without sleep, weight, waist circumference, hip circumference, BMI, waist-hip ratio, fasting blood sugar (FBS), triglycerides (TG), and cholesterol, compared to their active counterparts ($p < 0.05$). Additionally, the prevalence of hypertension, cardiac ischemia, Myocardial Infarction, and stroke was notably higher among the sedentary individuals compared to the active participants (Table 1).

According to the study, 2175 (21.7%) of the participants had T2DM. The mean age, midday sleep duration, 24-h rest duration, weight, waist circumference, hip circumference, BMI, waist-to-hip ratio, FBS, and TG levels were notably higher in individuals with diabetes compared to those without. Furthermore, the prevalence of diabetes was considerably higher among female participants, as well as in those who were widowed or had a deceased spouse. Additionally, individuals with a family history of diabetes among first- and second-degree relatives also exhibited a higher frequency of the condition (Table 2).

There was an increasing trend of diabetes based on BMI. The prevalence of diabetes increased from 4.8% in underweight individuals to 27.1% in obese participants (Figure 1). Furthermore, this prevalence was 15.3 in people with a normal waist circumference compared to 26.6% in participants with abnormal circumference (Figure 2).

The prevalence of diabetes was 77% in sedentary individuals and 16% in active individuals. The unadjusted and adjusted odds ratios for the relationship between activity and diabetes are presented in Table 3. Active individuals were found to have a lower likelihood of being diabetic (Model 1: OR = 0.62, $p < 0.001$). The odds of diabetes were significantly lower in active individuals after adjusting for demographic factors (Model 2: OR = 0.65, $p < 0.001$), TG and cholesterol levels (Model 3: OR = 0.68, $p = 0.001$), sleep status (Model 4: OR = 0.72, $p = 0.001$), and family history of diabetes (OR = 0.66, $p = 0.001$).

4 | Discussion

PA refers to all bodily movements that contribute to energy expenditure, blood glucose control, reduction of cardiovascular risk factors, and weight loss [28]. Multiple studies have confirmed the direct relationship between increased PA and a reduced incidence of type 2 diabetes [28–31]. In the present study, physical inactivity was found to be an important factor in the development of Myocardial Infarction, hypertension, and ischemic heart disease.

These findings are consistent with the work of Soares-Miranda et al., who reported that increased leisure-time activity, walking, and exercise intensity were significantly associated with reduced risk of stroke (particularly ischemic stroke) and coronary heart disease in American men and women (mean age 73 years) [32]. Similarly, Kim et al. found a significant link between PA and reduced risk of type 2 diabetes, hypertension, and stroke [33].

In contrast, a recent Mendelian randomization analysis by Doherty et al. investigated the potential relationships between sedentary behavior, PA measured by devices, and conditions such as heart failure, hypertension, coronary artery disease, stroke, and body fat percentage [34]. The differences in the findings may be attributed to variations in the definitions and assessments of PA and inactivity.

According to the findings of this study, sedentary individuals exhibited higher levels of cholesterol, blood glucose, blood lipids, weight gain, waist circumference, waist-to-hip ratio, and

TABLE 1 | Descriptive characteristics of participants based on physical activity level.

Variable		Physical activity level: Sedentary (< 41) Mean ± SD	Active (≥ 41) Mean ± SD	p-value[a]
Age		50.78 ± 9.19	49.03 ± 9.01	0.001
Education years		6.99 ± 5.35	5.82 ± 4.75	0.001
Socioeconomic status		0.06 ± 0.97	0.25 ± 1.05	0.001
Night sleep duration (h)		7.27 ± 1.67	6.37 ± 1.50	0.001
Mid-day napping (min)		0.69 ± 0.82	0.44 ± 0.66	0.001
Laying down without falling asleep (h)		1.66 ± 1.47	1.16 ± 0.92	0.001
Height (cm)		161.80 ± 10.25	161.75 ± 8.91	0.833
Weight (kg)		72.03 ± 14.70	69.14 ± 13.62	0.001
Waist circumference (cm)		96.31 ± 12.64	93.58 ± 12.21	0.001
Hip circumference (cm)		101.69 ± 10.26	99.99 ± 9.53	0.001
Body mass index		27.48 ± 5.35	26.45 ± 4.91	0.001
Waist–hip ratio		0.94 ± 0.07	0.93 ± 0.07	0.001
Fast blood sugar		106.13 ± 43.85	99.58 ± 35.84	0.001
Triglyceride		147.95 ± 92.63	129.35 ± 91.57	0.001
Cholesterol		182.95 ± 40.09	181.20 ± 37.91	0.085
Variable		***n* (%)**	***n* (%)**	***p*-value[b]**
Gender	Male	3181 (81.2)	736 (18.8)	0.486
	Female	4950 (81.2)	1149 (18.8)	
Marital status	Single	147 (84.5)	27 (15.5)	0.182
	Married	7150 (80.9)	1691 (19.1)	
	Widowed	706 (83.1)	144 (16.9)	
	Divorced	126 (84.6)	23 (15.4)	
Hypertension	Yes	2219 (86.5)	346 (13.5)	0.001
	No	5912 (79.3)	1539 (20.7)	
Cardiac Ischemic	Yes	813 (88.9)	101 (11.1)	0.001
	No	7318 (80.4)	1784 (19.6)	
Miocardial Infarction	Yes	293 (91.3)	28 (8.7)	0.001
	No	7838 (80.8)	1857 (19.2)	
Stroke	Yes	141 (90.4)	15 (9.6)	0.002
	No	7990 (81.0)	1870 (19.0)	

Note: $p < 0.05$ significant.
[a]The results of Independent-samples *t*-test.
[b]The results of chi-square exam.

BMI compared to their physically active counterparts. These results are consistent with the study by Selashhour et al., which examined the impact of a multidisciplinary program on biochemical and anthropometric parameters in overweight and obese elementary school students (girls). The intervention group demonstrated significant improvements in the investigated parameters, including triglycerides, blood glucose, weight loss, waist and hip circumference, and cholesterol levels, compared to the control group.

Furthermore, another study involved an 8-week exercise intervention program (3 days per week, 1 h per day) for the intervention group [35]. In addition to improvements in vaspin levels and weight loss, the intervention group also experienced positive changes in BMI, waist circumference, body fat percentage, fat mass, fat-free mass, total cholesterol, fasting blood glucose, and insulin levels. However, the intervention group did not exhibit significant changes in waist-to-hip ratio, triglycerides, HOMA-IR (homeostatic model assessment of insulin resistance), and QUICKI (quantitative insulin sensitivity check index) [36].

Furthermore, the sedentary participants exhibited a higher rate of midday napping, lying down without sleeping, and longer

TABLE 2 | Descriptive characteristics of participants base on type 2 diabetes mellitus.

Variable		Type 2 diabetes mellitus No Mean ± SD	Type 2 diabetes mellitus Yes Mean ± SD	*p*-value[a]
Age		49.18 ± 9.09	55.01 ± 8.00	0.001
Education years		7.06 ± 5.22	5.72 ± 5.30	0.001
Socioeconomic status		0.00 ± 1.00	0.16 ± 0.97	0.504
Night sleep duration (h)		7.13 ± 1.66	7.00 ± 1.73	0.002
Mid-day napping (min)		0.62 ± 0.79	0.73 ± 0.85	0.001
Laying down without falling asleep (h)		1.48 ± 1.32	1.89 ± 1.63	0.001
Height (cm)		162.06 ± 9.44	160.82 ± 11.76	0.001
Weight (kg)		70.69 ± 14.52	74.33 ± 14.26	0.001
Waist circumference (cm)		94.53 ± 12.60	100.36 ± 11.52	0.001
Hip circumference (cm)		101.10 ± 10.09	102.37 ± 10.28	0.001
Body mass index		26.92 ± 5.28	28.61 ± 5.10	0.001
Waist–hip ratio		0.93 ± 0.07	0.98 ± 0.06	0.001
Fast blood sugar		90.72 ± 11.02	160.03 ± 67.46	0.001
Triglyceride		135.41 ± 84.15	177.03 ± 112.65	0.001
Cholesterol		183.11 ± 37.88	180.87 ± 45.61	0.020
Variable		***n* (%)**	***n* (%)**	***p*-value[b]**
Gender	Male	3115 (79.5)	802 (20.5)	0.008
	Female	4726 (77.5)	1373 (22.5)	
Marital status	Single	158 (90.8)	16 (9.2)	0.001
	Married	6961 (78.7)	1880 (21.3)	
	Widowed	598 (70.4)	252 (29.6)	
	Divorced	123 (82.6)	26 (17.4)	
Family history of diabetes in a first-degree relative	No	5258 (84.5)	968 (15.5)	0.001
	Yes	2582 (68.1)	1207 (31.9)	
Family history of diabetes in a second-degree relative	No	6381 (79.0)	1695 (21.0)	0.001
	Yes	1459 (75.2)	480 (24.8)	

Note: $p < 0.05$ significant.
[a]The results of Independent-samples *t*-test.
[b]The results of chi-square exam.

nighttime sleep duration. These behavioral patterns have been reported in other studies involving sedentary individuals [37–39]. According to the World Health Organization (WHO) report, physical inactivity is the fourth leading cause of death globally. Considering the increasing prevalence of physical inactivity and its detrimental consequences, such as elevated blood glucose, high blood pressure, overweight, and obesity, PA is considered a suitable and cost-effective solution for their prevention [40].

The study by Al-Abri et al. found no significant differences in daytime insomnia and napping between the control and intervention groups of type 2 diabetes patients. However, the diabetic patients had considerably higher BMI, fasting glucose, and triglyceride levels, as well as lower total cholesterol and low-density lipoprotein levels compared to the controls. High-density lipoprotein levels were similar between the intervention and control groups [41]. Multiple investigations have reported a high prevalence of these variables in individuals with type 2 diabetes, demonstrating increased BMI, waist circumference, waist-hip ratio, and fasting blood glucose in this patient population [42, 43]. This study demonstrates a distinct positive correlation between elevated BMI and increased waist circumference, and a greater probability of developing diabetes. The findings indicate that the prevalence of diabetes rose markedly as body weight and abdominal adiposity escalated.

It is important to note that efficiency and practicality are two crucial features of screening, as BMI, which is calculated using weight and height, may not accurately reflect the distribution of fat in an individual, such as the difference between general obesity and abdominal obesity. It has been recognized that individuals with similar BMI may have different waist circumferences. Given that individuals with abdominal obesity are at a

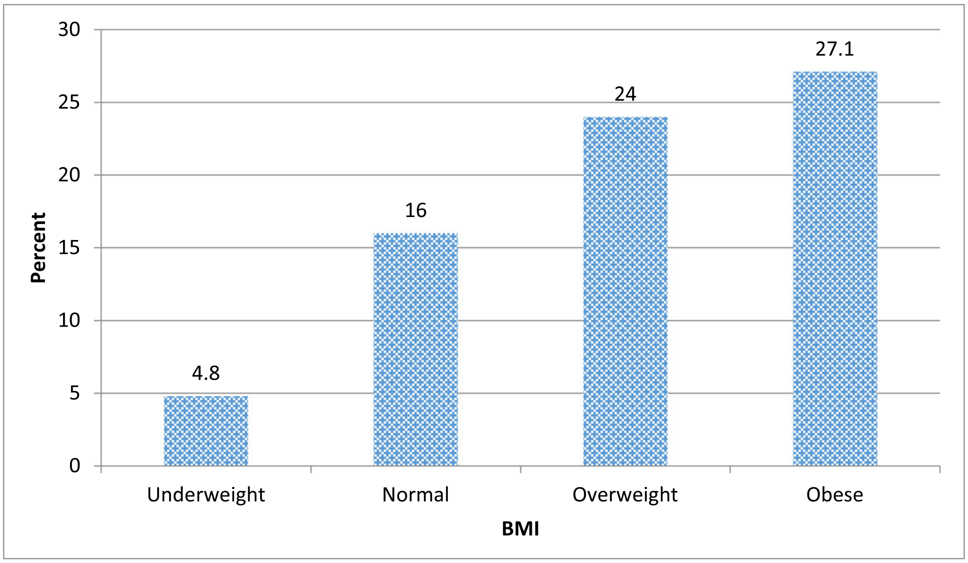

FIGURE 1 | Prevalence of diabetes based on BMI.

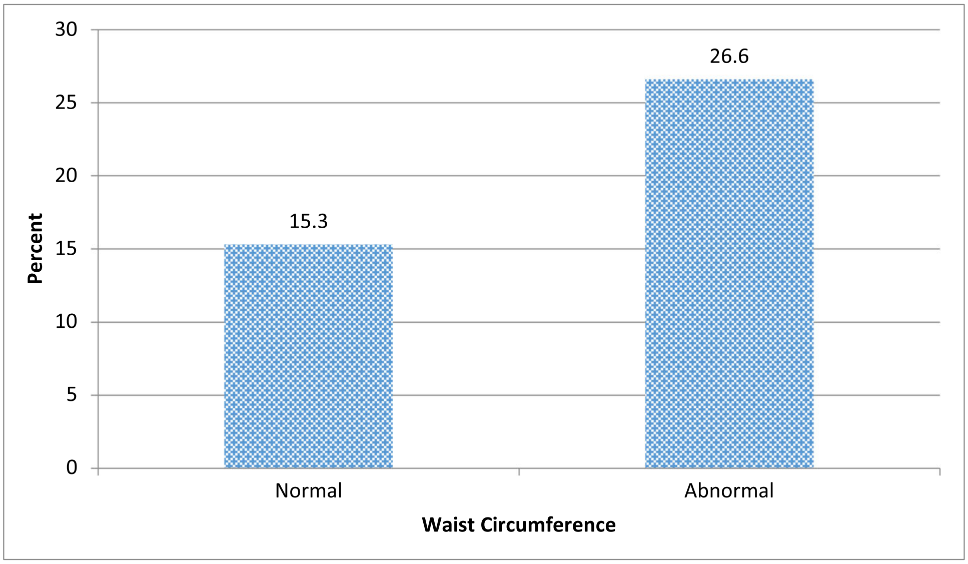

FIGURE 2 | Prevalence of diabetes based on waist circumference.

TABLE 3 | Crude and adjusted odds ratio of physical activity in people with type 2 diabetes mellitus.

	OR (active vs. sedentary)	95% CI	*p*-value*
Model 1	0.62	(0.53–0.71)	< 0.001
Model 2	0.65	(0.56–0.76)	< 0.001
Model 3	0.68	(0.60–0.78)	0.001
Model 4	0.72	(0.62–0.82)	0.001
Model 5	0.66	(0.58–0.76)	0.001

Note: Model 1: Unadjusted. Model 2: Adjusted for age and education. Model 3: Adjuster for TG and CHOL. Model 4: Adjuster for sleep duration 24 h, sleep duration mid-day and rest 1. Model 5: Adjuster for FH1_Diabetes and FH2_Diabetes.
*$p < 0.05$ significant.

higher risk of cardiovascular diseases and hypertension, measuring waist circumference and the waist-to-hip ratio is an essential criterion [43].

This comprehensive study highlights a significant association between sedentary lifestyle and increased risk of T2DM in the study population. Sedentary individuals exhibited higher mean values for age, education, sleep duration, and anthropometric measurements, as well as a staggering 77% prevalence of diabetes, compared to 16% in active participants. Multivariate analyses further confirmed the protective effect of PA against diabetes risk.

The strengths of the current study included its large sample size, which encompassed the Sistani and Baloch populations in southeastern Iran, as well as the use of a community-based, multi-stage cluster sampling method. However, the cross-sectional design was unable to establish causality. However, the study had several limitations, such as the absence of hemoglobin Ac measurements, reliance on self-reported questionnaires, and a specific focus on an urban population.

5 | Conclusion

In conclusion, the findings underscore the need for public health interventions to promote active lifestyles as a formidable approach to combat the rising tide of diabetes and associated conditions. Targeted strategies addressing both lifestyle and genetic vulnerabilities, particularly among females, bereaved individuals(those with a deceased spouse), and those with family history, are warranted. Prioritizing PA in T2DM prevention and management policies can help reduce the burden of this chronic disease and its complications.

These results emphasize the urgency for public health interventions to increase PA levels in the general population, which could potentially lower the prevalence of non-communicable diseases like T2DM and improve overall population health. Key public health recommendations for addressing sedentary behavior and the T2DM crisis include: Developing national awareness campaigns to educate the public on the importance of regular PA for disease prevention and health promotion. Expanding access to PA resources and infrastructure, such as public parks, recreational facilities, and active transportation options, to enable greater participation. Implementing workplace wellness initiatives that encourage and facilitate PA among employees. Strengthening cross-sectoral collaboration between the health, education, urban planning, and transportation sectors to create environments that support active lifestyles. Enhancing monitoring and evaluation systems to track progress, identify gaps, and inform the continuous improvement of PA promotion strategies.

Author Contributions

Tahereh Dehdari: conceptualization, investigation, writing – review and editing. **Fariba Shahraki-Sanavi:** writing – original draft, conceptualization, methodology, validation, visualization, writing – review and editing, software, formal analysis, project administration, data curation, supervision, resources, investigation. **Amir Nasiri:** conceptualization, investigation, writing – original draft, writing – review and editing. **Roghayeh Nouri:** writing – original draft, writing – review and editing. **Alireza A. Moghaddam:** methodology, data curation, writing – review and editing, conceptualization, investigation, supervision, resources, project administration. **Mahdi Mohammadi:** methodology, software, formal analysis, data curation, writing – review and editing, conceptualization, investigation, validation, resources, visualization.

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Ethics Statement

While each cohort center received the ethical approval from local universities, for the purpose of this study and pooling all PERSIAN data, the ethics committee of zahedan University of Medical Sciences approved the study (IR.ZAUMS.REC.1402.110).

Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Transparency Statement

The lead author Fariba Shahraki-Sanavi, Amir Nasiri affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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