THE ROLE OF BASELINE AND POST-PROCEDURAL FRONTAL PLANE QRS-T ANGLES IN PATIENTS WITH ACUTE STEMI

Michael Gamal Foad¹, Mahmoud Hassan Shah², Mohammad Gouda Mohammad³, Mohammad Mohsen Mohammad⁴

¹M.B.B.Ch. Faculty of Medicine – Zagazig University, Egypt.
²Professor of Cardiology, Faculty of Medicine, Zagazig University, Egypt
³Assistant Professor of Cardiology, Faculty of Medicine, Zagazig University, Egypt.
⁴Lecturer of Cardiology, Faculty of Medicine, Zagazig University, Egypt.
¹Email: dr.michaelgamal2008@gmail.com

ABSTRACT

In patients with an acute ST-segment elevation myocardial infarction (STEMI), immediate diagnosis is crucial. It can be more highlighted in which reperfusion therapy consider as soon as possible after diagnosis. Relieving ischemic pain, hemodynamic assessment, starting reperfusion therapy with PCI or using fibrinolysis agents, and antithrombotic therapy to prevent rethrombosis or acute stent thrombosis must be considered as initials goals after acute STEMI diagnosis. 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. To date, several electrocardiographic (ECG) parameters have been used for stratifying patients on hospital admission. 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 QRST angle. Frontal plane QRST [$\theta_{(QRST)}$] 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

Key words: Baseline and Post-Procedural Frontal Plane QRS-T Angles, Acute STEMI

ST-SEGMENT ELEVATION MYOCARDIAL INFARCTION

Definition

A clinical or pathologic event caused by myocardial ischemia when there is evidence of myocardial injury or necrosis is named as myocardial infarction (MI). Diagnosis is made when there is a rise of cardiac biomarkers (preferably cardiac troponin [cTn] with at least one value above the 99th percentile upper reference limit [URL] and at least one of the following: symptoms of ischemia, electrocardiographic [ECG] changes including pathologic Q waves, significant ST-segment elevation, or new left bundle branch block [LBBB]), identification of an intracoronary thrombus by angiography or autopsy, or imaging evidence of new loss of myocardial viability or new regional wall motion abnormality (1).

According to the assumed cause of myocardial ischemia, the clinical classification is as follows (2).

- Type 1 (spontaneous MI): MI caused by a pathologic process in the wall of the coronary artery such as plaque erosion or rupture, fissuring, or dissection, resulting in intraluminal thrombus
- Type 2 (MI secondary to an ischemic imbalance): MI consequent to enhanced oxygen demand or decreased supply such as coronary endothelial dysfunction, coronary artery spasm, coronary artery embolus, tachy- or bradyarrhythmias, anemia, respiratory failure, hypertension, or hypotension
Type 3 (MI resulting in death in unavailability of biomarker values): Sudden unexpected cardiac death before checking biomarkers to assess the change (3).

Type 4 (MI related to percutaneous coronary intervention [PCI]): When elevation of biomarker values (cTn is preferred) is greater than 5 × 99th percentile URL in patients with normal baseline values (< 99th percentile URL) or a rise of values more than 20% if the baseline values are elevated but stable or falling, PCI-related MI occurred. Type 4 also includes (3).

1. Symptoms of myocardial ischemia,
2. New pathologic Q waves or new LBBB,
3. Slow or no flow or embolization,
4. Patency loss of major coronary artery or a side branch, and
5. Imaging facts of new loss of viable myocardium or new regional wall motion abnormality present.

Type 5 (MI related to coronary artery bypass graft surgery [CABG])

CABG-associated MI explained by elevation of cardiac biomarker values greater than 10 × 99th percentile URL in patients with normal baseline cTn values. Also (4).

1. New pathologic Q waves or new LBBB,
2. Angiography-documented new graft or native coronary artery occlusion, or
3. Imaging evidence of new loss of viable myocardium or new regional wall motion abnormality.
4. In patients with an acute ST-segment elevation myocardial infarction (STEMI), immediate diagnosis is crucial. It can be more highlighted in which reperfusion therapy consider as soon as possible after diagnosis. Relieving ischemic pain, hemodynamic assessment, starting reperfusion therapy with PCI or using fibrinolysis agents, and antithrombotic therapy to prevent rethrombosis or acute stent thrombosis must be considered as initials goals after acute STEMI diagnosis (3).

ST-Segment Elevation Myocardial Infarction in Special Groups

Some special groups such as older adults (especially those with hypertension, chronic kidney disease, cerebrovascular events, and more complex STEMI appearances such as cardiac arrest and cardiogenic shock), women, and patients with cocaine-associated MI may have poor outcomes, so they need more attention in terms of STEMI. Although STEMI is common in older adults, approximately 60% to 65% of STEMIs happen in patients 65 years of age or older, and 28% to 33% occur in patients 75 of age or older. Patients 75 years of age or older have higher in-hospital mortality rates from electrical and mechanical complications. Primary PCI can lead to better outcomes than fibrinolysis in older adults who need more attention to prevent severe bleeding resulting from use of antithrombotic therapy (5).

An important issue to note is that death in patients with STEMI is higher among those with coronary artery stent thrombosis as opposed to ruptured plaque. The treatment choice is similar to that in spontaneous STEMI. Also, thrombolytic therapy could be used in STEMI patients with coronary artery stent thrombosis (7)

There is a need to pay close attention to assess specific groups in the ACS setting to implement timely and appropriate intervention procedures to achieve better outcomes (7).

The Frontal Plane QRS-T Angle

Availability of the limb leads of the 12-lead electrocardiogram (ECG) allows calculation of a mean QRS axis and a mean T axis, as is well known. These axes lie in the frontal plane of the body and can be used to calculate a very simple difference in angle between the two axes, namely the planar QRS-T axis (8).
It should be noted that the frontal plane QRS-T angle is normally derived from the limb leads of the 12-lead ECG, i.e. the frontal plane leads, whereas Figure 1 shows how a mean spatial QRS vector and mean spatial T vector can be projected onto the frontal plane to provide a frontal plane QRS and T axis which may or may not be the same axes as calculated from frontal plane leads depending on how the spatial vectors were derived (9).

Over the years, there have been a number of publications suggesting that a wide Frontal QRS-T angle in the ECG carries a poor prognosis. As summarized in the accompanying article by Aro et al., more recent studies have indicated that an abnormally large QRS-T angle predicts cardiac death in a clinical population and is a strong predictor of all-cause mortality in postmenopausal women. A wide QRS-T angle also predicted cardiac death in a general population aged 55 years and above (Turyan et al, 2017).

The normal limits of the frontal plane QRS-T angle are well known. For example, this writer published age- and sex-related normal limits some years ago. In young male individuals under 29 years of age, the normal range was from -39 to 71° (i.e. a span of 110°). In young women of the same age, the range was -46 to 59° (i.e. a span of 105°). In older male individuals over 50 years of age, the range was -82 to 40° (i.e. 120°). In older female individuals in the same age bracket, the range was -89 to 26° (i.e. a range of 117°). In their study, Aro et al. arbitrarily chose 100° as a threshold for an abnormal planar QRS-T angle but it should be noted that they measured angles to the nearest 10° so that if a planar QRS-T angle exceeded 100° in their study, it had a minimum value of 110° (10).

It is clearly simpler for the practising physician to assess QRS-T in the frontal plane with the widespread availability of automated ECG interpretation machines nowadays (11).

*Figure (1):* The illustration shows a spatial QRS vector QRSsp and a spatial T vector Tsp projected onto the frontal plane to give a frontal plane T axis denoted Tf and a frontal plane QRS axis denoted QRSf. The angle between the frontal plane QRS and T vectors is denoted with ‘a’ whereas the shaded angle between the spatial QRS and T vectors is denoted with ‘b’. QRSf and Tf are derived (12).

The conclusion from Aro et al. is that a wide frontal plane QRS-T angle carries a considerably increased risk of sudden arrhythmic death and all-cause mortality but not of non-arrhythmic cardiac mortality (11).

- Method of calculation of the (F QRS-T) angle

"f QRS-T angle"

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Approach to compute f QRS-T angle, which uses leads aVF, V2, V5 and V6. This approach includes several steps.

First, “net” values of QRS complex amplitudes are calculated in each of aVF, V2, V5 and V6 leads as $\text{QRS}_{\text{net}} = \text{R}_{\text{amp}} - |S/QS|_{\text{amp}}$. “Net” values of the T wave are calculated by measuring positive and negative T wave amplitudes, accordingly: $\text{T}_{\text{net}} = (+)\text{T}_{\text{amp}} - |(-)\text{T}_{\text{amp}}|$. Then, magnitudes of QRS and T are calculated according to equations:

$$\text{QRS}_{\text{sm}} = \left[ (\text{QRS}_{\text{net}}_{\text{V}6})^2 + (\text{QRS}_{\text{net}}_{\text{aVF}})^2 + (\text{QRS}_{\text{net}}_{\text{V}2})^2 \right]^{1/2}$$

And $\text{T}_{\text{sm}} = \left[ (\text{T}_{\text{net}}_{\text{V}5})^2 + (\text{T}_{\text{net}}_{\text{aVF}})^2 + (\text{T}_{\text{net}}_{\text{V}2})^2 \right]^{1/2}$.

Finally, fQRS-T angle (SS QRS-T angle) is calculated as following:

$$f\text{QRS–T angle} = \frac{(\text{QRS}_{\text{net}}_{\text{V}6} \times \text{T}_{\text{net}}_{\text{V}5}) + (\text{QRS}_{\text{net}}_{\text{aVF}} \times \text{T}_{\text{net}}_{\text{aVF}}) + (\text{QRS}_{\text{net}}_{\text{V}2} \times \text{T}_{\text{net}}_{\text{V}2})}{(\text{QRS}_{\text{sm}} \times \text{T}_{\text{sm}})}$$

**Prognostic Value of Frontal QRS-T Angle in Patients without Clinical Evidence of Cardiovascular Disease**

The QRS complex on a surface electrocardiogram (ECG) represents ventricular depolarization and the T wave represents ventricular repolarization. The frontal QRS-T angle, defined as the difference between QRS and T-wave axis, has been described as a marker of ventricular repolarization. Multiple epidemiologic studies to date have established that abnormal QRS-T angle predicts incident cardiovascular disease (CVD) events and mortality. Most studies, however, have been conducted on “spatial,” as opposed to “frontal” QRS-T angle.

Although spatial QRS-T angle is not routinely available in a clinical setting, frontal QRS-T is easily calculated on 12-lead ECG by subtracting T angle from the QRS angle. Moreover, there have been no studies to date examining the association of abnormal QRS-T angle with incident CVD events across a multiethnic cohort such as the Multi-Ethnic Study of Atherosclerosis (MESA) (13).

Therefore, Walsh et al., sought to describe the association of abnormal frontal QRS-T angle with incident CVD events in the MESA (14).

Walsh et al.’s findings showed that in a multiethnic population of adults aged 45 to 84 years free of CVD at enrollment, abnormal frontal QRS-T angle was associated with incident CVD events in multivariate-adjusted models. Walsh et al.’s study validated the role of frontal QRS-T angle in risk prediction of CVD among a multiethnic cohort (15).

QRS-T angle may play a role in quantifying the degree of abnormal repolarization and detect repolarization abnormalities before overt electrocardiographic changes (i.e., T-wave inversion or ST depression) occur (16).

Initial investigation into QRS-T angle by Kardys et al and Yamazaki et al demonstrated that spatial QRS-T angle was associated with incident CVD and total mortality in a graded fashion. Spatial QRS-T angle, however, is not routinely calculated on the 12-lead ECG and less available for the everyday clinician. Subsequent analysis by Zhang et al from the ∼14,000 participants in the Atherosclerosis Risk in Communities (ARIC) study demonstrated that frontal QRS-T angle, defined as the T-wave axis minus QRS axis on the standard 12-lead ECG, demonstrates similar predictive utility to spatial QRS-T for total mortality. Zhang et al went on to show that the QRS-T angle was predictive of incident coronary heart disease (CHD) only in women, with spatial QRS-T angle showing improved risk prediction for CHD events compared with frontal QRS-T angle (17).

**Prognostic value of frontal QRS-T angle in patients undergoing myocardial revascularization**

The frontal QRS-T angle (fQRS-Ta), defined as the absolute difference between the QRS and T axes, reflects the concordance of ventricular vectors of depolarization and repolarization; a broad fQRS-Ta usually represents an altered electrocardiographic marker of repolarization and/or depolarization sequence (18).
An abnormal fQRS angle has been associated with higher total and cardiovascular (CV) mortality risk or sudden cardiac death in primary prevention and its prognostic value has been also confirmed in ischemic and non-ischemic heart failure (HF) with preserved or reduced ejection fraction and in acute coronary syndrome (ACS) patients (19).

In the Lazzeroni et al.’s study, they found that post-cardiac rehabilitation fQRS predicts both overall and CV mortality in SCAD patients; furthermore, fQRS confirmed its independent, prognostic role even after adjustment for other predictive electrocardiographic markers such as PR, QRS, QTc intervals and the presence of both right and left bundle branch block. Lazzeroni et al.’s data also demonstrated that, if associated with QRS axis abnormalities, the prognostic value of fQRS further increases in SCAD patients even after individual adjustment for age, gender, PR and QTc intervals, LVEF and LV mass index (20).

The prognostic significance of fQRS has not been investigated until the last two decades when it emerged as a new interesting tool in CV risk stratification. A broad fQRS has been associated with higher risk of total mortality, CV death or sudden cardiac death, especially in women, while the association with incident coronary heart disease was not confirmed in men. (21).

On the other hand, a relationship between an abnormal fQRS and an increased risk for all-causes and cardiovascular mortality was found in both age/ethnicity in men, while these results were not confirmed in women. At variance with the above cited results, Lazzeroni et al.’s study seems to suggest that fQRS represents an independent predictor of death even after adjustment for gender, thereby confirming a recent community-based study showing that a fQRS angle greater than 90° is significantly associated with sudden cardiac death independently of age, LVEF and more specifically gender (20).

The predictive value of an abnormal fQRS has been also evaluated in secondary cardiovascular prevention by examining HF subjects with preserved or reduced LVEF as well as ACS patients. In the DEFINITE trial, a fQRS >90° was a significant predictor of adverse outcomes (death, appropriate ICD shock, or resuscitated cardiac arrest) in a population with non-ischemic cardiomyopathy and New York Heart Association class I to III HF (20).

More recently, the evaluation of the fQRS in a large cohort of HF patients followed for a mean of 576 days has suggested that the fQRS ≥125° is an incremental predictor of increased mortality in both genders and that fQRS was independently associated with the composite outcomes (cardiovascular hospitalization or death) (22).

The short- and long-term predictive value of fQRS in patients with ACS has been evaluated in the EMMACE-1 and 2, in which two-year mortality was lower in patients with fQRS 104°. Lazzeroni et al.’s results failed to confirm the prognostic value of fQRS in ACS patients, however, in the EMMACE studies fQRS was collected at admission before starting medical or interventional treatment while current ECG data were recorded in a non-acute clinical and ECG stabilized setting (at the end of a cardiac rehabilitation program). An interesting finding of Lazzeroni et al.’s study was also the lack of fQRS predictivity in a population never investigated before such as cardiac valve disease patients who underwent valveoplasty or replacement; since it is well established that after valve replacement the heart rapidly develops a favourable reverse remodelling with marked reduction of mass and increase of LV function, it may be reasonably speculated that also fQRS could favourably be influenced by the correction of valve dysfunction (4).

A collateral finding of Lazzeroni et al.’s study was an association between abnormal fQRS and diabetes, higher LDL and serum uric acid levels. Although their study was not designed to investigate these relationships, they propose some possible explanations. First, diabetic cardiomyopathy is characterized by diffuse alteration in electric activity of the myocardium as well as by systo-diastolic dysfunction and or myocardial ischemia; fQRS could reflect these features of diabetic cardiomyopathy. Moreover, an association between dyslipidemia and ischemic heart disease has been well established and fQRS could reflect electrocardiographic abnormalities of cardiac disease related with dyslipidemia. Similarly, a large number of evidences suggest a relationship between uric acid, cardiovascular disease and mortality; fQRS could reflect electric abnormalities related to hyperuricemia (20).
fQRSTa, collected at the end of the cardiac rehabilitation program, is a simple and useful marker able to predict overall and CV mortality in SCAD patients undergoing myocardial revascularization and that its predictive value may further improve when considered in association with QRS-axis abnormalities (23).

**The Role of Baseline and Post-Procedural Frontal Plane QRS-T Angles for Cardiac Risk Assessment in Patients with Acute STEMI**

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. To date, several electrocardiographic (ECG) parameters have been used for stratifying patients on hospital admission. 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 (24).

Frontal plane QRS-T [f(QRST)] 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. It can be easily measured from surface ECG by subtracting the QRS axis from the T axis, because QRS and Twave axes are usually available in the automatic reports of many 12-lead ECG devices. Previous studies had shown the prognostic value of the f(QRST) angle in the different populations. In addition to these studies, a previous study showed that a wide f(QRS-T) angle (>90°) is a good discriminator of long-term mortality in patients with left ventricular systolic dysfunction after an acute myocardial infarction (25).

Although the relationships between the baseline f(QRS-T) angle and the mortality of patients with acute STEMI has been investigated in previous studies, there is no study investigating the association of both baseline f(QRST) 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). (26).

Colluoglu et al., investigated the prognostic importance of the base line and postprocedural f(QRST) angles for the early risk stratification in patients with acute STEMI. The main finding of their study was that wider postprocedural f(QRST) angle, but not baseline f (QRS T) angle, was an independent predictor of inhospital mortality in acute STEMI patients. In addition, they detected that the reduction of f(QRST) angle after TT was associated with successful reperfusion (16).

QRST 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. Studies showed that the QRST angle was more robust and reproducible, and less susceptible to noise and problems of definition than other traditional electrocardiographic myocardial repolarization parameters. It can be calculated with two different methods (27)

Three-dimensional space, spatial QRST angle,

A projection on the frontal plane in a standard 12-lead ECG, frontal QRST angle.

The calculation of spatial angle is so complicated, required software programs and cannot be routinely calculated with daily used ECG devices (Conversely, f(QRST) 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. In addition, a previous study reported that f(QRST) angle is a suitable clinical substitute for the spatial QRST angle in risk prediction (28).

Normally, the directions of the myocardial depolarization axis and repolarization axis is in the similar orientation. Therefore, f(QRST) angle often tends to be a narrow angle (90° is an independent predictor of longterm mortality in acute STEMI patients. Similar to this study, we also found that patients with baseline f(QRST) angle ≥95.6° had significantly higher in hospital mortality rate. These results suggest that acute STEMI patients with the higher baseline f(QRST) angle have a higher cardiac risk. However, the most important novelty of Colluoglu et al.’ study is that they also evaluated the postprocedural f(QRST) angle in addition to baseline f(QRST). They found that postprocedural f(QRST) angle was significantly higher in patients who developed inhospital mortality than in patients who did not develop inhospital mortality. In addition, postprocedural f(QRS-T) angle ≥89.6° was an independent predictor of inhospital mortality in multivariate analysis which including also baseline f(QRST)
angle. According to these results, they can conclude that postprocedural f(QRST) angle has a higher prognostic significance more than baseline f(QRST) angle for predicting inhospital mortality (16).

Another important finding of Colluoglu et al., study was the relationship between f(QRST) angle and the success of TT. They detected that although baseline f(QRST) 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(QRST) angle was significantly reduced in successful thrombolysis group, whereas it was not reduced in failed thrombolysis group. Moreover, baseline and postprocedural f(QRST) angles were negatively correlated with electrocardiographic STR. According to their findings, the lack of significant decrease in f(QRST) angle after TT was associated with failed thrombolysis. Therefore, they suggest that the lack of decrease in f(QRST) angle after TT in STEMI patients treated with TT may be used as a new parameter to predict failed thrombolysis (16).

The association of the f(QRST) angle with the severity of coronary artery disease (CAD) have been investigated in previous 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 ≥95° than in patients with a planar QRS-T angle ≤90° (11).

Colluoglu et al. demonstrated that patients with baseline f(QRS-T) angle ≥95.6° had significantly higher frequency of three vessels disease compared to patients with baseline f(QRS-T) angle ≥ 95.6°. They thought the possible underlying mechanism between the baseline f(QRST) angle and three vessels’ diseases might be that the concomitant significant lesion in the non-infarct related coronary artery will result an increase in the frontal plane QRST angle. They also detected that patient with baseline f(QRS-T) angle ≥95.6° had more frequent proximal vessel disease. However, postprocedural f(QRST) angle have not been found to be associated with the proximal vessel disease and three vessels disease in their study. These findings suggest that baseline f(QRST) angle can be a useful parameter to demonstrate the severity of CAD, whereas postprocedural f(QRST) angle does not possess such quality. (16).

Raposeiras Roubin et al. reported that there was no relationship between f(QRST) angle and three vessels disease. This may be because that study included only acute STEMI patients who had depressed LVEF (≤40%). Further prospective studies with large number of patients are required to explain the association of baseline f(QRST) angle with the severity of CAD. (29)

Baseline characteristics, MI localization, and duration of chest pain were similar between groups in Colluoglu et al. study. However, they found that patients with baseline f(QRS-T) angle ≥95.6° had a lower LVEF, and higher peak CKMB values. Also, as the base line f(QRST) angle increased, LVEF decreased and peak CKMB increased significantly (16).

Previous studies have demonstrated that wider f(QRST) angle is significantly related to lower LVEF and higher peak cardiac marker levels. Moreover, Colluoglu et al. detected that wider postprocedural f(QRST) angle was associated with lower LVEF, and higher peak CKMB values. When all of these results were evaluated, They can suggest that both widened baseline f(QRST) and widened postprocedural f(QRST) angles in STEMI patients associated with extent of myocardial scar tissue irrespective of MI localization. The association of f(QRST) 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. This condition may manifest heterogeneity between depolarization and repolarization waveform to result in widened postprocedural f(QRST) angle on surface ECG (16).

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 has been used frequently to perform risk stratification. Recently, the most interested novel ECG parameter is f(QRST) angle. However, all previous studies used the baseline f(QRST) angle (30).

In conclusion, f(QRST) angle is an inexpensive, noninvasive and easily detectable parameter on 12 lead ECG. The first time that postprocedural f(QRST) angle has higher prognostic importance than baseline f(QRST) angle for predicting high risk patients in acute STEMI. In addition, postprocedural f(QRST) angle can be used as a simple tool to determine failed reperfusion in acute STEMI patients receiving TT. The evaluation of f(QRST)
angle on surface ECG during acute STEMI may be an acceptable noninvasive electrocardiographic marker for cardiac risk assessment in future (31).

REFERENCES


