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ORIGINAL ARTICLE

# Importance of assessing erectile dysfunction in patients with type 2 diabetes mellitus based on glucose fluctuation: a Cross-Sectional study

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## Abstract

**Purpose** To investigate the relationship between glucose fluctuation and erectile dysfunction (ED) in patients with type 2 diabetes mellitus (T2DM).

**Methods** This cross-sectional study included 317 male patients with T2DM. Participants were categorized into non-ED group (76 cases) and ED group (241 cases) based on International Index of Erectile Function-5 (IIEF-5) scores. Patients were additionally segmented into quartiles based on time in range (TIR). Demographic and laboratory data were collected, and glucose fluctuation indicators were ascertained using flash glucose monitoring.

**Results** The ED group exhibited significantly lower TIR and IIEF-5 scores compared to the non-ED group ($P < 0.05$). An increase in TIR levels corresponded with higher IIEF-5 scores and a significant reduction in ED incidence ($P < 0.05$). Spearman's correlation analysis indicated a positive correlation between IIEF-5 scores and TIR ($r = 0.48$, $P < 0.01$). Restricted cubic spline analysis revealed a negative linear association between TIR and ED (P for linearity <0.05). Multivariate logistic regression analysis, after adjusting for confounding factors, confirmed that low TIR is an independent risk factor for ED ($P < 0.05$).

**Conclusion** Glucose fluctuation in T2DM patients correlate with ED, with low TIR being independently and positively associated with ED incidence, suggesting it may be a significant risk factor for ED in patients with T2DM.

**Keywords** Erectile dysfunction · Type 2 diabetes mellitus · Continuous glucose monitoring · Glucose fluctuation · Time in range

## Introduction

The prevalence of diabetes is on the rise, with approximately 340 million people worldwide currently affected by the condition, projected to exceed 600 million by 2040 [1]. The global prevalence of diabetes has escalated from 4.7% in 1980 to 8.5% in 2014, with 95% of adult patients diagnosed with type 2 diabetes mellitus (T2DM) [2, 3]. The increasing standard of living, coupled with modern society's unhealthy lifestyle and dietary habits, has made T2DM and its complications a pervasive global health issue, jeopardizing human well-being.

Erectile dysfunction (ED) is defined as the incapacity to achieve or maintain an adequate penile erection for satisfactory sexual performance [4]. Compared to the general population of the same age, ED occurs earlier and is significantly more prevalent among individuals with diabetes [5]. A meta-analysis indicates that the overall prevalence of ED in male

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patients with this condition is 57.7%. Specifically, the prevalence rates are 37.5% in men with type 1 and 66.3% in men with type 2, which is 3.5 to 5 times higher than in those without the condition [6]. ED significantly impacts the quality of life of patients with diabetes. A research has found close relationships between ED and health literacy, antihyperglycemic drugs, psychological states, and treatment adherence [7], highlighting the importance of improving health literacy to make appropriate health decisions and enhance treatment compliance. Another prospective study suggests that antihyperglycemic drugs and diet may have a positive impact on ED, with GLP-1 receptor agonists showing better efficacy in improving ED compared to insulin [8].

Continuous glucose monitoring (CGM) provides continuous glucose status over several days. Flash glucose monitoring (FGM) continuously tracks interstitial glucose levels for up to 14 days [9], offering glucose fluctuation indicators including time in range (TIR), glucose coefficient of variation (CV), blood glucose standard deviation (SD), mean amplitude of glycemic excursions (MAGE), and the largest amplitude of glycemic excursions (LAGE). TIR represents the percentage of time glucose levels are within the target range (typically 3.9–10.0 mmol/L) [10]. In 2019, the American Diabetes Association included TIR as a metric for evaluating glucose fluctuations, and it was officially recommended for glycemic management in 2020 [11, 12].

Although global studies have analyzed the risk factors for ED in patients with diabetes [13], research on the relationship between glucose fluctuations and ED is scarce. This study aims to explore the correlation between TIR and ED in patients with T2DM.

## Subjects and methods

### Study subjects

This study included 317 male T2DM patients admitted to the Endocrinology Department of the Second People's Hospital of Hefei City from February 2023 to February 2024, who wore Abbott's flash glucose monitoring devices. Inclusion criteria included: (1) conformity with the 1999 World Health Organization diagnostic criteria for T2DM [14]; (2) married males; (3) having a regular sexual partner. Exclusion criteria included: (1) obvious genital anatomical deformities, spinal cord injuries, pelvic fractures, perineal and penile trauma, and other surgical histories that may cause ED; (2) patients with acute complications of diabetes, such as diabetic ketoacidosis, hyperosmolar coma, lactic acidosis, etc.; (3) recent use of medications that may affect erectile function. All patients provided informed consent, and the study was approved by the hospital's ethics committee, adhering to the principles of the Helsinki Declaration.

## Research methods

### Collection of clinical data

Demographic information such as age, diabetes duration, body mass index (BMI), diabetes complications, hypertension, cerebral infarction (CI), smoking and drinking, were collected. Laboratory tests included fasting blood glucose (FBG), glycated hemoglobin (HbA1c), total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL), low-density lipoprotein cholesterol (LDL), serum uric acid (UA), serum creatinine (Scr), urine albumin/creatinine ratio (UACR), 25 (OH)D, and testosterone (T).

### Ambulatory glucose monitoring

All patients wore the FreeStyle Libre flash glucose monitoring system. Glucose fluctuation indicators generated by the FGM over 14 days, including MG, TIR, CV, SD, MAGE, LAGE, were recorded and averaged.

### Erectile function assessment

The International Index of Erectile Function questionnaire(IIEF-5) [15] was distributed to male T2DM patients undergoing ambulatory glucose monitoring with FGM. After explaining the purpose and significance of the survey, patients voluntarily completed the questionnaire. The IIEF-5 consists of 5 questions, each with a maximum score of 5, for a total maximum score of 25. The questionnaire assesses patients' confidence in achieving and maintaining an erection, erectile function status, and overall satisfaction with sexual life. A total score below 22 indicates the presence of erectile dysfunction, while 22 or above indicates normal erectile function. Patients were divided into observation (IIEF-5 < 22) and control groups (IIEF-5 ≥ 22) based on the questionnaire scores.

### Diagnostic criteria for diabetes complications

According to the diagnostic criteria of diabetes complications in the guideline for the prevention and treatment of type 2 diabetes mellitus in China [16], diabetic retinopathy (DR), diabetic peripheral neuropathy (DPN), and diabetic peripheral vascular disease (PVD) were screened according to fundus photography, electro neurophysiology examination, carotid and lower extremity arterial ultrasound.

## Statistical methods

All statistical analyses were conducted by R Studio, version 4.3.0 (R Foundation for Statistical Computing). After performing the Kolmogorov-Smirnov test on all quantitative

data, it was found that none of the datasets conform to a normal distribution. Therefore, the data are presented as median and interquartile spacing [M (P25, P75)], and the comparison between the two groups used the Mann-Whitney U test. Categorical data are presented as cases (percentage) [n (%)], and chi-squared tests were used to compare groups.Based on the baseline TIR quartiles, the study participants were divided into four groups. Non-normally distributed data were expressed as median and interquartile spacing [M (P25, P75)], and comparisons between groups used the Kruskal-Wallis test. Categorical data are presented as cases (percentage) [n (%)], and chi-squared tests were used to compare groups.Spearman's correlation analysis was used to assess the correlation between IIEF-5 scores and glucose fluctuation indicators. Multiple logistic regression analysis was used to calculate odds ratios (ORs) to determine the association between TIR and ED. Restricted cubic spline curves were used to describe the dose-response relationship between TIR and the risk of ED. Receiver operating characteristic (ROC) curves were plotted to analyze the predictive value of TIR for ED, and the Youden index was used to determine the sensitivity and specificity of the predictive factors. Based on previous studies [17, 18], subgroup analysis was performed on age, 25(OH)D, testosterone, and BMI to analyze the impact of TIR on the incidence of ED in different subgroups of participants. A two-sided P-value < 0.05 was considered statistically significant.

## Results

Comparison of General Information (Table 1): Among the 317 T2DM patients, 241 were in the ED group, and 76 in the non-ED group. The ED group had significantly higher age, diabetes duration, HbA1c, TG, 25(OH)D, testosterone, and MG compared to the non-ED group, while TIR and IIEF-5 scores were lower. The differences in the incidence of cerebral infarction history and diabetic peripheral neuropathy between the two groups were statistically significant (P < 0.05).

Baseline Information Comparison Based on TIR Quartiles (Table 2): Participants were evenly divided into four groups based on TIR quartiles: Q1 group (≤63.41%), Q2 group (63.42–75.64%), Q3 group (75.65–86.96%), and Q4 group (≥86.97%). As shown in Table 2, there were statistically significant differences in FBG, HbA1c, TC,LDL, Scr,UA, 25(OH)D, MG, SD, MAGE, LAGE, CV among the four groups (P < 0.05), with higher prevalence of diabetic peripheral vascular disease in groups with lower TIR (P < 0.05). The prevalence of ED decreased as TIR increased (94.94, 79.75, 74.68, 55.00% respectively).

Multivariate Logistic Regression Analysis of Erectile Dysfunction in T2DM Patients (Table 3): With the presence or absence of ED (yes = 1, no = 0) as the dependent variable, and the variables with P < 0.05 in Table 1 as the independent variables, a multivariate logistic regression analysis was performed. In Model 1, without adjusting for variables, the prevalence of ED was lower in the other three groups compared to the reference quartile group (P < 0.01). In Model 2, after multivariable adjustment for age, diabetes duration, hypertension, cerebral infarction, smoking, drinking, it was found that the prevalence of ED was negatively correlated with TIR (P < 0.01). In Model 3, further adjustment for BMI, UACR, 25(OH)D, HbA1c, T, DR, DPN, PVD confirmed the negative correlation between ED prevalence and TIR, with ORs (95% CI) of 1.00 (Reference), 0.21 (0.06–0.80), 0.19 (0.05–0.72), and 0.07 (0.02–0.29) respectively (P < 0.05).

Correlation Analysis of IIEF-5 Scores with Glucose Fluctuation Indicators (Fig. 1): Spearman's correlation analysis revealed a negative correlation between IIEF-5 scores and MG (r = −0.18, P < 0.01), SD (r = −0.11, P = 0.043), and a significant positive correlation with TIR (r = 0.48, P < 0.01).

Restricted Cubic Spline Analysis of TIR and ED Prevalence (Fig. 2): Restricted cubic spline curves were used to describe the dose-response relationship between TIR and the adjusted odds ratio for ED. A negative linear association between TIR and ED was observed (P for linearity <0.05).

ROC Curve Analysis of the Diagnostic Value of TIR for Erectile Dysfunction in T2DM Patients (Fig. 3 and Table S1): The study utilized ROC curve analysis to elucidate the predictive value of TIR for ED. The AUC for TIR's predictive value for ED was 0.72 [95% CI (0.66–0.79)], with the highest predictive value at a cutoff of 77.76. This indicates that TIR has good diagnostic and predictive value for ED in T2DM patients.

Subgroup Analyses and Interactions (Fig. 4 and Table S2): After stratification by age (<50 or ≥50), 25(OH)D (<30.00 ng/mL or ≥30.00 ng/mL), testosterone (median split), BMI (<25 kg/m$^2$or ≥25 kg/m$^2$), the results between TIR and the risk of ED prevalence were consistent.

## Discussion

In this cross-sectional study, we identified that low TIR levels are an independent risk factor for the development of ED in male T2DM patients, and TIR has good predictive value for ED occurrence. This study contributes to the prevention and treatment of ED in male T2DM patients, thereby improving patients' quality of life and family happiness.

**Table 1** Characteristics of the study population

| | Total ($n = 317$) | Non-ED group ($n = 76$) | ED group ($n = 241$) | Z/$\chi^2$ | *P* |
|---|---|---|---|---|---|
| Age (years) | 53.00 (46.00, 57.00) | 46.00 (42.00, 51.25) | 54.00 (49.00, 58.00) | Z = −6.60 | **<0.01** |
| Diabetes duration (years) | 6.00 (2.00, 11.00) | 4.00 (2.00, 8.00) | 7.00 (3.00, 12.00) | Z = −3.45 | **<0.01** |
| BMI (kg/m$^2$) | 25.10 (23.50, 27.50) | 25.10 (23.98, 27.62) | 25.10 (23.40, 27.40) | Z = −1.23 | 0.22 |
| FBG (mmol/L) | 7.60 (6.21, 9.27) | 7.21 (6.40, 8.93) | 7.73 (6.17, 9.33) | Z = −0.97 | 0.33 |
| HbA1c (%) | 8.50 (7.40, 10.25) | 8.20 (6.83, 10.00) | 8.60 (7.60, 10.30) | Z = −2.04 | **0.04** |
| TG (mmol/L) | 1.74 (1.15, 2.66) | 2.16 (1.35, 3.01) | 1.67 (1.12, 2.43) | Z = −2.63 | **<0.01** |
| TC (mmol/L) | 4.46 (3.62, 5.02) | 4.42 (3.61, 5.08) | 4.54 (3.63, 5.01) | Z = −0.30 | 0.77 |
| LDL (mmol/L) | 2.83 (2.20, 3.39) | 2.73 (2.16, 3.30) | 2.85 (2.20, 3.40) | Z = −0.56 | 0.58 |
| HDL (mmol/L) | 1.03 (0.87, 1.19) | 0.98 (0.87, 1.16) | 1.05 (0.88, 1.21) | Z = −1.14 | 0.25 |
| UA (umol/L) | 342.90 (292.00, 389.70) | 354.15 (313.93, 407.35) | 338.10 (289.30, 386.30) | Z = −1.49 | 0.14 |
| Scr (umol/L) | 66.90 (59.40, 75.60) | 67.45 (61.53, 74.73) | 66.50 (59.20, 75.90) | Z = −0.23 | 0.82 |
| UACR (mg/g) | 12.60 (9.10, 24.60) | 11.90 (8.40, 19.75) | 12.80 (9.30, 25.00) | Z = −1.02 | 0.31 |
| 25 (OH)D (ng/mL) | 30.00 (23.00, 37.00) | 38.00 (31.75, 43.00) | 27.00 (22.00, 33.00) | Z = −7.43 | **<0.01** |
| T (ng/mL) | 4.03 (3.13, 4.88) | 4.83 (3.85, 5.67) | 3.80 (3.05, 4.62) | Z = −5.15 | **<0.01** |
| MG (mmol/L) | 8.30 (7.42, 9.40) | 8.10 (7.16, 8.96) | 8.50 (7.43, 9.60) | Z = −2.26 | **0.02** |
| SD (mmol/L) | 2.10 (1.67, 2.55) | 2.00 (1.55, 2.40) | 2.15 (1.70, 2.60) | Z = −1.83 | 0.07 |
| MAGE (mmol/L) | 3.76 (2.93, 4.70) | 3.58 (2.67, 4.45) | 3.81 (2.99, 4.89) | Z = −1.90 | 0.06 |
| TIR (%) | 75.65 (63.47, 86.97) | 85.63 (75.47, 92.84) | 73.98 (61.07, 83.24) | Z = −5.87 | **<0.01** |
| LAGE (mmol/L) | 9.80 (7.47, 13.00) | 9.10 (6.87, 12.38) | 9.90 (7.60, 13.14) | Z = −1.57 | 0.12 |
| CV (%) | 24.40 (19.80, 29.87) | 23.85 (19.41, 29.00) | 24.42 (20.30, 30.10) | Z = −0.76 | 0.45 |
| IIEF-5 | 17.00 (13.00,21.00) | 23.00 (22.00,24.00) | 15.00 (12.00,18.00) | Z = −13.17 | **<0.01** |
| Hypertension, *n* (%) | | | | $\chi^2 = 0.50$ | 0.48 |
| No | 164 (51.74) | 42 (55.26) | 122 (50.62) | | |
| Yes | 153 (48.26) | 34 (44.74) | 119 (49.38) | | |
| CI, *n* (%) | | | | $\chi^2 = 4.89$ | **0.03** |
| No | 256 (80.76) | 68 (89.47) | 188 (78.01) | | |
| Yes | 61 (19.24) | 8 (10.53) | 53 (21.99) | | |
| Smoking, *n* (%) | | | | $\chi^2 = 0.24$ | 0.62 |
| No | 137 (43.22) | 31 (40.79) | 106 (43.98) | | |
| Yes | 180 (56.78) | 45 (59.21) | 135 (56.02) | | |
| Drinking, *n* (%) | | | | $\chi^2 = 0.05$ | 0.83 |
| No | 176 (55.52) | 43 (56.58) | 133 (55.19) | | |
| Yes | 141 (44.48) | 33 (43.42) | 108 (44.81) | | |
| DR, *n* (%) | | | | $\chi^2 = 2.59$ | 0.11 |
| No | 241 (76.03) | 63 (82.89) | 178 (73.86) | | |
| Yes | 76 (23.97) | 13 (17.11) | 63 (26.14) | | |
| DPN, *n* (%) | | | | $\chi^2 = 7.63$ | **<0.01** |
| No | 132 (41.64) | 42 (55.26) | 90 (37.34) | | |
| Yes | 185 (58.36) | 34 (44.74) | 151 (62.66) | | |
| PVD, *n* (%) | | | | $\chi^2 = 2.64$ | 0.10 |
| No | 109 (34.38) | 32 (42.11) | 77 (31.95) | | |
| Yes | 208 (65.62) | 44 (57.89) | 164 (68.05) | | |

Z: Mann-Whitney test, $\chi^2$: Chi-square test

*ED* erectile dysfunction, *BMI* body mass index, *CI* cerebral infarction, *FBG* fasting blood glucose, *HbA1c* glycated hemoglobin, *TC* total cholesterol, *TG* triglycerides, *HDL* high-density lipoprotein cholesterol, *LDL* low-density lipoprotein cholesterol, *UA* serum uric acid, *Scr* serum creatinine, *UACR* urine albumin/creatinine ratio, *T* testosterone, *MG* mean glucose, *TIR* time in range, *CV* glucose coefficient of variation, *SD* blood glucose standard deviation, *MAGE* mean amplitude of glycemic excursions, *LAGE* and the largest amplitude of glycemic excursions, *DR* diabetic retinopathy, *DPN* diabetic peripheral neuropathy, *PVD* and diabetic peripheral vascular disease, *IIEF-5* The International Index of Erectile Function questionnaire

ED is a major health issue affecting middle-aged and older men, with any disease affecting penile arteries, nerves, hormone levels, smooth muscle tissue, vascular endothelium, or tunica albuginea potentially causing ED, severely impacting patients' psychological health, quality of life, spousal relationships, and family life. Compared to the general population, patients with diabetes experience ED earlier and with greater severity, leading to poorer quality of life [19].

Previous studies have indicated that the prevalence of ED in male T2DM patients exceeds 50%, with the

**Table 2** Characteristics of the study population based on TIR levels

| | Q1 group (TIR ≤ 63.41%) | Q2 group (63.41% <TIR ≤ 75.64%) | Q3 group (75.64% <TIR ≤ 86.96%) | Q4 group (&jt; 86.96%) | $\chi^2$ | *P* |
|---|---|---|---|---|---|---|
| Age (years) | 54.00 (48.00,58.00) | 53.00 (46.00,57.00) | 52.00 (44.00,57.00) | 52.00 (47.00,56.00) | $\chi^2 = 2.23$# | 0.53 |
| Diabetes duration (years) | 6.00 (2.00,12.00) | 5.00 (3.00,9.50) | 6.00 (2.00,11.00) | 5.00 (2.00,10.00) | $\chi^2 = 0.43$# | 0.93 |
| BMI (kg/m$^2$) | 24.20 (22.80,27.25) | 25.70 (23.45,27.75) | 25.20 (23.45,27.10) | 25.25 (24.10,28.15) | $\chi^2 = 7.02$# | 0.07 |
| FBG (mmol/L) | 8.79 (7.28,10.52) | 7.70 (6.38,9.30) | 7.60 (5.95,9.13) | 6.82 (5.76,7.69) | $\chi^2 = 30.81$# | **<0.01** |
| HbA1c (%) | 10.00 (8.70,11.40) | 8.80 (7.80,10.50) | 7.90 (7.20,9.50) | 7.15 (6.50,8.30) | $\chi^2 = 82.22$# | **<0.01** |
| TG (mmol/L) | 1.85 (1.10,2.79) | 1.79 (1.15,2.68) | 1.71 (1.20,2.47) | 1.69 (1.15,2.49) | $\chi^2 = 0.36$# | 0.95 |
| TC (mmol/L) | 4.66 (3.90,5.01) | 4.45 (3.64,4.94) | 4.62 (3.79,5.31) | 4.10 (3.17,4.76) | $\chi^2 = 8.60$# | **0.04** |
| LDL (mmol/L) | 3.02 (2.41,3.58) | 2.85 (2.22,3.29) | 2.92 (2.17,3.59) | 2.58 (1.76,3.05) | $\chi^2 = 12.05$# | **<0.01** |
| HDL (mmol/L) | 1.01 (0.86,1.18) | 1.04 (0.88,1.21) | 1.09 (0.89,1.23) | 0.98 (0.87,1.13) | $\chi^2 = 3.10$# | 0.38 |
| UA (umol/L) | 329.30 (279.55,375.20) | 326.60 (285.95,358.45) | 354.20 (294.65,396.30) | 376.45 (321.30,435.62) | $\chi^2 = 25.76$# | **<0.01** |
| Scr (umol/L) | 64.50 (55.75,71.80) | 65.90 (59.90,75.95) | 66.90 (60.10,75.40) | 70.55 (62.53,79.02) | $\chi^2 = 11.54$# | **<0.01** |
| UACR (mg/g) | 14.00 (9.80,23.80) | 13.00 (8.00,28.40) | 11.90 (9.40,19.20) | 12.10 (8.47,29.03) | $\chi^2 = 1.45$# | 0.69 |
| 25 (OH)D (ng/mL) | 28.00 (22.00,33.00) | 27.00 (22.50,35.50) | 30.00 (25.00,37.50) | 33.50 (24.00,37.00) | $\chi^2 = 10.43$# | **0.02** |
| T (ng/mL) | 3.67 (2.91,4.63) | 3.87 (2.92,4.79) | 4.15 (3.53,4.78) | 4.36 (3.14,5.11) | $\chi^2 = 7.75$# | 0.05 |
| IIEF-5 | 13.00 (10.00,17.00) | 15.00 (13.00,19.00) | 18.00 (16.00,22.00) | 20.50 (17.00,23.00) | $\chi^2 = 69.69$# | **<0.01** |
| MG (mmol/L) | 10.01 (9.52,11.21) | 8.72 (7.97,9.20) | 7.92 (7.40,8.68) | 7.27 (6.46,7.80) | $\chi^2 = 158.20$# | **<0.01** |
| SD (mmol/L) | 2.51 (2.20,3.21) | 2.21 (1.80,2.60) | 2.10 (1.80,2.44) | 1.58 (1.25,1.90) | $\chi^2 = 105.19$# | **<0.01** |
| MAGE (mmol/L) | 4.50 (3.64,5.64) | 3.80 (3.29,4.83) | 4.05 (3.05,4.78) | 2.79 (2.13,3.58) | $\chi^2 = 68.77$# | **<0.01** |
| LAGE (mmol/L) | 11.96 (9.48,13.98) | 10.23 (8.46,14.05) | 10.40 (8.10,12.75) | 7.02 (5.68,8.96) | $\chi^2 = 64.76$# | **<0.01** |
| CV (%) | 26.32 (22.30,32.03) | 26.54 (21.41,31.23) | 25.88 (21.64,30.95) | 20.22 (17.46,23.73) | $\chi^2 = 44.92$# | **<0.01** |
| Hypertension, *n* (%) | | | | | $\chi^2 = 4.09$ | 0.25 |
| No | 44 (55.70) | 45 (56.96) | 41 (51.90) | 34 (42.50) | | |
| Yes | 35 (44.30) | 34 (43.04) | 38 (48.10) | 46 (57.50) | | |
| CI, *n* (%) | | | | | $\chi^2 = 3.80$ | 0.28 |
| No | 68 (86.08) | 66 (83.54) | 62 (78.48) | 60 (75.00) | | |
| Yes | 11 (13.92) | 13 (16.46) | 17 (21.52) | 20 (25.00) | | |
| Smoking, *n* (%) | | | | | $\chi^2 = 1.66$ | 0.65 |
| No | 38 (48.10) | 34 (43.04) | 30 (37.97) | 35 (43.75) | | |
| Yes | 41 (51.90) | 45 (56.96) | 49 (62.03) | 45 (56.25) | | |
| Drinking, *n* (%) | | | | | $\chi^2 = 2.40$ | 0.49 |
| No | 45 (56.96) | 46 (58.23) | 38 (48.10) | 47 (58.75) | | |
| Yes | 34 (43.04) | 33 (41.77) | 41 (51.90) | 33 (41.25) | | |
| DR, *n* (%) | | | | | $\chi^2 = 6.29$ | 0.10 |
| No | 52 (65.82) | 63 (79.75) | 64 (81.01) | 62 (77.50) | | |
| Yes | 27 (34.18) | 16 (20.25) | 15 (18.99) | 18 (22.50) | | |
| DPN, *n* (%) | | | | | $\chi^2 = 5.10$ | 0.16 |
| No | 31 (39.24) | 32 (40.51) | 41 (51.90) | 28 (35.00) | | |
| Yes | 48 (60.76) | 47 (59.49) | 38 (48.10) | 52 (65.00) | | |
| PVD, *n* (%) | | | | | $\chi^2 = 13.33$ | **<0.01** |
| No | 14 (17.72) | 31 (39.24) | 30 (37.97) | 34 (42.50) | | |
| Yes | 65 (82.28) | 48 (60.76) | 49 (62.03) | 46 (57.50) | | |
| ED, *n* (%) | | | | | $\chi^2 = 35.58$ | **<0.01** |
| No | 4 (5.06) | 16 (20.25) | 20 (25.32) | 36 (45.00) | | |
| Yes | 75 (94.94) | 63 (79.75) | 59 (74.68) | 44 (55.00) | | |

*ED* erectile dysfunction, *BMI* body mass index, *CI* cerebral infarction, *FBG* fasting blood glucose, *HbA1c* glycated hemoglobin, *TC* total cholesterol, *TG* triglycerides, *HDL* high-density lipoprotein cholesterol, *LDL* low-density lipoprotein cholesterol, *UA* serum uric acid, *Scr* serum creatinine, *UACR* urine albumin/creatinine ratio, *T* testosterone, *MG* mean glucose, *TIR* time in range, *CV* glucose coefficient of variation, *SD* blood glucose standard deviation, *MAGE* mean amplitude of glycemic excursions, *LAGE* and the largest amplitude of glycemic excursions, *DR* diabetic retinopathy, *DPN* diabetic peripheral neuropathy, *PVD* and diabetic peripheral vascular disease, *IIEF-5* The International Index of Erectile Function questionnaire

severity of ED closely related to age, diabetes duration, and glycemic control [20]. In our study, we also found that patients in the ED group were significantly older and had longer diabetes duration and higher glycated hemoglobin levels compared to the non-ED group. This suggests that ED is an important complication in the progression of diabetes, significantly affected by the control of diabetes.

**Table 3** Multiple logistic regression analysis of ED in T2DM patients

| | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | OR (95%CI) | *P* | OR (95%CI) | *P* | OR (95%CI) | *P* |
| TIR quantile | | | | | | |
| Q1 | 1.00 (Reference) | | 1.00 (Reference) | | 1.00 (Reference) | |
| Q2 | 0.21 (0.07–0.66) | **<0.01** | 0.18 (0.05–0.60) | **<0.01** | 0.21 (0.06–0.80) | **0.02** |
| Q3 | 0.16 (0.05–0.49) | **<0.01** | 0.14 (0.04–0.48) | **<0.01** | 0.19 (0.05–0.72) | **0.02** |
| Q4 | 0.07 (0.02–0.20) | **<0.01** | 0.04 (0.01–0.15) | **<0.01** | 0.07 (0.02–0.29) | **<0.01** |

*OR* Odds Ratio, *CI* Confidence Interval

Model 1: Crude

Model 2: Adjust: Age, Diabetes duration, Hypertension,Cerebral infarction, smoking, drinking

Model 3: Adjust: Age, Diabetes duration, Hypertension, Cerebral infarction, smoking, drinking, BMI, UACR, 25(OH)D, HbA1c,Testosterone, DR, DPN, PVD

*ED* erectile dysfunction, *BMI* body mass index, *HbA1c* glycated hemoglobin, *UACR* urine albumin/creatinine ratio, *TIR* time in range, *DR* diabetic retinopathy, *DPN* diabetic peripheral neuropathy, *PVD* and diabetic peripheral vascular disease

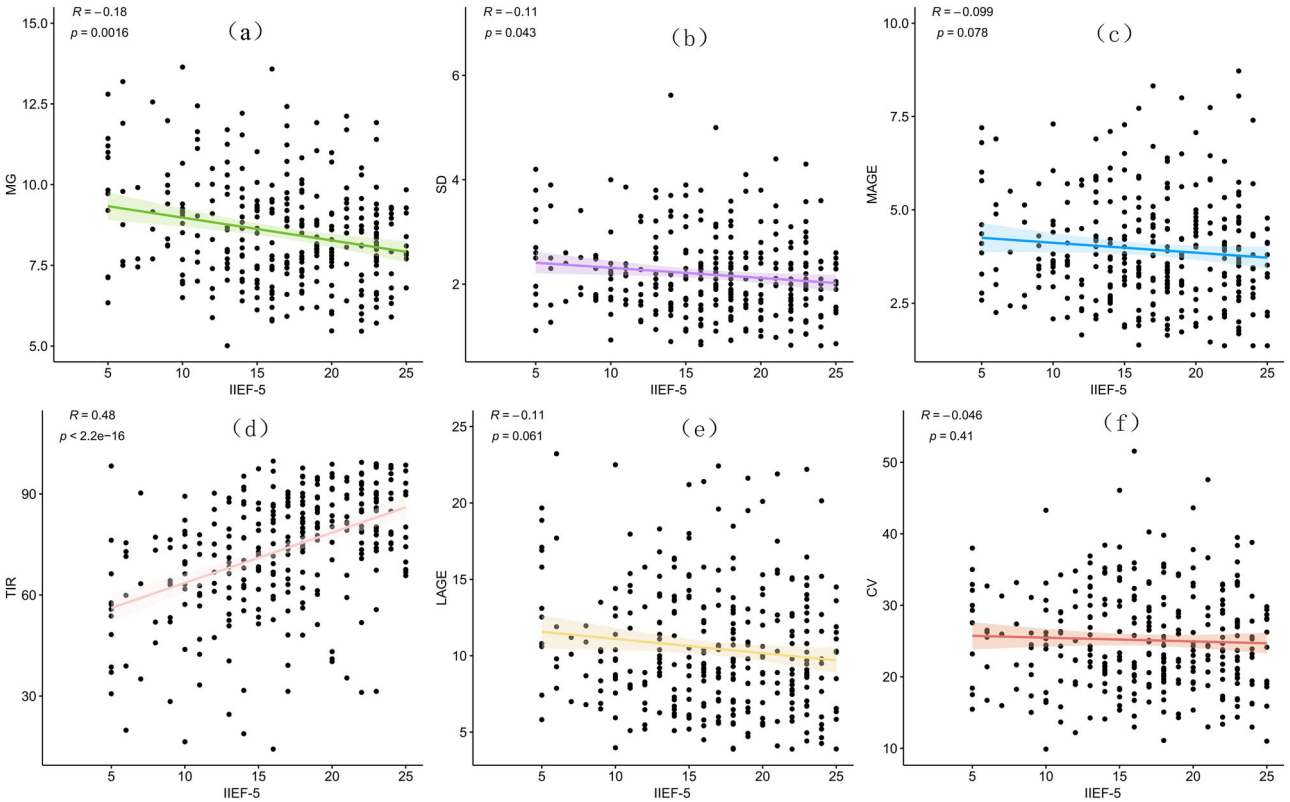


**Fig. 1** Correlation Analysis of IIEF-5 Scores with Glucose Fluctuation Indicators. **a** The correlation of IIEF-5 scores and MG. **b** The correlation of IIEF-5 scores and SD. **c** The correlation of IIEF-5 scores and MAGE. **d** The correlation of IIEF-5 scores and TIR. **e** The correlation of IIEF-5 scores and LAGE. **f** The correlation of IIEF-5 scores and CV. MG mean glucose, TIR time in range. CV glucose coefficient of variation, SD blood glucose standard deviation, MAGE mean amplitude of glycemic excursions, LAGE and the largest amplitude of glycemic excursions, IIEF-5 The International Index of Erectile Function questionnaire

The causes of ED are often linked to systemic diseases, including aging, cardiovascular and cerebrovascular diseases, hypertension, dyslipidemia, metabolic syndrome, smoking, excessive alcohol consumption, medication factors, and psychological factors, among others. In our study, we found that the incidence of cerebral infarction and diabetic peripheral neuropathy in the ED group was higher than in the non-ED group. The mechanism by which patients with diabetes develop erectile dysfunction may be related to increased oxidative stress in the body under

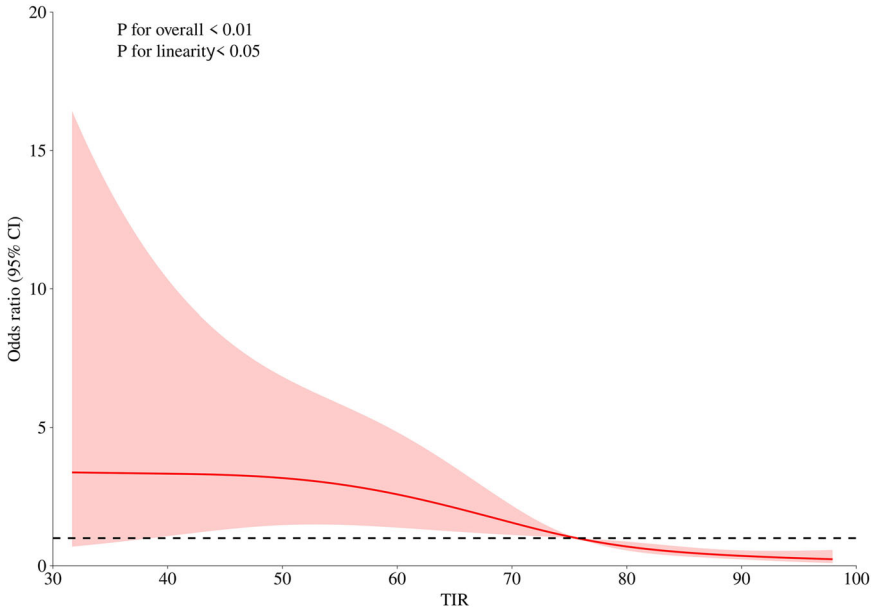


**Fig. 2** Restricted cubic spline analysis of TIR and ED prevalence. ED erectile dysfunction, TIR time in range

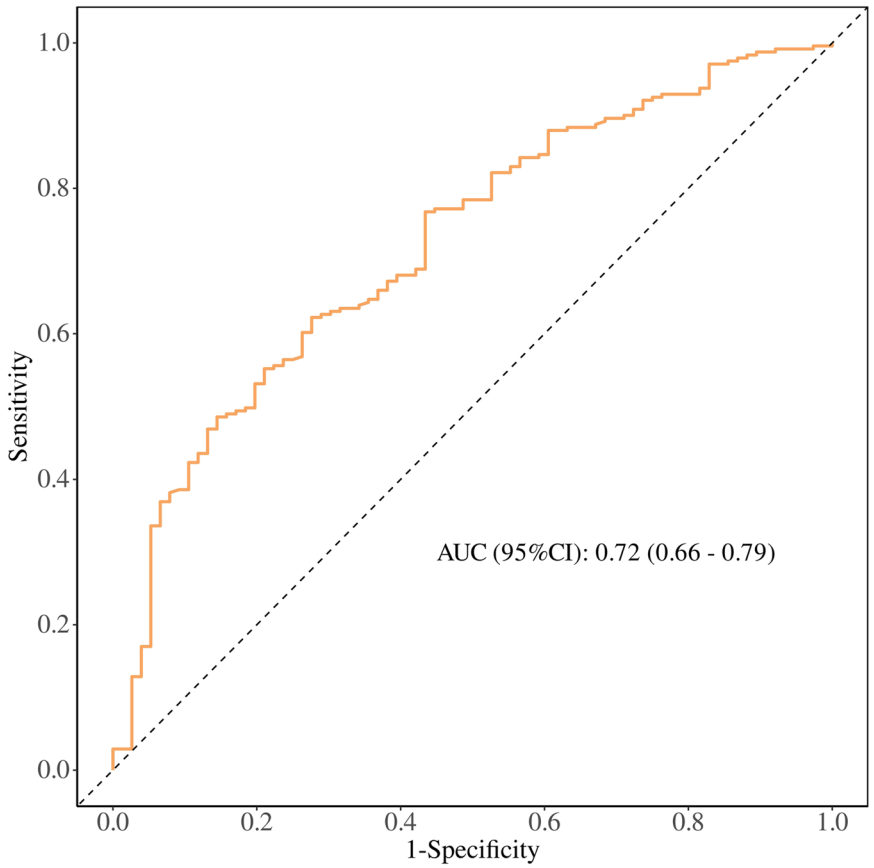


**Fig. 3** Receiver operating characteristic (ROC) Curve Analysis of the Diagnostic Value of TIR for Erectile Dysfunction in T2DM Patients

hyperglycemic conditions, macrovascular/microvascular changes, vascular alterations in nerve nourishment, small nerve fiber pathology, and abnormal venous closure in the corpus cavernosum [21, 22]. Sky KH Chew et al. [23] discovered in a cross-sectional study that the presence and severity of diabetic retinopathy are independently associated with erectile dysfunction. Shaishav Dhage et al. [22] demonstrated a potential correlation between small nerve fiber pathology and the occurrence of ED in patients with diabetes. During the process of erection, the release of nitric

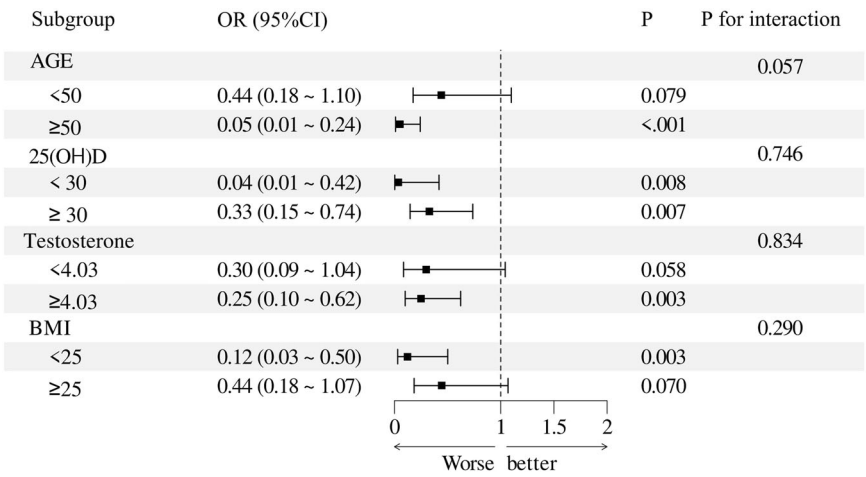


**Fig. 4** Subgroup analyses and interactions. BMI body mass index

oxide and other endothelial cell factors leads to the relaxation of the smooth muscle in the cavernosal vessels and an increase in arterial blood flow, while reducing blood outflow from the veins [24]. As a result, blood accumulates in the penile corpora, increasing the internal pressure and ultimately leading to orgasm and erection.

Studies by S. Ghazi et al. [17] have found that decreased serum testosterone levels are independently associated with ED in male T2DM patients, and Professor Nicola Caretta [18] demonstrated a significant association between 25-hydroxyvitamin D deficiency and ED in male T2DM patients, which was also confirmed in our study. Testosterone in men plays a crucial role in penile erection, maintaining the structural regulation of penile tissue and modulating the activity of neurotransmitters related to erection, affecting the hemodynamics of penile cavernosal blood flow. Since the vitamin D receptor (VDR) is present in the testes, hypothalamus, and pituitary gland [25, 26], 25(OH)D may have a direct effect on gonadal function, thereby affecting testosterone secretion. Additionally, 25(OH)D is associated with the endothelial function of the cavernosal artery, oxidative stress, inflammatory response, thrombosis, calcium regulation, and lipoprotein metabolism [27, 28], with its mechanism related to the dose-dependent activation of VDR.

HbA1c, previously considered the "gold standard" for assessing glycemic control, does not require fasting blood sampling and is widely used in clinical settings due to its simplicity. However, clinical practice and scientific research have revealed that for about 20% of patients with diabetes, HbA1c cannot accurately reflect their average blood glucose levels and does not adequately reflect the fluctuations in blood glucose [29]. In recent years, the relationship between blood glucose fluctuation and diabetic chronic complications has gradually attracted attention. Blood glucose fluctuation participates in the occurrence and development of diabetic chronic complications through multiple pathways, such as activating oxidative stress responses, affecting coagulation activity, and exacerbating inflammatory responses. FGM offers both retrospective and real-time glucose value reading capabilities, continuously monitoring interstitial glucose levels, and forming a dynamic glucose profile (AGP), providing comprehensive and data-driven indicators of glycemic control, including TIR, CV, SD, LAGE, and MAGE. Among these, TIR, as one of the "three core indicators" of the AGP report [14], provides valuable information on the frequency and duration of hyperglycemia or hypoglycemia.

Existing studies have proven that HbA1c and disease duration in T2DM patients are related to the timing and severity of ED occurrence [20], but the relationship between blood glucose fluctuation and ED is rarely reported. Spearman's correlation analysis observed significant correlations between male T2DM patients' IIEF-5 scores and TIR, SD, and MG, with non-ED patients showing a clear increase in TIR and a decrease in MG and SD compared to the ED group, suggesting that ED patients have greater glucose fluctuation amplitudes, and the correlation between TIR and IIEF-5 is more significant than other indicators. Restricted cubic spline analysis also observed a negative linear association between TIR and ED. Therefore, all samples were further divided into quartiles based on TIR, and multivariate logistic regression analysis was performed, showing that after adjusting for various confounding factors, TIR is still significantly negatively correlated with ED, with ORs (95% CI) of 1.00 (Reference), 0.21 (0.06–0.80), 0.19 (0.05–0.72), and 0.07 (0.02–0.29) respectively ($P < 0.05$). This indicates that low TIR is an independent risk factor for ED in male T2DM patients and suggests that large glucose fluctuation amplitudes may be one of the important risk factors for T2DM patients with ED.

This study has certain limitations. Firstly, this study used the IIEF-5 to assess ED and did not employ objective indicators such as penile color Doppler ultrasound and

nocturnal penile tumescence and rigidity based on the Rigiscan device [30], which are expensive and complex to operate, making them difficult to apply in large-sample studies. The IIEF-5 questionnaire, while widely used and clinically practical, relies on self-reported data, which may be subject to recall bias or social desirability bias. Secondly, our study recruited participants from a single center, which may limit the generalizability of our findings to other populations or settings. Thirdly, Although we adjusted for several potential confounders in our analysis, other factors such as psychological status and antihyperglycemic drugs were not included in our analysis. Additionally, this study is cross-sectional, and its results can only indicate the correlation between blood glucose fluctuation indicators and ED, not causality, and the specific pathophysiological mechanisms need further research for clarification. Therefore, it is necessary to expand the sample size in the future to facilitate prospective studies.

## Conclusion

In summary, the results of this study reveal a correlation between blood glucose fluctuation indicators and ED, with low TIR being independently and positively associated with ED, potentially serving as a significant risk factor for ED in T2DM patients. In clinical practice, to reduce the risk of ED in T2DM patients, personalized blood glucose-lowering strategies should be developed, focusing not only on achieving HbA1c targets but also on stable blood glucose control, especially the TIR indicator, to reduce the frequency and duration of hyperglycemia and hypoglycemia, and to maintain patients' blood glucose within the ideal target range, thereby improving the quality of life for male T2DM patients.

## Data availability

No datasets were generated or analysed during the current study.

**Supplementary information** The online version contains supplementary material available at https://doi.org/10.1007/s12020-025-04206-x.

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**Author contributions** Wu Dai and Shenhang Yao designed the study, Shenhang Yao and Xiangxiang Shan collected the data, Shenhang Yao and Ben Hu analyzed the data and wrote the manuscript. Shimei Xing and Yonghong Cao contributed to modify the manuscript. All authors read and approved the final manuscript.

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## Compliance with ethical standards

**Conflict of interest** The authors declare no competing interests.

**Ethics approval and informed consent** The study conforms to the principles of the Helsinki Declaration, and it was approved by the Ethics Committee of the Second People's Hospital of Hefei (No. 2023-research-051). Each patient signed an informed permission form.

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