ORIGINAL ARTICLE

Assessing arrhythmic risk in chronic kidney disease: A study of the index of cardiac-electrophysiological balance

Serdar Söner[1], Adnan Duha Cömert[1], Yusuf Hosoglu[2]

[1]Department of Cardiology, Health Sciences University, Gazi Yasargil Training and Research Hospital, Diyarbakir, Türkiye, [2]Department of Cardiology, Adiyaman Training and Research Hospital, Adiyaman, Türkiye

Background: Chronic kidney disease (CKD) patients are at high risk of cardiovascular death and malignant arrhythmia. We aimed to determine at which CKD stage, the change in the index of cardiac-electrophysiological balance (ICEB) value is more evident. Consequently, we included patients across all CKD stages in our research. **Materials and Methods:** A total of 429 patients were followed up at the nephrology and cardiology outpatient clinics between April and November 2023 enrolled in the study. Patients were categorized into five groups based on their glomerular filtration rate (GFR) – Group 1: GFR ≥90, Group 2: GFR = 60–89, Group 3: GFR = 30–59, Group 4: GFR = 15–29 and not on hemodialysis, and Group 5: GFR ≤15 and on hemodialysis. Electrocardiograms were recorded, and ICEB and corrected ICEB (ICEBc) values were calculated for all patients. **Results:** The mean age was 52.52 ± 14.58 years, and the total number of female patients was 235 (54.8%). In *post hoc* analysis, the difference of ICEBc value differed between Groups 1 and 5 (95% confidence interval: 0.0217–0.5226; $P = 0.024$). There were no statistically significant differences between Group 1 and the other groups. Corrected QT values were significantly different between Group 5 and Groups 1, 2, and 3 ($P < 0.001$, $P < 0.001$, and $P = 0.005$, respectively). The QT intervals were different between Group 1 and Groups 3, 4, and 5 ($P = 0.003$, $P = 0.003$, and $P = 0.008$, respectively). **Conclusion:** The study demonstrated that the ICEBc value gradually increased with the progression of CKD stages, with a statistically significant change observed in stage 5. However, there was no significant difference in ICEB values across stages.

Key words: Chronic kidney disease, index of cardiac-electrophysiological balance, sudden cardiac death

How to cite this article: Söner S, Cömert AD, Hosoglu Y. Assessing arrhythmic risk in chronic kidney disease: A study of the index of cardiac-electrophysiological balance. J Res Med Sci 2025;30:36.

INTRODUCTION

Chronic kidney disease (CKD) progressively develops, marked by sustained renal damage and a decreased glomerular filtration rate (GFR) persisting beyond 3 months. Individuals with CKD are often confronted with cardiovascular complications, including arrhythmias, coronary artery disease (CAD), and heart failure, which significantly contribute to increased morbidity and mortality rates. Among these, arrhythmias, particularly atrial fibrillation (AF) and ventricular tachyarrhythmias, are significantly prevalent.[1,2] Rapid hemodynamic changes, particularly those affecting cardiac perfusion and function or electrolyte concentrations, especially potassium, during dialysis, may further elevate the risk of arrhythmias. CKD often progresses silently, especially in its early stages, without notable clinical symptoms.[3] Early identification of high-risk cardiovascular disease (CVD) patients in this population is critical for improving cardiovascular outcomes. The 12-lead electrocardiogram (ECG) remains a widely accessible and cost-effective tool for diagnosing and screening CVD.

The QT interval reflects the period of ventricular depolarization and repolarization, affected by several factors including autonomic activity, genetic

Access this article online

Quick Response Code:

Website: https://journals.lww.com/jrms

DOI: 10.4103/jrms.jrms_67_25

Address for correspondence: Dr. Serdar Söner, Department of Cardiology, Health Sciences University, Gazi Yasargil Training and Research Hospital, 21070, Diyarbakir, Türkiye.
E-mail: drserdar_89@hotmail.com
Submitted: 21-Jan-2025; **Revised:** 29-Apr-2025; **Accepted:** 29-May-2025; **Published:** 15-Jul-2025

predisposition, acid–base imbalances, medications, underlying heart conditions, and fluctuations in electrolytes.[4] Studies on QT levels in patients with end-stage renal disease (ESRD) have reported various changes in parameters such as QT, corrected QT (QTc), and QTc dispersion and that these changes are affected by other comorbid conditions, especially diabetes mellitus (DM) and CAD.[5-7] Various ECG markers are associated with sudden cardiac death (SCD) in CKD patients, and a recent multicenter study in ESRD patients indicated that the time from the peak to the end of QT duration may help predict SCD.[8,9]

The index of cardiac-electrophysiological balance (ICEB), calculated as the QT/QRS ratio, represents an innovative, noninvasive marker designed to forecast the occurrence of malignant ventricular arrhythmias. Evidence suggests a relationship between increased or decreased ICEB values and ventricular arrhythmogenic risk; higher ICEB values are linked to torsades de pointes (TdP), while lower values are associated with non-TdP-mediated ventricular tachycardia and ventricular fibrillation.[10,11]

This study aims to determine whether the previously observed prolongation of QT/QTc intervals in CKD patients is accompanied by changes in ICEB values and to identify the CKD stage at which these changes in ICEB/corrected ICEB (ICEBc) become most apparent.

MATERIALS AND METHODS

Patients

In this cross-sectional study, 602 patients receiving care at nephrology and cardiology outpatient clinics were included between April and November 2023. Ethical clearance was granted by the local committee (26.04.2024/34). Exclusion criteria included unavailable or poor-quality ECG scans ($n = 96$), hypertrophic or restrictive cardiomyopathy ($n = 4$), AF ($n = 19$), bundle branch block with QRS ≥120 msc ($n = 11$), chronic lung disease ($n = 7$), advanced liver disease ($n = 3$), severe obesity (body mass index ≥40 kg/m²) ($n = 8$), suboptimal echocardiographic visualization ($n = 2$), major valvular abnormalities or past valvular surgeries ($n = 16$), pregnancy, amyloidosis ($n = 2$), and prior kidney transplant or rejection ($n = 5$). Ultimately, the analysis included 429 patients. After fasting overnight, blood samples were collected to measure laboratory parameters. GFR levels were determined using the Modification of Diet in Renal Disease formula[12] (mL/min/1.73 m²), with a GFR value >90 mL/min considered normal. Participants were categorized into five groups based on their GFR levels: Group 1 (≥90), Group 2 (60–89), Group 3 (30–59), Group 4 (15–29) (not undergoing hemodialysis), and Group 5 comprising individuals with ESRD and GFR below 15 (undergoing hemodialysis).

Electrocardiogram analysis

12-lead ECGs (SCHILLER Cardiovit AT-102 G2, Germany) were obtained while patients were in the supine position, using a calibration of 10 mm/mV and a standard speed of 25 mm/s. Resting sinus rhythm, ECGs were analyzed by two cardiologists who were blinded to which group the patients were in. Each ECG was scanned and magnified 400% using Adobe Photoshop. Heart rate (bpm), duration of P, PR interval, QRS, and QT (from V5 and DII leads) durations were calculated. The QTc interval was calculated with Bazett's formula: QT interval divided by the square root of the RR interval. ICEB value is calculated as QT/QRS, and ICEBc value is calculated as QTc/QRS.

Statistical analysis

Data were processed using SPSS v24 (SPSS Inc, Chicago, IL, USA). The normality of the distributions was verified through the Kolmogorov–Smirnov test and by visual inspection of histograms. Categorical variables were expressed as numbers and percentages. For continuous variables, the mean and standard deviation were used for those with normal distributions, while the median (25^{th}–75^{th} percentiles) was employed for those with nonnormal distributions. To compare categorical parameters, the Chi-square test was used. The Kruskal–Wallis *H*-test identified statistically significant differences between the five groups for variables with nonnormal distributions. For parameters that followed a normal distribution, a one-way ANOVA test was conducted to assess differences between the groups. *Post hoc* comparisons were carried out using Tukey's test when variances were homogeneous, and Tamhane's T2 test was used when variances were nonhomogeneous. $P < 0.05$ was considered statistically significant.

RESULTS

Of the 429 patients included in the analysis, the mean age was 52.5 ± 14.6 years, with females making up 54.8% of the total sample. Due to the varying severity of CKD among patients, the prevalence of comorbidities such as smoking, DM, hypertension (HT), CAD, and previous percutaneous coronary intervention rates differed across the five groups. All groups' baseline characteristics and echocardiographic findings are shown in Table 1. Laboratory parameters were significantly different in all groups due to different CKD stages. Laboratory findings are shown in Table 2, and electrocardiographic measurements are shown in Table 3. According to the one-way ANOVA test, heart rate, PR, QRS, QT, QTc intervals, and ICEBc were significantly different between the groups, while ICEB and P-wave duration were not. ECG findings by the groups are also schematized in Figure 1.

In *post hoc* analyses, QTc values were significantly different between Group 5 and Groups 1, 2, and 3 ($P < 0.001$, $P < 0.001$,

Table 1: Baseline characteristics and echocardiography findings according to the groups

Variables	Group 1 (*n*=86), *n* (%)	Group 2 (*n*=86), *n* (%)	Group 3 (*n*=75), *n* (%)	Group 4 (*n*=84), *n* (%)	Group 5 (*n*=98), *n* (%)	*P*
Age (year)	57.40±9.79	67.62±9.5	71.29±9.04	64.62±18.1	54.03±15.81	<0.001
Female gender	53 (61.6)	50 (58.1)	45 (60)	37 (44)	50 (51)	0.12
Comorbidities						
Smoking	23 (26.7)	15 (17.4)	12 (16.2)	32 (38.6)	28 (29.8)	0.006
HT	46 (53.5)	61 (70.9)	62 (83.8)	71 (85.7)	91 (92.9)	<0.001
DM	21 (24.4)	28 (32.6)	37 (49.3)	45 (53.6)	34 (34.7)	<0.001
CAD	30 (34.9)	46 (53.5)	45 (60)	41 (48.8)	32 (32.7)	0.001
CABG history	3 (3.5)	10 (11.6)	6 (8)	11 (13.1)	5 (5.1)	0.098
PCI history	16 (18.6)	25 (29.1)	23 (30.7)	25 (29.8)	10 (10.2)	0.003
HL	29 (33.7)	33 (38.4)	27 (36)	26 (31)	22 (22.4)	0.169
COPD	7 (8.1)	7 (8.1)	6 (8)	16 (19)	9 (9.1)	0.083
Medications						
ASA	37 (43)	45 (52.3)	43 (57.3)	37 (44)	34 (34.7)	0.03
Clopidogrel	10 (11.6)	16 (18.6)	15 (20)	18 (21.4)	13 (13.3)	0.335
Ticagrelor	6 (7)	3 (3.5)	3 (4)	0	0	0.023
Anticoagulant	0	1 (1.2)	6 (8)	5 (6)	0	0.002
ACE-I	27 (31.4)	28 (32.6)	29 (38.7)	24 (28.6)	23 (23.5)	0.288
ARB	21 (24.4)	28 (32.6)	28 (37.3)	19 (22.6)	24 (24.5)	0.166
Beta-blocker	34 (39.5)	46 (53.5)	46 (61.3)	49 (58.3)	49 (50)	0.049
Diuretic	23 (26.7)	38 (44.2)	41 (54.7)	44 (52.4)	45 (45.9)	0.003
CCB	17 (19.8)	27 (31.4)	32 (42.7)	42 (50)	58 (59.2)	<0.001
Statin	26 (30.2)	31 (36)	30 (40)	21 (25)	16 (16.3)	0.005
Oral antidiabetic	15 (17.4)	17 (19.7)	26 (34.6)	32 (38.1)	24 (24.5)	0.002
Echocardiography (cm)						
EF	58.37±5.37	57.77±5.23	52.31±10.69	49.31±11.38	55.37±7.29	<0.001
IVS	1.075±0.12	1.1±0.13	1.14±0.11	1.17±0.17	1.21±0.017	<0.001
LVDd	4.64±0.39	4.7±0.36	4.86±0.47	4.86±0.6	4.82±0.53	0.007
LAd	3.66±0.41	3.89±0.46	3.99±0.5	3.98±0.49	3.93±0.58	<0.001

ACEI-I=Angiotensin-converting enzyme inhibitors; ARB=Aldosterone receptor blocker; ASA=Acetylsalicylic acid; CABG=Coronary artery bypass grafting; CAD=Coronary artery disease; CCB=Calcium channel blocker; COPD=Chronic obstructive pulmonary disease; DM=Diabetes mellitus; EF=Ejection fraction; HL=Hyperlipidemia; HT=Hypertension; IVS=Interventricular septum; LAd=Left atrial diameter; LVDd=Left ventricular end-diastolic diameter; PCI=Percutaneous coronary intervention

Table 2: Laboratory findings according to the groups

Variables	Group 1 (*n*=86)	Group 2 (*n*=86)	Group 3 (*n*=75)	Group 4 (*n*=84)	Group 5 (*n*=98)	*P*
Urea (mg/dL)	32 (24-38)	39 (33-48)	58 (51-73)	88 (70-123)	108 (88-138)	<0.001
Creatinine (mg/dL)	0.7 (0.6-0.8)	0.86 (0.78-1)	1.3 (1.1-1.4)	2.7 (2.3-2.7)	6.6 (4.9-8.7)	<0.001
eGFR (dk/1.73 m^2)	90	74 (67-84)	42 (40-55.5)	22 (17-25)	7 (6-10)	<0.001
Albumin (g/L)	40.96±3.67	40.15±4	36.67±5.88	30.17±6.77	32.27±6.3	<0.001
Na (mmol/L)	139±2.6	139±2.3	139±3.65	136±4.8	137±3.4	<0.001
K (mmol/L)	4.27±0.35	4.42±0.42	4.37±0.59	4.51±0.79	4.7±0.86	<0.001
Triglyceride (mg/dL)	142 (98-211)	158 (101-233)	143 (104-199)	136 (92-187)	133 (89-193)	0.43
Total cholesterol (mg/dL)	191±37	189±54	181±57	168±60	165.2±43	0.001
HDL (mg/dL)	46±11.3	43±9.6	42±11.4	38±9.2	41±10.7	<0.001
LDL (mg/dL)	114±0.28	114±44	107±43	100±44	95±32	0.003
WBC (10^3/UL)	8.91±2.67	8.74±2.14	8.73±2.57	9.69±3.98	8.01±2.79	0.005
NEU (10^3/UL)	5.71±2.28	5.39±1.68	5.74±1.9	7.15±3.85	5.7±2.56	<0.001
LYM (10^3/UL)	2.45±0.87	2.53±0.86	2.18±0.99	1.63±0.96	1.52±0.7	<0.001
HB (g/dL)	13.94±1.8	13.54±1.78	12.51±1.79	10.29±2.12	10.34±2.05	<0.001
HCT (g/dL)	42.77±4.94	41.81±5.16	38.95±5.37	32.05±6.26	32.08±6.37	<0.001
Platelet (103/UL)	284±83	267±69	252±82	260±84	220.2±83	<0.001
HbA1c (%)	6.54±1.62	6.75±1.64	7.14±1.82	6.87±2.11	5.89±1.43	<0.001
T3 (pg/mL)	3.21±0.72	3.04±0.67	2.72±0.67	2.32±0.55	2.4±0.62	<0.001
T4 (ng/dL)	1.27±0.3	1.27±0.28	1.25±0.35	1.25±0.27	1.21±0.27	0.57
TSH (mU/L)	1.3 (0.8-1.9)	1.2 (0.6-1.7)	1.1 (0.6-1.8)	1.5 (0.8-2.9)	1.5 (0.7-2.2)	0.077

eGFR=Estimated glomerular filtration rate; Na=Sodium; K=Potassium; HDL=High-density lipoprotein; LDL=Low-density lipoprotein; WBC=White blood cells; NEU=Neutrophils; LYM=Lymphocytes; HB=Hemoglobin; HCT=Hematocrit; TSH=Thyroid-stimulating hormone

Table 3: Electrocardiographic findings of according to the groups

Variables	Group 1 (*n*=86)	Group 2 (*n*=86)	Group 3 (*n*=75)	Group 4 (*n*=84)	Group 5 (*n*=98)	*P*
Heart rate (bpm)	79.59±12.78	76.66±13.03	77.25±14.07	80.43±16.35	83.95±13.35	0.004
P (ms)	106.9±13.9	110.4±20.93	108.4±21.12	106.7±17.53	106.2±0.16.51	0.54
PR interval (ms)	147±19.23	160.5±25.43	157.8±27.54	154.9±28.6	150.1±23.79	0.003
QRS (ms)	87.51±9.08	85.33±9.35	90.65±11.57	89.64±12.87	89.62±10.89	0.012
QT (ms)	373.5±32.57	382.26±34.62	393.6±36.32	396.1±45.69	391.6±38.98	<0.001
QTc (ms)	426.9±24.74	427.59±23.74	442.2±31.17	452.3±34.57	459.3±31.79	<0.001
ICEB (QT/QRS)	4.3±0.47	4.52±0.056	4.41±0.72	4.5±0.79	4.42±0.61	0.172
ICEBc (QTc/QRS)	4.92±0.49	5.07±0.57	4.96±0.73	5.14±0.77	5.19±0.69	0.019
RR (msn)	772.5±129.8	805.5±129.7	801.5±140.5	776±159.9	732.1±117	0.002

ICEB=Index of cardiac-electrophysiological balance

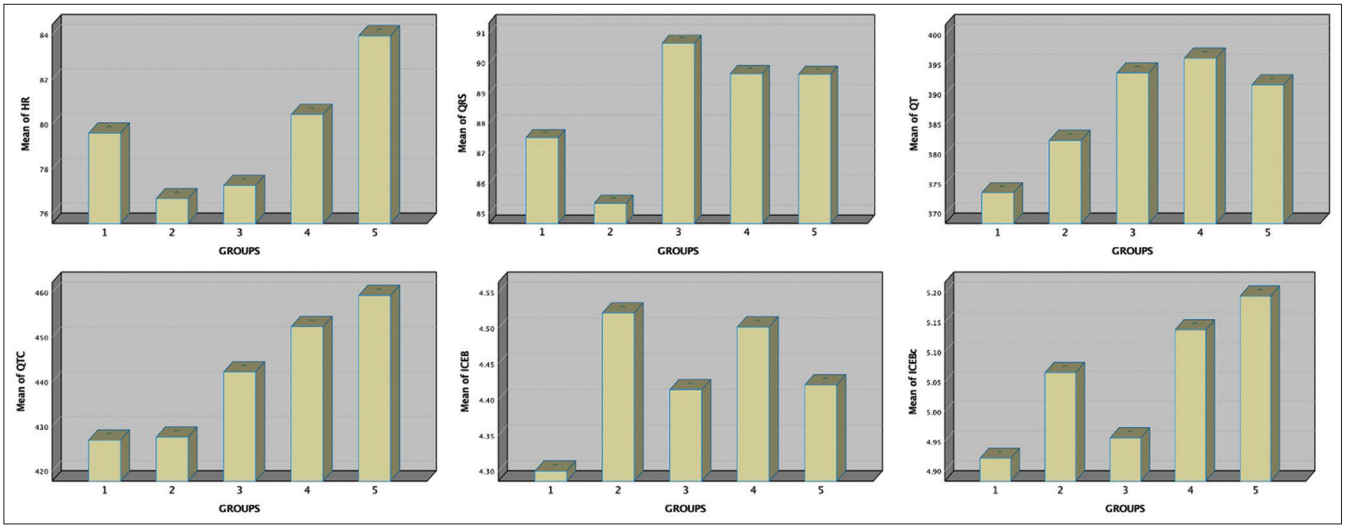

Figure 1: Mean electrocardiogram findings according to the groups. ICEB = Cardiac-electrophysiological balance; ICEBc = Corrected ICEB; QTc = Corrected QT

and *P* = 0.005, respectively). QT intervals were different between Group 1 and Groups 3, 4, and 5 (*P* = 0.003, *P* = 0.003, *P* = 0.003, and *P* = 0.008, respectively). ICEBc value differed between Groups 1 and 5 (*P* = 0.024).

DISCUSSION

This research highlights the association between the progression of CKD stages and the indices measuring ICEB. It was observed that ICEBc values showed a progressive rise, especially in patients at the ESRD stage undergoing hemodialysis (Group 5). In addition, we observed higher values for heart rate, PR interval, and QT/QTc values in CKD patients, indicating potential alterations in cardiac electrophysiology associated with progressive renal impairment.

Prolonged QTc interval is a known predictor of arrhythmogenic risk, particularly in the ESRD population. Typically, QTc intervals >460 msc in women and 450 msc in men are considered clinically significant for arrhythmia risk.[13] According to previous studies, ESRD patients had a longer QTc interval, which is linked to SCD, ventricular arrhythmia, and overall mortality.[14-16] However, there are contradictions and differences in the literature regarding the effect of routine hemodialysis treatment on QT/QTc intervals in ESRD patients. For instance, Morris *et al*.[17] found that in hemodialysis patients with CKD, the length of QTc max and QTd increased and that the increases persisted even after hemodialysis. On the other hand, Sivri and Çelik all found that Tp-e, Tp-e/QT, Tp-e/QTc, QT/QRS, and QTc/QRS parameters increased considerably following hemodialysis, although QT and QTc intervals remained unchanged.[18] Some studies have observed that hemodialysis has a neutral effect on QTc.[19,20] Our findings align with previous studies, indicating elevated QT/QTc intervals in patients at Stages 3–4 of CKD and those undergoing hemodialysis. However, the absence of pre- and posthemodialysis data for ESRD patients in our study presents a limitation. In contrast to our findings, Sivri and Çelik reported significant increases in ICEB and ICEBc following hemodialysis in ESRD patients when compared to healthy controls.[18] Our findings differ from theirs regarding ICEB values, possibly due to the division of our study population into the five groups. If the population were divided into only ESRD patients and a control group, the results might align with their study.

The QTc interval was considerably longer as the severity of CKD increased. In particular, prolonged QTc intervals

were reported in 45%, 59%, 59.3%, and 74.6% of patients in CKD Stages 2, 3, 4, and 5, respectively, with a significant proportion of individuals 15%, 13.6%, 22%, and 23.5% exhibiting marked QTc prolongation.[21] In our study, the increase in QTc values was proportional to CKD severity, similar to the trend observed with ICEBc values.

Several contributing factors may explain the delayed ventricular repolarization observed in CKD patients. The prevalence of DM is notably high in CKD patients compared to the general population. Metabolic abnormalities may lead to an increase in oxidative stress. The primary metabolic mechanism, oxidative stress, has been linked to extended QTc interval and action potential duration in DM.[22] HT is also more common in CKD patients. Acute variations in blood pressure, modifications in the autonomic nervous system, and cardiomyocyte hypertrophy are some of the mechanisms that contribute to the prolonging of the QT interval in hypertensive patients.[23,24] Elevated levels of uric acid can exacerbate oxidative stress and inflammatory reactions, which can alter the electrical characteristics of the heart and raise the risk of arrhythmic episodes.[25] Furthermore, myocardial hypertrophy and cardiac fibrosis are linked to hyperphosphatemia, and both conditions can lengthen the QT interval.[26] Hypocalcemia is common in CKD patients and has a significant correlation with prolonged QTc.[27] On the other hand, hemodialysis's quick fluid clearance might cause a sudden drop in blood volume, which could cause hypotension, tissue ischemia, cardiac remodeling, and arrhythmia.[28] Intradialytic hypotension, in particular, is an independent risk factor for cardiovascular morbidity and mortality in hemodialysis patients.[29]

Limitations

This study has several limitations. First, due to its cross-sectional design, it is not possible to establish a causal relation between the progression of CKD and the changes in ICEB and ICEBc values. Longitudinal studies are necessary to determine whether these indices can predict arrhythmic events and cardiovascular mortality over time. Second, this research was conducted at a single center, which may limit the generalizability of the findings to other populations and clinical settings. Multicenter studies with larger and more diverse patient populations are needed to validate our results. Third, patients with several comorbid conditions were excluded from the study, which may have introduced selection bias. These exclusion criteria were necessary to control for confounding variables but may limit their applicability in the larger group of CKD patients who often have multiple comorbidities. While every effort was made to ensure accurate ECG measurements, including blinding and the use of magnified digital images, inherent variability in manual QT interval measurement cannot be entirely ruled out. Automated ECG analysis systems could enhance measurement precision in future.

CONCLUSION

This study demonstrates that ICEBc values progressively increase with advancing CKD stages, with significant changes observed in Stage 5. This suggests that ICEBc may be a valuable indicator for assessing arrhythmic risk in CKD patients, particularly those with ESRD who are undergoing hemodialysis.

Data availability statement

The data supporting this study are available from the corresponding author upon reasonable request.

Acknowledgments

We thank Hebun Var for his important support in the study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Boriani G, Savelieva I, Dan GA, Deharo JC, Ferro C, Israel CW, *et al*. Chronic kidney disease in patients with cardiac rhythm disturbances or implantable electrical devices: Clinical significance and implications for decision making-a position paper of the European Heart Rhythm Association endorsed by the Heart Rhythm Society and the Asia Pacific Heart Rhythm Society. Europace 2015;17:1169-96.
2. Kollu K, Altintepe L, Duran C, Topal M, Ecirli S. The assessment of P-wave dispersion and myocardial repolarization parameters in patients with chronic kidney disease. Ren Fail 2018;40:1-7.
3. GBD Chronic Kidney Disease Collaboration. Global, regional, and national burden of chronic kidney disease, 1990-2017: A systematic analysis for the Global Burden of Disease Study 2017. Lancet 2020;395:709-33.
4. Ibrahim AO, Prabhakar AP, Lopez-Candales A. QTc interval: A frequently unrecognized electrocardiographic interval. Am J Med Sci 2024;368:532-7.
5. Matsumoto Y, Mori Y, Kageyama S, Arihara K, Sato H, Nagata K, *et al*. Changes in QTc interval in long-term hemodialysis patients. PLoS One 2019;14:e0209297.
6. Kantarci G, Ozener C, Tokay S, Bihorac A, Akoğlu E. QT dispersion in hemodialysis and CAPD patients. Nephron 2002;91:739-41.
7. Sohal PM, Goel A, Gupta D, Aslam N, Sandhu J, Sandhu JS, *et al*. Effect of hemodialysis on corrected QT interval and QTc dispersion. Indian J Nephrol 2018;28:335-8.
8. Waks JW, Tereshchenko LG, Parekh RS. Electrocardiographic predictors of mortality and sudden cardiac death in patients with end stage renal disease on hemodialysis. J Electrocardiol 2016;49:848-54.
9. Lee HJ, Choe AR, Lee H, Ryu DR, Kang EW, Park JT, *et al*. Clinical associations between serial electrocardiography measurements and sudden cardiac death in patients with end-stage renal disease undergoing hemodialysis. J Clin Med 2021;10:1933.
10. Robyns T, Lu HR, Gallacher DJ, Garweg C, Ector J, Willems R, *et al*. Evaluation of index of cardio-electrophysiological balance (iCEB) as a new biomarker for the identification of patients at increased arrhythmic risk. Ann Noninvasive Electrocardiol 2016;21:294-304.
11. Lu HR, Yan GX, Gallacher DJ. A new biomarker – Index of cardiac

electrophysiological balance (iCEB) – Plays an important role in drug-induced cardiac arrhythmias: Beyond QT-prolongation and Torsades de Pointes (TdPs). J Pharmacol Toxicol Methods 2013;68:250-9.
12. Levey AS, Bosch JP, Lewis JB, Greene T, Rogers N, Roth D. A more accurate method to estimate glomerular filtration rate from serum creatinine: A new prediction equation. Modification of diet in renal disease study group. Ann Intern Med 1999;130:461-70.
13. Zhang Y, Post WS, Blasco-Colmenares E, Dalal D, Tomaselli GF, Guallar E. Electrocardiographic QT interval and mortality: A meta-analysis. Epidemiology 2011;22:660-70.
14. Straus SM, Kors JA, De Bruin ML, van der Hooft CS, Hofman A, Heeringa J, *et al*. Prolonged QTc interval and risk of sudden cardiac death in a population of older adults. J Am Coll Cardiol 2006;47:362-7.
15. Genovesi S, Rossi E, Nava M, Riva H, De Franceschi S, Fabbrini P, *et al*. A case series of chronic haemodialysis patients: Mortality, sudden death, and QT interval. Europace 2013;15:1025-33.
16. Parekh RS, Meoni LA, Jaar BG, Sozio SM, Shafi T, Tomaselli GF, *et al.* Rationale and design for the predictors of arrhythmic and cardiovascular risk in end stage renal disease (PACE) study. BMC Nephrol 2015;16:63.
17. Morris ST, Galiatsou E, Stewart GA, Rodger RS, Jardine AG. QT dispersion before and after hemodialysis. J Am Soc Nephrol 1999;10:160-3.
18. Sivri S, Çelik M. Evaluation of index of cardiac-electrophysiological balance before and after hemodialysis in patients with end-stage renal disease. J Electrocardiol 2019;54:72-5.
19. Kalantzi K, Gouva C, Letsas KP, Vlachopanou A, Foulidis V, Bechlioulis A, *et al*. The impact of hemodialysis on the dispersion of ventricular repolarization. Pacing Clin Electrophysiol 2013;36:322-7.
20. Drighil A, Madias JE, Benjelloun M, Kamoum H, Bennis A, Azzouzi L, *et al*. Changes in the QT intervals, QT dispersion, and amplitude of T waves after hemodialysis. Ann Noninvasive Electrocardiol 2007;12:137-44.
21. Sherif KA, Abo-Salem E, Panikkath R, Nusrat M, Tuncel M. Cardiac repolarization abnormalities among patients with various stages of chronic kidney disease. Clin Cardiol 2014;37:417-21.
22. Zhang Y, Xiao J, Wang H, Luo X, Wang J, Villeneuve LR, *et al*. Restoring depressed HERG K+ channel function as a mechanism for insulin treatment of abnormal QT prolongation and associated arrhythmias in diabetic rabbits. Am J Physiol Heart Circ Physiol 2006;291:H1446-55.
23. Marfella R, Gualdiero P, Siniscalchi M, Carusone C, Verza M, Marzano S, *et al*. Morning blood pressure peak, QT intervals, and sympathetic activity in hypertensive patients. Hypertension 2003;41:237-43.
24. Piccirillo G, Viola E, Bucca C, Santagada E, Raganato P, Tondo A, *et al*. QT interval dispersion and autonomic modulation in subjects with anxiety. J Lab Clin Med 1999;133:461-8.
25. Crișan TO, Cleophas MC, Oosting M, Lemmers H, Toenhake-Dijkstra H, Netea MG, *et al*. Soluble uric acid primes TLR-induced proinflammatory cytokine production by human primary cells via inhibition of IL-1Ra. Ann Rheum Dis 2016;75:755-62.
26. Zhang Y, Post WS, Dalal D, Bansal S, Blasco-Colmenares E, Jan De Beur S, *et al*. Serum 25-hydroxyvitamin D, calcium, phosphorus, and electrocardiographic QT interval duration: Findings from NHANES III and ARIC. J Clin Endocrinol Metab 2011;96:1873-82.
27. Vandael E, Vandenberk B, Vandenberghe J, Willems R, Foulon V. Risk factors for QTc-prolongation: Systematic review of the evidence. Int J Clin Pharm 2017;39:16-25.
28. Flythe JE, Kimmel SE, Brunelli SM. Rapid fluid removal during dialysis is associated with cardiovascular morbidity and mortality. Kidney Int 2011;79:250-7.
29. Stefánsson BV, Brunelli SM, Cabrera C, Rosenbaum D, Anum E, Ramakrishnan K, *et al*. Intradialytic hypotension and risk of cardiovascular disease. Clin J Am Soc Nephrol 2014;9:2124-32.