

T-Wave Normalization During Follow-Up After Early and Late Mechanical Recanalization of Infarct-Related Artery With and Without Stent Implantation

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Key Words: electrocardiogram; myocardial infarction; percutaneous coronary intervention.

Summary. *Objective.* The aim of this study was to evaluate T-wave normalization during the 6-month follow-up in the patients who underwent early or late mechanical recanalization of the infarct-related artery with and without stent implantation.

Material and Methods. A total of 248 consecutive patients were divided into the following groups: early angioplasty (≤ 24 hours) without ($n=114$) or with stents ($n=6$) and late angioplasty (>24 hours) without ($n=114$) or with stents ($n=14$). The changes in T-wave recovery, QRS score, and echocardiographic left ventricular ejection fraction were compared between the groups.

Results. At 3 months, a greater percentage of patients in the group of early angioplasty with stents had again positive T wave than in the group of early angioplasty without stents (75% vs. 35%, $P=0.05$). After 6 months, all patients in the group of early angioplasty with stents had again positive T wave. A significant increase in left ventricular ejection fraction after 3 months was also observed only in the groups of early angioplasty, especially that with stents (30.0% [SD, 3.5%] vs. 38.4% [SD, 5.2%], $P=0.008$). However, there was no significant difference in the QRS score in this group comparing the data at discharge and after 3 months (5.4 [SD, 4.3] vs. 5.0 [SD, 1.9], $P>0.05$).

Conclusions. The group of early angioplasty with stents showed the best recovery of T wave and left ventricular ejection fraction, but the QRS score did not change significantly from discharge to the 3-month follow-up, so the evolution of T wave corresponded to an improvement in ejection fraction at follow-up better than the evolution of QRS score.

Introduction

Primary percutaneous coronary intervention (PCI) with stent implantation has become accepted as the preferred interventional strategy in ST-segment elevation myocardial infarction (STEMI) (1, 2). Myocardial reperfusion therapy results in better function of the left ventricle (LV) and improved survival after acute myocardial infarction (AMI) in cases of early and successful recanalization of the infarct-related artery (IRA) and complete myocardial reperfusion, but late recanalization (3 or more days after AMI) or incomplete myocardial reperfusion is associated with an increased risk of death and LV dysfunction (3, 4). However, recently Sone et al. have reported a remarkable recovery of a 65-year-old man with marked ST-elevation myocardial infarction, who was treated with PCI more than 2 days after onset (5). Whilst an improvement in perfusion is the usual finding after successful angioplasty, there is considerable disparity between the angiographic appearance of restored TIMI flow in IRA and the electrocardiographic (ECG) signs of myocardial tissue reperfusion insufficiency manifested by persistent ST-segment elevation after recanalization (6).

Ito et al. (7) demonstrated that the restoration of normal epicardial blood flow was not sufficient to ensure adequate myocardial reperfusion; the latter required perfusion at the level of the coronary microcirculation and myocytes. Myocardial perfusion in the distribution of the dilated artery was shown to improve progressively up to 3 months, but thereafter, no improvement was seen (8, 9).

Despite the changes in ST-segment deviation amplitude have been extensively studied, the significance of T-wave changes is less clear, especially in the follow-up period. Only few studies have investigated the significance of T-wave direction in leads with ST-segment elevation (10). ST-segment or T-wave changes may be secondary to the abnormalities of depolarization, i.e., pre-excitation, or abnormalities of QRS voltage or duration. On the other hand, ST-segment and T-wave abnormalities may be unrelated to any QRS abnormality, and in this case, they are called primary repolarization abnormalities. These are caused by ischemia, pericarditis, myocarditis, drugs (digoxin, antiarrhythmic drugs), and electrolyte, particularly potassium, abnormalities. T-wave inversion in the anterior precordial leads may be seen in cases of acute pulmonary embolism, while flattened T waves with prominent U waves and ST-segment depression may reflect hypokalemia or effect of digitalis therapy. There are a wide variety

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of causes for T-wave inversion. Various other entities may cause T-wave inversion, notably acute pericarditis or myocarditis, myocardial contusion, central nervous system disease such as a subarachnoid hemorrhage, memory T-wave phenomenon, and normal variants of repolarization (11). The configuration of the T waves may carry different meanings at different stages after STEMI. It is well known that the amplitude of the ST-segment resolution is influenced mostly by epicardial ischemia and is less influenced by the degree of subendocardial ischemia. Thus, ST-segment resolution may correlate better with the amelioration of epicardial ischemia caused by the restoration of flow through the IRA or by the recruitment of collaterals and less with the status of the subendocardial zones. It is possible that the configuration of the T waves is related more to the subendocardial perfusion status. Because myocardial necrosis starts from the subendocardium and expands toward the epicardium, the configuration of the T waves after reperfusion therapy may correlate better with the recovery of LV function and prognosis.

Previous studies have shown that the QRS score is informative in the assessment of MI size and myocardial viability after reperfusion therapy (12). Although some authors showed that the predischarge QRS score was predictive of infarct size only in patients with completely resolved ST segment and with negative T wave (13), the informative value of the QRS score in the acute stage of MI is undoubtedly clear. However, its value in the follow-up period is less clear, since it was shown that the QRS normalization during a 1-year follow-up was unaffected by an aggressive treatment strategy with revascularization via balloon angioplasty or bypass surgery (14). Previously, we have reported that the QRS score might be not predictive of improvement in LV ejection fraction at follow-up (15, 16). Thus, our aim was not only to show differences in the normalization of T waves after early and late mechanical recanalization of IRA with and without stent implantation, but also to compare the evolution of T wave and QRS score with the changes of LV ejection fraction at follow-up.

Material and Methods

Our previous study reported the changes in the QRS score and echocardiographic characteristics at hospital and at the 3-month follow-up in the same cohort (15). Now we have added the data on T-wave recovery as well as additional 3 months of follow-up. A total of 248 consecutive patients were divided into the following groups: early angioplasty (≤ 24 hours) without stents ($n=114$) or with stents ($n=6$) and late angioplasty (>24 hours) without stents ($n=114$) or with stents ($n=14$). Serial 12-lead ECGs, recorded at admission, on the first day after PCI, at discharge, and after 3 and 6 months, were analyzed, and 4 ECG

stages of AMI were defined by the same criteria (17) as in our previous study (15), and an additional stage V suggested by us was added:

- Stage I, the ST-segment elevation ≥ 0.1 mV, a positive T wave, and normal Q wave;
- Stage II, the ST-segment elevation ≥ 0.1 mV, abnormal Q wave. In accordance with the Selvester QRS scoring system (18), Q wave was considered abnormal if it was present in leads V1, V2, V3 or it was ≥ 20 ms in lead V4 or it was ≥ 30 ms in any other lead except III and aVR;
- Stage III, the ST segment is still elevated, but a negative T wave begins to form;
- Stage IV, the ST segment is in an isoelectric line with the negative T wave;
- Stage V, the ST segment is in an isoelectric line and again positive T wave (19).

The Selvester QRS score simplified and modified by Wagner et al. (20) was determined manually for each electrocardiogram.

The observer of ECG data, as well as echocardiographic data, was experienced and blinded to the other results of this study.

Statistical Analysis. Values were expressed as mean (standard deviation). Statistical significance was accepted when P was ≤ 0.05 . Differences in continuous variables between the 2 groups were assessed using the unpaired Student t test. Differences in the same groups between the baseline data and those at 3 months were assessed using the paired t test.

Results

Baseline Characteristics. There were no significant differences regarding the location of AMI comparing 4 patients' groups: in the group of early PCI, 35.1%, 59.6%, and 5.3% of patients without stents and 33.3%, 50%, and 16.7% of patients with stents had anterior-lateral, inferior-posterior, and mixed MI, respectively; the corresponding percentages in the group of late PCI were 44.7%, 47.4%, and 7.9% and 42.9%, 42.9%, and 14.3%, respectively. There were 7% and 10.5% of women in the groups of early and late PCI without stents, respectively, and 0% and 7% in the groups of early and late PCI with stents, respectively. The patients were matched by age and the QRS score at admission (Table 1). However, LV ejection fraction at admission was lower in the groups of early PCI (without or with stents) than in the corresponding groups of late PCI. Naturally, the patients who underwent late PCI (without or with stents) had AMI of greater ECG stage.

Changes in Electrocardiographic and Echocardiographic Data. There were no significant differences in the QRS score comparing all groups at admission, but the QRS score after PCI and at discharge was significantly greater in the groups of early PCI (without or with stents) than in the groups of late

Table 1. Characteristics of Study Population

Characteristic	Early PCI			Late PCI		
	Without Stents (n=114)	With Stents (n=6)	P	Without Stents (n=114)	With Stents (n=14)	P
Age, years	58.2 (10.6)	54.5 (9.5)	NS	58.9 (10.7)	57.6 (15.1)	NS
Echocardiographic LV ejection fraction at admission, %	40.0 (7.4)†	33.8 (7.2)†	0.02	43.4 (8.4)	44.1 (7.2)	NS
ECG stage at admission	1.7 (0.8)*†	1.8 (0.7)*	NS	2.6 (1.2)*	2.7 (1.4)*	NS
ECG stage after PCI	2.9 (0.9)	3.0 (1.1)	NS	3.3 (0.9)	3.6 (0.8)	NS
ECG stage at discharge	3.7 (0.7)	3.8 (1)	NS	3.9 (0.5)	4.1 (0.7)	NS
QRS score at admission	2.6 (2.5)*	3.3 (2.1)*	NS	2.5 (2.4)‡	2.0 (1.8)	NS
QRS score after PCI	3.6 (2.5)†	4.2 (2.3)†	NS	2.9 (2.1)	2.4 (1.7)	NS
QRS score at discharge	3.6 (2.4)†	4.8 (4.1)†	NS	3.0 (2.2)	1.4 (1.6)	0.004

Values are mean (standard deviation). PCI, percutaneous coronary intervention; LV, left ventricular; NS, not significant.

* $P < 0.05$, versus after PCI and at discharge within the group; † $P < 0.05$, early PCI versus late PCI comparing the groups without or with stents; ‡ $P < 0.05$, versus at discharge within the group.

Table 2. Changes of Electrocardiographic and Echocardiographic Data 3 Months after Early and Late Mechanical Recanalization of Infarct-Related Artery With and Without Stent Implantation

Characteristic	Early PCI			Late PCI		
	Without Stents (n=114)	With Stents (n=6)	P	Without Stents (n=114)	With Stents (n=14)	P
QRS score	n=40	n=5		n=44	n=5	
At discharge	3.5 (2.3)	5.4 (4.3)	NS	2.3 (2.0)	1.6 (1.7)	NS
After 3 months	3.9 (0.6)	5.0 (1.9)	NS	2.2 (1.8)	1.8 (1.8)	NS
Echocardiographic LV ejection fraction, %	n=40	n=5		n=44	n=5	
At discharge	39.4 (6.0)*	30.0 (3.5)*	NS	39.9 (8.9)	40.4 (10.0)	NS
After 3 months	41.9 (7.3)	38.4 (5.2)	NS	43.5 (6.8)	45.0 (3.1)	NS
Again positive T wave (ECG stage V) after 3 months, %	n=79	n=4		n=61	n=8	
	35	75	0.05	43	50	NS

Values are mean (standard deviation) unless otherwise indicated. PCI, percutaneous coronary intervention; LV, left ventricular; NS, not significant.

* $P < 0.05$, versus 3 months within the groups.

PCI (Table 1). The QRS score at discharge was significantly greater than that at admission only in the groups of early or late PCI without stent implantation. No significant differences in the QRS score were documented comparing the data at discharge and after 3 months in all groups (Table 2). However, LV ejection fraction significantly increased after 3 months in the group of early PCI, especially in that with stent implantation ($P=0.008$).

There were no significant differences in the ECG stage at discharge comparing all 4 groups (Table 1). However, after 3 months, a significantly greater percentage of patients who underwent early PCI with stents had again positive T wave (ECG stage V) as compared with those who underwent early PCI without stents (Table 2). Therefore, the most rapid normalization of the T wave was in the group of early PCI with stent implantation, as well as normalization of the echocardiographic LV ejection fraction, while there were no significant differences in the QRS score comparing the data at discharge and after 3 months in all groups. After 6 months, all patients in the group of early PCI with stents had again positive T wave (ECG stage V) (Fig.).

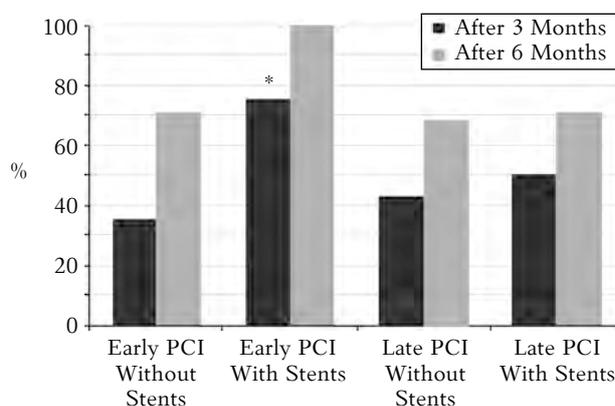


Fig. T-wave normalization during follow-up after early and late percutaneous coronary intervention (PCI) of infarct-related artery with and without stent implantation

* $P=0.05$ versus early PCI without stents at 3 months.

Discussion

In this study, after 3 months, a greater percentage of patients who underwent early angioplasty with stents had again positive T wave than those without stents, and after 6 months, all patients in the group of early angioplasty with stents had again

positive T wave. LV ejection fraction after 3 months increased also only in the early angioplasty group especially with stents, but there were no significant differences between the QRS score at discharge and after 3 months in this group.

Atak et al. (21) showed that the presence of isoelectric ST segment and negative T wave at pre-discharge (at the end of the first week) indicated a high probability of myocardial viability and that T-wave negativity was less specific but more sensitive than the isoelectricity of ST segment. Lancellotti et al. (22) reported that in late period persistent negative T waves had a significant negative influence on long-term survival. Sakata et al. (23) showed that the earlier (at 3 months, 6 months, or 12 months) the negative T waves reverted to positive, the greater the tendency for an improvement in LV function was, but LV function did not change in the group with negative T wave at 12 months. During our previous study, we have also noticed a tendency to earlier T-wave recovery to positive at follow-up in the group with an improvement in regional myocardial perfusion than in the group without a follow-up improvement in regional myocardial perfusion (19). We suggested that this T-wave recovery to positive could be expressed in the additional ECG stage V of MI added to the conventional 4 ECG stages, reflecting simultaneous alterations in ST segment, T wave, and QRS complex. By using 5 ECG stages, it would be possible to reflect the velocity of ECG evolution in Q-wave MI, showing a rapid evolution of ECG stages – at least 2 ECG stages throughout the first 2 days until stage IV in the first week and stage V during the first year – which predicts a potential recovery of myocardial perfusion and LV function. The present study, comparing patients who underwent early PCI (≤ 24 hours) without or with stents and late PCI (> 24 hours) without or with stents, shows that most patients in the group of early angioplasty with stents had again positive T wave (ECG stage V) after 3 and 6 months. LV ejection fraction increased after 3 months also only in the groups of early angioplasty especially with stents.

Because a final infarct size is a major determinant of LV function, a relation between the QRS score and LV ejection fraction could be expected. However, previous studies showed that the relationship between the QRS score after thrombolytic therapy on day 7 and ejection fraction at 1 month was not linear (the authors concluded that it is likely to reflect effects of ventricular loading conditions and compensatory changes in the contractile function of noninfarcted regions on the ejection fraction) (24) and that the QRS normalization during the 1-year follow-up seems unaffected by an aggressive treatment strategy with revascularization via balloon angioplasty or bypass surgery, since the consider-

able normalization of the QRS complex also occurs after AMI treated with thrombolytic therapy (14). Our previous study (25), using a 29-point Selvester QRS scoring system simplified and modified by Wagner, as well as a study by Adler et al. (26) using a 32-point QRS scoring system, showed that the QRS score was predictive of LV function and infarct size only in cases of sufficient myocardial reperfusion after intravenous thrombolysis. We also showed that thrombolysis had a positive impact on subsequent myocardial functional recovery only in cases of sufficient myocardial reperfusion, although the QRS score decreased during the 3-year follow-up in the group of insufficient myocardial reperfusion after thrombolysis as well as in the group of sufficient myocardial reperfusion after thrombolysis (25). Our other study (16) showed that the QRS normalization predicted a decrease in the echocardiographic dyssynergic score and an increase in ejection fraction only in patients with sufficient mechanical, thrombolytic, and spontaneous myocardial reperfusion assessed by the rate of changes in ECG stages, while QRS normalization in the group of insufficient myocardial reperfusion was not related to myocardial functional recovery during the 1-year follow-up. The present study shows that the QRS score alone is not predictive of improvement in LV ejection fraction at follow-up, because echocardiographic LV ejection fraction increased after 3 months in the group of early PCI, especially with stent implantation, while there were no significant differences in the QRS score comparing the data at discharge and after 3 months. However, the informative value of QRS score in the acute stage of MI was clearly shown (12, 24). Our study also showed that myocardial injury estimated by the QRS score did not increase from admission to hospital until discharge in the group of PCI (early or late) with stent implantation, while in the group of PCI without stent implantation, especially in cases of early PCI, it increased. Therefore, in our study, the evolution of T wave corresponded to an improvement in LV ejection fraction at follow-up better than the evolution of QRS score, and we propose that T-wave changes shown at follow-up may add a diagnostic and prognostic value of T wave. Recently, Weir et al. reported that infarct size measured by contrast-enhanced cardiac magnetic resonance imaging was greater than that determined based on the QRS score in the acute and subacute phases of infarction (27). Thus, there is an ongoing discussion in the medical literature regarding which marker of reperfusion is better. We think that it is more reasonable to assess myocardial reperfusion and prognosis by the rate of ECG stage dynamics, because the assessment of ST segment and T wave only at one moment, for example, at discharge, does not consider

the ECG data on admission or at the beginning of mechanical or thrombolytic recanalization. Neither does it consider their evolution, nor the changes in the QRS complex. Moreover, we suggest using 5 ECG stages reflecting simultaneous alterations in ST segment, T wave, and QRS complex.

Limitations. This was a nonrandomized study in which the groups differing in some clinical characteristics were compared. However, the conclusions can be drawn because LV ejection fraction at admission was lowest in the group of early PCI with stent implantation, so the worst results in this most sick group could be expected. Nevertheless, the best results were observed in this group of patients. Another limitation of this study is a small number of patients examined at follow-up: comparing the ECG and echocardiographic data after 3 months with the data at discharge, at discharge we also analyzed only the data of those patients who arrived after 3 months

(Table 2). However, we showed the significant differences in the normalization of T waves after early and late mechanical recanalization of IRA with and without stent implantation compared with the evolution of QRS score and LV ejection fraction at follow-up.

Conclusions

In this study, the group of early PCI with stent implantation had the best recovery of T wave and LV ejection fraction, but the QRS score did not change significantly from discharge to the 3-month follow-up, so the evolution of T wave corresponded to an improvement in ejection fraction at follow-up better than the evolution of QRS score. At 6 months, all patients in the group of early angioplasty with stents had again positive T wave.

Statement of Conflict of Interest

The authors state no conflict of interest.

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