The role of baseline and post-procedural frontal plane QRS-T angles for cardiac risk assessment in patients with acute STEMI

Tugce Colluoglu¹ | Zulkif Tanriverdi² | Baris Unal³ | Emin Evren Ozcan⁴ | Huseyin Dursun⁴ | Dayimi Kaya⁴

¹Department of Cardiology, Karabuk Education and Research Hospital, Karabuk, Turkey

²Department of Cardiology, Faculty of Medicine, Harran University, Sanliurfa, Turkey

³Clinic of Cardiology, Cumra State Hospital, Konya, Turkey

⁴Department of Cardiology, Faculty of Medicine, Dokuz Eylul University, Izmir, Turkey

Correspondence

Tugce Colluoglu, Department of Cardiology, Karabuk Education and Research Hospital, Karabuk, Turkey.
Email: tugcecolluoglu48@gmail.com

Abstract

Background: To our knowledge, no study so far investigated the importance of post-procedural frontal QRS-T angle f(QRS-T) in ST segment elevation myocardial infarction (STEMI). The aim of our study was to investigate the role of baseline and post-procedural f(QRS-T) angles for determining high risk STEMI patients, and the success of reperfusion.

Methods: A total of 248 patients with first acute STEMI that underwent primary percutaneous coronary intervention (pPCI) or thrombolytic therapy (TT) between 2013 and 2014 were included in this study. Baseline f(QRS-T) angle was defined as the angle which measured from the first ECG at the time of hospital admission. Postprocedural f(QRS-T) angle was defined according to the treatment strategy as follows: the angle which measured from the post-PCI ECG in patients treated with pPCI; the angle which measured from the ECG taken 90 min after onset of therapy in patients treated with TT.

Results: The baseline ($101.9^\circ \pm 48.0$ vs. $72.1^\circ \pm 49.1$, $p = 0.014$) and postprocedural f(QRS-T) angles ($95.7^\circ \pm 48.1$ vs. $58.1^\circ \pm 47.1$, $p = 0.002$) were significantly higher in patients who developed in-hospital mortality than the patients who did not develop in-hospital mortality. Also, f(QRS-T) angle measured at 90 min was significantly lower in patients with successful thrombolysis group compared to failed thrombolysis group ($53.2^\circ \pm 42.8$ vs. $77.3^\circ \pm 52.9$, $p = 0.033$), whereas baseline f(QRS-T) angle was similar between two groups ($78.6^\circ \pm 53.4$ vs. $78.9^\circ \pm 54.0$, $p = 0.976$). Multivariate analysis showed that postprocedural f(QRS-T) angle $\geq 89.6^\circ$ (odds ratio: 3.541, 95% confidence interval: 1.235–10.154, $p = 0.019$), but not baseline f(QRS-T) angle, was independent predictor of in-hospital mortality.

Conclusion: f(QRS-T) angle may be used as a beneficial tool for determining high risk patients in acute STEMI. Unlike previous studies, we showed for the first time that that postprocedural f(QRS-T) can predict in-hospital mortality and TT failure.

KEYWORDS

baseline f(QRS-T) angle, postprocedural f(QRS-T) angle, risk assessment, ST elevated myocardial infarction

1 | INTRODUCTION

Acute ST segment elevation myocardial infarction (STEMI) is still associated with increased risk of death and recurrent cardiovascular events despite considerable progress in therapy options. Therefore, early risk stratification in patients with acute STEMI is very important for determining their optimal management (Hudzik, Lekston, & Gasior, 2016). To date, several electrocardiographic (ECG) parameters have been used for stratifying patients on hospital admission (Schweitzer & Keller, 2001). However, novel ECG parameters have recently emerged to identify high risk patients in acute STEMI. One of these novel ECG parameters is the frontal plane QRS-T angle.

Frontal plane QRS-T [f(QRS-T)] angle which defined as the angle between the directions of ventricular depolarization (QRS axis) and repolarization (T axis), was described as a novel marker of ventricular repolarization heterogeneity (Macfarlane, 2012; Oehler, Feldman, Henrikson, & Tereshchenko, 2014). It can be easily measured from surface ECG by subtracting the QRS axis from the T axis, because QRS and T-wave axes are usually available in the automatic reports of many 12-lead ECG devices (Macfarlane, 2012; Oehler et al., 2014; Pavri et al., 2008; Zhang, Rautaharju, Prineas, Tereshchenko, & Soliman, 2017). Previous studies had shown the prognostic value of the f(QRS-T) angle in the different populations (Aro et al., 2012; Gotsman et al., 2013; Oehler et al., 2014). In addition to these studies, a previous study (Raposeiras-Roubin et al., 2014) showed that a wide f(QRS-T) angle ($>90^\circ$) is a good discriminator of long-term mortality in patients with left ventricular systolic dysfunction after an acute myocardial infarction.

Although the relationships between the baseline f(QRS-T) angle and the mortality of patients with acute STEMI has been investigated in previous studies (Raposeiras-Roubin et al., 2014; Sawant, Narra, Mills, & Srivatsa, 2013), to our knowledge, there is no study investigating the association of both baseline f(QRS-T) and postprocedural f(QRS-T) angles with poor prognostic events in patients with acute STEMI undergoing revascularization therapy (primary percutaneous coronary intervention, pPCI + thrombolytic therapy, TT). The aim of our study was to evaluate the prognostic importance of baseline and postprocedural f(QRS-T) angles in patients with acute STEMI. In addition, the clinical usefulness of baseline and postprocedural f(QRS-T) angles for predicting reperfusion success in patients who received TT will be investigated.

2 | METHODS

2.1 | Patient selection

We retrospectively investigated the archived records of 301 consecutive patients with the diagnosis of first acute STEMI who were admitted to Dokuz Eylul University and were treated with pPCI or TT between 2013 and 2014. All patients had the following criteria: age over 18 years, presenting with first acute STEMI,

being treated with coronary angiography (CAG) in our catheter laboratory. Major exclusion criterias were the occurrence of complete and incomplete right or left bundle branch block, pacemaker rhythm, history of coronary artery bypass graft (CABG) and coronary artery disease. In addition, 15 patients could not undergo CAG were also excluded. Consequently, 248 patients with the diagnosis of first acute STEMI were included in our study. The diagnosis of acute STEMI was based on the European Society of Cardiology (ESC) 2012 STEMI guideline of "Third Universal Definition of Myocardial Infarction" (Thygesen et al., 2012).

2.2 | Electrocardiography

A 12 lead ECGs were recorded for all patients at hospital admission, immediately after pPCI and 90 min after thrombolytic treatment. ECG recordings were taken using a 0.16–100 Hz filter range, 25 mm/s speed, and 10 mm/mV height. All of the ECG recordings were analyzed by two independent physicians. Frontal QRS and T-wave axes were available in the automatic reports of the ECG machine. The f(QRS-T) angle was calculated from these axes as absolute difference between frontal plane QRS axis and frontal plane T axis. If the angle exceeds 180° , it was calculated by subtracting from 360° (Jogu et al., 2017; Macfarlane, 2012; Oehler et al., 2014; Zhang et al., 2017). Because our calculation of f(QRS-T) angle was based on automatic report of ECG machine, the subjective component of the individual measurements have been eliminated. Baseline f(QRS-T) angle was defined as the angle which measured from the first ECG at the time of hospital admission. Postprocedural f(QRS-T) angle was defined according to the treatment strategy as follows: the angle which measured from the post-PCI ECG in patients treated with pPCI; the angle which measured from the ECG taken 90 min after onset of therapy in patients treated with TT. ST segment resolution (STR) was calculated as the baseline sum of ST segment elevation minus the sum of ST segment elevation at the end of thrombolytic treatment ECG divided by the initial ST segment elevation (De Lemos et al., 2000). Successful thrombolysis was defined as $\geq 50\%$ decrease in ST elevation and the loss of chest pain after TT. Failed thrombolysis was defined as $< 50\%$ decrease in ST elevation after TT (De Lemos et al., 2001).

2.3 | Coronary angiography

The PCI procedures were performed according to standard clinical protocols via the femoral route. Standard left or right Judkins diagnostic and guiding catheters were used in all procedures. All angiographic data of patients were assessed from the catheterization laboratory records and evaluated by two independent interventional cardiologists. The angiographically critical lesion was defined as the presence of $\geq 50\%$ stenosis in the left main coronary artery and $\geq 70\%$ in the other major epicardial coronary arteries. Each culprit lesion in the epicardial coronary artery was classified as proximal,

mid, and distal according to the definition by American College of Cardiology and American Heart Association (Austen et al., 1975; Serruys et al., 1999).

2.4 | Statistical analysis

SPSS for Windows version 21.0 (SPSS Inc., IL, USA) was used for statistical analysis. Continuous variables were expressed as means $\pm$ standard deviations and categorical variables were expressed as percentages. Continuous data were compared using Student's *t* test. Categorical data were compared using the chi-square test. Pearson's correlation coefficient was used for correlation analysis. Receiver operating characteristic (ROC) curve analysis was performed to determine the optimal cut-off value of baseline and postprocedural f(QRS-T) angles for predicting in-hospital mortality. Variables entered into multivariate model included those with *p* values <0.1 from the univariate analysis.

Multivariate logistic regression analysis was performed to determine the independent predictors of in-hospital mortality. A value of *p* < 0.05 was considered statistically significant.

3 | RESULTS

3.1 | Baseline characteristics of patients

The mean age of the patients was 58.8 ± 12.7 , with 77.4% men. One hundred and forty-two patients underwent pPCI, whereas 106 patients underwent TT. In-hospital mortality was developed in 20 patients. When pPCI group compared to TT group, it was found that basal demographic characteristics, baseline and postprocedural f(QRS-T) angles, MI localization, and in-hospital mortality rate were similar between two groups. However, STR was significantly higher in TT group than in pPCI group (Table 1).

TABLE 1 Comparison of clinical characteristics, laboratory, and angiographic variables according to treatment modality

	Primary PCI (<i>n</i> = 142)	Thrombolytic therapy (<i>n</i> = 106)	<i>p</i> -value
Age, years	57.9 ± 13.4	59.9 ± 11.6	0.213
Sex, male (%)	114 (80.3)	78 (73.6)	0.212
Hypertension (%)	58 (40.8)	51 (48.1)	0.254
Diabetes Mellitus (%)	35 (24.6)	29 (27.4)	0.629
Duration of chest pain on admission (min)	141.0 ± 136.7	150.9 ± 188.6	0.647
Medications			
Beta-blockers	110 (77.5)	77 (72.6)	0.383
ACE-I or ARB	118 (83.1)	86 (81.1)	0.688
LVEF (%)	46.9 ± 8.8	45.6 ± 10.2	0.267
Creatinine (mg/dl)	1.3 ± 0.4	1.2 ± 0.1	0.821
Peak CK-MB (ng/ml)	142.7 ± 103.0	167.4 ± 104.4	0.064
ST segment resolution (%)	56.1 ± 40.2	67.0 ± 24.5	0.010
Baseline f(QRS/T) (°)	71.0 ± 46.6	78.7 ± 53.3	0.245
Postprocedural f(QRS/T) (°)	62.1 ± 49.4	58.5 ± 46.0	0.571
MI localization			
Anterior MI (%)	66 (46.5)	37 (34.9)	0.067
Other MI (%)	76 (53.5)	69 (65.1)	
Infarct-related artery			
LAD (%)	75 (52.8)	41 (38.7)	0.087
CX (%)	22 (15.5)	21 (19.8)	
RCA (%)	45 (31.7)	44 (41.5)	
Proximal vessel disease (%)	79 (55.6)	65 (61.3)	0.369
Three vessels disease (%)	20 (14.1)	25 (23.6)	0.055
In-hospital mortality (%)	9 (6.3)	11 (10.4)	0.248

Note. Min, minute; SBP, systolic blood pressure; DBP, diastolic blood pressure; PCI, percutaneous coronary intervention; ACE-I, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; LVEF, left ventricular ejection fraction; BUN, blood urine nitrogen; CK-MB, creatinine kinase-MB; MI, myocardial infarction; LAD, left anterior descending artery; CX, circumflex artery; RCA, right coronary artery.

3.2 | Findings according to baseline f(QRS-T) angle

The baseline f(QRS-T) angle was significantly higher in patients who developed in-hospital mortality than the patients who did not develop in-hospital mortality ($101.9^\circ \pm 48.0$ vs. $72.1^\circ \pm 49.1$, $p = 0.014$). ROC curve analysis was performed to determine the optimal cut-off value of baseline f(QRS-T) angle for predicting in-hospital mortality. Baseline f(QRS-T) angle $\geq 95.6^\circ$ predicted in-hospital mortality with a specificity 72.1% and a sensitivity of 66.7% (Figure 1a). Our study group was divided into two groups according to this cut-off value: those with baseline f(QRS-T) angle $< 95.6^\circ$ (173 patients) and those with baseline f(QRS-T) angle $\geq 95.6^\circ$ (75 patients). Patients with baseline f(QRS-T) angle $\geq 95.6^\circ$ were older, had a higher frequency of diabetes mellitus, a lower left ventricular ejection fraction (LVEF), a lower rate of STR, higher levels of blood urea nitrogen and higher peak CK-MB values compared to patients with baseline f(QRS-T) angle $< 95.6^\circ$. These patients had also more frequent proximal vessel disease, more frequent three vessels disease, and higher rate of in-hospital mortality. No significant differences were observed between two groups regarding other clinical features and infarct-related artery localization (Table 2).

3.3 | Findings according to postrevascularization f(QRS-T) angle

The postprocedural f(QRS-T) angle was significantly higher in patients who developed in-hospital mortality than the patients who did not develop in-hospital mortality ($95.7^\circ \pm 48.1$ vs. $58.1^\circ \pm 47.1$, $p = 0.002$). ROC curve analysis was performed to determine the optimal cut-off value of postprocedural f(QRS-T) angle for predicting in-hospital mortality. Postprocedural f(QRS-T) angle $\geq 89.6^\circ$ predicted in-hospital mortality with a specificity of 77.8% and sensitivity of 62.5% (Figure 1b). Also, it was found that the area under curve (AUC) of the postprocedural f(QRS-T) angle (0.725) was higher than the AUC of the baseline f(QRS-T) angle (0.678). Patients were divided into two groups according to this cut-off value: those with postprocedural f(QRS-T) angle $< 89.6^\circ$ (189 patients) and those with postprocedural f(QRS-T) angle $\geq 89.6^\circ$ (59 patients). When patients

with postprocedural f(QRS-T) angle $\geq 89.6^\circ$ compared to postprocedural f(QRS-T) angle $< 89.6^\circ$, it was found that patients with postprocedural f(QRS-T) angle $\geq 89.6^\circ$ had a lower left ventricular ejection fraction (LVEF), a lower rate of STR, and higher peak CK-MB values compared to patients with postprocedural f(QRS-T) angle $< 89.6^\circ$. In addition, patients with postprocedural f(QRS-T) angle $\geq 89.6^\circ$ had a higher rate of in-hospital mortality (Table 3). Furthermore, as demonstrated in Figure 2a, postprocedural f(QRS-T) angle was not significantly changed in patients who developed in-hospital mortality (from $101.9^\circ \pm 48.0$ to $99.1^\circ \pm 47.3$, $p = 0.697$), whereas it was significantly reduced in patients who did not develop in-hospital mortality (from $72.1^\circ \pm 49.2$ to $58.5^\circ \pm 47.3$, $p < 0.001$).

3.4 | Thrombolytic therapy subgroup

One hundred and six (42.7%) patients underwent TT in our study. Successful thrombolysis was observed in 78 patients after TT, whereas failed thrombolysis was observed in 28 patients after TT according to electrocardiographic criteria. Our study group was divided into groups according to the presence of STR on ECG after TT. f(QRS-T) angle measured at 90 min was detected to be lower in patients with successful thrombolysis group compared to failed thrombolysis group. However, there was no significant difference in terms of baseline f(QRS-T) angle between two groups (Table 4). More importantly, as showed in Figure 2b, 90th min f(QRS-T) angle was significantly reduced in patients with successful thrombolysis (from $78.6^\circ \pm 53.4$ to $53.2^\circ \pm 42.9$, $p < 0.001$), whereas it was not reduced in patients with failed thrombolysis (from $76.7^\circ \pm 56.4$ to $77.3^\circ \pm 52.9$, $p = 0.961$).

3.5 | Correlation analysis of baseline and postprocedural f(QRS-T) angles with other parameters

Baseline f(QRS-T) angle was positively correlated with number of vessel with critical stenosis ($r = 0.244$, $p < 0.001$), and peak CK-MB ($r = 0.206$, $p = 0.001$) whereas negatively correlated with LVEF ($r = -0.157$, $p = 0.014$), and STR ($r = -0.166$, $p = 0.010$); even if they were weak. In addition, although they were weak, postprocedural f(QRS-T) angle was positively correlated with age ($r = 0.152$,

FIGURE 1 (a) ROC curve analysis of baseline f(QRS-T) angle for predicting in-hospital mortality (b) ROC curve analysis of postprocedural f(QRS-T) angle for predicting in-hospital mortality

TABLE 2 Comparison of clinical characteristics, laboratory, and angiographic variables according to baseline f(QRS-T) angle

	Baseline f(QRS-T) <95.6° (n = 173)	Baseline f(QRS-T) ≥95.6° (n = 75)	p-value
Age	57.3 ± 11.8	62.2 ± 14.0	0.005
Sex, male (%)	139 (80.3)	53 (70.7)	0.094
Hypertension (%)	69 (39.9)	40 (53.3)	0.050
Diabetes Mellitus (%)	37 (21.4)	27 (36)	0.016
Duration of chest pain on admission (min)	144.3 ± 168.3	147.2 ± 142.3	0.899
Medications			
Beta-blockers	132 (76.3)	55 (73.3)	0.618
ACE-I or ARB	140 (80.9)	64 (85.3)	0.404
LVEF (%)	47.0 ± 9.6	43.6 ± 9.6	0.013
Creatinine (mg/dl)	0.9 ± 0.4	1.0 ± 0.5	0.122
Peak CK-MB (ng/ml)	139.4 ± 102.4	196.1 ± 98.9	<0.001
ST segment resolution (%)	64.3 ± 34.6	53.0 ± 33.8	0.020
Baseline f(QRS-T) (°)	46.4 ± 26.5	137.1 ± 26.5	<0.001
Postprocedural f(QRS-T) (°)	47.0 ± 42.4	91.8 ± 45.6	<0.001
MI localization			
Anterior MI (%)	67 (38.7)	36 (48)	0.174
Other MI (%)	106 (61.3)	39 (52)	
Infarct-related artery			
LAD (%)	73 (42.2)	43 (57.3)	0.089
CX (%)	33 (19.1)	10 (13.3)	
RCA (%)	67 (38.7)	22 (29.3)	
Proximal vessel disease (%)	93 (53.8)	51 (68)	0.037
Three vessels disease (%)	22 (12.7)	23 (30.7)	0.001
In-hospital mortality (%)	8 (4.6)	12 (16)	0.003

Note. Min, minute; SBP, systolic blood pressure; DBP, diastolic blood pressure; PCI, percutaneous coronary intervention; ACE-I, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; LVEF, Left ventricular ejection fraction; BUN, blood urine nitrogen; CK-MB, creatinine kinase-MB; MI, myocardial infarction; LAD, left anterior descending artery; CX, circumflex artery; RCA, right coronary artery.

$p = 0.019$), and peak CK-MB ($r = 0.198$, $p = 0.0012$), whereas negatively correlated with LVEF ($r = -0.239$, $p < 0.001$), and STR ($r = -0.173$, $p = 0.008$).

3.6 | Independent predictors of in-hospital mortality

Univariate and multivariate logistic regression analysis were performed to determine the independent predictors of in-hospital mortality. In univariate analysis, age, female gender, LVEF, baseline f(QRS-T) angle $\geq 95.6^\circ$, postprocedural f(QRS-T) angle $\geq 89.6^\circ$ and three vessels disease were found to be associated with in-hospital mortality. Multivariate logistic regression analysis showed that age (OR: 1.080, 95% CI: 1.032–1.131, $p = 0.001$), LVEF (OR: 0.918, 95% CI: 0.863–0.976, $p = 0.006$), and postprocedural f(QRS-T) angle $\geq 89.6^\circ$ (OR: 3.541, 95% CI: 1.235–10.154, $p = 0.019$) were the independent predictors of in-hospital mortality (Table 5).

It was found that patients with postprocedural f(QRS-T) angle $\geq 89.6^\circ$ had a 3.54-fold increased risk for in-hospital mortality.

4 | DISCUSSION

In this study, we investigated the prognostic importance of the baseline and postprocedural f(QRS-T) angles for the early risk stratification in patients with acute STEMI. The main finding of our study was that wider postprocedural f(QRS-T) angle, but not baseline f(QRS-T) angle, was an independent predictor of in-hospital mortality in acute STEMI patients. In addition, we detected that the reduction of f(QRS-T) angle after TT was associated with successful reperfusion. To our knowledge, this is the first study demonstrating the prognostic importance of postprocedural f(QRS-T) angle in patients with acute STEMI.

	Postprocedural f(QRS-T) <89.6° (n = 189)	Postprocedural f(QRS-T) ≥89.6° (n = 59)	p-value
Age, years	58.3 ± 12.3	60.5 ± 13.8	0.249
Sex, male (%)	146 (77.2)	46 (78)	0.908
Hypertension (%)	86 (45.5)	23 (39)	0.378
Diabetes Mellitus (%)	47 (24.9)	17 (28.8)	0.545
Duration of chest pain on admission (min)	146.9 ± 162.1	139.8 ± 157.0	0.768
Medications			
Beta-blockers	146 (77.2)	41 (69.5)	0.227
ACE-I or ARB	156 (82.5)	48 (81.4)	0.835
LVEF (%)	46.8 ± 9.8	43.3 ± 8.9	0.018
Creatinine (mg/dl)	0.93 ± 0.45	0.99 ± 0.47	0.388
Peak CK-MB (ng/ml)	152.4 ± 107.3	169.6 ± 94.5	0.272
ST segment resolution (%)	64.0 ± 31.5	50.2 ± 42.4	0.009
Baseline f(QRS-T) (°)	65.2 ± 45.5	102.6 ± 51.6	<0.001
Postprocedural f(QRS-T) (°)	39.5 ± 29.0	130.2 ± 27.8	<0.001
MI localization			
Anterior MI (%)	79 (41.8)	24 (40.7)	0.879
Other MI (%)	110 (58.2)	35 (59.3)	
Infarct-related artery			
LAD (%)	89 (47.1)	27 (45.8)	0.524
CX (%)	30 (15.9)	13 (22)	
RCA (%)	70 (37)	19 (32.2)	
Proximal vessel disease (%)	104 (55)	40 (67.8)	0.083
Three vessels disease (%)	35 (18.5)	10 (16.9)	0.785
In-hospital mortality (%)	10 (5.3)	10 (16.9)	0.011

Note. Min, minute; SBP, systolic blood pressure; DBP, diastolic blood pressure; PCI, percutaneous coronary intervention; ACE-I, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; LVEF, Left ventricular ejection fraction; BUN, blood urine nitrogen; CK-MB, creatinine kinase-MB; MI, myocardial infarction; LAD, left anterior descending artery; CX, circumflex artery; RCA, right coronary artery.

TABLE 3 Comparison of clinical characteristics, laboratory, electrocardiographic, and angiographic variables according to postprocedural f(QRS-T) angle

FIGURE 2 (a) Comparison of baseline and postprocedural f(QRS-T) angles between in-hospital mortality (+) and mortality (-) groups (b) Comparison of baseline and 90 min f(QRS-T) angles in successful and failed thrombolysis groups in acute STEMI patients treated with thrombolytic therapy

QRS-T angle is a novel marker of myocardial depolarization and repolarization heterogeneity. It is defined as the angle between electrical directions of ventricular depolarization and repolarization (Macfarlane, 2012; Raposeiras-Roubin et al., 2014; Zhang et al., 2017). Studies showed that the QRS-T angle was more robust and reproducible, and less susceptible to noise and problems of definition than other traditional electrocardiographic myocardial repolarization parameters (Dilaveris, Antoniou, Gatzoulis, & Tousoulis, 2017; Raposeiras-Roubin et al., 2014; Zhang et al., 2017). It can be calculated with two different methods: (a) three-dimensional space, spatial QRS-T angle, (b) a projection on the frontal plane in a standard 12-lead ECG, frontal QRS-T angle (Macfarlane, 2012; Oehler et al., 2014). The calculation of spatial angle is so complicated, required software programs and cannot be routinely calculated with daily used ECG devices (Macfarlane, 2012; Oehler et al., 2014). Conversely, f(QRS-T) angle can be easily calculated from surface ECG by subtracting the QRS axis from T axis, because most ECG devices report automatically QRS and T axes (Li et al., 2013). In addition, a previous study reported that f(QRS-T) angle is a suitable clinical substitute for the spatial QRS-T angle in risk prediction (Zhang, Prineas, Case, Soliman, & Rautaharju, 2007). We therefore used frontal QRS-T angle in this study.

Normally, the directions of the myocardial depolarization axis and repolarization axis is in the similar orientation. Therefore, f(QRS-T) angle often tend to be a narrow angle ($<45^\circ$) (Gungor et al., 2017; Raposeiras-Roubin et al., 2014; Tan et al., 2017). A wider f(QRS-T) angle is associated with discordance between ventricular depolarization phase and repolarization phase and it was found to be associated with poor outcomes in different populations (Pavri et al., 2008; Raposeiras-Roubin et al., 2014). However, limited data are available for evaluating the association of f(QRS-T) angle with poor adverse events in patients with acute STEMI. In a recent study, Raposeiras-Roubin et al., 2014, showed that f(QRS-T) angle $>90^\circ$ is an independent predictor of long-term mortality in acute STEMI patients. Similar to this study, we also found that patients with baseline f(QRS-T) angle $\geq 95.6^\circ$ had significantly higher in-hospital mortality rate. These results suggest that acute STEMI patients

with the higher baseline f(QRS-T) angle have a higher cardiac risk. However, the most important novelty of our study is that we also evaluated the postprocedural f(QRS-T) angle in addition to baseline f(QRS-T). We found that postprocedural f(QRS-T) angle was significantly higher in patients who developed in-hospital mortality than in patients who did not develop in-hospital mortality. In addition, postprocedural f(QRS-T) angle $\geq 89.6^\circ$ was an independent predictor of in-hospital mortality in multivariate analysis which including also baseline f(QRS-T) angle. According to these results, we can conclude that postprocedural f(QRS-T) angle has a higher prognostic significance more than baseline f(QRS-T) angle for predicting in-hospital mortality. To our knowledge, this is the first study demonstrating the association of postprocedural f(QRS-T) angle with in-hospital mortality in patients with acute STEMI. We think that the possible underlying mechanism for the association between wider f(QRS-T) angle and in-hospital mortality may be due to the presence of larger infarct area, poorer left ventricular function, and higher incidence three vessels disease in these patients.

Another important finding of our study was the relationship between f(QRS-T) angle and the success of TT. We detected that although baseline f(QRS-T) angle was similar between successful and failed thrombolysis groups, f(QRS-T) angle measured at 90 min was significantly lower in successful thrombolysis group compared to failed thrombolysis group. In addition, f(QRS-T) angle was significantly reduced in successful thrombolysis group, whereas it was not reduced in failed thrombolysis group. Moreover, baseline and postprocedural f(QRS-T) angles were negatively correlated with electrocardiographic STR. According to our findings, the lack of significant decrease in f(QRS-T) angle after TT was associated with failed thrombolysis. Therefore, we suggest that the lack of decrease in f(QRS-T) angle after TT in STEMI patients treated with TT may be used as a new parameter to predict failed thrombolysis. This is the first study showing the relationship between f(QRS-T) angle and failed thrombolysis. We think that these findings will need to be validated in larger prospective studies.

The association of the f(QRS-T) angle with the severity of coronary artery disease (CAD) have been investigated in previous

TABLE 4 Comparison of clinical characteristics, electrocardiographic, and angiographic variables according to success of thrombolysis

	Successful thrombolysis (n = 78)	Failed thrombolysis (n = 28)	p-value
MI localization			
Anterior MI (%)	27 (34.6)	10 (35.7)	0.917
Other MI (%)	51 (65.4)	18 (64.3)	
Door-to-needle time (min)	19.4 $\pm$ 3.2	19.8 $\pm$ 4.2	0.462
Baseline f(QRS-T) angle ($^\circ$)	78.6 $\pm$ 53.4	78.9 $\pm$ 54.0	0.976
90th min f(QRS-T) angle ($^\circ$)	53.2 $\pm$ 42.8	77.3 $\pm$ 52.9	0.033
ST segment resolution (%)	74.5 $\pm$ 23.2	46.3 $\pm$ 14.3	<0.001

Note. MI, myocardial infarction; min, minute.

	Univariate analysis		Multivariate analysis	
	OR (95% CI)	p	OR (95% CI)	p
Age	1.103 (1.055–1.102)	<0.001	1.080 (1.032–1.131)	0.001
Female gender	3.151 (1.234–8.046)	0.016	2.280 (0.780–6.661)	0.132
Hypertension	1.303 (0.522–3.253)	0.571		
Diabetes Mellitus	1.615 (0.615–4.246)	0.331		
Duration of chest pain on admission	1.000 (0.997–1.003)	0.965		
Door-to-needle time	1.004 (0.990–1.018)	0.561		
LVEF	0.900 (0.852–0.951)	<0.001	0.918 (0.863–0.976)	0.006
Peak CK-MB (ng/ml)	1.014 (1.001–1.028)	0.039	1.010 (0.992–1.027)	0.273
MI localization	1.807 (0.720–4.533)	0.208		
ST segment resolution (%)	1.007 (0.991–1.023)	0.417		
Baseline f(QRS-T) $\geq 95.6^\circ$	3.929 (1.564–10.062)	0.004	1.176 (0.365–3.785)	0.786
Postprocedural f(QRS-T) $\geq 89.6^\circ$	3.653 (1.439–9.275)	0.006	3.541 (1.235–10.154)	0.019
Proximal vessel disease (%)	1.759 (0.653–4.742)	0.264		
Three vessels disease (%)	3.441 (1.316–9.000)	0.012	2.258 (0.709–7.190)	0.168

Note. LVEF, left ventricular ejection fraction; MI, myocardial infarction.

TABLE 5 Univariate and multivariate analysis for determining the independent predictors of in-hospital mortality

studies. In a previous study, it was found that the prevalence of 2- or 3-vessel obstructive CAD was significantly higher in patients with a planar QRS-T angle $>90^\circ$ than in patients with a planar QRS-T angle $\leq 90^\circ$ (Palaniswamy et al., 2009). Similar to this study, we demonstrated that patients with baseline f(QRS-T) angle $\geq 95.6^\circ$ had significantly higher frequency of three vessels disease compared to patients with baseline f(QRS-T) angle $<95.6^\circ$. We think the possible underlying mechanism between the baseline f(QRS-T) angle and three vessels diseases might be that the concomitant significant lesion in the noninfarct-related coronary artery will result an increase in the frontal plane QRS-T angle. In addition to this study, we also detected that patients with baseline f(QRS-T) angle $\geq 95.6^\circ$ had more frequent proximal vessel disease. However, postprocedural f(QRS-T) angle have not been found to be associated with the proximal vessel disease and three vessels disease in our study. These findings suggest that baseline f(QRS-T) angle can be a useful parameter to demonstrate the severity of CAD, whereas postprocedural f(QRS-T) angle does not possess such quality. In contrast to these findings, Raposeiras-Roubin et al., 2014, reported that there was no relationship between f(QRS-T) angle and three vessels disease. This may be because that study included only acute STEMI patients who had depressed LVEF ($\leq 40\%$). Further prospective studies with large number of patients are required to explain the association of baseline f(QRS-T) angle with the severity of CAD.

Baseline characteristics, MI localization, and duration of chest pain were similar between groups in our study. However, we found that patients with baseline f(QRS-T) angle $\geq 95.6^\circ$ had

a lower LVEF, and higher peak CK-MB values. Also, as the baseline f(QRS-T) angle increased, LVEF decreased and peak CK-MB increased significantly. Similar to our study, previous studies have demonstrated that wider f(QRS-T) angle is significantly related to lower LVEF and higher peak cardiac marker levels (Li et al., 2013; Lown et al., 2012). Moreover, we detected that wider postprocedural f(QRS-T) angle was associated with lower LVEF, and higher peak CK-MB values. When all of this results were evaluated, we can suggest that both widened baseline f(QRS-T) and widened postprocedural f(QRS-T) angles in STEMI patients associated with extent of myocardial scar tissue irrespective of MI localization. The association of f(QRS-T) angle with larger scar tissue can be explained as follows: ischemic or infarcted myocardial zone is electrically inert resulting abnormal conduction occurs through infarct area due to regional cellular changes (Herweg, Marcus, & Barold, 2016). This condition may manifest heterogeneity between depolarization and repolarization waveform to result in widened postprocedural f(QRS-T) angle on surface ECG.

Early risk stratification in acute STEMI process is an important issue to determine high risk patients, and improve clinical outcomes. Because twelve lead ECG is a cheap and easily accessible tool, it have been used frequently to perform risk stratification. Recently, the most interested novel ECG parameter is f(QRS-T) angle. However, all previous studies used the baseline f(QRS-T) angle. Unlike other studies, we have showed for the first time that the concept of postprocedural f(QRS-T) angle can be a useful tool to determine high risk patients with STEMI in this study. Although we provided important

information about the postprocedural f(QRS-T) angle, we think that these findings should be supported by larger prospective studies.

Our study's limitations included retrospective design and having relatively small number of patients. Another limitation is that we evaluated in-hospital all cause mortality, but did not investigate causes of the in-hospital mortality. To investigate the association between arrhythmic complications and f(QRS-T) angle could provide additional contribution to this study. Third, both pPCI and TT patients were included and evaluated together in this study. Separate analysis may be useful, but when we compared two groups, we found that basal demographic characteristics, baseline and postprocedural f(QRS-T) angles, MI localization and in-hospital mortality rate were similar between two groups. We think, this comparison strengthens our results. Fourth, we did not record the time of in-hospital mortality and long-term follow-up was not assessed. It could be interesting to investigate long-term prognostic value of f(QRS-T) angle in STEMI patients. Finally, although we used multivariate analysis to adjust for potential confounders, there may residual confounding from unmeasured covariates. Larger studies are needed to better elucidate the prognostic importance of postprocedural f(QRS-T) angle in patients with acute STEMI.

In conclusion, f(QRS-T) angle is an inexpensive, noninvasive and easily detectable parameter on 12 lead ECG. In this study, we have shown for the first time that postprocedural f(QRS-T) angle has higher prognostic importance than baseline f(QRS-T) angle for predicting high risk patients in acute STEMI. In addition, postprocedural f(QRS-T) angle can be used as a simple tool to determine failed reperfusion in acute STEMI patients receiving TT. Therefore, we think that the evaluation of f(QRS-T) angle on surface ECG during acute STEMI may be an acceptable noninvasive electrocardiographic marker for cardiac risk assessment in future.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

ORCID

Tugce Colluoglu <http://orcid.org/0000-0002-2227-6177>

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How to cite this article: Colluoglu T, Tanriverdi Z, Unal B, Ozcan EE, Dursun H, Kaya D. The role of baseline and post-procedural frontal plane QRS-T angles for cardiac risk assessment in patients with acute STEMI. *Ann Noninvasive Electrocardiol*. 2018;23:e12558. <https://doi.org/10.1111/anec.12558>