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Frontal QRS-T Angle as a Prognostic Marker of Long-Term Mortality in Hemodialysis Patients

Frontal QRS-T Açısının Hemodiyaliz Hastalarında Uzun Dönem Mortaliteyi Öngörmedeki Prognostik Değeri

ABSTRACT

Objective: The electrocardiogram is a crucial, cost-effective, and noninvasive tool for assessing the risk of cardiac morbidity and mortality. The frontal QRS-T angle is a marker of ventricular repolarization. This study investigated whether the frontal QRS-T angle could predict mortality in hemodialysis patients over a seven-year follow-up period.

Method: The study included 110 patients undergoing regular hemodialysis. Frontal QRS-T angles greater than 90 degrees were classified as wide. Patients were categorized based on the width of the QRS-T angle and the presence or absence of mortality. Electrocardiogram (ECG) parameters measured included the QRS, T axis, TP/QT ratio, fragmented QRS, TPe/QTc ratio, and the frontal QRS-T angle, defined as the absolute difference between the frontal QRS and T axes.

Results: A total of 37 patients (34%) had a wide frontal QRS-T angle. The mean age was significantly higher in both the wide frontal QRS-T angle group and the mortality group. Ejection fraction was lower in the mortality group. The frontal QRS-T angle was wider in the mortality group (94 [31-113] vs. 33 [16-80], P < 0.001). In univariate and multivariate logistic regression analyses, having a wide QRS-T angle was associated with increased mortality (odds ratio [OR]: 8.08, confidence interval [CI]: 2.75-23.74, P < 0.001). Additionally, the presence of fragmented QRS also increased mortality risk (OR: 11.25, CI: 2.98-42.49, P < 0.001).

Conclusion: Our findings demonstrate the independent prognostic value of the frontal QRS-T angle in patients undergoing hemodialysis, irrespective of ejection fraction status. This suggests that it may serve as a valuable tool in routine cardiovascular risk assessments, contributing to improved management strategies for this high-risk population.

Keywords: Frontal QRS-T angle, hemodialysis, long-term mortality

ÖZET

Amaç: Elektrokardiyogram (EKG), kardiyak morbidite ve mortalite riskinin değerlendirilmesinde maliyet etkin, hızlı ve noninvaziv bir yöntemdir. Frontal QRS-T açısı, ventriküler repolarizasyonun önemli belirteçlerinden biridir. Bu çalışmada, hemodiyaliz hastalarında frontal QRS-T açısının 7 yıllık takip sürecinde mortaliteyi öngörüp öngöremeyeceği araştırılmıştır.

Yöntem: Çalışmaya 110 hemodiyaliz hastası dahil edilmiştir. Geniş frontal QRS-T açısı, >90° olarak tanımlanmıştır. Hastalar QRS-T açısının genişliğine ve ölüm durumuna göre iki farklı grupta değerlendirilmiştir. Ölçülebilir EKG parametreleri arasında QRS aksı, T dalga aksı, TP/QT oranı, fragmented QRS, TPe/QTc oranı ve frontal QRS-T açısı yer almıştır. Frontal QRS-T açısı, frontal düzlemdeki QRS ve T vektörleri arasındaki mutlak açı farkı olarak tanımlanmıştır.

Bulgular: Hastaların 37'sinde (%34) geniş frontal QRS-T açısı saptanmıştır. Geniş QRS-T açısına sahip ve hayatını kaybeden grupta ortalama yaş daha yüksekti. Ayrıca, mortalite grubunda ejeksiyon fraksiyonu daha düşük saptanmıştır. Frontal QRS-T açısı, mortalite grubunda anlamlı olarak daha geniş bulunmuştur (94 [31-113] vs. 33 [16-80], P < 0,001). Tek - çok değişkenli lojistik regresyon analizlerinde, geniş açılı grupta yer almak mortalite riskini artırmıştır (OR: 8,08; GA: 2,75–23,74; P < 0,001). Benzer şekilde, fragmented QRS varlığı da mortalite ile ilişkili saptanmıştır (OR: 11,25; GA: 2,98–42,49; P < 0,001).

Sonuç: Bulgularımız, frontal QRS-T açısının ejeksiyon fraksiyonundan bağımsız olarak hemodiyaliz hastalarında mortaliteyi öngörmede bağımsız bir prognostik gösterge olduğunu ortaya koymaktadır. Bu açıdan, frontal QRS-T açısının kardiyovasküler risk değerlendirme sürecine entegre edilmesi, bu kırılgan hasta grubunda daha etkili risk yönetimi stratejileri geliştirilmesine fayda sağlayabilir.

Anahtar Kelimeler: Frontal QRS-T açısı, hemodiyaliz, uzun dönem mortalite

ORIGINAL ARTICLE
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Cardiovascular disease remains the leading cause of mortality among patients with end-stage renal disease undergoing hemodialysis. The electrocardiogram (ECG) is an effective tool for assessing the risk of cardiac morbidity and overall mortality due to its affordability, noninvasive nature, and ability to deliver rapid results. The frontal QRS-T angle (fQRSTa), derived from the QRS axis and the T wave axis on a 12-lead ECG, serves as an important marker of ventricular repolarization.[1,2] Numerous studies have employed both frontal and spatial methods to calculate the fQRSTa. In these studies, the diagnostic and prognostic benefits of each method are often directly compared. Each study has reported different values and established its own threshold values and reference ranges.[3,4] Some studies have established a correlation between a wide fQRSTa and adverse cardiac events in hemodialysis patients.[5] As a result, developing predictive parameters to assess cardiac conditions in patients undergoing hemodialysis has become essential. ECG remains a fundamental, noninvasive tool for the early detection of electrical and structural cardiac abnormalities. This study aimed to evaluate the long-term prognostic value of the frontal QRS-T angle in chronic hemodialysis patients, with particular emphasis on its association with all-cause mortality over a seven-year follow-up period.

ABBREVIATIONS

BMI	Body mass index
CAD	Coronary artery disease
CI	Confidence interval
CRP	C-reactive protein
DM	Diabetes mellitus
ECG	Electrocardiogram
EF	Ejection fraction
fQRSTa	Frontal QRS-T angle
HF	Heart failure
HT	Hypertension
IVSWT	Interventricular septal wall thickness
LV	Left ventricle
LVEDD	Left ventricular end-diastolic diameter
LVEF	Left ventricular ejection fraction
LVESD	Left ventricular end-systolic diameter
MI	Myocardial infarction
PWT	Posterior wall thickness
QTc	Corrected QT interval
RA	Right atrium
ROC	Receiver operating characteristic
SCD	Sudden cardiac death
SPSS	Statistical Package for the Social Sciences
TP-e	Tpeak to Tend Interval
TP/QT	Tpeak to Tend interval/QT interval ratio
TP/QTc	Tpeak to Tend interval/Corrected QT interval ratio

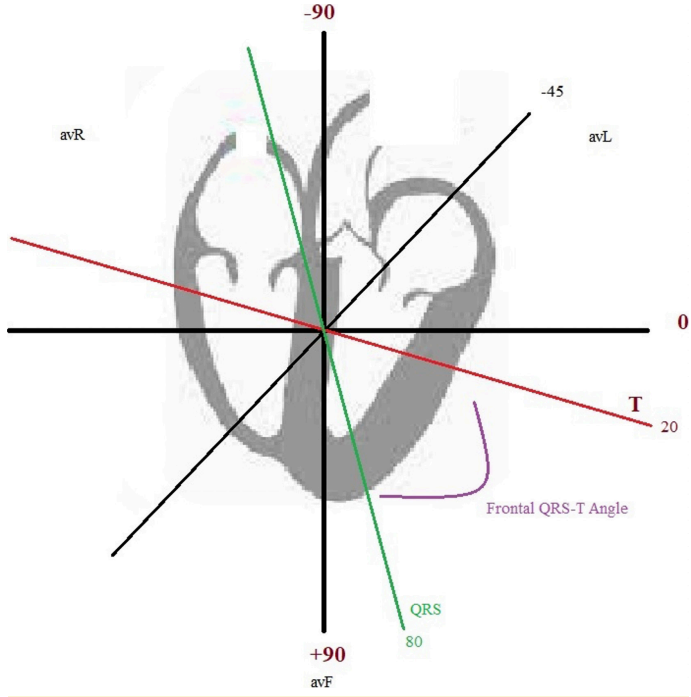

Figure 1. Assessment of the frontal QRS-T angle in a planar plane.

Materials and Methods

A total of 110 hemodialysis patients were enrolled in this retrospective study, which was conducted through a review of archived patient records. Only hemodialysis patients were included; those receiving peritoneal dialysis were excluded. ECG data were collected during the initial cardiology outpatient visits between January 2017 and January 2024. Due to the retrospective nature of the study, the mean follow-up duration was calculated only for deceased patients, averaging 3.62 ± 1.7 years. All patients underwent standard intermittent hemodialysis. Dialysis frequency was either two or three sessions per week, depending on clinical indication. The hemodialysis technique and equipment were consistent across the study population. Patients with atrial fibrillation, pacemakers, right or left bundle branch block, or left anterior hemiblock were excluded from the study. A standard 12-lead ECG was recorded on the day of hemodialysis, using a paper speed of 25 mm/s and an amplitude calibration of 10 mm/mV. QRS duration, QRS axis, and T wave axis were determined automatically. The frontal QRS-T angle was calculated as the absolute difference between the QRS axis and the T wave axis in the frontal plane, in line with previous definitions.[6,7] ECGs were recorded on non-dialysis days (at least one day apart from any hemodialysis session). Specifically, the QRS axis, T wave axis, TP/QT ratio, fragmented QRS, TPe/QTc ratio, and fQRSTa were documented. The frontal QRS-T angle was automatically calculated by the digital ECG system, based on the difference between the frontal plane QRS and T-wave axes, as previously described by Oehler et al.[1] in 2014.[1,6] The fQRSTa is defined as the absolute difference between the frontal plane QRS axis and the T wave axis. In other words, it represents the angle between the frontal QRS and T vectors (Figure 1). Angles exceeding 180° were adjusted using the formula (360 - angle). A wide QRS-T angle, considered abnormal in prior studies, is defined as greater than 90°.[6] The QT interval was measured from the onset of the QRS to the end of the T wave and corrected using Bazett's formula (QTc). The Tp-e interval was defined as the distance from the T-wave peak to its end in the precordial leads. Fragmented QRS was identified by the presence of R' waves or notching in at least two contiguous

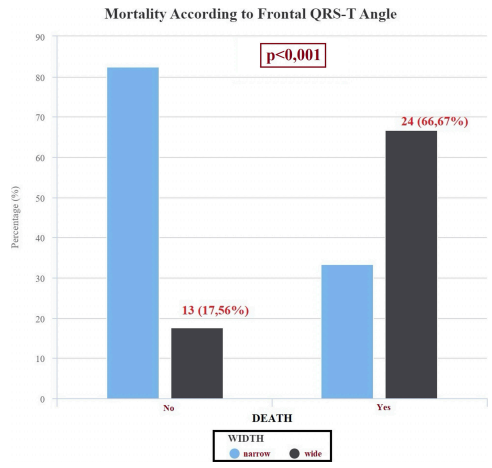

Figure 2. Mortality distribution according to the frontal QRS-T angle.

leads. Patients were grouped based on both the width of the frontal QRS-T angle (wide vs. normal) and mortality status at follow-up (mortality present vs. absent) for comparative analysis. Echocardiographic and laboratory parameters evaluated in the study included left ventricular ejection fraction (LVEF), interventricular septal wall thickness (IVSWT), posterior wall thickness (PWT), left ventricular end-diastolic diameter (LVEDD), and left ventricular end-systolic diameter (LVESD), as well as serum creatinine, potassium (K), hemoglobin (Hb), and calcium (Ca) levels. LVEF was measured using the modified Simpson's method during standard transthoracic echocardiography. Patients with significant left ventricular hypertrophy (wall thickness > 15 mm) were excluded from the study. These parameters were compared between patients with wide and normal frontal QRS-T angles, as well as between those with and without all-cause mortality. Laboratory tests, ECG, and echocardiography were performed on the same day. Ethical approval was obtained from the Institutional Ethics Committee. Additionally, written informed consent was secured from all participants prior to enrollment. The study was approved by the Trakya University Faculty of Medicine Non-Interventional Scientific Research Ethics Committee (Approval Number: 14/10, Date: 02.09.2024). A clinical trial number is not applicable.

Statistical Analysis

All statistical analyses were conducted using SPSS software (version 25.0; SPSS Inc., Chicago, IL). The distribution of continuous variables was assessed using the Shapiro-Wilk test. As most variables were not normally distributed, results were expressed as median (interquartile range, Q1–Q3), and comparisons between groups were performed using the Mann-Whitney U test. Categorical variables were compared using the chi-square or Fisher's exact test, as appropriate. Receiver operating characteristic (ROC) curve analysis was performed to explore the predictive power of the variables, and the area under the curve (AUC) was calculated to assess their overall effectiveness in outcome discrimination. Multivariate logistic regression analysis was conducted to identify independent predictors of the outcome. All statistical tests were two-sided, and a p-value of less than 0.05 was considered statistically significant.

Results

A total of 110 participants were recruited, with a median age of 57 years. Two group comparisons were conducted: one based on the width of the fQRSTa and the other based on mortality status after a seven-year follow-up. During this period, 36 patients (32.73%) were identified as deceased and classified in the mortality group. Among these patients, 24 (67%) exhibited a wide frontal QRS-T angle (fQRSTa), as shown in Figure 2. Patients with an fQRSTa greater than 90 degrees were categorized in the wide group (33.6%), while those with angles below this threshold were classified in the control (normal) group (66.4%). The parameters for both groups are presented in Table 1. The wide group showed a higher prevalence of females and older patients (Table 1). Additionally, body mass index was significantly higher in the wide QRS group (P = 0.005). Older patients were more frequently represented in the mortality group. Notably, both the mortality group and the wide fQRSTa group had a significantly higher incidence of diabetes mellitus (DM). A comparison of electrocardiographic measurements between the groups is shown in Table 2. In the wide group, the median fQRSTa was 96 (range: 94–120). In the mortality group, the fQRSTa was significantly higher (P < 0.001). Fragmented QRS was also more prevalent in the mortality group.

Table 1. Baseline demographic characteristics of the study population by frontal QRS-T angle and mortality status

Variable	Wide frontal QRS-T angle (n = 37)	Normal frontal QRS-T angle (n = 73)	P	Mortality present (n = 36)	Mortality absent (n = 74)	P
Age	63 (57-70)	57 (45-62)	< 0.001	62 (57-71)	57 (45-64)	0.001
Gender - Female	23 (62.16%)	36 (49.31%)	0.202	21 (58.33%)	38 (51.35%)	0.491
HT	32 (86.48%)	54 (73.97%)	0.133	31 (86.11%)	55 (74.32%)	0.160
DM	24 (64.86%)	20 (27.39%)	< 0.001	21 (58.33%)	23 (31.08%)	0.006
Non-smoker	12 (32.43%)	26 (35.61%)	0.533	32 (88.88%)	66 (89.18%)	0.962
CAD	7 (18.91%)	5 (6.84%)	0.055	7 (19.44%)	6 (8.10%)	0.060
Dyslipidemia	9 (24.32%)	6 (8.21%)	0.451	7 (19.44%)	8 (10.81%)	0.216
BMI	29.3 (25-32)	25.4 (22-29)	0.005	29 (26-34)	25 (22-28)	< 0.001

BMI, Body mass index; CAD, Coronary artery disease; DM, Diabetes mellitus; HT, Hypertension.

Table 2. Electrocardiographic parameters of the study population

Variable	Wide fQRSTa (n = 37)	Normal fQRSTa (n = 73)	P	Mortality present (n = 36)	Mortality absent (n = 74)	P
QRS (ms)	92 (84–105)	90 (84–99)	0.403	94 (90–134)	88 (82–98)	0.001
QTc (ms)	439 (416–461)	432 (408–452)	0.268	435 (406–459)	432 (410–452)	0.760
QRS°	-25 (-44–4.5)	34 (1–59)	< 0.001	-2 (-22–49)	19 (-11–50)	0.110
T°	73 (39–98)	58 (41–66)	0.002	68 (51–78)	58 (38–71)	0.054
Tpe	90 (80–110)	70 (65–80)	< 0.001	80 (60–80)	80 (60–80)	0.628
TP/QT	0.22 (0.19–0.30)	0.20 (0.17–0.23)	< 0.001	0.20 (0.18–0.22)	0.20 (0.17–0.24)	0.730
TP/QTc	0.21(0.17–0.25)	0.17 (0.15–0.19)	< 0.001	0.18 (0.16–0.21)	0.18 (0.15–0.21)	0.426
Fragmented QRS	11 (29.72%)	10 (13.69%)	0.043	16 (44.44%)	5 (6.75%)	< 0.001
Frontal QRS–T angle	96 (94–120)	24 (8–50)	< 0.001	94 (31–113)	33 (16–80)	< 0.001

Table 3. Echocardiographic and laboratory parameters of the study population

Variable	Wide fQRSTa (n = 37)	Normal fQRSTa (n = 73)	P	Mortality present (n = 36)	Mortality absent (n = 74)	P
LVEF, %	51 (48–56)	55 (52–60)	0.002	52 (50–57)	55 (50–60)	0.033
IVSWT, mm	12 (10.5–14)	12 (10–15)	0.713	12 (11–14)	12 (10–15)	0.697
PWT, mm	11 (10–12)	11 (10–13)	0.311	11.5 (10.5–13.5)	11 (10–13)	0.675
LVEDD, mm	45 (42.5–48)	46 (42–48.5)	0.696	46.5 (43–48)	46 (41–48)	0.541
LVESD, mm	30 (28–32)	30 (28–32)	0.534	30 (28–33)	29 (27–31)	0.707
Creatinine, mg/dL	4.8 (3.08–6.83)	4.31 (3.3–5.8)	0.599	4.3 (3.3–5.8)	4.56 (3.1–6.6)	0.819
K, mg/dL	4.4 (3.95–4.95)	4.4 (3.9–4.9)	0.685	4.5 (4.05–4.97)	4.4 (3.9–4.9)	0.447
Hb, mg/dL	11.6 (10–12.3)	11.2 (10.4–11.9)	0.325	11.05 (9.8–11.9)	11.55 (10.75–12.35)	0.063
Ca, mg/dL	9.2 (9–10)	9.6 (88.7–9.9)	0.947	9.2 (8.6–9.9)	9.7 (9–10.1)	0.061

Ca, Calcium; Creatinine, Serum Creatinine; CRP, C-Reactive protein; fQRSTa, Frontal QRS–T angle; Hb, Hemoglobin; IVSWT, Interventricular septal wall thickness; K, Potassium; LVEDD, Left ventricular end-diastolic diameter; LVEF, Left ventricular ejection fraction; LVESD, Left ventricular end-systolic diameter; N, Number of patients; PWT, Posterior wall thickness.

Table 3 compares selected echocardiographic and laboratory parameters in the study population, stratified by frontal QRS-T angle width and all-cause mortality status. Patients with a wide frontal QRS-T angle had significantly lower LVEF compared to those with a normal angle (51% (48–56) vs. 55% (52–60), P = 0.002). No statistically significant differences were observed between the groups in IVSWT, PWT, LVEDD, or LVESD (P > 0.05 for all). Similarly, laboratory markers, including serum creatinine, K, Hb, and Ca levels, were comparable between the two groups. In the subgroup analysis based on mortality status, ejection fraction (EF) was again significantly lower in patients in the mortality group compared to those survivors (52% (50–57) vs. 55% (50–60), P = 0.033). No significant differences were observed in structural echocardiographic parameters or serum creatinine and potassium levels between the mortality groups. However, a non-significant trend toward lower hemoglobin and calcium levels was noted among deceased patients compared to survivors (Hb: P = 0.063; Ca: P = 0.061).

A significant correlation was found between the presence of DM and belonging to the wide fQRSTa group (r = 0.3613, P < 0.001). Additionally, a negative correlation was observed between LVEF and the frontal QRS angle (r = -0.2119, P = 0.021). These correlation assessments are presented in Figure 3. The negative relationship between LVEF and fQRSTa is further illustrated in Figure 4. The diagnostic performance of FQRSTa in predicting mortality was evaluated. ROC and sensitivity-specificity curves are shown in Figure 5. The cut-off value determined to predict mortality for fQRSTa was > 92, with sensitivity and specificity estimated at 66.6% and 82.4%, respectively (AUC: 0.71, confidence interval: 0.61–0.79, P < 0.001). Regression analyses were conducted to identify independent predictors of mortality. In the univariate model, age, DM, fQRSTa, wide group classification, and presence of fragmented QRS were all found to be significant (Table 4). In the multivariate analyses, being in the wide fQRSTa group and the presence of fragmented QRS were identified as independent risk factors (Table 4).

Discussion

The main findings of our research are as follows:

1) We established that the fQRSTa, derived from ECG measurements, serves as a significant predictor of mortality in patients undergoing hemodialysis.
2) Our analysis revealed that an fQRSTa exceeding 92 is notably associated with increased mortality.
3) In diabetic patients, we observed both an increased fQRSTa and a significant correlation with other clinical parameters.
4) Furthermore, we found that an increase in fQRSTa in hemodialysis patients is associated with a decrease in LVEF.

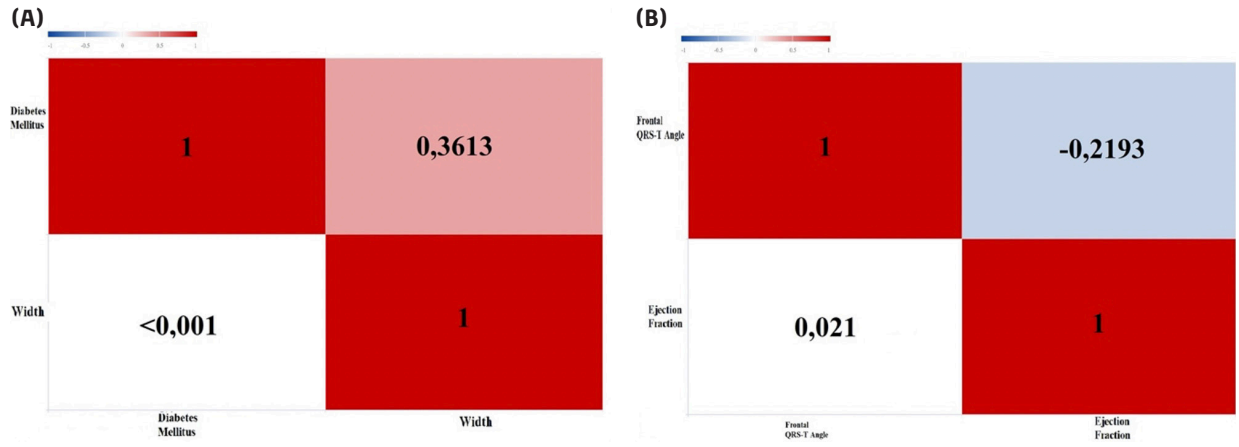

Figure 3. Correlogram showing the relationships between diabetes mellitus, wide frontal QRS-T angle group, and left ventricular ejection fraction (LVEF).

Table 4. Univariate, multivariate, and stepwise binary logistic regression analysis of mortality

Log reg	Univariate model			Multivariate model			Stepwise model		
Variables	**OR**	**95% CI**	**p**	**OR**	**95% CI**	**p**	**OR**	**95% CI**	**p**
Age	1.07	1.03-1.11	< 0.001	1.04	0.98-1.10	0.129	0.03	1	0.138
DM	1.08	1.02-1.16	0.049	0.83	0.25-2.70	0.758	–	–	–
Width	9.38	3.75-23.45	< 0.001	8.60	1.05-70.02	0.044	8.08	2.75-23.74	< 0.001
Frontal QRS-T	1.02	1.00-1.03	< 0.001	1.00	0.97-1.02	0.969	–	–	–
Fragmented QRS	11.04	3.59-33.86	< 0.001	12.17	2.90-51.09	< 0.001	11.25	2.98-42.49	< 0.001
LVEF	0.96	0.91-1.02	0.24	1.01	0.93-1.09	0.755	–	–	–

OR, Odd ratios; CI, Confidence interval; DM, Diabetes mellitus; LVEF, Left ventricular ejection fraction.

In hemodialysis patients, the development of myocardial fibrosis may lead to uremic cardiomyopathy. This condition impairs both depolarization and repolarization processes, resulting in a widened fQRSTa. Additionally, autonomic dysfunction associated with end-stage renal disease, along with dialysis-related fluctuations in electrolytes (particularly potassium and calcium) may contribute to repolarization instability.[1,2,8] These electrical disturbances can increase the risk of arrhythmias and sudden cardiac death (SCD). Based on our findings, the fQRSTa appears to be a simple, noninvasive, and practical risk marker that could be incorporated into routine clinical assessments of dialysis patients.

A recent cohort study conducted in Japan demonstrated that QT prolongation, elevated heart rate, and left ventricular hypertrophy on ECG were strongly associated with an increased risk of SCD in patients undergoing hemodialysis.[9] This important finding highlights the complex cardiac risks faced by this vulnerable population and underscores the need for vigilant monitoring and timely intervention. Building on these insights, our study further reveals that an increased fQRSTa correlates with a heightened risk of overall mortality. This suggests that the fQRSTa may serve as a valuable prognostic marker of cardiac health in hemodialysis patients, requiring further investigation into its role in risk stratification. Collectively, these findings reinforce the importance of comprehensive cardiovascular assessments in individuals receiving hemodialysis, with the goal of improving prediction and management of adverse clinical outcomes.

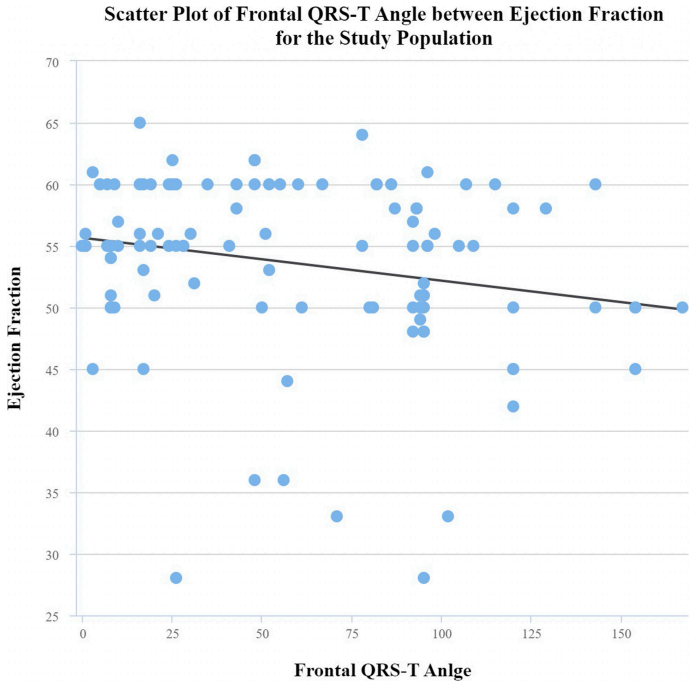

Figure 4. Scatter plot illustrating the correlation between left ventricular ejection fraction (LVEF) and frontal QRS-T angle.

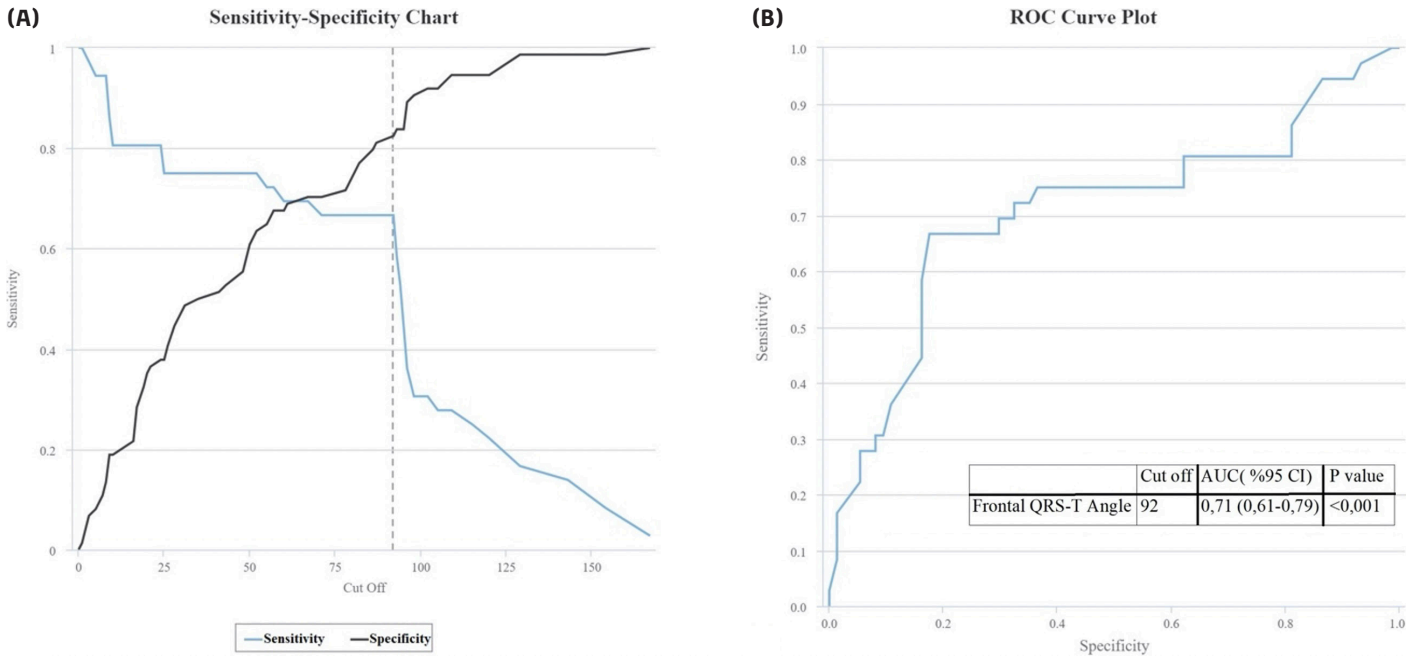

Figure 5. Receiver operating characteristic (ROC) curve and sensitivity-specificity chart of the mortality group.

In a separate investigation focusing on fragmented QRS in dialysis patients, researchers found that patients with fragmented QRS had a higher incidence of ventricular premature contractions and non-sustained ventricular tachycardia on ECG Holter monitoring. This highlights the potential arrhythmic implications of fragmented QRS in this population.[10,11] In our study, we similarly found that the presence of fragmented QRS in hemodialysis patients not only correlates with increased mortality risk but also serves as an independent predictor of adverse clinical outcomes. This finding highlights the importance of monitoring fragmented QRS as a critical parameter in the cardiac assessment of hemodialysis patients, suggesting that it may warrant closer clinical scrutiny and management to mitigate associated risks.

Recent evidence from a study involving diabetic patients indicates that the QRS-T angle is specifically associated with the risk of SCD, rather than with other forms of mortality. This finding suggests a potential pathway for improving SCD risk stratification in patients with type 2 diabetes.[12] A wide fQRSTa has been recognized as a strong, independent, and long-term prognostic indicator for myocardial infarction and all-cause of mortality in diabetic populations, as demonstrated in another study.[6] In our study, we identified a higher prevalence of DM in the wide fQRSTa group, as well as an increased proportion of diabetic patients in the mortality group. These findings support the consideration of DM as a significant contributing factor.

Similarly, in a study conducted by Usalp and Bağırtan on patients with ischemic stroke, a significant association was observed between the fQRSTa and mortality.[13] These findings suggest that the fQRSTa may have prognostic value across various clinical populations, including both stroke and hemodialysis patients, highlighting the potential utility of ECG parameters in broader risk stratification. Our study adds to this evidence by demonstrating that the fQRSTa is also an independent predictor of mortality in the hemodialysis population.

The literature includes studies that have used the fQRSTa as a diagnostic and prognostic marker in patients with myocarditis, valvular diseases, cardiomyopathies, heart failure (HF), and even non-cardiac conditions, demonstrating its utility in assessing cardiac function and predicting adverse clinical outcomes.[7,14–17] In a different investigation focusing on patients with heart failure with preserved ejection fraction (HFpEF), the prognostic relevance of various electrocardiographic parameters, particularly the fQRSTa, was highlighted.[18,19] That study showed that the fQRSTa is a significant indicator of adverse outcomes in this population. Our findings extend this concept by demonstrating that the fQRSTa also holds independent prognostic value for mortality in hemodialysis patients, regardless of LVEF status. Given these insights, the fQRSTa emerges as a valuable metric in the initial cardiovascular assessment of hemodialysis patients, paralleling its established role in the evaluation of individuals with HFpEF. This suggests that incorporating the fQRSTa into routine clinical practice may enhance risk stratification and management strategies for this vulnerable population.

Additionally, patients with a wide fQRSTa showed no evidence of excess left ventricular hypertrophy (LVH), as IVSWT and PWT were similar between groups. Likewise, Cr, K, Hb, and Ca levels were comparable, indicating no significant underlying electrolyte or laboratory imbalances. The only significant difference was a lower LVEF observed in both the wide fQRSTa and mortality groups. In contrast, IVSWT, PWT, chamber size, Cr, and K levels showed no differences by mortality status. Hb and Ca levels were lower in the mortality patients but did not reach statistical significance. These findings suggest that a widened frontal QRS-T angle indicates a higher mortality risk independent of LVH or major metabolic disturbances. In other words, the prognostic value of a wide QRS-T angle in hemodialysis patients is not merely a surrogate for structural heart disease or electrolyte imbalance. This independence from LVH and metabolic factors underscores

the QRS-T angle as a valuable tool for risk stratification in dialysis patients. It complements traditional measures such as LVEF and emphasizes the significance of electrical remodeling in cardiovascular risk.[20]

The future of artificial intelligence (AI) and electrocardiography represents a critical area of focus in cardiovascular research. Recent literature has shown a surge in studies exploring the application of AI in cardiological conditions, including coronary artery disease and arrhythmias.[21] Additionally, research has highlighted the role of AI in predicting hospital admissions due to HF among peritoneal dialysis patients.[22] This study underscores the potential value of integrating electrocardiography and artificial intelligence into the early evaluation of hemodialysis patients to optimize mortality risk prediction and ultimately improve patient outcomes.

Study Limitations

Given the limited sample size in our study, the findings should be interpreted as preliminary. This exploratory analysis lays the groundwork for future investigations in larger patient cohorts, which may enhance the strength and external validity of the results. Another limitation is the absence of serial ECG recordings. Since the frontal QRS-T angle may vary over time, repeated measurements could better capture its prognostic dynamics. Additionally, follow-up duration could not be precisely calculated for all patients due to the retrospective design. Further research involving larger populations will be essential to confirm these findings and refine the clinical implications derived from this initial analysis.

Conclusion

In conclusion, our study highlights the fQRSTa as a significant predictor of mortality in hemodialysis patients, particularly when the angle exceeds 92 degrees. We also found that the fQRSTa is markedly elevated in diabetic patients and correlates with various clinical parameters. Notably, an increased fQRSTa is associated with reduced LVEF, reinforcing its potential as a valuable biomarker for assessing cardiovascular health in this high-risk population. These findings support the integration of fQRSTa into routine clinical evaluations to enhance patient management and improve outcomes.

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