Indian Heart Journal 70 (2018) S359–S364

Contents lists available at ScienceDirect

Indian Heart Journal

journal homepage: www.elsevier.com/locate/ihj

Original Article

Correlation of QRS duration with myocardial blush grade as a marker of myocardial reperfusion in primary percutaneous coronary intervention

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A R T I C L E I N F O

Article history:
Received 25 July 2018
Accepted 19 October 2018
Available online 2 November 2018

Keywords:
Invasive
MBG
Noninvasive
Primary PCI
QRS duration

A B S T R A C T

Background: The association between duration of QRS and myocardial reperfusion is not very well established. Our aim was to assess the relationship between measurements of QRS duration and myocardial blush grade (MBG) in patients with ST-elevation myocardial infarction (STEMI) who were treated with a primary percutaneous coronary intervention (PCI).
Methods: Between January 2016 and June 2017, 200 patients with STEMI who presented within 12 h of symptom onset and taken up for primary PCI were analyzed with electrocardiogram (ECG) before and after the procedure. Two study groups were then defined on the basis of microvascular perfusion: group A (MBG 0-1) and group B (MBG 2-3).
Results: Group A had a total of 80 patients, and group B had 120 patients. The baseline characteristics were similar in the two groups. QRS duration was found to be longer in group A compared with group B at both the immediate ECG (95.5 ± 15.63 vs 80.87 ± 12.80 msec, $p < 0.001$, respectively) and at the 60th minute ECG (96.95 ± 16.2 vs 78.82 ± 12.08 msec, $p < 0.001$, respectively) post angioplasty. Significant difference was detected between the two groups post-angioplasty at both the immediate (10.99 ± 10.05 vs −6.64 ± 10.61 msec, $p < 0.001$) and the 60th minute (13.03 ± 11.64 vs −7.95 ± 11.11 msec, $p < 0.001$) ECG. Using receiver operator curve analysis, we found that QRS complex narrowing of 4.5 msec post angioplasty was the best cutoff value for predicting reperfusion.
Conclusion: QRS duration change post angioplasty is strongly correlated with the myocardial reperfusion in patients presenting with STEMI.

1. Introduction

Primary percutaneous coronary intervention (PCI) is the treatment of choice for patients presenting with ST-elevation myocardial infarction (STEMI). Patency of the infarct-related artery (IRA) along with a good microvascular flow is the ultimate goal of reperfusion therapy. But restoration of the epicardial flow does not necessarily lead to restoration at the tissue level in all cases.[1–3] Electrocardiographic (ECG) assessment of reperfusion therapy is mainly based on changes of the ST-segment, but the significance of the QRS duration is still not very well established. Prolonged QRS duration is associated with an increased risk of impaired ventricular systolic function and adverse effects.[4–6] While ST-segment resolution is related to myocardial perfusion and cell membrane integrity, myocardial blush grade (MBG) reflects myocardial perfusion and microvascular patency. MBG has been found to be a predictor [independent of thrombolysis in myocardial infarction (TIMI) flow] of both in-hospital and long-term mortality in patients with acute myocardial infarction who underwent primary angioplasty.[7–9] It is a qualitative visual assessment of the amount of contrast medium filling a territory supplied by an epicardial coronary artery. Studies are lacking that can assess the correlation between the noninvasive (QRS duration) and the invasive marker

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https://doi.org/10.1016/j.ihj.2018.10.412

(MBG) of myocardial reperfusion. In the present study, we assessed the relationship between the QRS duration and the MBG in patients undergoing primary PCI. The rationale was to test that whether any change in QRS duration in postintervention patients will reflect impaired or good microvascular perfusion as assessed by the MBG. Studies by Erdogan et al. and Magdy et al. have not performed any follow-up in their studies. Hence, we planned to conduct a proper clinical follow-up of at least 6 months duration in our study.[10,11]

2. Patients and methods

It is an observational prospective study conducted in Gobind Ballabh Pant Institute of Postgraduate Medical Education & Research, a tertiary care setup in New Delhi, India, after gaining clearance from the ethical committee of Maulana Azad Medical College and associated hospitals. An informed consent was obtained from all patients. Two hundred patients with STEMI, all aged >18 years, and presenting to our emergency department within 12 h of symptom onset between January 2016 and June 2017 and undergoing primary angioplasty were enrolled in our study. STEMI was defined as the presence of at least two of the following: chest pain lasting longer than 30 min, increase in the creatinine kinase myocardial band, and new ST-segment elevation of >1 mm in at least two consecutive precordial or inferior leads. Patients with known bundle branch block or fascicular block, patients with intraventricular conduction disturbances or second- or third-degree atrioventricular block or with electrolyte imbalances, cardiomyopathies, chronic kidney or liver diseases, history of previous PCI or old MI, or in shock or pregnancy were excluded from our study.

After detailed clinical examination, all patients were administered 300 mg of aspirin and 600 mg of clopidogrel (or 60 mg of prasugrel/180 mg of ticagrelor) loading dose before the procedure. All the patients were then subjected to the following investigations—complete blood count, creatinine phosphokinase-muscle/brain (CPK-MB), liver and kidney function tests, random blood sugar, viral markers, serum sodium and potassium, and preprocedure echocardiography.

3. Electrocardiogram

A 12-lead ECG with a paper speed of 50 mm/s and amplification of 10 mm/mV was obtained before procedure and at immediate postprocedure and at 60 min after primary PCI. QRS duration was measured from the onset of QRS to the J-point by using the EEPEE software (version 0.9.5, GPLv2, 1991, Free Software Foundation, Inc, Boston, USA) from the IRA leads (Fig. 1). The average value of the measurements obtained by two investigators for three consecutive beats was taken into account for statistical analysis. The interobserver and intraobserver variability was very low (<3% and <2%, respectively).

3.1. Echocardiography

Echocardiography was performed before intervention and within 24 h after the primary PCI. All echocardiographic examinations were performed using the PHILIPS ECHO machine (model UTAP20W, Koninklijke, Philips N.V.) and 2.5–3.5 MHz transducers. The left ventricular ejection fraction (LVEF) was calculated according to the modified Simpson's method. The 17-segment model was used for scoring the severity of segmental wall motion abnormalities by wall motion score index (WMSI) according to the American Society of Echocardiography.[12] All patients were restudied after 6 months.

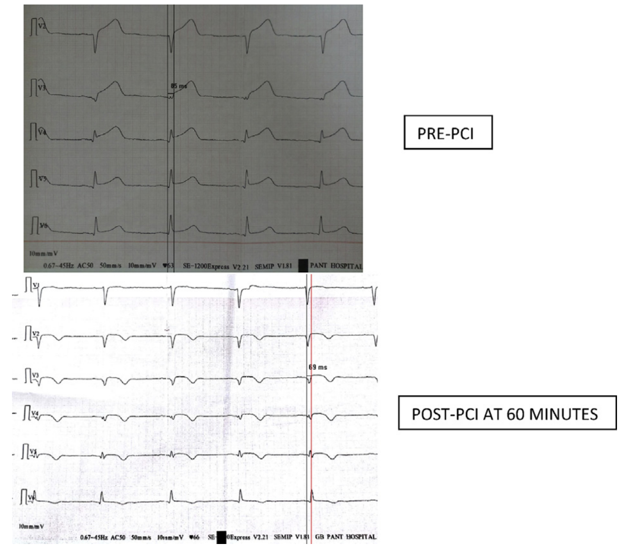

Fig. 1. QRS duration changes in pre-PCI and post-PCI ECG. PCI, percutaneous coronary intervention; ECG, electrocardiogram.

3.2. Angiographic evaluation

GE INNOVA (Model 2100-IQ, GE Healthcare, France) angiographic machine was used for the primary PCI. At the start of the procedure, 100U/kg of heparin was given, and the use of GpIIb/IIIa inhibitor (abciximab) was left to the discretion of the operator. All patients underwent initial balloon angioplasty and coronary stenting, if felt to be needed by the primary operator. The purpose of PCI was to obtain a residual stenosis of <20% in the IRA by visual evaluation. The final coronary angiogram run was long enough to visualize the venous phase of the contrast passage, and MBG was then calculated manually by two blinded experienced interventional cardiologists based on the assessment of contrast opacification of the myocardial territory subtended by the IRA. A third reader's opinion was used in case of any discordance. MBG was graded as 0 = no myocardial blush or contrast density, 1 = minimal myocardial blush or contrast density, 2 = myocardial blush or contrast density which exists to a lesser extent and its clearance is diminished compared with noninfarct-related coronary artery, and 3 = normal myocardial blush or contrast density comparable with that obtained during angiography of a contralateral or ipsilateral noninfarct-related coronary artery.[13] Intraobserver and interobserver agreement was 95% and 90%, respectively, as was assessed by checking the reproducibility of the MBG scores by two observers viewing about 30% of the angiograms. The other variables assessed were the number of coronary arteries involved in individual cases, the IRA and the Thrombolysis In Myocardial Infarction (TIMI) flow.

3.3. Statistical analysis

The data obtained were analyzed using SPSS, version 21.0. Continuous variables were expressed as mean ± standard deviation values. The Spearman correlation coefficient was calculated to evaluate the association between two continuous variables. Statistical test such as unpaired *t*-test, chi-square test, and multivariate analysis was used to assess the correlation between QRS duration and MBG after primary PCI. The predictive impact of postprocedure QRS duration narrowing on MBG was analyzed by the receiver operator curve (ROC), and the sensitivity and specificity of the best cutoff value were determined. Probability value (*p* value) was used to determine the level of significance; *p* value < 0.05 was considered as significant, p value < 0.01 was considered as highly significant.

4. Results

Two hundred patients included in the study were divided into two groups according to the reperfusion status, as assessed by the MBG; group A with MBG of 0−1 ($n = 80$), considered as impaired reperfusion and group B with MBG of 2−3 ($n = 120$), which constituted the reperfusion group.

The baseline clinical, echocardiographic, and angiographic parameters are shown in Table 1. The two groups were similar in terms of age, gender, blood pressure, hypertension, diabetes, blood sugar status, and serum creatinine ($p > 0.05$). Clinically, although group A had more number of patients in Killip class II and III, they were statistically insignificant in comparison to group B ($p > 0.05$). Regarding echocardiography at the baseline, patients in group A had a mean LVEF of 38.62% ± 4.93, and group B had 41.62 ± 6.22. Although the two groups were statistically similar ($p > 0.05$) in terms of admission LVEF, the trend suggested a lower EF and a higher WMSI in patients of group A with impaired reperfusion. Regarding angiographic characteristics, both anterior wall myocardial infarction (AWMI) and non-AWMI were equally represented in the two study groups (69% vs 65% and 31% vs 35%, respectively). Similarly, representation of the coronaries in terms of the IRA and the number of vessels involved was similar in between the two groups. Thrombosuction was equally performed among the two groups, but no statistically significant difference was observed among the two groups. The pain-to-balloon time and the serum CPK-MB levels were significantly higher in group A in comparison to group B.

4.1. ECG findings

When the two groups were compared in terms of ECG parameters, they had a similar QRS duration at admission (88.9 ± 11.18 vs 91.85 ± 13.86 msec, $p = 0.098$, respectively). On correlation analysis, preangioplasty QRS duration was not found to be correlated with age ($r = 0.010$, $p = 0.890$) or pain-to-balloon time ($r = 0.019$, $p = 0.788$). When we compared the QRS duration of the post angioplasty ECG, QRS duration was found to be longer in group A compared with group B at both the immediate ECG (95.5 ± 15.63 vs 80.87 ± 12.80 msec, $p < 0.001$, respectively) and at the 60th minute ECG (96.95 ± 16.2 vs 78.82 ± 12.08 msec, $p < 0.001$, respectively) post angioplasty. When the amount of change in QRS duration was taken into consideration, a significant difference was detected between the two groups post angioplasty at both the immediate (10.99 ± 10.05 vs −6.64 ± 10.61 msec, $p < 0.001$) and the 60th minute (13.03 ± 11.64 vs −7.95 ± 11.11 msec, $p < 0.001$) ECG.

The regression analysis was performed with age, pain-to-balloon time, QRS duration at admission, and change in the QRS duration post angioplasty to understand the independent impact of individual variables, and the change in QRS duration after reperfusion was found to be an independent predictor of myocardial reperfusion [$\beta = 0.033$, odds ratio = 1.034, 95% confidence interval (CI) = 1.012−1.057, $p = 0.003$].

On correlation analysis, there was a positive correlation between the immediate ($r = 0.232$, $p < 0.001$) and at 60th minute QRS duration narrowing with the MBG ($r = 0.228$, $p < 0.001$), as shown in Fig. 2. ROC analysis was performed for QRS narrowing at immediate and at 60 min post angioplasty for predicting successful myocardial reperfusion. The area under curve (AUC) for the immediate QRS narrowing was 0.897 (95% CI = 0.849−0.944), while the AUC for the 60th minute QRS narrowing was 0.914 (95% CI = 0.914, 0.873−0.944). Although the difference of AUC between the two is not statistically significant, the magnitude of AUC was higher at 60th minute than that at immediate post angioplasty. So, QRS narrowing at 60th minute could better discriminate between the two reperfusion groups. We found that QRS complex narrowing of 4.5 msec post angioplasty was the best cutoff value for predicting reperfusion with a sensitivity of 84.2% and a specificity of 87.5% in predicting reperfusion, as shown in Fig. 3. ROC analysis was also

Table 1
The baseline clinical, echocardiographic, and angiographic parameters.

Parameters	Group A (MBG 0 -1) [$n = 80$]	Group B (MBG 2 -3) [$n = 120$]	p value
Age (years)	48.98 ± 13.15	47.69 ± 9.31	0.416
Male gender [n (%)]	76 (95)	107 (89.2)	0.147
Hypertension [n (%)]	16 (20)	27 (22.5)	>0.05
Diabetes [n (%)]	14 (17.5)	22 (18.3)	>0.05
Pulse (beats/min) [mean ± SD]	82.63 ± 11.32	82.12 ± 10.1	0.738
Systolic blood pressure (mmHg) [mean ± SD]	120.42 ± 18.2	122.7 ± 19.98	0.415
Diastolic blood pressure (mmHg) [mean ± SD]	73.65 ± 10.40	76.28 ± 9.57	0.067
Hemoglobin (gm/dl) [mean ± SD]	12.26 ± 1.47	12.38 ± 1.66	0.614
Serum creatinine (mg/dl) [mean ± SD]	0.83 ± 0.20	0.86 ± 0.18	0.363
CPK-MB (U/L) [mean ± SD]	78.33 ± 33.89	60.6 ± 32.41	<0.001
WMSI [median (range)]	2 (2-2)	2 (2-2)	0.941
LVEF (%) [mean ± SD]	38.62 ± 4,93	41.62 ± 6.22	0.66
Pain-to-balloon time (hours)	7.30 ± 1.21	4.26 ± 1.20	<0.001
Killip class on presentation [n (%)]			
I	73 (91.25)	117 (97.5)	0.704
II-III	7 (8.75)	3 (2.5)	
IRA [n (%)]			
LAD	57 (71.2)	70 (58.3)	0.177
LCX	8 (10.0)	18 (15.0)	
RCA	15 (18.8)	32 (26.7)	
DVD [n (%)]	9 (11.3)	16 (13.3)	0.770
TVD [n (%)]	5 (6.3)	10 (8.3)	0.760
Thrombosuction [n (%)]	24 (30)	30 (25)	0.435
TIMI flow at the end of PCI [n (%)]			
0−1	5 (6.2)	0 (0)	<0.001
2−3	75 (93.8)	120 (100)	

CPK-MB, creatinine phosphokinase-muscle/brain; DVD, double-vessel disease; WMSI, wall motion score index; LVEF, left ventricle ejection fraction; IRA, infarct-related artery; LAD, left anterior descending; LCX, left circumflex; PCI, percutaneous coronary intervention; RCA, right coronary artery; TVD, triple vessel disease; TIMI, thrombolysis in myocardial infarction; MBG, myocardial blush grade.

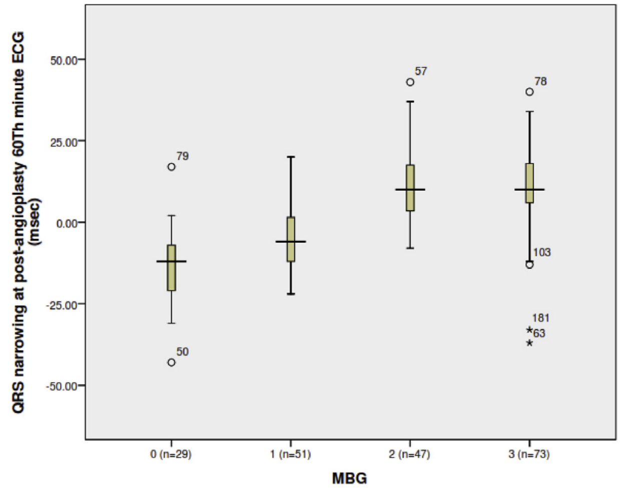

Fig. 2. Correlation of the QRS narrowing at the 60th minute post PCI with the MBG. PCI, percutaneous coronary intervention; MBG, myocardial blush grade.

performed to determine the best cutoff value of the QRS duration after reperfusion at immediate and at 60 min for predicting the reperfusion status. It showed that the QRS complex duration cutoff of 89.5 ms at both immediate and at 60 min post angioplasty was the best discriminating value for the reperfusion status (sensitivity 77.5%, specificity 67.5% and sensitivity 81.7%, specificity 74.3%, respectively), as shown in Fig. 4. There was a negative correlation between the pain-to-balloon time and the immediate ($r = -0.144$, $p = 0.042$) and the 60th minute ($r = -0.147$; $p = 0.038$) QRS narrowing, as shown in Fig. 5. In our study, ST resolution was statistically more in group B patients compared with group A (Chi square = 17.46, p value < 0.001). We observed a significant and positive correlation between ST-segment resolution and QRS duration at immediate post angioplasty and after 60 min ($p < 0.05$).

4.2. Six-month follow-up

All our patients were followed up clinically upto 6 months. At the end of 6 months, NYHA functional class, LVEF, and QRS duration were measured systematically in all the patients. We found that patients with impaired reperfusion had a worse functional status (NYHA II-IV) (64.9% vs 13.8%, $p < 0.001$) and a lower mean EF (37.0 ± 9.88 vs 48.19 ± 9.77, $p < 0.001$) than patients with normal microvascular perfusion. Also, at the end of 6 months, QRS duration almost remained the same compared with the post angioplasty measurements. Three patients who had a diminished MBG and a prolonged QRS after PCI had sudden cardiac death during the follow-up period.

5. Discussion

In the present study, we have shown a positive correlation between QRS narrowing after PCI and adequate microvascular reperfusion. Persistence of QRS prolongation is associated with a poor microvascular flow. QRS prolongation is associated with increased risk of arrhythmia, heart failure, and ischemia leading to increased long-term mortality.[14–17] Prolonged ischemia to Purkinje-ventricular conduction system leads to QRS prolongation.[18–21] In our study also, patients who had a longer pain-to-balloon time, had a prolonged QRS duration, suggestive of ischemia as a mechanism for its prolongation. De Luca et al. has also shown that there is a higher 1-year mortality in patients who underwent successful primary PCI but presented late and had impaired reperfusion after primary PCI.[22] It indicates extensive microvascular damage, leading to LV dysfunction in long term. Moreover, with the passage of time, the thrombus becomes organized, resulting in distal microembolization and hence poor myocardial perfusion.[23] Tsukahara et al. had reported that 79% of patients who presented with intermediate QRS prolongation have reverted back to normal QRS duration after successful angioplasty, which might have been caused by extensive ischemia and a poor

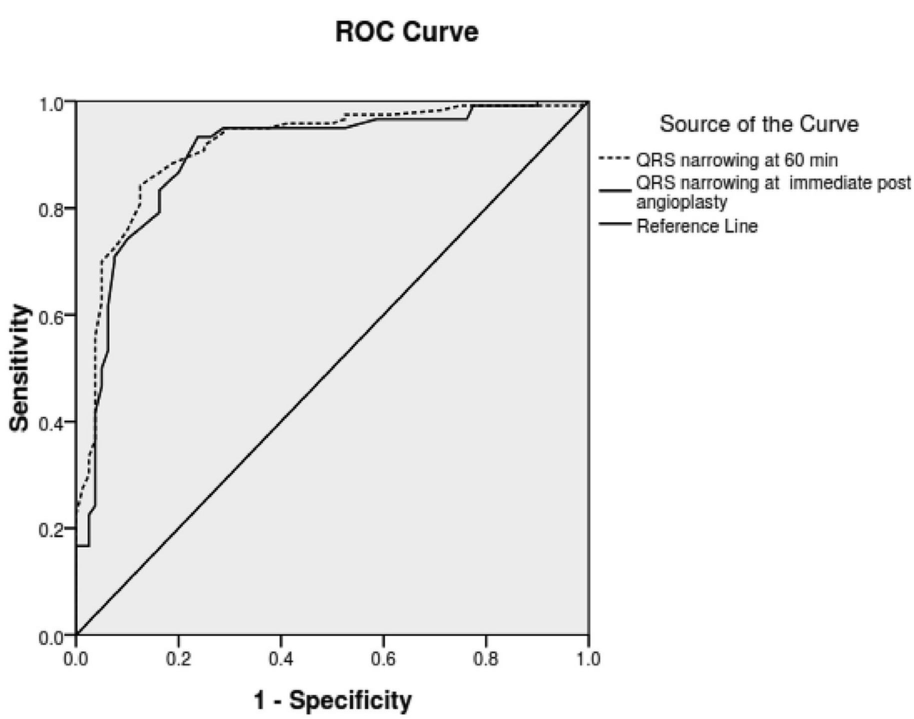

Fig. 3. ROC analysis for the QRS narrowing at immediate and at 60 min post PCI. PCI, percutaneous coronary intervention; ROC, receiver operator curve.

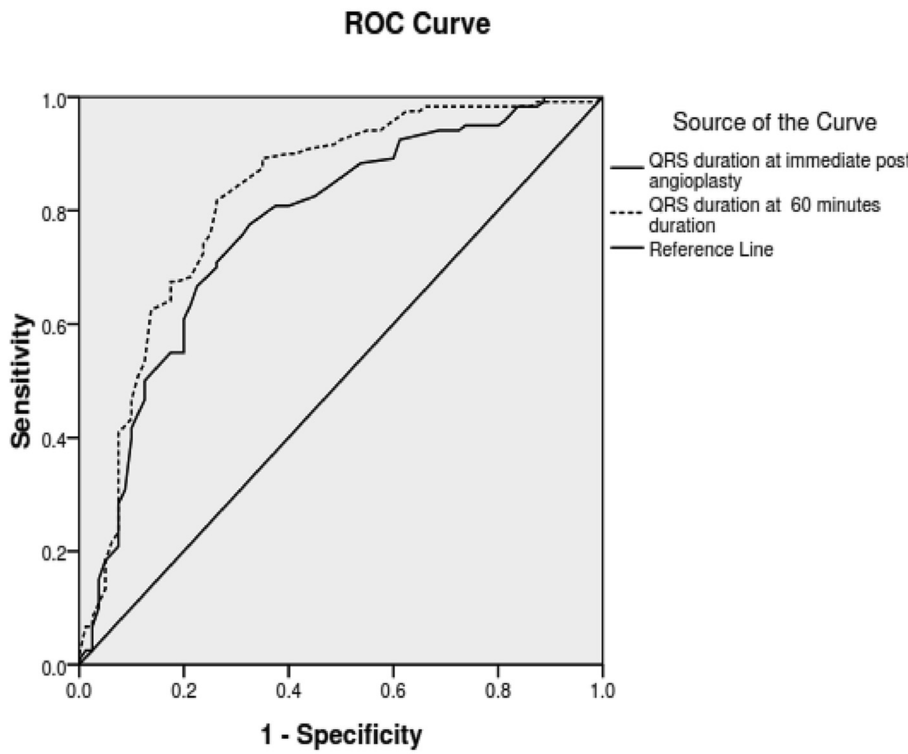

Fig. 4. ROC analysis for the QRS duration at immediate and at 60 min after PCI. PCI, percutaneous coronary intervention; ROC, receiver operator curve.

metabolic state rather than by myocardial fibrosis and increased myocardial mass.[5]

Erdogan et al. in a study of 148 patients had shown that patients in the impaired reperfusion group had a significantly longer QRS duration after primary PCI at both immediate and after 60 min post angioplasty. He had shown that QRS narrowing in the 60th-minute ECG was an independent ECG marker of reperfusion.[10] Similarly, Magdy et al. has shown in the study of 100 patients that QRS narrowing was significant in patients with a good MBG both at the end of 60th and 90th minutes post angioplasty.[11] All these studies further confirm ischemia as a cause of QRS prolongation and thus, explain the dynamic nature of QRS changes in these patients.

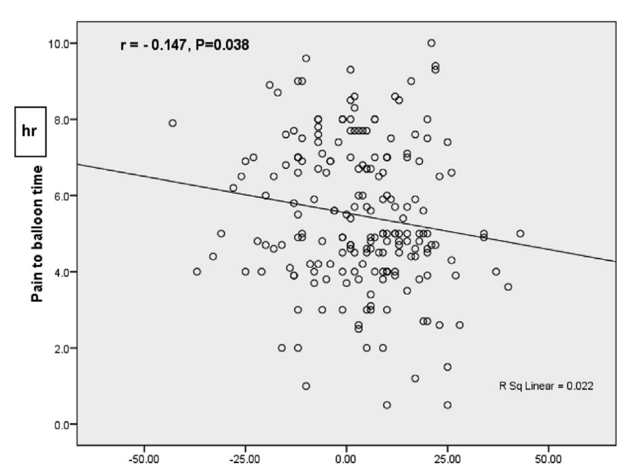

Fig. 5. Negative correlation between the pain-to-balloon time and the 60th minute QRS narrowing.

Success of primary PCI can be assessed by various methods, including TIMI flow classification, MBG grading, and ST-segment resolution. But MBG is a better predictor of clinical outcomes in comparison to the TIMI flow.[24,25]

In our study, we found that QRS narrowing of 4.5 msec post angioplasty was the best cutoff value for predicting reperfusion with a sensitivity of 84.2% and a specificity of 87.5%. However, the studies conducted by Erdogan et al. and Magdy et al. have shown that QRS narrowing of 10 msec was the best discriminative value for reperfusion assessment, which had a sensitivity of 90% and a specificity of around 80%.[10,11] Difference in this cutoff value may be because we had used a computerized method of calculating the QRS duration using EEPEE software, which is more precise and specific than the manual method. Also, the pain-to-balloon time in our patients were longer in most cases, and hence, this could have affected the QRS narrowing after successful PCI.

Patients who presented with AWMI had a wider QRS complex because of the amount of ischemic territory involved, in comparison to the patients who had the left circumflex artery or right coronary artery involvement. Hence, restoration of the early myocardial flow is must in patients with AWMI to improve the prognosis.

Patients with good microvascular reperfusion had a better ST-segment resolution, which leads to good left ventricular (LV) function recovery. Arnaldo Poli et al. had shown in his study of 114 patients that 60 patients who had a good MBG and ST-segment recovery both, had a better LV function recovery both immediately and after 6 months post angioplasty.[26] These patients had a better functional integrity of the microvascular network which leads to an early contractile recovery of a predominantly stunned myocardium. Follow-up of our patients at 6 months has shown that patients with normalization of the QRS complex and a good MBG had a better LV function recovery, which improves the long-term prognosis of these patients. Three of our patients who had prolonged QRS after PCI and a diminished MBG expired during the follow-up period, which may point toward the possibility that predicting reperfusion with QRS narrowing after primary PCI may be helpful in risk stratification of these patients in longer term follow-up.

5.1. Limitations

First, it is often difficult to determine precisely the junction between the end of the QRS complex and the beginning of the ST-segment during acute STEMI. Second, the interobserver and the intraobserver variabilities of the subjective assessment of the blush grades are certainly a limitation. Finally, a shorter duration of follow-up of 6 months is not enough to draw conclusions. A longer follow-up could give additional prognostic information.

6. Conclusion

QRS duration change post angioplasty is strongly correlated with the myocardial reperfusion in patients presenting with STEMI. Prolongation of the QRS duration post angioplasty is indicative of impaired microvascular reperfusion, whereas a QRS complex narrowing of at least 4.5 msec is helpful in predicting successful reperfusion. Analysis of MBG is helpful in predicting the time course and magnitude of LV function recovery and the symptom status.

Conflicts of interest

All authors have none to declare.

References

1. Niccoli G, Burzotta F, Galiuto L, et al. Myocardial no-reflow in humans. *J Am Coll Cardiol*. 2009;54:281–292.
2. Roe MT, Ohman EM, Maas AC, et al. Shifting the open-artery hypothesis downstream: the quest for optimal reperfusion. *J Am Coll Cardiol*. 2001;37: 9–18.
3. Ito H, Tomooka T, Sakai N, et al. Lack of myocardial perfusion immediately after successful thrombolysis. A predictor of poor recovery of left ventricular function in anterior myocardial infarction. *Circulation*. 1992;85:1699–1705.
4. Schroder R, Dissmann R, Bruggemann T, et al. Extent of early ST segment resolution: a simple but strong predictor of outcome in patients with acute myocardial infarction. *J Am Coll Cardiol*. 1994;24:284–391.
5. Tsukahara K, Kimura K, Kosuge M, et al. Clinical implications of intermediate QRS prolongation in the absence of bundle-branch block in patients with ST-segment elevation acute myocardial infarction. *Circ J*. 2005;69:29–34.
6. Masami K, Toshiaki E, Kiyoshi H E, et al. High QRS Score on Admission Strongly Predicts Impaired myocardial reperfusion in patients with a first anterior acute myocardial infarction. *Circ J*. 2011;75:626–632.
7. Hristo T, Morris M. Myocardial Blush Grade: an interventional method for assessing myocardial perfusion. *Isr Med Assoc J*. 2008;10:465–467.
8. De Luca G, Van't Hof AWJ, Ottervanger JP, et al. Ageing, impaired myocardial perfusion, and mortality in patients with ST-segment elevation myocardial infarction treated by primary angioplasty. *Eur Heart J*. 2005;26:662–666.
9. Constantini CO, Stone GW, Mehran R, et al. Frequency, correlates, and clinical implications of myocardial perfusion after primary angioplasty and stenting, with and without glucoprotein IIb/IIIa inhibition, in acute myocardial infarction. *J Am Coll Cardiol*. 2004;44:305–312.
10. Erdogan I, Fehmi K, Orhan M, et al. A new electrocardiographic marker of myocardial reperfusion in patients with acute ST-segment elevation myocardial infarction treated with primary percutaneous intervention: the value of QRS duration. *EuroIntervention*. 2012;7:1406–1412.
11. Magdy G, Ashmawy H, Mahmoud K, et al. QRS complex duration is a marker of reperfusion in patients presenting with acute ST-segment elevation myocardial infarction. *J Cardiovasc Dis Diagn*. 2017;5:3.
12. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American society of echocardiography and the European association of cardiovascular imaging. *Euro Heart J Cardiovascular Imag*. 2015;16:233–271.
13. Van't Hof AWJ, Liem A, Suryapranata H, et al. Angiographic assessment of myocardial reperfusion in patients treated with primary angioplasty for acute myocardial infarction-myocardial blush grade. *Circulation*. 1998;97: 2302–2306.
14. Lakshminarayan Y, Nagesh A, Hicham S, et al. Association of QRS duration and outcomes after myocardial infarction: the VALIANT TRIAL. *Heart Rhythm*. 2006;3:313–316.
15. Brenyo A, Zareba w. Prognostic significance of QRS duration and morphology. *Cardiol J*. 2011;18:8–17.
16. Karahan Z, Yaylak B, Ugurlu M, et al. QRS duration: a novel marker of microvascular reperfusion as assessed by myocardial blush grade in ST elevation myocardial infarction patients undergoing a primary percutaneous intervention. *Coron Artery Dis*. 2015;26:583–586.
17. Ari H, Cetinkaya S, Ari S, et al. The prognostic significance of a fragmented QRS complex after primary percutaneous coronary intervention. *Heart Ves*. 2012;27:20–28.
18. Gilmour RF, Evans JJ, Zipes DP. Purkinje-muscle coupling and endocardial response to hyperkalemia, hypoxia and acidosis. *Am J Physiol*. 1984;247: H303–H311.
19. Grant RP, Dodge HT. Mechanisms of QRS complex prolongation in man: left ventricular conduction disturbances. *Am J Med*. 1956;20:834–852.
20. Hamilin RL, Pipers FS, Hellerstein HK, et al. QRS alteration immediately following production of left ventricular free wall ischemia in dogs. *Am J Physiol*. 1968;215:1032–1040.
21. Mendez C, Mueller WJ, Merideth J, et al. Interaction of transmembrane potentials in canine Purkinje fibers and at Purkinje fiber-muscle junctions. *Circ Res*. 1969;24:361–372.
22. De Luca G, van't Hof AW, de Boer MJ, et al. Time-to-treatment significantly affects the extent of ST-segment resolution and myocardial blush in patients with acute myocardial infarction treated by primary angioplasty. *Eur Heart J*. 2004;25:1009–1013.
23. Henriques JP, Zijlstra F, Otterwanger JP, et al. Incidence and clinical significance of distal embolization during primary angioplasty for acute myocardial infarction. *Eur Heart J*. 2002;23:1112–1117.
24. Gibson CM, Cannon CP, Murphy SA, et al. Relationship of TIMI myocardial perfusion grade to mortality after administration of thrombolytic drugs. *Circulation*. 2000;101:125–130.
25. Henriques JP, Zijlstra F, van't Hof AW, et al. Angiographic assessment of reperfusion in acute myocardial infarction by myocardial blush grade. *Circulation*. 2003;107:2115–2119.
26. Arnaldo P, Raffaela F, Pietro V, et al. Integrated analysis of myocardial blush and ST-Segment elevation recovery after successful primary angioplasty. Real-time grading of microvascular reperfusion and prediction of early and late recovery of left ventricular function. *Circulation*. 2002;106:313–318.