ORIGINAL ARTICLE – **ADULT CARDIAC**

Preoperative frontal QRS-T angle is an independent correlate of hospital length of stay and predictor of haemodynamic support requirement following off-pump coronary artery bypass graft surgery

Erkan Kaya[a,*], Kubilay Karabacak[a], Murat Kadan[a], Kadri Murat Gurses[b], Duygu Kocyigit[b], Suat Doganci[a], Vedat Yildirim[c] and Ufuk Demirkilic[a]

[a] Department of Cardiovascular Surgery, Gulhane Military Medical Academy, Ankara, Turkey
[b] Department of Cardiology, Hacettepe University Faculty of Medicine, Ankara, Turkey
[c] Department of Anaesthesiology and Reanimation, Gulhane Military Medical Academy, Ankara, Turkey

* Corresponding author. Department of Cardiovascular Surgery, Gulhane Military Medical Academy, 06010 Etlik, Ankara Turkey. Tel: +90-312-3046001; fax: +90-312-2308109; e-mail: erkankaya76@yahoo.com (E. Kaya).

Abstract

OBJECTIVES: With the adoption of novel operative techniques and aggressive care protocols that facilitate earlier extubation and mobilization of patients, postoperative length of stay (LOS) following coronary artery bypass graft surgery (CABG) has declined. However, there is paucity of information regarding preoperative electrocardiographic predictors of LOS following CABG. In this study, we investigated whether frontal QRS-T angle, which is an abnormal repolarization marker in prediction of various cardiovascular events, was an independent correlate of postoperative hospital LOS for off-pump CABG. Furthermore, we evaluated independent predictors of vasopressor agent/intra-aortic balloon pump (IABP) support requirement following off-pump CABG.

METHODS: In this observational study, 78 patients with stable angina, who were scheduled for elective coronary artery bypass surgery following diagnosis of obstructive coronary artery disease by conventional angiography, were enrolled.

RESULTS: Left ventricular ejection fraction (LVEF) was significantly lower and vasopressor agent/IABP support requirement and incidence of sustained atrial or ventricular arrhythmias was higher in patients with wide QRS-T angle ($P < 0.05$). Postoperative hospital LOS was also longer in this group. From the preoperative characteristics, wide frontal QRS-T angle was found to be an independent correlate of postoperative hospital LOS (B ± SD: 11.97 ± 0.62, $P \leq 0.01$). Wide frontal QRS-T angle was also found to be an independent predictor of vasopressor agent/IABP support requirement postoperatively (OR: 7.87, $P \leq 0.01$).

CONCLUSIONS: Prediction of the hospital LOS and patient outcome following CABG is of great importance. Being easily obtainable via standard 12-lead electrocardiogram and its low cost may make frontal QRS-T angle a beneficial marker for reducing both patient-based morbidity and economic burden.

Keywords: QRS-T angle • Coronary artery bypass graft surgery • Hospital length of stay • Inotropic support

INTRODUCTION

With the adoption of novel operative techniques and aggressive care protocols that facilitate earlier extubation and mobilization of patients, postoperative length of stay (LOS) following coronary artery bypass graft surgery (CABG) has declined [1]. Although reductions in postoperative LOS have been documented in numerous studies [2, 3], comprehensive evaluation of perioperative characteristics for predicting LOS following CABG is still lacking.

Since prolonged hospital stay following CABG is known to be linked with increased costs and limited number of patients being served at health-care centres with fixed resources [4], identifying factors associated with prolonged hospital stay is of vital importance. Up to now, several preoperative and postoperative factors have been suggested to have contributory role [4]. In a previous study, the only independent predictor of prolonged intensive care unit (ICU) stay following CABG was reported to be the requirement of inotropic support. However, there is paucity of information regarding preoperative electrocardiographic predictors of LOS following CABG.

A wide QRS-T angle has emerged as an abnormal electrocardiographic repolarization marker in stratifying cardiac risk in various study populations. Wide spatial and frontal QRS-T angle values have

been shown to be predictive of cardiovascular disease events including incident heart failure [5], ventricular arrhythmias, sudden cardiac death [6]. Wide QRS-T angle has also been found to be associated with cardiac mortality in the general population [7].

In this study, we investigated whether frontal QRS-T angle was an independent correlate of postoperative hospital LOS for off-pump CABG. Furthermore, we evaluated independent predictors of vasopressor agent/intra-aortic balloon pump (IABP) support requirement following off-pump CABG.

MATERIALS AND METHODS

Study population

In this observational study, 78 patients with stable angina, who were scheduled for elective coronary artery bypass surgery following diagnosis of obstructive coronary artery disease by conventional angiography between January 2013 and June 2014, were enrolled.

Patients with history of acute coronary syndrome, previous cardiothoracic surgery, moderate–severe valvular disease, congenital heart disease, heavy alcohol consumption, serum creatinine in excess of 1.20 mg/dl or abnormal thyroid function were excluded from the study.

Baseline demographic and clinical characteristics, including age, gender, body mass index (BMI), smoking history and comorbidities including hypertension, diabetes mellitus were recorded for all patients. Routine laboratory tests including complete blood count and biochemistry tests, a standard 12-lead electrocardiography (ECG) and spirometry were performed in all patients. Furthermore, patients underwent transthoracic echocardiographic examination to assess left ventricular (LV) and valvular function. LV systolic function was quantified from LV end-diastolic and systolic dimensions. The study was in compliance with the principles outlined in the Declaration of Helsinki and approved by the Institutional Ethics Committee.

Off-pump coronary artery bypass graft surgery procedure and postoperative follow-up

Off-pump CABG was performed through a median sternotomy approach. Conduits for off-pump CABG included the internal mammary artery or saphenous veins or a combination of the two. Patients were continuously monitored for at least 72 h postoperatively.

End-points of the study were postoperative hospital length-of-stay and postoperative low cardiac output syndrome development. Low cardiac output was considered in those who met the following criteria before discharge from the first hospitalization in ICU immediately after surgery: Need for inotropic support with vasoactive drugs (dopamine 4 μg/kg/min at least for 12 h and/or dobutamine) to maintain systolic blood pressure above 90 mmHg or need for mechanical circulatory support with intra-aortic balloon pump to maintain systolic blood above 90 mmHg and signs of impairment of body perfusion—hypothermia, hypotension, oliguria/anuria, lowered level of consciousness or a combination of these signs [8]. Sustained atrial or ventricular arrhythmias were defined as episodes of atrial flutter, atrial fibrillation or ventricular tachycardia that lasted longer than 30 s. Postoperative hospital LOS was calculated as the number of days between the date of operation and discharge. Criteria for discharge were as follows: stable cardiac rhythm, haematocrit of ≥25%, oral intake of at least 1000 calories per day,

successful independent ambulation and the ability to climb one flight of stairs and no significant wound complications [9].

Electrocardiographic measurements

A standard 12-lead ECG was recorded with the subject at rest in supine position, using a paper speed of 25 mm/s and a calibration of 1 mV/10 mm. Frontal plane QRS-axis and T-axis were included in the standard 12-lead ECG strips from automated ECG machines. Frontal QRS-T angle was calculated as the absolute value of the difference between the frontal plane QRS-axis and T-axis (Fig. 1). If such a difference exceeded 180°, then frontal QRS-T angle was calculated as 360° minus the absolute value of the difference between the frontal plane QRS-axis and T-axis.

Up to now, an absolute value has not been identified to distinguish the normal and abnormal frontal QRS-T angles. Previous studies that were focused on the predictive role of frontal QRS-T angle in cardiovascular diseases determined the cut-off value at either 100° [10] or 90° [11]. In our study, we preferred the cut-off value for frontal QRS-T angle of 90°.

Statistical analysis

Normally distributed continuous parameters are presented as mean ± standard deviation and skewed continuous parameters are expressed as median (range defined as minimum–maximum). Categorical data are presented as frequencies and percentages and are compared using χ^2 test. Parametric test assumptions were checked before the analysis. Normality of the variables was tested by Shapiro–Wilks test and homogeneity of the variables was tested by Levene test. Comparisons of the independent groups according to continuous variables were done by independent samples *t*-test or Mann–Whitney *U*-test as appropriate. Categorical variables were compared by χ^2 test. If expected counts were less than 5, Fisher's exact test was used. McNemar's test was used to assess the significance of the difference between two correlated proportions. Univariate and multivariate logistic regression analyses were performed to determine the independent predictors of vasopressor agent/IABP support requirement. Multiple linear regression analysis was used to determine independent factors of hospital LOS. Statistical analyses were performed, using the SPSS statistical software (version 21.0; SPSS, Inc., Chicago, IL, USA). A two-tailed $P < 0.05$ was considered statistically significant.

RESULTS

A total of 78 patients (61.3 ± 11.3 years; 70.5% male gender) with stable angina, who were scheduled for elective coronary artery bypass surgery following diagnosis of obstructive coronary artery disease by conventional angiography, were included in this study. Preoperative characteristics of the study population are given in Table 1.

Perioperative characteristics regarding the frontal QRS-T angle are given in Table 2. Nineteen patients had wide frontal QRS-T angle (≥90°). Left ventricular ejection fraction (LVEF) was significantly lower (44.5 ± 12.6 vs 57.9 ± 7.8%, $P < 0.01$) in patients with wide QRS-T angle. Vasopressor agents or IABP support requirement (36.8 vs 8.5%, $P = 0.01$) and incidence of sustained atrial or ventricular arrhythmias (31.6 vs 8.5%, $P = 0.02$) were higher and postoperative hospital LOS was longer [7 (5–17) vs 6
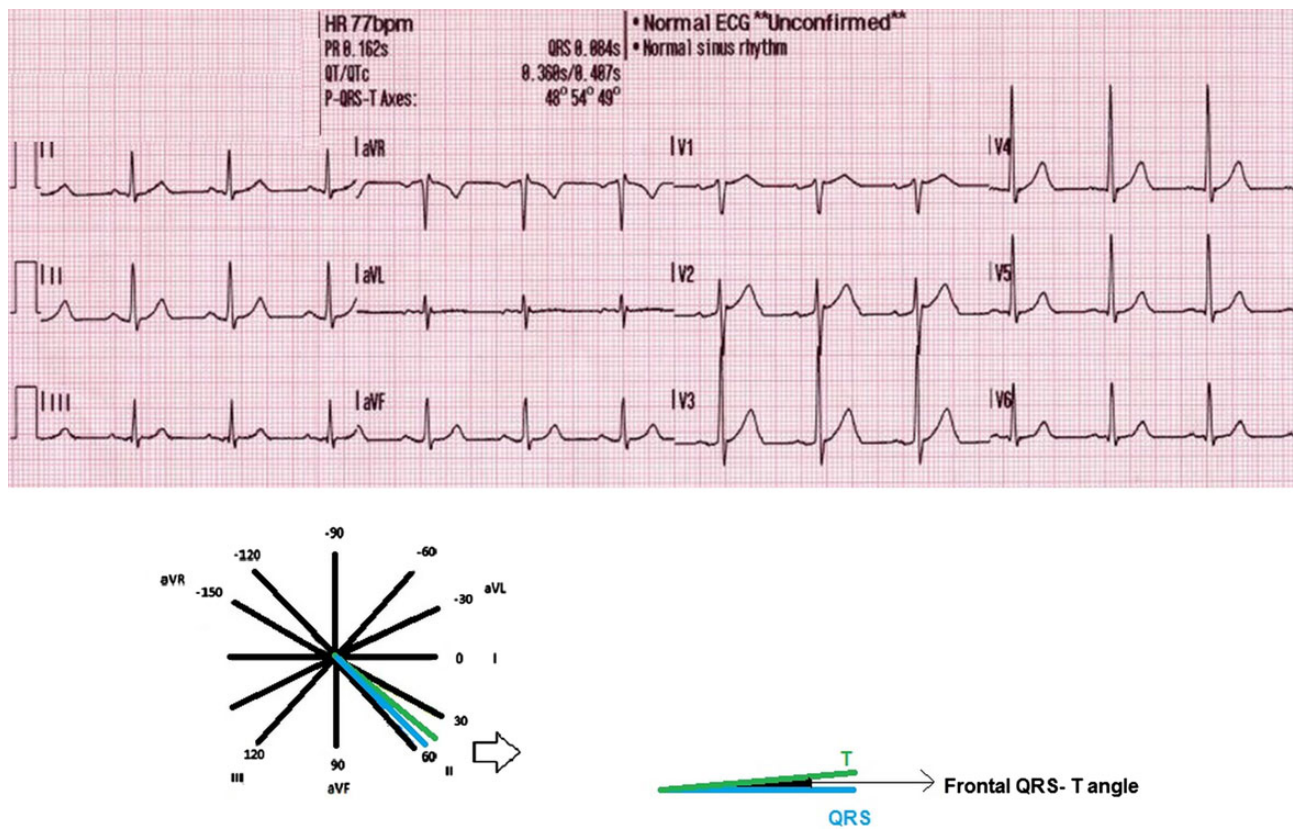
Figure 1: Depiction of how the frontal QRS-T angle is calculated. I, II and III stand for limb leads; aVL: augmented vector left; aVR: augmented vector right; aVF: (augmented vector left) stand for augmented limb leads.

Table 1: Preoperative characteristics of the study population ($n = 78$)

Preoperative characteristics	
Age (years)	61.3 ± 11.3
Gender: male, n (%)	55 (70.5)
BMI (kg/m^2)	28.4 ± 4.2
Hypertension, n (%)	44 (56.4)
Diabetes mellitus (%)	26 (33.3)
Smoking (%)	50 (64.1)
FEV$_1$/FVC ratio (%)	81.5 ± 7.8
β-Blocker treatment, n (%)	37 (47.5)
Serum creatinine (mg/dl)	0.9 ± 0.2
Heart rate (beats/min)	66.0 ± 11.0
P wave duration (ms)	110.0 ± 13.0
QRS duration (ms)	94.0 ± 11.0
QRS-T angle (°)	43.0 (1.0–176.0)
QRS-T < 90°, n (%)	59 (75.6)
QRS-T ≥90°, n (%)	19 (24.4)
QTc (ms)	417.9 ± 43.5
Bundle branch block, n (%)	10 (12.8)
EF (%)	54.6 ± 10.8

BMI: body mass index; EF: ejection fraction; FEV$_1$: forced expiratory volume (at the end of first second of forced expiration); FVC: forced vital capacity; QTc: corrected QT interval.

(2–17) days, $P = 0.02$] in the group of patients with wide frontal QRS-T angle. Other parameters did not show a statistically significant difference (Table 2). In Spearman correlation analysis, LVEF and frontal QRS-T angle were found to be negatively correlated ($r = -0.564$, $P < 0.01$).

In multivariate linear regression analysis between postoperative hospital LOS and preoperative characteristics including age, gender, BMI, hypertension, diabetes mellitus, FEV$_1$/FVC, QRS/T-angle and LV ejection fraction, wide frontal QRS-T angle [B ± SD: 1.97 ± 0.62, 95% confidence interval (CI): 0.73–3.71, $P < 0.01$] and diabetes mellitus (B ± SD: 1.62 ± 0.51, 95% CI: 0.60–2.53, $P < 0.01$) were found to be independent correlates (Table 3).

Preoperative characteristics of the study population regarding vasopressor agent/IABP support requirement are given in Table 4. Patients requiring vasopressor agent/IABP support had significantly lower LVEF (44.9 ± 13.5 vs 56.2 ± 9.5%, $P = 0.01$). Prevalence of patients with wide frontal QRS-T angle was more common in patients who required vasopressor agent/IABP support (75.0 vs 18.2%, $P = 0.01$) (Table 4).

Univariate regression analysis model showed that wide frontal QRS-T angle (OR: 6.29, 95% CI: 1.70–23.26, $P = 0.01$) and LVEF (OR: 0.93, 95% CI: 0.88–0.99, $P = 0.01$) were significantly associated with vasopressor agent/IABP support requirement (Table 5). Multivariate regression analysis demonstrated that only wide frontal QRS-T angle (OR: 7.87, 95% CI: 1.98–31.25, $P < 0.01$) was an independent predictor of vasopressor agent/IABP support requirement (Table 5).

DISCUSSION

In this observational study, we demonstrated that wide frontal QRS-T angle is independently correlated with hospital LOS in

Table 2: Perioperative characteristics of the study population regarding the QRS-T angle (n = 78)

	QRS-T angle <90° (n = 59)	QRS-T angle ≥90° (n = 19)	P-value
Preoperative characteristics			
Age (years)	60.1 ± 11.6	64.8 ± 9.3	0.11
Gender: male, n (%)	42 (71.2)	13 (68.4)	1.00
BMI (kg/m^2)	28.5 ± 4.1	27.9 ± 4.6	0.59
Hypertension, n (%)	32 (54.2)	12 (63.2)	0.60
Diabetes mellitus, n (%)	17 (28.8)	9 (47.4)	0.17
Smoking, n (%)	37 (62.7)	13 (68.4)	0.79
FEV$_1$/FVC ratio (%)	82.0 ± 8.2	79.7 ± 6.5	0.32
β-Blocker treatment, n (%)	28 (47.5)	9 (47.4)	1.00
Serum creatinine (mg/dl)	0.9 ± 0.2	0.9 ± 0.2	0.56
EF (%)	57.9 ± 7.8	44.5 ± 12.6	<0.00
Number of graft vessels	2 (1–4)	2 (1–4)	0.66
Postoperative characteristics			
Vasopressor agents or intra-aortic balloon pump support, n (%)	5 (8.5)	7 (36.8)	0.01
Sustained atrial or ventricular arrhythmias, n (%)	5 (8.5)	6 (31.6)	0.02*
Postoperative hospital LOS (days)	6 (2–17)	7 (5–17)	0.02*

BMI: body mass index; EF: ejection fraction; FEV$_1$: forced expiratory volume (at the end of first second of forced expiration); FVC: forced vital capacity; LOS: length of stay.
*P < 0.05.

Table 3: Multivariate regression analysis between postoperative hospital LOS and preoperative characteristics

	Postoperative hospital LOS (days)		
	B ± SD	95% CI	P-value
Age (years)	−0.01 ± 0.02	−0.05 to 0.04	0.80
Gender: male, n (%)	0.88 ± 0.53	−0.18 to 1.94	0.10
BMI (kg/m^2)	−0.07 ± 0.06	−0.19 to 0.05	0.27
Hypertension (%)	0.45–0.53	−0.61 to 1.50	0.40
Diabetes mellitus, n (%)	1.62 ± 0.51	0.60 to 2.63	<0.01*
FEV$_1$/FVC (%)	−0.00 ± −0.03	−0.07 to 0.06	0.90
QRS-T ≥90°, n (%)	1.97 ± 0.62	0.73 to 3.21	<0.01*
EF (%)	0.04 ± 0.03	−0.01 to 0.09	0.14

B: β coefficient; BMI: body mass index; CI: confidence interval; EF: ejection fraction; FEV$_1$: forced expiratory volume (at the end of first second of forced expiration); FVC: forced vital capacity; LOS: length of stay; SD: standard deviation.
*P < 0.05.

patients undergoing elective off-pump CABG. Wide frontal QRS-T angle is also an independent predictor of vasopressor agent/IABP support requirement. To the best of our knowledge, this is the first study investigating these relationships.

Over the past years, attempts [4, 12, 13] have been made to develop predictive models of hospital, particularly ICU, stay following CABG. However, the majority of the reported models have been considered to have modest predictive ability [14]. Several preoperative factors, including recent myocardial infarction [15], smoking [15], number of diseased arteries [16] and preoperative LV end-diastolic pressure [16] have been assessed for their predictive role in LOS. Of postoperative factors, contributory roles of low cardiac output syndrome [14, 15, 17], postoperative use of vasopressor agents [14], development of atrial arrhythmias [17–19], respiratory complications [17, 18] and renal insufficiency [18] have

been evaluated. However, none of the previous studies have focused on preoperative electrocardiographic features.

QRS-T angle is an electrocardiographic marker of ventricular repolarization. A wide QRS-T angle reflects an altered spatial sequence of ventricular repolarization as a primary repolarization abnormality, as secondary to altered ventricular depolarization sequence, or as a combination of both [20]. Frontal QRS-T angle is a measure easily derived from the standard 12-lead ECG and has been demonstrated to have a strong correlation with the spatial QRS-T angle for risk prediction [7].

Abnormalities in the frontal QRS-T angle have been shown to be associated with electrical instability, placing patients at higher risk for malignant ventricular arrhythmias, appropriate implantable cardioverter-defibrillator shock [21] and sudden cardiac death [10]. Furthermore, wide frontal QRS-T angle has been found to be linked with increased risk for cardiovascular [11] and all-cause mortality [10]. In our study, wide QRS-T angle was found to be an independent correlate of hospital LOS following off-pump CABG.

Previously, prolongation of the QT interval in patients with heart failure was shown to predict mortality after surgical revascularization, suggesting that abnormalities in cardiac repolarization are of importance for the outcome after CABG [22]. Although our study is not prospective and does not focus on adverse outcomes such as postoperative mortality, results of the aforementioned study are consistent with the idea of the relationship between a marker of abnormal ventricular repolarization and postoperative unfavourable end-points. Sustained atrial or ventricular arrhythmias may be the link between them, due to the increased risk of atrial [23, 24] or ventricular arrhythmias secondary to ventricular repolarization abnormalities. Higher incidence of sustained atrial or ventricular arrhythmias in the patient group with a wide QRS-T angle may support this hypothesis.

Michalopoulos et al. have demonstrated in their study that the only independent predictor of prolonged ICU stay following CABG was requirement of inotropic support [14] and suggested that inotropic support would reflect poor cardiac function due to intraoperative complications (e.g. myocardial ischaemia or

Table 4: Preoperative characteristics of the study population regarding postoperative vasopressor support (*n* = 78)

	Vasopressor agents/IABP support – (*n* = 66)	Vasopressor agents/IABP support + (*n* = 12)	*P*-value
Age (years)	60.9 ± 11.6	63.4 ± 8.7	0.43
Gender: male, *n* (%)	46 (69.7)	9 (75.0)	1.00
BMI (kg/m^2)	28.5 ± 4.1	27.4 ± 4.8	0.41
Hypertension, *n* (%)	37 (56.1)	7 (58.3)	1.00
Diabetes mellitus, *n* (%)	20 (30.3)	6 (50.0)	0.20
Smoking, *n* (%)	42 (63.6)	8 (66.7)	1.00
FEV$_1$/FVC ratio (%)	81.4 ± 7.9	81.9 ± 7.7	0.83
β-Blocker treatment, *n* (%)	32 (48.5)	5 (47.7)	0.76
Serum creatinine (mg/dl)	0.9 ± 0.2	0.9 ± 0.2	0.56
Heart rate (beats/min)	64 ± 9	70 ± 15	0.41
P-wave duration (ms)	108 ± 11	114 ± 17	0.35
QRS duration (ms)	92 ± 9	99 ± 15	0.41
QRS-T ≥ 90°, *n* (%)	12 (18.2)	9 (75.0)	0.01*
QTc (ms)	415.5 ± 39.1	431.1 ± 63.3	0.26
Bundle branch block, *n* (%)	8 (15.2)	2 (16.7)	0.25
Number of graft vessels	2 (1–4)	2 (1–4)	0.53
EF (%)	56.2 ± 9.5	44.9 ± 13.5	0.01*

BMI: body mass index; EF: ejection fraction; FEV$_1$: forced expiratory volume (at the end of first second of forced expiration); FVC: forced vital capacity; IABP: intra- aortic balloon pump; QTc: corrected QT interval.
*P < 0.05.

Table 5: Univariate and multivariate binomial regression analyses demonstrating the relationship between baseline characteristics and postoperative vasopressor agents/IABP support requirement

	Univariate analysis			Multivariate analysis		
	OR	95% CI	*P*-value	OR	95% CI	*P*-value
Diabetes mellitus (%)	0.44	0.13–1.51	0.19	2.17	0.54–8.77	0.28
QRS-T angle ≥90°	6.29	1.70–23.26	0.01*	7.87	1.98–31.25	<0.01*
EF (%)	0.93	0.88–0.99	0.01*	0.97	0.91–1.04	0.38

CI: confidence interval; EF: ejection fraction; IABP: intra- aortic balloon pump; OR: odds ratio.
*P < 0.05.

infarction), inadequate revascularization, low cardiac output syndrome and related to systemic inflammatory response syndrome and stunned myocardium or inadequate myocardial protection during CABG [14]. In a previous study, widened QRS-T angle was found to be independently associated with a worse LV myocardial performance index [25]. In our study, wide QRS-T angle significantly predicted vasopressor agent/IABP support requirement independent of other parameters including LVEF. This finding suggests that myocardial repolarization abnormalities may necessitate vasopressor agent or IABP support even in the lack of worse LV systolic functions. Understanding the underlying mechanisms merits further studies.

Study limitations

There are some limitations of this study. Firstly, this is a retrospective observational study. Secondly, our analysis is based on a single-centre registry, with a relatively small sample size. Finally, this study only reveals an association, not a causal relationship.

CONCLUSION

Prolonged LOS not only increases the overall costs but also limits medical service distribution. As a result, predicting the duration of stay and patient outcome is important. Results of our study suggest that the hospital LOS following off-pump CABG is significantly correlated with preoperative frontal QRS-T axis. A wide frontal QRS-T angle is also an independent predictor of vasopressor agent/IABP support requirement following off-pump CABG surgery. Being simple, easily obtainable via standard 12-lead electrocardiogram and its reproducibility and low cost may make frontal QRS-T angle a beneficial marker for reducing both patient-based morbidity and economic burden on health-care system.

Conflict of interest: none declared.

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