

The Relationship Between Target Vessel and Ventricular Repolarisation in Chronic Total Occlusion

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Abstract

Background

Although the anatomical territory may influence ischaemic burden and scar, whether the occluded epicardial vessel is associated with a distinct baseline surface-ECG repolarisation phenotype in chronic total occlusion (CTO) remains uncertain.

Objectives

To compare baseline QTc, Tp-e, and Tp-e/QTc among LAD, LCx, and RCA CTO cases, and to quantify unadjusted and covariate-adjusted vessel effects.

Methods

This retrospective observational analysis included 271 unique patients undergoing percutaneous coronary intervention (PCI) due to CTO following the exclusion of 80 duplicate records. Target-vessel groups comprised 86 LAD, 55 LCx, and 130 RCA cases; 259 patients had complete baseline QTc and Tp-e data.

Results

Mean QTc was 417.8 ± 25.2 ms for LAD, 428.2 ± 41.2 ms for LCx, and 419.9 ± 31.4 ms for RCA CTOs (Welch $p = 0.266$; Kruskal–Wallis $p = 0.675$). Among CTO cases involving the LAD, LCx and RCA, Tp-e was 94.5 ± 12.5 , 93.4 ± 14.9 , and 93.7 ± 12.1 ms (Welch $p = 0.876$), and Tp-e/QTc was 0.227 ± 0.031 , 0.219 ± 0.038 , and 0.224 ± 0.034 (Welch $p = 0.524$), respectively. In the 241 cases with non-missing data, adjusted global p-values were 0.141 for QTc, 0.860 for Tp-e, and 0.433 for Tp-e/QTc. No adjusted pairwise contrast remained significant following Holm correction. Excluding QTc values > 500 ms yielded an unadjusted global $p = 0.960$ and an adjusted $p = 0.638$.

Conclusions

Target-vessel location alone does not define a distinct baseline repolarisation phenotype. Future studies should integrate vessel territory with scar burden, ischaemia, collateral quality, concurrent medications, and standardised longitudinal ECG assessment.

INTRODUCTION

The presence of a chronic total coronary occlusion (CTO) has been associated with a poorer prognosis compared to patients presenting with multivessel disease (MVD) or single-vessel disease (SVD) without CTO[1]. However, the extent to which CTOs increase the risk of ventricular arrhythmia and mortality remains unclear. To date, studies comparing the incidence of ventricular arrhythmia in patients with and without CTO have yielded conflicting results[2, 3]. One hypothesis is that CTO adversely affects cardiac electrical stability, rendering patients with CTO more susceptible to ventricular arrhythmias (VAs) and thereby increasing the mortality risk[1, 4].

While the QRS complex mirrors ventricular depolarisation (VD), ventricular repolarisation (VR) encompasses the duration from the end of the QRS complex to the end of the T wave. Evaluating these intervals aids clinicians in predicting the likelihood of developing ventricular dysfunction and arrhythmias[5]. It has long been established that an increase in ventricular repolarisation dispersion predisposes individuals to ventricular arrhythmias, making the Tp-e interval a valuable non-invasive marker of the arrhythmogenic substrate[6].

In recent years, novel ECG parameters, namely the Tp-e interval, the Tp-e/QT ratio (TQR), and the Tp-e/QTc ratio (TQcR), have been utilised to predict ventricular arrhythmias. These parameters have been reported to possess superior predictive capacity compared to conventional QT measurements, and they may serve as more accurate and sensitive indicators for identifying repolarisation abnormalities associated with serious arrhythmic events[7].

The anatomical location of the affected coronary artery can influence the ischaemic burden and the extent of myocardial scarring. However, whether the specific occluded epicardial vessel in CTO dictates a distinct ventricular repolarisation phenotype on the baseline surface ECG remains to be determined. Accordingly, the present study investigated whether baseline ventricular repolarisation characteristics differ across LAD, LCx, and RCA CTOs based on QTc, Tp-e, and Tp-e/QTc, and to evaluate the target-vessel effect using both unadjusted and covariate-adjusted analyses.

MATERIALS AND METHODS

Study Population:

This retrospective, cross-sectional study included 271 consecutive patients who presented to the cardiology department with chest pain between January 2024 and March 2026 and were diagnosed with CTO during coronary angiography.

Demographics and clinical characteristics, such as age, gender, smoking status, diabetes mellitus, hypertension, coronary artery disease, hyperlipidaemia, and statin use, were obtained from the hospital's electronic medical records.

The study protocol was approved by the Antalya City Hospital Ethics Committee (Approval No. : 23/220; April 27, 2026), and the study was conducted in accordance with the principles of the Declaration of

Helsinki.

Biochemical laboratory parameters of all participants were recorded. For analysis, standard resting 12-lead electrocardiograms (ECGs) obtained prior to the procedure were retrieved from the institution's digital archive. All ECG recordings were obtained using the GE Healthcare MAC 5500 HD electrocardiography system (GE Healthcare, Chicago, IL, USA) at a paper speed of 25 mm/s and a calibration of 10 mm/mV.

ECG Analysis:

All ECG recordings were independently evaluated by two experienced cardiologists in the hospital's electrocardiography laboratory. The QT interval was measured as the duration from the onset of the QRS complex to the end of the T wave, with the TP segment considered the isoelectric line where appropriate. QT interval measurements in leads DII and V5 were obtained using the electronic calculation function of the ECG device. The corrected QT interval (QTc) was calculated using Bazett's formula ($QTc = QT/\sqrt{RR}$).

The Tp-e interval, defined as the duration between the peak and the end of the T wave, was measured in lead V5, provided that ST-segment deviation was < 1.5 mm and the T wave showed positive deflection. When these criteria were not met, lead V4 or lead V6 was used as alternatives. Tp-e measurements were performed using the micro-grid sampling method. The Tp-e/QTc ratio was calculated by dividing the Tp-e interval by the QTc value.

The primary electrocardiographic endpoints of the study were defined as baseline QTc, Tp-e, and the Tp-e/QTc ratio. All measurements were conducted in a blinded manner regarding the patients' target-vessel groups.

Exclusion Criteria:

Patients with signs of atrial flutter, second- or third-degree atrioventricular block, ventricular pre-excitation, or a paced rhythm on the baseline ECG were excluded from the study.

Covariates:

The primary adjusted model included baseline variables plausibly associated with ventricular repolarisation or target-vessel characteristics, namely age, gender, baseline left ventricular ejection fraction (LVEF), diabetes, hypertension, chronic kidney disease, smoking status, and baseline heart rate. Procedural success was deliberately excluded from the primary model as it is assessed after baseline ECG assessment and could represent a mediator, consequence of anatomy, or collider rather than a baseline confounder.

A sensitivity analysis was additionally performed by adjusting for procedural success to evaluate the robustness of the findings to model specification. The interpretation of this sensitivity analysis is purely associational and does not imply that procedural success is an appropriate confounder for a baseline outcome.

Statistical Analysis:

Continuous variables are summarised as mean $\pm$ SD and median [IQR], while categorical variables are expressed as n (%) using available denominators. Baseline clinical characteristics were compared across the three vessels with the Welch ANOVA for continuous variables and the Pearson chi-square test for categorical variables. The maximum absolute pairwise standardised difference was reported to characterise the magnitude of group imbalance independently of sample size.

For each ECG outcome, the primary unadjusted global comparison used the Welch ANOVA as group sizes and variances differed. The Welch F statistic, numerator and denominator degrees of freedom, and two-sided p-values were reported. The Kruskal–Wallis test was employed as a distribution-free sensitivity analysis. When pairwise unadjusted estimates were examined, Games–Howell comparisons were used since they accommodate unequal variances and sample sizes while controlling the familywise error within each outcome.

Primary adjusted analyses used ordinary least squares regression incorporating HC3 robust standard errors. The target vessel was represented by LCx and RCA indicator variables, with the LAD serving as the reference. A joint two-degree-of-freedom robust Wald test was performed to assess the overall vessel factor. Adjusted marginal means and 95% confidence intervals (CIs) were estimated at the mean covariate profile of the complete-case model sample. Pairwise contrasts were reported for LCx versus LAD, RCA versus LAD, and LCx versus RCA. Nominal contrast p-values were adjusted using the Holm method within each ECG outcome.

Complete-case analysis was applied to all multivariable models, and no imputation was performed. Primary adjusted models included 241 patients. Sensitivity analyses excluded baseline QTc values > 500 ms and, separately, incorporated procedural success into the covariate set. Model diagnostics included variance inflation factors (VIFs), Breusch–Pagan tests, and Cook's distance. All statistical tests were two-sided, and primary emphasis was placed on point estimates and 95% CIs rather than relying on non-significant results to declare equivalence. The analyses were conducted using Python version 3.13.5, alongside NumPy 2.3.5, SciPy 1.17.0, and statsmodels 0.14.6.

RESULTS

Cohort and Baseline Characteristics

The 271-patient cohort comprised 86 LAD CTOs (31.7%), 55 LCx CTOs (20.3%), and 130 RCA CTOs (48.0%). Baseline QTc, Tp-e, and Tp-e/QTc were jointly available in 259 patients, comprising 83 with LAD,

53 with LCx, and 123 with RCA CTOs. After excluding cases with missing covariates, the primary adjusted models included 241 patients.

Baseline age and gender distributions were comparable across the target-vessel groups. Diabetes was less frequent in CTOs involving the RCA (41.5%) than in LAD CTOs (58.1%) or LCx (60.0%) CTOs (global $p = 0.017$; maximum pairwise standardised difference, 0.38). Hypertension was most prevalent in LCx CTOs (87.3% vs 70.9% for LAD CTOs and 70.8% for RCA CTOs; $p = 0.045$), and baseline LVEF was highest in RCA CTOs ($50.7 \pm 10.3\%$ vs $45.9 \pm 12.0\%$ for LAD CTOs and $47.2 \pm 12.7\%$ for LCx CTOs; $p = 0.011$). Platelet counts differed significantly across the groups ($p = 0.038$). Procedural success was numerically lower in the RCA CTO group (68.5%) compared to the LAD (82.6%) and LCx (78.2%) CTO groups, ($p = 0.053$). A comprehensive summary of the baseline characteristics is presented in Table 1.

Table 1
Baseline Characteristics by Target Vessel in CTO

Variable	LAD	LCx	RCA	Maximum pairwise standardised difference	Global p-value
Age, years	60.3 ± 11.0 (n = 86)	62.0 ± 9.1 (n = 55)	62.1 ± 10.4 (n = 130)	0.175	0.432
Male gender	71 (84.5%)	44 (81.5%)	110 (88.0%)	0.182	0.496
Diabetes mellitus	50 (58.1%)	33 (60.0%)	54 (41.5%)	0.376	0.017
Hypertension	61 (70.9%)	48 (87.3%)	92 (70.8%)	0.414	0.045
Chronic kidney disease	5 (5.8%)	5 (9.1%)	4 (3.1%)	0.254	0.228
Cerebrovascular disease	0 (0.0%)	2 (3.6%)	4 (3.1%)	0.275	0.234
Current/former smoking	49 (57.0%)	30 (54.5%)	68 (53.5%)	0.069	0.884
LVEF, %	45.9 ± 12.0 (n = 80)	47.2 ± 12.7 (n = 50)	50.7 ± 10.3 (n = 119)	0.433	0.011
Successful PCI for CTO	71 (82.6%)	43 (78.2%)	89 (68.5%)	0.332	0.053
WBC, cell/μL	9505.1 ± 2865.6 (n = 86)	9106.7 ± 2503.6 (n = 55)	8691.3 ± 2630.3 (n = 130)	0.299	0.107
Haemoglobin, g/dL	14.0 ± 2.1 (n = 86)	13.5 ± 2.1 (n = 55)	13.6 ± 2.0 (n = 130)	0.243	0.287
Platelets, ×10 ³ /μL	272.8 ± 80.7 (n = 86)	260.6 ± 76.4 (n = 55)	245.8 ± 69.4 (n = 130)	0.365	0.038
Creatinine, mg/dL	1.0 ± 0.3 (n = 86)	1.0 ± 0.4 (n = 55)	1.0 ± 0.4 (n = 130)	0.151	0.545
Total cholesterol, mg/dL	185.9 ± 51.6 (n = 86)	192.7 ± 58.7 (n = 55)	180.8 ± 51.3 (n = 130)	0.224	0.424

Values are expressed as mean ± SD with available n, median [IQR] with available n for electrical risk score (ERS), or n (%) based on available denominators. Global p-values are derived from the Welch ANOVA for continuous/ordinal variables or the chi-square test for categorical variables. The maximum pairwise standardised difference is reported as an absolute value. Target-vessel coding is subject to source verification. CTO = chronic total occlusion; HDL = high-density lipoprotein; LAD = left anterior descending artery; LCx = left circumflex artery; LDL = low-density lipoprotein; LVEF = left ventricular ejection fraction; PCI = percutaneous coronary intervention; RCA = right coronary artery.

Variable	LAD	LCx	RCA	Maximum pairwise standardised difference	Global p-value
	81)	51)	128)		
Triglycerides, mg/dL	192.6 ± 149.8 (n = 80)	164.2 ± 79.0 (n = 49)	184.7 ± 143.5 (n = 128)	0.222	0.288
HDL cholesterol, mg/dL	41.0 ± 13.4 (n = 81)	42.6 ± 10.8 (n = 51)	40.9 ± 11.1 (n = 128)	0.149	0.643
LDL cholesterol, mg/dL	113.8 ± 44.7 (n = 81)	115.6 ± 50.4 (n = 50)	105.8 ± 39.4 (n = 128)	0.231	0.272
Heart rate, beats/min	80.2 ± 16.6 (n = 83)	76.3 ± 15.1 (n = 53)	77.9 ± 14.3 (n = 123)	0.241	0.363
QT interval, ms	379.5 ± 40.5 (n = 75)	398.7 ± 58.1 (n = 51)	381.9 ± 36.6 (n = 114)	0.396	0.119
Electrical risk score	2.0 [2.0–3.0] (n = 83)	2.0 [1.0–3.0] (n = 53)	2.0 [2.0–3.0] (n = 123)	0.238	0.356
Values are expressed as mean ± SD with available n, median [IQR] with available n for electrical risk score (ERS), or n (%) based on available denominators. Global p-values are derived from the Welch ANOVA for continuous/ordinal variables or the chi-square test for categorical variables. The maximum pairwise standardised difference is reported as an absolute value. Target-vessel coding is subject to source verification. CTO = chronic total occlusion; HDL = high-density lipoprotein; LAD = left anterior descending artery; LCx = left circumflex artery; LDL = low-density lipoprotein; LVEF = left ventricular ejection fraction; PCI = percutaneous coronary intervention; RCA = right coronary artery.					

Table 2
Unadjusted Baseline Ventricular Repolarisation Metrics by Target Vessel

Outcome	LAD	LCx	RCA	Welch F	df	Welch p-value	Kruskal-Wallis p-value
QTc, ms	417.8 ± 25.2; 415.0 [399.5– 438.0] (n = 83)	428.2 ± 41.2; 418.0 [402.0– 446.0] (n = 53)	419.9 ± 31.4; 415.0 [400.0– 437.5] (n = 123)	1.338	2, 124.1	0.266	0.675
Tp-e, ms	94.5 ± 12.5; 95.0 [85.0– 100.0] (n = 83)	93.4 ± 14.9; 90.0 [85.0– 100.0] (n = 53)	93.7 ± 12.1; 90.0 [85.0– 100.0] (n = 123)	0.132	2, 125.3	0.876	0.947
Tp-e/QTc ratio	0.227 ± 0.031; 0.222 [0.205– 0.249] (n = 83)	0.219 ± 0.038; 0.220 [0.190– 0.233] (n = 53)	0.224 ± 0.034; 0.221 [0.198– 0.244] (n = 123)	0.649	2, 128.7	0.524	0.441
Data within each vessel column represent mean ± SD, median [IQR], and available n. Welch ANOVA is the primary unadjusted global comparison; Kruskal–Wallis is a distribution-free sensitivity analysis.							
The Welch ANOVA serves as the primary unadjusted global comparison, with the Kruskal–Wallis test employed as a distribution-free sensitivity analysis. The Tp-e/QTc ratio was recalculated as the Tp-e interval divided by the QTc. LAD = left anterior descending artery; LCx = left circumflex artery; QTc = corrected QT interval; RCA = right coronary artery; Tp-e = T-wave peak-to-end interval.							

Table 3
Covariate-Adjusted Marginal Means and Global Vessel Tests

Outcome	N	Adjusted LAD mean (95% CI)	Adjusted LCx mean (95% CI)	Adjusted RCA mean (95% CI)	Robust F	Global p-value
QTc, ms	241	415.6 (409.5 to 421.8)	427.4 (416.2 to 438.7)	422.0 (416.0 to 428.0)	1.977	0.141
Tp-e, ms	241	94.6 (91.8 to 97.4)	93.9 (89.7 to 98.1)	93.6 (91.3 to 95.9)	0.151	0.860
Tp-e/QTc ratio	241	0.228 (0.221 to 0.235)	0.221 (0.210 to 0.232)	0.223 (0.217 to 0.229)	0.840	0.433
The HC3 robust models are adjusted for age, gender, baseline LVEF, diabetes, hypertension, chronic kidney disease, smoking status, and baseline heart rate. Adjusted means are estimated at the mean covariate profile of the complete-case sample. The global p-value is derived from a joint two-degree-of-freedom Wald test of the LCx and RCA indicator variables, with the LAD serving as the reference vessel.						

Table 4
Unadjusted and Adjusted Pairwise Target-Vessel Contrasts

Outcome	Contrast	Games–Howell difference (95% CI)	Games–Howell p-value	Adjusted difference (95% CI)	Nominal p-value	Holm p-value
QTc, ms	LCx vs LAD	10.3 (-4.7 to 25.4)	0.235	11.8 (-1.0 to 24.6)	0.070	0.211
QTc, ms	RCA vs LAD	2.1 (-7.3 to 11.4)	0.859	6.4 (-2.6 to 15.4)	0.164	0.327
QTc, ms	LCx vs RCA	8.2 (-6.9 to 23.4)	0.398	5.4 (-7.3 to 18.2)	0.403	0.403
Tp-e, ms	LCx vs LAD	-1.0 (-6.9 to 4.8)	0.909	-0.7 (-5.6 to 4.3)	0.790	1.000
Tp-e, ms	RCA vs LAD	-0.8 (-4.9 to 3.4)	0.892	-1.0 (-4.6 to 2.6)	0.587	1.000
Tp-e, ms	LCx vs RCA	-0.2 (-5.7 to 5.3)	0.995	0.3 (-4.6 to 5.3)	0.899	1.000
Tp-e/QTc ratio	LCx vs LAD	-0.007 (-0.022 to 0.008)	0.491	-0.007 (-0.020 to 0.006)	0.280	0.839
Tp-e/QTc ratio	RCA vs LAD	-0.002 (-0.013 to 0.008)	0.862	-0.005 (-0.015 to 0.004)	0.295	0.839
Tp-e/QTc ratio	LCx vs RCA	-0.005 (-0.019 to 0.010)	0.712	-0.002 (-0.015 to 0.011)	0.760	0.839
Differences are calculated as the second named vessel minus the reference vessel. The Games–Howell comparisons account for unequal variances and group sizes. Adjusted contrasts are derived from the primary HC3 model, with the Holm correction applied to the three pairwise contrasts within each outcome. CI = confidence interval; LAD = left anterior descending artery; LCx = left circumflex artery; QTc = corrected QT interval; RCA = right coronary artery; Tp-e = T-wave peak-to-end interval.						

Unadjusted Repolarisation Comparisons

Mean baseline QTc was 417.8 ± 25.2 ms in LAD CTOs, 428.2 ± 41.2 ms in LCx CTOs, and 419.9 ± 31.4 ms in RCA CTOs. The global Welch ANOVA revealed no significant differences ($F = 1.34$; $df = 2, 124.1$; $p = 0.266$), with the Kruskal-Wallis test yielding concordant results ($p = 0.675$). The wider dispersion observed within the LCx group was partially driven by a few markedly prolonged values.

Similarly, baseline Tp-e intervals were nearly identical across the groups (94.5 ± 12.5 ms for LAD, 93.4 ± 14.9 ms for LCx, and 93.7 ± 12.1 ms for RCA; Welch $p = 0.876$; Kruskal–Wallis $p = 0.947$). The Tp-e/QTc ratio was likewise comparable among the cohorts (0.227 ± 0.031 , 0.219 ± 0.038 , and 0.224 ± 0.034 ;

Welch $p = 0.524$; Kruskal–Wallis $p = 0.441$). None of the Games–Howell pairwise comparisons demonstrated statistically significant differences.

Adjusted Global and Pairwise Analyses

In the multivariable analysis of 241 complete cases, the primary adjusted joint vessel effect remained statistically non-significant for QTc (robust $F = 1.98$; $p = 0.141$), Tp-e ($F = 0.15$; $p = 0.860$), and Tp-e/QTc ($F = 0.84$; $p = 0.433$). Adjusted QTc means were 415.6 ms (95% CI, 409.5–421.8) for LAD CTOs, 427.4 ms (95% CI, 416.2–438.7) for LCx CTOs, and 422.0 ms (95% CI, 416.0–428.0) for RCA CTOs.

The largest adjusted QTc contrast was observed between the LCx and LAD groups, with a difference of + 11.8 ms (95% CI: –1.0 to 24.6 ms; nominal $p = 0.070$; Holm-adjusted $p = 0.211$). The contrast for RCA versus LAD was + 6.4 ms (95% CI: –2.6 to 15.4 ms; Holm-adjusted $p = 0.327$), while that for LCx versus RCA was + 5.4 ms (95% CI: –7.3 to 18.2 ms; Holm-adjusted $p = 0.403$). Thus, while the point estimates suggested a modestly longer QTc interval in LCx CTOs, the confidence intervals remained entirely compatible with no true difference, and all multiplicity-corrected results demonstrated no statistical significance.

The adjusted Tp-e contrasts were negligible, yielding differences of – 0.7 ms for LCx versus LAD, – 1.0 ms for RCA versus LAD, and + 0.3 ms for LCx versus RCA, with all Holm-adjusted p -values equalling 1.000. Similarly, the adjusted Tp-e/QTc contrasts ranged minimally from – 0.007 to – 0.002, and all associated Holm-adjusted p -values were 0.839. Ultimately, the adjusted confidence intervals confirmed the absence of any clinically distinct, vessel-specific repolarisation patterns.

Sensitivity and Diagnostic Analyses

Four LCx cases and one RCA case had baseline QTc > 500 ms. After excluding these values, mean QTc converged to 417.8 ± 25.2 ms for LAD, 419.1 ± 25.9 ms for LCx, and 418.6 ± 28.1 ms for RCA groups. The Welch p -value was 0.960, the Kruskal–Wallis p -value was 0.994, and the adjusted global p -value was 0.638 ($n = 236$).

Furthermore, the incorporation of procedural success into the primary covariate set did not alter the clinical interpretation, resulting in global p -values of 0.189 for QTc, 0.932 for Tp-e, and 0.562 for Tp-e/QTc. Maximum VIFs were approximately 1.37 in the primary models. Finally, HC3 standard errors were retained across all analyses, including the ratio model where the Breusch-Pagan test indicated the presence of heteroscedasticity.

DISCUSSION

The present study investigated whether the target coronary vessel is associated with baseline ventricular repolarisation characteristics in patients with chronic total occlusion. The primary finding of this study was that baseline QTc, Tp-e, and Tp-e/QTc values did not differ significantly among the LAD, LCx, and RCA CTO groups. This lack of difference remained unchanged after adjusting for clinical covariates, and

no pairwise comparison retained statistical significance following the application of the Holm correction for multiple comparisons. Furthermore, the robustness of these findings was supported by a sensitivity analysis excluding patients with baseline QTc values > 500 ms, confirming that the findings were not driven by extreme outliers with excessively prolonged repolarisation.

It has been widely hypothesised that chronic total occlusions adversely affect cardiac electrical stability, thereby rendering patients more susceptible to ventricular arrhythmias and increasing mortality risk[1, 4]. Indeed, in the eCTOpY-in-ICD study, the presence of a CTO in patients with an implantable cardioverter-defibrillator (ICD) was associated with a higher frequency of appropriate device therapies and a poorer prognosis during long-term follow-up. Furthermore, the same study demonstrated that rates of appropriate device therapy were similar among patients with a CTO in the right coronary artery, left anterior descending artery, or circumflex artery, whereas survival was highest among those with CTO in the circumflex artery[8].

Given that the pathophysiology of ventricular arrhythmias is highly complex and important, the underlying aetiology of the CTO may be equally critical. In line with this, Di Marco et al. reported that the presence of a CTO in a previously infarcted myocardial region (infarct-related artery [IRA]-CTO) is associated with a higher incidence of VAs (particularly rapid ventricular tachycardia [VT] and ventricular fibrillation [VF]) as well as more frequent ICD therapies[9, 10]. Although the exact mechanism by which an IRA-CTO increases arrhythmic risk remains to be fully elucidated, the primary substrate for VAs in patients with ischaemic cardiomyopathy is well known to be myocardial scar tissue resulting from a prior myocardial infarction[11]. In this context, surface ECG parameters such as QTc, Tp-e, and the Tp-e/QTc ratio are employed to non-invasively assess ventricular repolarisation and stratify potential arrhythmogenic risk. The slow conduction channels required to sustain the re-entrant circuit of VT may be located within the scar tissue itself or,[12] more frequently, within the 'border zone' where fibrotic tissue intermingles with viable myocytes[11, 13]. An IRA-CTO can induce ischaemia surrounding this post-infarction necrotic core, thereby increasing the electrical instability of the myocardial scar, particularly within the border zone. Furthermore, recent evidence suggests that a CTO may be associated with a certain degree of resting ischaemia, even when non-invasive stress tests yield negative results[14]. From this perspective, the electrical impact of a CTO is not dictated merely by the identity of the target vessel (e.g., LAD, LCx, or RCA); indeed, even CTOs within the same coronary artery can exhibit profound differences regarding the resulting ischaemia, scar burden, collateral circulation, and myocardial viability. The absence of significant differences in baseline QTc, Tp-e, and Tp-e/QTc values among the target vessels in the present study may align with this more complex, multifactorial pathophysiological model. Findings of this study also suggest that repolarisation parameters assessed via surface ECG may not fully reflect the regional electrical heterogeneity associated with CTO. Although parameters such as QTc, Tp-e, and Tp-e/QTc offer non-invasive insights into the general characteristics of ventricular repolarisation, they cannot directly evaluate ischaemia, fibrosis, or the scar border zone within specific myocardial regions[15–17].

Particularly given the heterogeneous distribution of the arrhythmogenic substrate associated with a CTO, regional electrophysiological shifts may occur without manifesting as distinct global alterations on the surface ECG. Therefore, the finding of similar QTc, Tp-e, and Tp-e/QTc values across target vessels does not necessarily imply that the myocardial electrical substrate is identical across different coronary territories. Advanced imaging techniques, specifically the assessment of myocardial scar and viability via cardiac magnetic resonance imaging (MRI), alongside a more detailed characterisation of collateral circulation, could provide a deeper understanding of how target-vessel anatomy relates to ventricular repolarisation.

As surface ECG indices, QTc, Tp-e, and the Tp-e/QTc ratio evaluate distinct facets of ventricular repolarisation and are inherently linked to arrhythmogenic risk. While QTc reflects the total duration of ventricular depolarisation and repolarisation,[18] the Tp-e interval serves as a proposed marker for the dispersion of ventricular repolarisation[6, 19]. Derived by dividing the Tp-e interval by the QTc, the Tp-e/QTc ratio helps evaluate repolarisation heterogeneity independently of heart rate and QT duration[15–17].

Nonetheless, that these parameters were comparable across target-vessel groups does not mean these ECG metrics lack clinical utility for arrhythmic risk stratification. On the contrary, our findings indicate that these parameters may reflect a patient's overall electrical and structural myocardial profile rather than the anatomical location of the CTO. Therefore, although assessing QTc, Tp-e, and Tp-e/QTc in the context of a CTO appears valuable, target-vessel anatomy should not be used as the single determinant when interpreting these parameters.

A clinically significant implication of these findings is that baseline ventricular repolarisation characteristics in CTO patients cannot be predicted solely based on the anatomical location of the target vessel. The absence of significant differences in QTc, Tp-e, and Tp-e/QTc values among LAD, LCx, and RCA CTO groups suggests that target-vessel data alone may be insufficient for the initial assessment of electrical risk. Therefore, when evaluating arrhythmogenic risk in CTO patients, it may be more valuable to consider factors such as prior myocardial infarction, myocardial scar and ischaemic burden, collateral circulation, left ventricular function, and concomitant clinical features alongside coronary anatomical characteristics. In particular, assessing the scar and myocardial viability via cardiac MRI, combined with serial ECG measurements, can help characterise the electrical substrate beyond target-vessel anatomy.

LIMITATIONS:

Our study is not without limitations. First, the retrospective and single-centre design of the study limits the generalisability of the findings and precludes causal inferences. Second, due to the lack of data regarding the comprehensive assessment of myocardial scar, fibrosis, viability, ischaemic burden, and collateral circulation, the anatomical substrate underlying potential regional electrical heterogeneity could not be directly characterised. Third, ventricular repolarisation was assessed using surface ECG parameters; since these measurements reflect global repolarisation characteristics, they may fail to

capture subtle regional electrical changes associated with a CTO. Finally, the lack of serial ECGs and long-term clinical follow-up data precluded an assessment of whether repolarisation features change on a target-vessel basis following CTO revascularisation, and whether such shifts relate to arrhythmic risk. In conclusion, larger, prospective, multicentre studies incorporating cardiac MRI, detailed collateral circulation assessment, and serial ECG tracking are required to better elucidate these associations.

CONCLUSIONS

Baseline QTc, Tp-e, and Tp-e/QTc were comparable across LAD, LCx, and RCA CTOs in unadjusted and multivariable-adjusted analyses. Target-vessel location alone does not define a distinct surface-ECG repolarisation phenotype. Future studies should combine standardised ECG measurements with detailed anatomical, ischaemic, collateral, and scar characterisation.

PERSPECTIVES

Competency in Patient Care

The specific occluded epicardial vessel alone does not signal a distinctly higher-risk baseline repolarisation profile and should not serve as an isolated surrogate for electrical risk.

Translational Outlook

Multimodal prospective studies are needed to test whether lesion location, collateral physiology, viable ischaemic mass, and myocardial scar (rather than simple LAD, LCx, or RCA labelling) explain repolarisation heterogeneity and its subsequent response to CTO revascularisation.

Declarations

Funding Declaration

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Ethics Approval and Consent to Participate

The study protocol was approved by the Antalya City Hospital Ethics Committee, Antalya City Hospital, Antalya, Türkiye (Approval No.: 23/220; April 27, 2026) and was conducted in accordance with the principles of the Declaration of Helsinki. Due to the retrospective nature of the study, the requirement for informed consent to participate was waived.

Consent for Publication

Not Applicable.

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Figures

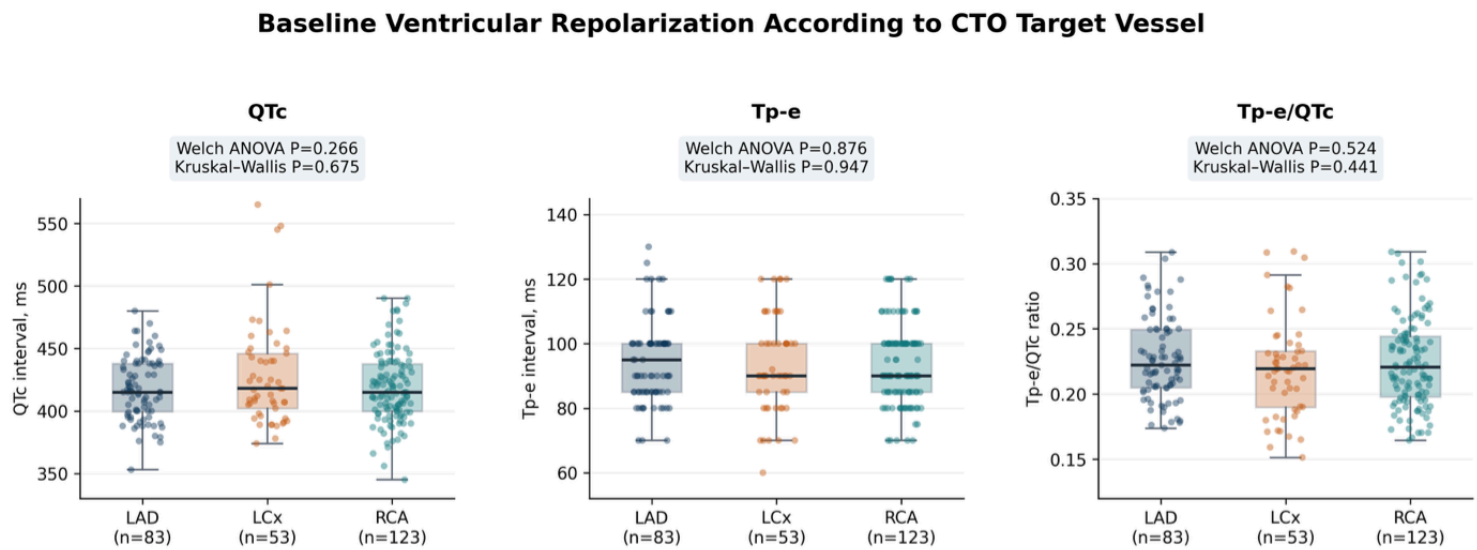


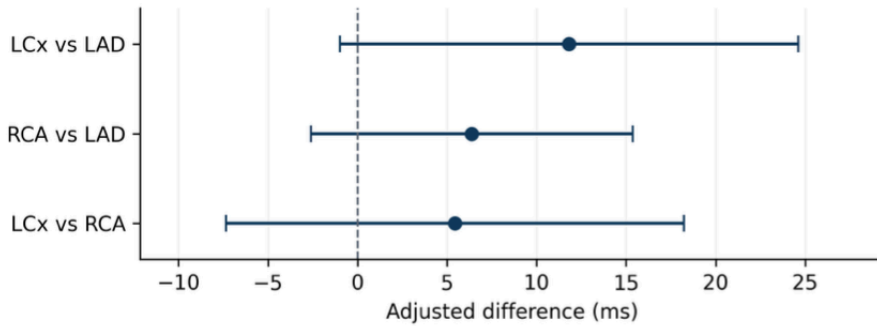
Figure 1

Baseline QTc, Tp-e, and Tp-e/QTc by Target Vessel in CTO

Box plots show the distributions with individual observations overlaid. Welch ANOVA and Kruskal–Wallis p-values are displayed in dedicated annotation boxes above each panel, separate from the box-and-whisker plots. CTO = chronic total occlusion; LAD = left anterior descending artery; LCx = left circumflex artery; QTc = corrected QT interval; RCA = right coronary artery; Tp-e = T-wave peak-to-end interval.

Adjusted Pairwise Target-Vessel Contrasts

A. QTc, ms — global adjusted P=0.141



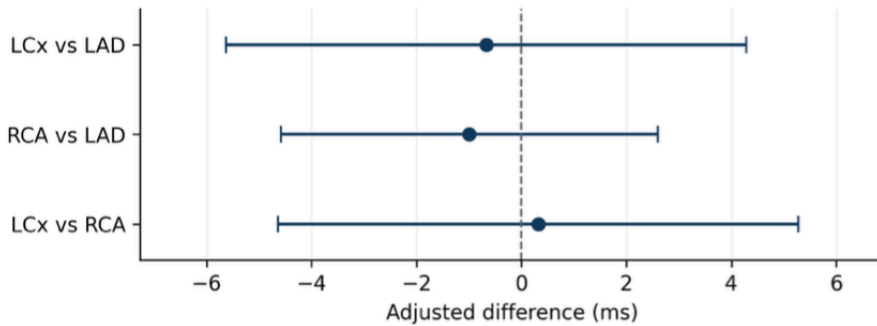
Adjusted difference (95% CI); Holm P

11.8 (-1.0 to 24.6); $P_h=0.211$

6.4 (-2.6 to 15.4); $P_h=0.327$

5.4 (-7.3 to 18.2); $P_h=0.403$

B. Tp-e, ms — global adjusted P=0.860



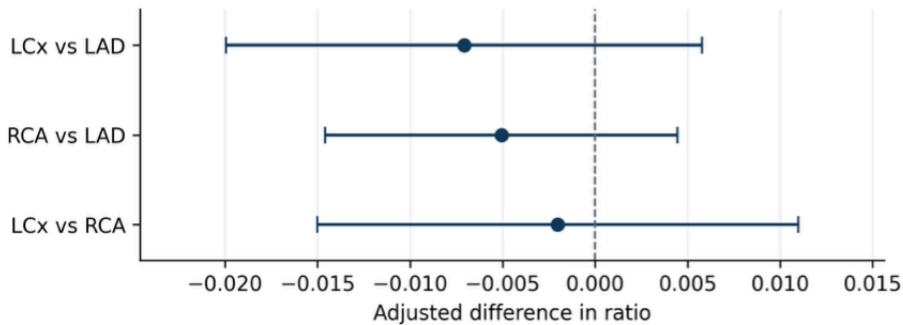
Adjusted difference (95% CI); Holm P

-0.7 (-5.6 to 4.3); $P_h=1.000$

-1.0 (-4.6 to 2.6); $P_h=1.000$

0.3 (-4.6 to 5.3); $P_h=1.000$

C. Tp-e/QTc ratio — global adjusted P=0.433



Adjusted difference (95% CI); Holm P

-0.007 (-0.020 to 0.006); $P_h=0.839$

-0.005 (-0.015 to 0.004); $P_h=0.839$

-0.002 (-0.015 to 0.011); $P_h=0.839$

Figure 2

Adjusted Pairwise Target-Vessel Contrasts

Forest plots show the adjusted mean differences and 95% CIs obtained from the primary HC3 robust models, with text columns reporting the Holm-corrected p-values. The models are adjusted for age, gender, baseline LVEF, diabetes, hypertension, chronic kidney disease, smoking status, and baseline heart rate. CI = confidence interval; LAD = left anterior descending artery; LCx = left circumflex artery; LVEF = left ventricular ejection fraction; QTc = corrected QT interval; RCA = right coronary artery; Tp-e = T-wave peak-to-end interval.