

Original Article

The Utility of the Lorenz Plot in Assessing Electrocardiographic Waveforms in Type 2 Diabetes with Sinus Rhythm: A Preliminary Controlled Clinical Observation

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ABSTRACT

Background: Analysis of the Lorenz plot (LP) has been studied in tachyarrhythmias resulting from many causes. Patients with diabetes have abnormal electrocardiographic (ECG) findings related to prolonged QT intervals and ventricular repolarization, which are causes of ventricular arrhythmias. This preliminary controlled observational clinical study aimed to demonstrate the shape and pattern of LP analysis in patients with diabetes with normal sinus rhythm.

Methods: A total of 100 participants (42 healthy individuals and 58 patients with diabetes) were recruited from 2 diabetes centers in 2025. Characteristics of the participants and ECG records were obtained. Each record was analyzed by determining measurements related to different intervals and the LP up to 9 R-R(n) intervals.

Results: Significantly shorter R-R(n) intervals, QRS dispersion, and TQ intervals, and significantly prolonged P-R intervals, QRS duration, and QT and JT intervals were observed in patients with diabetes compared with healthy participants. The LP analysis revealed that the patterns and morphologies were comet and comet-club (in healthy participants) and torpedo and cigarette (in patients with diabetes), respectively. A significant positive correlation between the Tp-e/QTc value and R-R(n)+1 was observed.

Conclusions: Patients with diabetes have a distinct pattern and shape of the LP compared with healthy participants, and the R-R(n)+1 interval was significantly positively correlated with the Tp-e/QTc ratio. (*Iranian Heart Journal 2026; 27(4): 40-49*)

KEYWORDS: Lorenz plot; sinus rhythm; diabetes mellitus; Tp-e/QTc

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Received: July 25, 2025

Accepted: August 7, 2026

Patients with type 2 diabetes mellitus (T2D) are more prone to abnormal cardiac rhythms and conduction defects. Several forms of cardiac arrhythmias have been observed in patients with T2D, including sinus tachycardia, sinus bradycardia, heart block, atrial fibrillation,

ventricular tachycardia, and paroxysmal supraventricular tachycardia, with incidences varying according to multiple factors related to abnormal glucose metabolism and concomitant diseases.^{1, 2} An association between cardiac arrhythmias and extracardiac complications of T2D, such as

microalbuminuria and chronic kidney disease, has been reported, making electrocardiography (ECG) a valuable evaluation technique.^{3, 4} Oral antidiabetic drug users, such as those taking sodium-glucose cotransporter inhibitors, have a significantly lower risk of developing atrial fibrillation, atrial flutter, and supraventricular tachycardia.⁵ A significant and prolonged QT interval in patients with T2D is a known ECG finding attributed either to macrovascular complications of diabetes or to pharmacotherapy, as reported among sulfonylurea users.⁶

The Lorenz plot or Poincaré plot (LP) is a scatterplot generated by plotting each R-R(n) interval on the ECG against the subsequent R-R(n+1) interval, with each pair represented as a dot. This plot has served as a useful analytical tool for assessing cardiac rhythm in humans presenting with tachyarrhythmias.⁷ The utility of the LP in predicting the development of cardiac arrhythmias has gained increased interest in medical research because of its ability to plot a curve using progressive changes in the R-R(n) interval.⁸ The distribution of dots in the LP shows distinct patterns in tachyarrhythmias, providing information about the causes of tachycardia and potentially improving the diagnostic assessment of tachyarrhythmias.⁹ There is no specific number of heartbeats required for analysis, and 1 study reported that a segment window length of 85 heartbeats was sufficient to detect paroxysmal tachycardia in patients with atrial fibrillation.¹⁰ Esperer et al¹¹ demonstrated 10 characteristic shapes or patterns of the LP associated with specific cardiac arrhythmias. A recent study demonstrated a distinct LP pattern in neonates presenting with atrial tachycardia, which allowed clinicians to arrange appropriate management.¹² The rationale for this study is that asymptomatic patients with T2D and a normal sinus rhythm confirmed by ECG

may develop cardiac arrhythmias at any time and may have a characteristic LP pattern. Accordingly, this preliminary controlled clinical observational study aimed to demonstrate the pattern and shape of the LP compared with those in healthy participants and to identify characteristics of other ECG measurements, such as the corrected QT interval, P-R(n) interval, and others.

METHODS

Study Design

This preliminary controlled clinical observational study was conducted in the Department of Physiology-Medical Physics, College of Medicine, University of Diyala, in cooperation with Ishtar Medical Institute during 2025. The institutional scientific committee approved this study according to the Helsinki Declaration (Code No. 2025MSN918). The authors interviewed the participants, explained the purpose of the study, and stated that they could withdraw at any time. There is no impact with their present drugs when they add or discontinue any of them.

Participants

The participants were recruited from outpatient clinics belonging to 2 diabetes centers. The eligible patients were of both sexes, aged 20 to 75 years. The criteria of inclusion included healthy participants as negative controls and patients with T2D treated with oral antidiabetic drugs. The excluded participants included patients with diabetes with overt clinical complications, gestational diabetes, cardiovascular drug users (eg, β -adrenoceptor blocking agents, calcium entry blockers, antiarrhythmics, and medications causing prolonged QT interval, eg, antimicrobials), pregnancy, and terminal illnesses. At the time of inclusion, the participants, any patients who were treated with medicines that potentially cause

changes in the ECG parameters, were not included for the reason that the results could bias the results, as the objective of this study is to show the pattern of LPs, which can predict patients who will be potentially at risk of arrhythmias. The participants were recruited randomly (using random tables) and grouped into 2 groups:

Group I (n = 42): healthy participants (negative controls)

Group II (n = 58): patients with T2D

The anthropometric measurements, including waist circumference (WC, cm), body weight (kg), and height (m), were determined using a metallic tape for WC measurement and an electronic stadiometer for weight and height measurements. Body mass index (BMI) was calculated by dividing the weight (kg) by the squared height (m^2). Each participant was asked to undergo an ECG.

Primary Outcome Measurement: R-R interval (s), and the following (R-R) interval plus 1 was measured (R-R (n) +1), and termed (window 1). Then the measurements of the following windows were done for up to 8 windows.

Secondary Outcome Measurement: The secondary outcome measures included the ECG intervals that indicated a risk determinant for ventricular repolarization and/or ventricular arrhythmia.

ECG Measurements: An ECG was obtained from each participant for analysis. The ECG machine specifications were 12 standard leads, a sensitivity of 10 mm/mV, and a recording speed of 25 mm/s. ECG recordings from patients and healthy participants who were in sinus rhythm without evidence of ectopic beats or ventricular hypertrophy were obtained. ECGs were performed by professional nurses who were blinded to the participants' health status. Multiple nurses performed the ECGs rather than 1 or 2 designated nurses. Hence, the possibility of

artifacts in the ECG recordings was considered negligible. All ECG waveforms were verified by visual inspection.

ECG recording strips were scanned, and the scanned images were magnified using Windows Photo Viewer on a personal computer to facilitate measurement. Two independent readers performed the measurements. A coefficient of variation of 5% in the readings necessitated measurement by an additional reader. Some ECG data were printed electronically on the recording strip, whereas other measurements were calculated using specific formulas. The following data were obtained from each ECG recording strip: heart rate (beats/min); R-R interval (ms); P-R interval (ms); QRS wave duration (s); QTm (measured QT interval) (s); QTc (corrected QT interval, Framingham formula) (ms); JTm (measured JT interval) (s); JTc (corrected JT interval) (s); and JT index.

QTc (corrected QT interval) was calculated using the following Framingham formula: $QTc = QT + 0.154 \times (1 - RR)$.¹³ The duration of the T wave from initiation to its peak (Tp) and from its peak to the end of the T wave (Tp-e), as well as the Tp-e/QT ratio, were also measured.

The cutoff values for QTc in men were less than 430 ms (normal), 430 to 450 ms (borderline), and greater than 450 ms (prolonged); in women, the corresponding values were 450 ms (normal), 450 to 470 ms (borderline), and greater than 470 ms (prolonged).¹⁴

LP Analysis

The R-R(n) +1 (segment window) indicates the duration of the R-R in the following rate, and up to 8 heartbeats were calculated. A window of 8 beats was considered because this number is the lowest number that was obtained from strip II ECG. The LP is created by plotting scatter dots using the R-R(n) interval on the x-axis and the R-R of the next

heartbeat (represented as R-R(n) +1) on the y-axis.

The shape of the LP was determined by the dots fitted with the mean RR(n) interval as it is located in the center (centric dots), the length of the line passing through and along the line of the mean RR(n) interval, and the dots distributed on both sides of the mean RR(n) interval (eccentric dots). The pattern and the morphology of the LP were determined according to Romito et al.¹⁵

Statistical Analysis

The results were presented as numbers, percentages, medians (interquartile ranges), and means (SDs). Data normality was assessed using the Shapiro-Wilk test. Normally distributed data are presented as means (SDs), and data with non-normal distributions are presented as medians (interquartile ranges). The data were analyzed using the Kruskal-Wallis test (one-way analysis of variance) and the independent-samples, two-tailed, two-sample *t* test. Multivariate linear regression with collinearity statistics and bootstrapping (*n* = 1000) was performed to determine whether the QTc interval is predicted by diabetes. A variance inflation factor value of less than 5 indicates that the results are unaffected by the sample size. The LP was

generated using a scatter diagram by plotting the R-R(n) interval on the x-axis and the following heartbeat R-R(n)+1 on the y-axis. The Spearman correlation test was used to determine the correlation between the Tp-e/QTc ratio and R-R(n)+1. A *P* value of .05 was the threshold for statistical significance.

RESULTS

Table 1 presents the differences in characteristics and ECG measurements between healthy participants and patients with diabetes. There is no significant difference between groups in sex distribution and BMI. Significantly higher values in age and waist circumference were observed in Group II compared with Group I. The ECG findings included significant short R-R interval, QRS dispersion, and TQ interval among Group II participants compared with Group I. Significant prolongation of the P-R interval, QRS period, QT interval and index, and JT interval and index was observed among Group II participants. There were no significant differences in the voltage criteria between groups. Table 2 shows that the significantly higher value of QTc is significantly related to diabetes mellitus and not to age, BMI, and waist circumference (Table 2).

Table 1. Characteristics and Electrocardiographic Findings of the Participants

Determinant	Group I (No. = 42)	Group II (No. = 58)	<i>P</i>
Sex (female : male)	25:17	41:17	.245
Age, y	47.5 (43, 52)	61 (54.5, 69)	<.001
Body mass index, kg/m ²	28.8 (26.9, 30.7)	28.6 (25.3, 31.5)	.487
Waist circumference, cm	95.5 (89, 104)	104 (97, 111)	.001
Fasting plasma glucose, mg/dL	90.5 (82.8, 95.3)	140 (110.5, 172.5)	<.001
Heart rate, beats/min	74.5 (68, 79.5)	78 (70.8, 86)	.062
R-R interval, ms	800 (720, 880)	760 (696.2, 840)	.044
P-R interval, ms	140 (125, 160)	156 (142, 174.5)	.001
QRS duration, ms	85 (69.5, 93.1)	92 (84, 98)	.001
QRS dispersion, ms	20 (15.8, 25)	16 (12, 20)	.007
QTm, ms	370 (350, 390)	381 (369, 404)	.002
QTc (Framingham), ms	393.9 (373, 411.3)	424 (409.1, 432.7)	<.001
QT index	95.1 (92.1, 103.3)	104.5 (101.5, 107.6)	<.001
T-Q interval, ms	625 (570, 720)	600 (520, 652.5)	.033
JTm, ms	285 (264.8)	294 (279, 308)	.087
JTc, ms	311.9 (300, 338.1)	329.1 (321.9, 339.7)	.001

JT index	95.1 (90.1, 103.4)	100.5 (98, 104.4)	.002
Tp, ms	110 (80, 140)	100 (80, 132.5)	.858
Tp-e, ms	70 (60, 80)	80 (60, 91.3)	.507
Tp-e/QTm	0.196 (0.159, 0.222)	0.198 (0.156, 0.222)	.875
Tp-e/QTc	0.180 (0.150, 0.207)	0.179 (0.140, 0.216)	.652
Voltage criteria: R1 + S5, mV	0.59 (0.35, 0.83)	0.5 (0.35, 0.7)	.316
Voltage criteria: R5 + S1, mV	1.75 (1.25, 2.1)	1.55 (1.3, 1.95)	.522

Data are expressed as median (IQR). *P* values were calculated using a nonparametric independent-samples Kruskal-Wallis test for continuous data and a χ^2 test for categorical data.

QTc: corrected QT interval; QTm: measured QT interval; JTc: corrected JT interval; JTm: measured JT interval; Tp: time from onset of the T wave to its peak; Tp-e: time from the peak to the end of the T wave

Table 2. Linear Regression Analysis of Predictors of the QTc Interval

Model / Predictor	R^2	<i>F</i>	<i>P</i>	β Coefficient (95% CI)	<i>P</i>	Tolerance	Variance Inflation Factor	Bootstrap β Coefficient (95% CI)
Reference								
Age				0.511 (-0.016 to 1.038)	.057	.823	1.215	0.511 (0.043 to 1.071)
Body mass index				-0.510 (-2.201 to 1.180)	.550	.461	2.167	-0.510 (-2.374 to 1.125)
Waist circumference	0.059	1.982	.122	0.040 (-0.628 to 0.708)	.906	.470	2.127	0.040 (-0.692 to 0.711)
Model 1	0.260	8.258	<.001					
Age				-0.225 (-0.776 to 0.327)	.421	.597	1.674	-0.225 (-0.743 to 0.287)
Body mass index				0.209 (-1.324 to 1.743)	.787	.446	2.243	0.209 (-1.160 to 1.819)
Waist circumference				-0.523 (-1.158 to 0.112)	.106	.413	2.420	-0.523 (-1.232 to 0.080)
Diabetes mellitus				32.3 (19.6 to 45.0)	<.001	.554	1.807	32.3 (20.8 to 43.7)

The variance inflation factor threshold < 5 and the bootstrap results for correlations (*n* = 1000) indicate no apparent effect of sample size.

QTc: corrected QT interval; R^2 : coefficient of determination

Table 3 shows nonsignificant differences between heartbeats and the following heartbeats between each group or between groups. The maximum R-R interval was observed at windows 7 and 8 for both groups. The analysis of the LP for Groups I and II is shown in Figure 1. The cluster of eccentric dots gives the appearance of the comet-torpedo pattern with a morphology of a comet or clubbing, or cigarette form. Figure 2 illustrates clearly window 8, which shows that the ratio of the maximum length of the line passing through and along the line of mean RR(*n*) to the maximum width (a perpendicular line passing from the eccentric

dots to the major axis of mean R-R(*n*), is more than 1, and there is no branching arising from the centric dots. Therefore, the pattern of comet and the morphology of the comet club in Group I and the pattern of the torpedo and the morphology of the cigarette in Group II are demonstrated.

The baseline Tp-e/QTc value, as a variable used to assess the risk of ventricular arrhythmias, showed a nonsignificant difference between Groups I and II. It is nonsignificantly correlated with heartbeat 0 in both Group I (*r* = -0.023, *df* = 40, *P* = .887) and Group II (*r* = 0.231, *df* = 56, *P* = .081). It is positively and significantly

correlated at heartbeat number 8 (represented by window 8) in Group II ($r = 0.278$, $df = 56$,

$P = .035$), while this correlation was negative and nonsignificant in Group I (Figure 3).

Table 3. Mean (SD) of the R-R Heartbeat and the Following R-R Heartbeat for the Participants

R-R interval (s)	Group I (No. = 42)	Group II (No. = 58)	<i>P</i>
0	0.818 (0.129)	0.783 (0.112)	.166
1	0.806 (0.119)	0.780 (0.111)	.125
2	0.819 (0.130)	0.783 (0.116)	.157
3	0.802 (0.130)	0.787 (0.117)	.198
4	0.815 (0.115)	0.785 (0.115)	.201
5	0.815 (0.112)	0.783 (0.118)	.167
6	0.811 (0.113)	0.782 (0.118)	.228
7	0.828 (0.121)	0.785 (0.113)	.072
8	0.825 (0.113)	0.786 (0.116)	.098
<i>F</i>	0.134	0.022	
<i>P</i>	.998	1.000	

The results are expressed as mean (SD). *P* and *F* values were calculated using one-way ANOVA (comparison between the R-R(n) heartbeats (s) and the following R-R(n) +1 heartbeats (s) in each group) and an independent two-sample *t* test (comparison between Groups I and II for each R-R heartbeat).

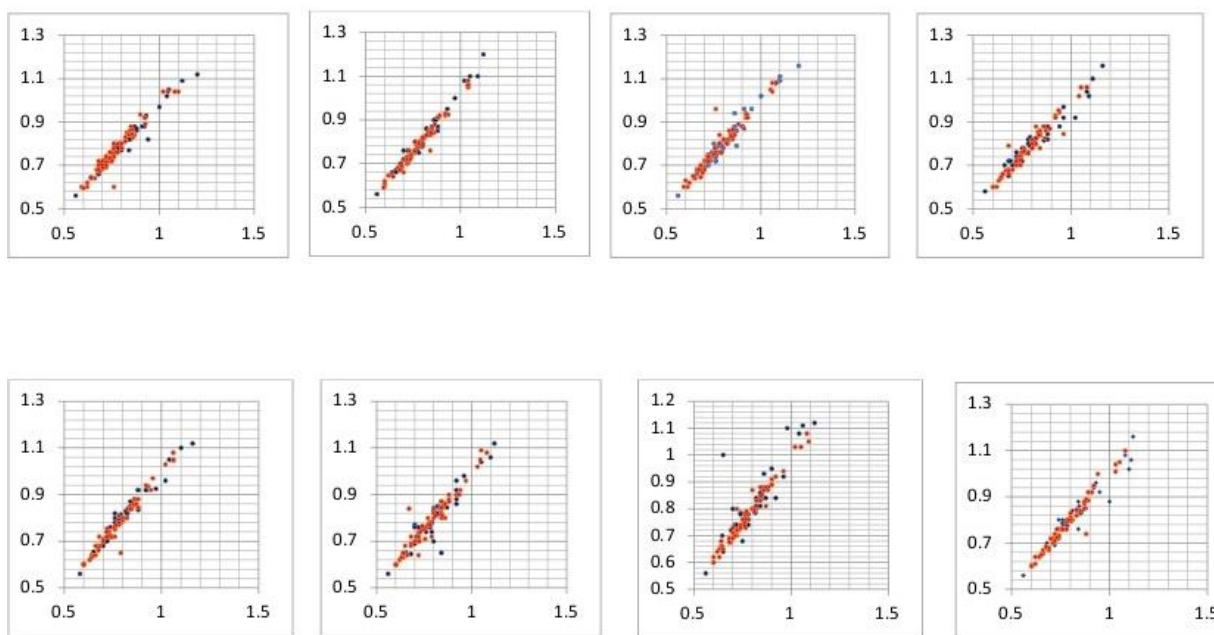


Figure 1. Lorenz plots of 8 windows belonging to the participants with sinus rhythm. The blue dots represent Group I, and the red dots represent Group II. The shape of the plots is altered when the values of the x-axis (an R-R(n) interval of the heartbeats) exceeded 1.0 s, which is observed in all windows and both groups.

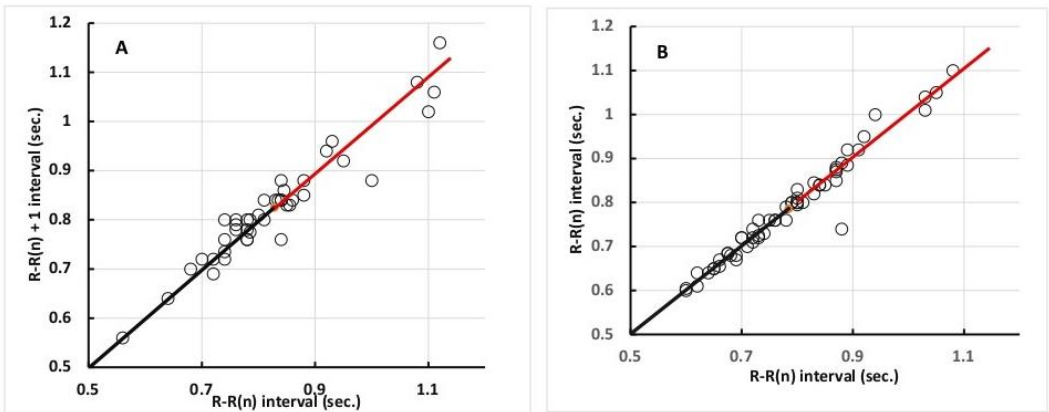
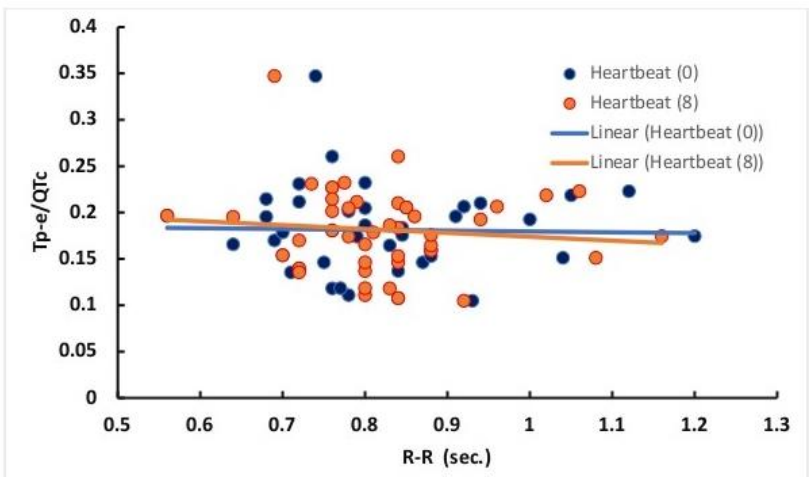


Figure 2. The Lorenz plot of window 8 shows a pattern of comet and a morphology of comet club in Group I [A] and a pattern of torpedo and a morphology of cigarette in Group II [B].



A

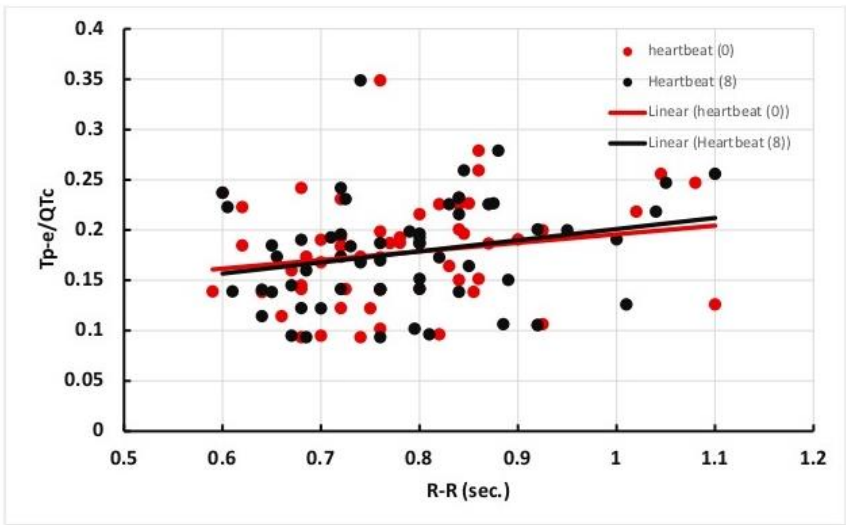


Figure 3. A nonsignificant inverse correlation between R-R interval and Tp-e/QTc in Group I at heartbeat 0 and 8, and a positive significant correlation in Group II at heartbeat 8.

DISCUSSION

The results of the present study show that the pattern and morphology of the LP in patients with T2D and sinus rhythm differ from those of the corresponding patterns in healthy participants, and that the $R-R(n)+1$ interval is significantly and directly correlated with an index of ventricular repolarization represented by the $Tp-e/QTc$ ratio. This observation could be used to identify patients at risk of developing ventricular arrhythmias. Incorporation of the LP with other ECG waveforms, including P-QRST, could predict the development of arrhythmias.¹⁶

In most previous studies, long-term assessment of heart rate variability and dynamic changes in beat-to-beat rhythm has been achieved using a Holter monitor.¹⁷ In this study, a simple procedure using a lead II strip with 9 consecutive beats as a window segment could be sufficient to detect the specific LP pattern in healthy participants and patients with T2D. Many confounding factors can affect beat-to-beat heart rate variability. Increasing age is associated with a worse prognosis in patients with ventricular arrhythmias.¹⁸ In the current study, patients in Group II were older than those in Group I, but all participants were in sinus rhythm, suggesting that age had a negligible effect on the LP. Central obesity is a characteristic feature of T2D, as evidenced by a significantly higher median waist circumference. Waist circumference is an important risk factor for autonomic nervous system dysfunction, with a significant positive correlation between waist circumference and heart rate variability in the time and frequency domains.¹⁹ In addition, glycemic indices and central obesity are important risk factors because of their effects on the prolonged QTc interval and determinants of ventricular repolarization, as listed in Table 1.^{20,21} Table 2 shows that the shape and pattern of the LP

in T2D are not related to heart rate variability, as there were no significant differences between Groups I and II for any window segment.

In Figure 1, the relationship between $R-R(n)$ and $R-R(n)+1$ is linear because both groups had a normal heart rate range of 80 to 100 beats/min and sinus rhythm; in contrast, the relationship is nonlinear in people with tachyarrhythmias.²² At any segment, the linear relationship is a consistent finding; therefore, Holter monitoring is unnecessary for assessing the LP in participants with sinus rhythm.²³ In Figure 2, the shape and morphology in Group II showed a distinct cigarette-shaped characteristic, with most dot clusters located on the identity line and closely distributed on both sides of the identity line. This finding agrees with results reported by other studies, which identified a cigarette-shaped morphology using short-term ECG in patients with sinus rhythm.²⁴ This morphology differs from that observed in healthy participants with sinus arrhythmia. Consequently, data from healthy participants should be included when assessing LP morphology as an indicator of cardiac arrhythmias.

The alteration in the $R-R(n)$ interval showed an inverse, nonsignificant relationship with the $Tp-e/QTc$ ratio in Group I, whereas this relationship was significantly positive in Group II (Figure 3). This finding indicates that patients with T2D and sinus arrhythmia could be at risk of developing ventricular arrhythmias because prolongation of the $R-R(n)$ interval causes prolongation of the $Tp-e/QTc$ ratio.^{25,26} The significant positive correlation between heartbeat 8 (represented by window 8) and the $Tp-e/QTc$ ratio was weak ($r = .278$, $P = .035$). Thus, extending the analysis to more windows may disclose this finding. Moreover, heart rate and rhythm variability have been shown to be associated with diabetes mellitus and may occur at any beat.

The strength of the current study is the demonstration of differences in LP pattern and morphology between healthy participants and patients with T2D and of the relationship between LP morphology and the Tp-e/QTc ratio, a marker of ventricular repolarization. Limitations of the study include the small sample size and the absence of Holter monitoring. These limitations do not affect the results because this work is a preliminary report, and Holter monitoring was considered unnecessary because the participants had sinus rhythm.

CONCLUSIONS

The shape and morphology of the LP are a useful supplementary tool in assessing patients with diabetes with sinus arrhythmias, and it suggests that those people are at risk for prolonged ventricular repolarization parameters.

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