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Resting 12-Lead Electrocardiogram as a Reliable Predictor of Functional Recovery after Recanalization of Chronic Total Coronary Occlusions

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Summary

Background: A major goal of revascularization is the recovery of left ventricular (LV) function. Nuclear imaging techniques are widely used for detecting recovery of function with a good sensitivity, but only moderate specificity. Predictors of recovery in chronic total coronary occlusions (CTO) are not investigated.

Hypothesis: The 12-lead-resting electrocardiogram (ECG) is a predictor of LV recovery after successful recanalization of CTO.

Methods: Successful recanalization of CTO was performed in 127 patients. Of these, 62 patients, who constitute the study group, had impaired regional wall motion prior to recanalization. The 12-lead resting ECG was evaluated for Q-wave areas and parameters of QT dispersion. Impairment of regional wall motion was evaluated by LV angiogram at baseline and at follow-up.

Results: Angiographic follow-up after 5 ± 1.4 months documented reocclusion in eight patients. Complete follow-up with a patent coronary artery and an ECG without bundle-branch block was available in 43 patients. Wall motion severity index (WMSI) improved from -2.92 ± 0.28 to -1.34 ± 0.61 ($p < 0.001$) in patients without Q waves, whereas it was unchanged in patients with Q waves (-3.01 ± 0.30 and -2.81 ± 0.32). Absence of Q waves at baseline predicted recovery of regional wall motion with 89% sensitivity and 67% specificity. Positive predictive value for recovery was 68% in patients without Q waves, but only 11% in patients with Q waves. In multivariate analysis, only absence of Q waves predicted improvement in WMSI ($p = 0.01$).

Conclusions: In patients with recanalization of CTO, recovery of regional wall motion is reliably predicted by analysis of the resting 12-lead ECG for pathologic Q waves.

Key words: electrocardiography, angioplasty, regional wall motion, chronic total coronary occlusion

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Introduction

The goal of revascularization therapy in coronary artery disease (CAD) with depressed left ventricular (LV) function is the recovery of regional and global ventricular function, based on the recovery of viable, but hibernating myocardium.[1–3]

There are various imaging techniques for detecting viable myocardium before planned revascularization in CAD. Echocardiography at rest[4] or during dobutamine infusion,[2, 5–7] and nuclear imaging techniques—thallium-201 scintigraphy,[5, 6] positron emission tomography[2, 7]—are used for detecting myocardial viability and predicting subsequent recovery of function. All these techniques have a sensitivity of 81 to 93% and a moderate specificity of 50 to 80% for contractile recovery.[8] Therefore, and because of the costly and time-consuming nature of these imaging techniques, inexpensive methods of similar accuracy would be desirable.

Various ECG parameters at rest or during exercise were applied to assess myocardial viability or recovery of function—for example, QT dispersion and T-wave normalization[9, 10]—in a population with severely diseased but mostly patent arteries. The extent of Q waves in the resting ECG was used to assess a QRS score (Selvester Score) to predict infarct size and LV function after myocardial infarction (MI).[11, 12]

Successful recanalization of a chronic total coronary occlusion (CTO) by percutaneous coronary intervention (PCI) can recruit viable myocardium, lead to recovery of impaired regional or global LV function,[3, 13] and may even improve survival.[14] On the other hand, recanalization of a scarred area does not seem to be justified. We studied the value of the resting ECG to predict recovery of regional impaired LV function in the well-defined clinical setting of a recanalization of CTO.

Materials and Methods

Study Group

During a period from January 1999 to October 2002, recanalization of CTO (> 2 weeks) was successfully performed in 127 patients at our institution. The study group of 62 patients was recruited from this consecutive series, based on the presence of impaired regional wall motion in the area of the occluded coronary artery (wall motion severity index [WMSI] ≤ -2.0 standard deviation [SD]/chord). Angiographic follow-up evaluation was declined by one patient, and three patients died during follow-up (one of them suddenly). Therefore, complete angiographic follow-up 5.0 ± 1.4 months after recanalization was available in 58 patients.

Seven patients with intraventricular conduction defects precluding the analysis of the 12-lead ECG for Q waves had to be excluded. The two patients with recanalization of the left circumflex artery were also excluded because of the known variability in ECG changes in posterior infarctions. Furthermore, patients with reocclusion of the recanalized vessel at follow-up were excluded, which left 43 patients for subsequent analysis. The study had been approved by the institutional ethics committee and all patients gave informed consent.

Analysis of the Resting Electrocardiogram

Standard 12-lead resting ECG (50 mm/s paper speed) obtained prior to recanalization was independently assessed by three physicians blinded to angiographic data. Q waves and amplitude measurements were assessed from simultaneously acquired leads with standard equipment. Leads III and aVF were analyzed in the case of occlusions of the right coronary artery (RCA). Presence of Q waves ≥ 30 ms in both leads were considered as Q-wave area in an RCA occlusion.[15] Similarly, any Q wave in lead V_3 and V_4 or R waves ≤ 0.2 mV in these leads were considered as Q-wave area in left anterior descending (LAD) occlusion, if these criteria were fulfilled in both leads (V_3 and V_4).[12] Q waves as defined above had to be present in at least five contiguous QRS complexes. Interobserver agreement between three investigators regarding the classification of Q waves was 98, 98, and 96%, respectively (Cohen's kappa 0.92–0.96). In addition, parameters of QT dispersion were calculated in patients with sinus rhythm;[9] at least eight single leads could be evaluated for QT intervals in each 12-lead ECG. QT intervals were assessed without (QT) and with (QTc) adjustment for RR intervals using Bazett's formula ($QTc = QT/RR^{1/2}$). QT dispersion was defined as the difference between maximum and minimum QT interval, and QTc dispersion was calculated accordingly. The QRS and T-wave vector was analyzed in leads III and aVF for RCA occlusions and in leads V_3 and V_4 for LAD occlusions to describe a concordant or discordant pattern. Discordance was defined as a positive QRS vector with inverted T waves or a negative QRS vector with positive T waves in both contiguous leads.

Angioplasty Procedure

A standard femoral approach with #6F and #7F guiding catheters, as previously described, was chosen.[16] Stents were used in all patients; in 48% of lesions multiple stents were implanted. Additional PCI in a stenotic but not occluded vessel was performed up to 6 months before or after recanalization in 11 patients.

Quantitative Angiography

Biplane LV angiograms were obtained in all patients before recanalization and repeated at follow-up. Left ventricular function was analyzed with standard software (LVA 4.0, Pie Medical Imaging, Maastricht, The Netherlands) from digitized angiograms by a single observer who was blinded to ECG and clinical findings. In the territory of the recanalized artery, the regional WMSI (SD/chord)[17] was determined. The measurement of WMSI as SDs from normal provides a measure of significance of abnormal wall motion.[17] Recovery of regional wall motion was defined as an improvement of WMSI by ≥ 1 SD/chord.[18, 19] Clinically relevant restenosis at follow-up was characterized by a ≥ 70% diameter stenosis, reocclusion as absence of antegrade flow in the target vessel.

Statistical Analysis

Values are expressed as mean ± SD, unless otherwise indicated. All tests of statistical significance were two-sided; a value of $p < 0.05$ was considered statistically significant.

The relation of various clinical and ECG parameters to the recovery of regional wall motion was determined by a multivariate logistic regression model after forced entry of all variables. Recovery of regional wall motion was defined as a discrete variable (no change–improvement). Continuous covariates were categorized (QRS duration–steps of 5 ms, LV ejection fraction [LVEF]–steps of 5%, WMSI–steps of 0.5 SD/chord); other covariates were dichotomous. The multivariate analysis was also repeated without categorizing covariates. Odds ratios with 95% confidence intervals were calculated as an estimate of improvement of regional wall motion.

All statistical calculations were done with SPSS® 11.5.1 (SPSS Inc., Chicago, Ill., USA).

Results

Follow-Up Angiography

Complete angiographic follow-up was performed 5.0 ± 1.4 months after recanalization in 58 patients. Reocclusion of the recanalized vessel was documented in eight patients (14%); only one of these patients showed improvement in regional wall motion. Restenosis within the stented area was seen in 24 patients (41%) at follow-up.

Resting Electrocardiogram and Recovery of Regional Wall Motion

Baseline characteristics of the 43 patients without reocclusion at follow-up are shown in Table I. Recovery of regional wall motion (≥ 1 SD/chord) occurred in 19 (44%) of these patients.

Using the baseline ECG to predict recovery of regional wall motion (Table II), the absence of Q waves in the recanalized region was significantly associated with recovery, whereas the presence of Q waves indicated lack of recovery of regional wall motion after recanalization. Absence of Q waves was associated with an improvement in WMSI from −2.92 ± 0.28 at baseline to −1.34 ± 0.61 at follow-up ($p < 0.001$), whereas in Q wave areas no change in WMSI was detected, that is, −3.01 ± 0.30 and −2.81 ± 0.32 ($p = 0.11$) (Fig. 1).

Absence of Q waves in the baseline ECG predicted recovery of regional wall motion with an 89% sensitivity and a 67% specificity. Positive predictive value for recovery was 68% in patients without Q waves, but only 11% in patients with Q waves.

A concordant QRS-T-wave pattern in patients without Q waves had an 83% specificity accompanied with a lower sen-

TABLE I Baseline characteristics of the different groups

	Regional left ventricular function following revascularization		
	Improvement n = 19	No improvement n = 24	p Value
Age (years)	61.4 ± 9.6	62.3 ± 12.3	0.79
Male sex (%)	13 (68)	18 (75)	0.63
CCS angina class			0.26
I/II (%)	7 (37)	13 (54)	
III/IV (%)	12 (63)	11 (46)	
NYHA functional class			0.06
I/II (%)	18 (95)	17 (71)	
III/IV (%)	1 (5)	7 (29)	
Diabetes mellitus (%)	7 (37)	7 (29)	0.59
Duration of CTO ≥ 3 months (%)	7 (37)	8 (33)	0.81
RCA occlusion (%)	14 (74)	12 (50)	0.12
Single-vessel disease (%)	6 (32)	11 (46)	0.34
Left ventricular ejection fraction (%)	54 ± 14	45 ± 17	0.08
Wall motion severity index (SD/chord)	−2.83 ± 0.42	−3.06 ± 0.78	0.24

Data presented are mean value ± SD or number (%) of patients.
Abbreviations: CCS = Canadian Cardiovascular Society classification of chest pain, NYHA = New York Heart Association classification of heart failure, CTO = chronic total coronary occlusion, RCA = right coronary artery, SD/chord = standard deviation/chord.

TABLE II Baseline ECG of the different groups

	Regional left ventricular function following revascularization		
	Improvement n = 19	No Improvement n = 24	p Value
Sinus rhythm (%)	18 (95)	24 (100)	0.44
QRS duration (ms)	89.2 ± 12.3	96.2 ± 11.7	0.06
QT dispersion (ms)	85.3 ± 41.8	83.3 ± 43.1	0.88
QTc dispersion (ms)	91.1 ± 48.5	91.9 ± 48.8	0.96
T-wave inversion (%)	10 (59)	16 (67)	0.61
Absence of a Q-wave pattern (%)	17 (89)	8 (33)	< 0.001
Concordant QRS—T pattern (%)	13 (68)	14 (58)	0.50
Absence of Q waves and concordant QRS—T pattern (%)	11 (58)	4 (20)	0.005

Data presented are mean value ± SD or number (%) of patients.
Abbreviations: QTc = corrected QT interval, SD = standard deviation.

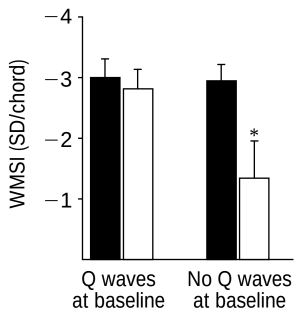

FIG. 1 Comparison between wall motion severity index (WMSI) at baseline (black bars) and at follow-up (white bars) in the groups with or without Q waves in the baseline ECG. *p < 0.001 compared with baseline. SD/chord = standard deviation/chord.

sitivity (58%) for prediction of recovery and was a significant univariate predictor for recovery (Table II).

In a multivariate logistic regression model, including all univariate predictors and relevant clinical and ECG parameters, only absence of Q waves in the region of the recanalized artery predicted functional recovery of wall motion (Fig. 2).

Parameters of QT dispersion, ST- or T-wave changes were not associated with recovery.

Recovery of Global Left Ventricular Ejection Fraction

Successful recanalization with an open artery at follow-up was associated with an improvement in global LV function. In the group with improvement in regional wall motion, the LVEF increased from 54 ± 14 to 75 ± 7% (p < 0.001), whereas the increase was much lower in the group without improvement in regional wall motion, that is, 45 ± 17 to 51 ± 17% (p = 0.001) (Fig. 3). Medical therapy for LV dysfunction (angiotensin-converting enzyme inhibitor, beta blocker) was similar in the different groups.

Discussion

We investigated patients with and without Q waves in the resting ECG and successfully recanalized CTOs. The recovery of regional wall motion after recanalization was predicted by the presence and extent of Q waves. The absence of Q waves in the recanalized area predicted recovery of impaired regional LV function with an 89% sensitivity and a 67% specificity. Presence of Q waves was highly specific (89%) for lack of recovery in our study. However, based on findings in nuclear imaging studies (in particular positron emission tomography imaging and dobutamine stress echocardiography), myocardial viability was observed in ~ 60% of Q-wave areas.[4, 20, 21] However, only 50–80% of viable myocardium detected by different imaging techniques do in fact recover after revascularization.[8]

The discrepancy of our results with the aforementioned studies could be explained as follows: First, those studies

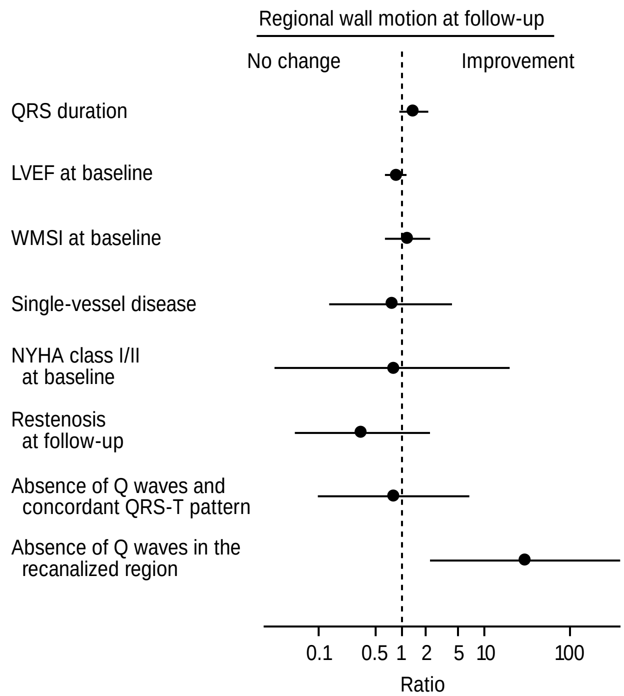

FIG. 2 Predictors for improvement in regional wall motion in a multivariate analysis. Ratios for predicting improvement are presented as mean ± 95% confidence interval. LVEF = left ventricular ejection fraction, NYHA = New York Heart Association. Other abbreviations as in Figure 1.

proved viability and recovery of ventricular function in patients with diseased, but not chronically occluded coronary arteries. Only one study investigated functional recovery of hibernating myocardium in patients with CTO, but without Q-wave MI.[3] Second, the amount of viability in Q-wave areas is less than in non-Q-wave areas.[5, 21] Third, the ultrastructural changes in viable, but hibernating myocardium are different with lack of recovery after revascularization in advanced stages.[22, 23] In patients suffering from CTO, the structural changes in the myo-

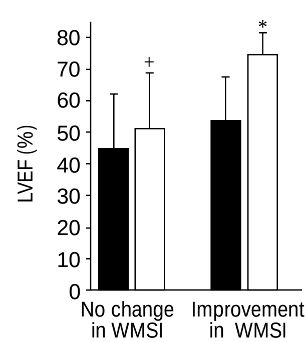

FIG. 3 Changes in global left ventricular ejection fraction (LVEF) from baseline (black bars) to follow-up (white bars) depending on changes in regional wall motion. +p = 0.001 compared with baseline; *p < 0.001 compared with baseline. Abbreviations as in Figure 1.

cardium are suggested to be very profound in the case of Q waves, resulting in lack of recovery after recanalization. Therefore, Q waves in the area of a CTO are not comparable to Q-wave areas in open arteries regarding recovery of function. Our results in patients with mildly depressed global LV function are also not applicable to patients with ischemic cardiomyopathy and severely depressed LVEF.[24]

Reocclusion of the recanalized artery impedes LV recovery, as previously described.[13] Therefore, patients with a reoccluded artery at follow-up were excluded from final ECG analysis. However, nonocclusive restenosis in the stented area had no adverse effect on the recovery of LV function.[25]

Conclusion

In patients with recanalization of CTO, recovery of regional wall motion is reliably predicted by analysis of the resting 12-lead ECG for pathologic Q waves. In this specific clinical setting, the readily available and inexpensive ECG is comparable with costly and time-consuming imaging techniques.

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