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Electrocardiographic Q-Wave "Remodeling" in Reperfused ST-Segment Elevation Myocardial Infarction

Validation Study With CMR

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OBJECTIVES The aim of this study was to evaluate the evolution in Q-wave expression during the first 5 years after a primary, successfully reperfused ST-segment elevation myocardial infarction (MI), using cardiac magnetic resonance (CMR) for infarct location, and to depict changes in infarct size and left ventricular remodeling over time.

BACKGROUND In the absence of QRS confounders, abnormal Q waves are usually diagnostic of myocardial necrosis. It is hypothesized that Q-wave regression after MI could be related to smaller infarct sizes. Late gadolinium enhancement accurately depicts MI of any age.

METHODS Forty-six MI patients underwent electrocardiography and CMR at 1 week (baseline), 4 months, 1 year, and 5 years post-infarction. Conventional CMR parameters were analyzed, and infarct presence, location, and size were assessed using late gadolinium enhancement CMR. Infarct locations were anterior or nonanterior (inferior and/or lateral), using late gadolinium enhancement CMR as a reference. For each time point, patients were classified as having a diagnostic/nondiagnostic electrocardiogram (ECG) using the European Society of Cardiology/American College of Cardiology Foundation/American Heart Association/World Heart Federation consensus criteria for previous Q-wave infarct.

RESULTS At baseline, 11 patients (23%) did not meet the criteria for Q-wave MI. Non–Q-wave infarcts were significantly smaller than Q-wave infarcts ($p < 0.0001$). All anterior Q-wave infarcts ($n = 17$) were correctly localized, whereas in 7 of 19 nonanterior Q-wave infarcts, the location or extent of the infarct was misjudged by electrocardiography. At 4-month/1-year follow-up, in 10 patients (3 anterior/7 nonanterior), the ECG became nondiagnostic. The ECG remained nondiagnostic at 5-year follow-up. A cutoff infarct size of 6.2% at 1 year yielded a sensitivity of 89% and a specificity of 74% to predict the presence or absence of Q waves.

CONCLUSIONS The incidence of nondiagnostic ECGs for previous MI using the current European Society of Cardiology/American College of Cardiology Foundation/American Heart Association/World Heart Federation criteria is substantial and increases with time post-infarction from 23% immediately post-infarction to 44% at 5-year follow-up. (J Am Coll Cardiol Img 2012;5:1003–13) © 2012 by the American College of Cardiology Foundation

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In the absence of QRS confounders, abnormal Q waves on the surface electrocardiogram (ECG) are usually diagnostic of myocardial necrosis. They develop in the first hours after the onset of an ST-segment elevation myocardial infarction (STEMI) and persist for a variable amount of time, often indefinitely (1). Based on the depth and width and ratio to an R-wave, several validated criteria for abnormal Q waves are available: European Society of Cardiology/American College of Cardiology Foundation/American Heart Association/World Heart Federation (ESC/ACCF/AHA/WHF) consensus criteria, Minnesota code, Novacode, and WHO MONICA (2). Regression of Q waves after myocardial infarction (MI) is related to lower left ventricular (LV) end-diastolic pressures, higher ejection fraction, and reduced risk of LV aneurysm formation and congestive heart failure, suggesting that Q-wave loss may be related to smaller infarct sizes. Nowadays, in the "era of reperfusion therapy" and primary percutaneous coronary interventions (PCIs), the disappearance of Q waves occurs even more frequently (3).

ABBREVIATIONS AND ACRONYMS

AAR = area at risk

CMR = cardiac magnetic resonance

ECG = electrocardiogram

ESC/ACCF/AHA/WHF = European Society of Cardiology/American College of Cardiology Foundation/American Heart Association/World Heart Federation

LGE = late gadolinium enhancement

LV = left ventricular

MI = myocardial infarction

PCI = percutaneous coronary intervention

Late gadolinium enhancement (LGE) cardiac magnetic resonance (CMR) is a well-validated tool for accurate and reproducible visualization of irreversible myocardial damage in the acute and chronic settings of MI (4). Several studies have shown that the presence of diagnostic Q waves is primarily determined by MI size rather than its transmural extent (5–9). The larger the endocardial extent of MI is, more likely it is that the ECG will be diagnostic for Q-wave MI (10). Moreover, ECG-derived estimates available for infarct size estimation correlate only modestly with those of LGE CMR (11).

The objective of the present study was to assess the electrocardiographic changes in Q-wave expression in the first 5-year period after a first reperfused STEMI and to relate electrocardiographic findings to parameters gauging infarct extent and LV remodeling as assessed by CMR.

METHODS

Study population. From a double-blind, randomized, controlled study that investigated the effect of autologous bone marrow–derived stem cell transfer on LV remodeling after STEMI treated by primary PCI (within 12 h from symptom onset), we retrospectively identified 48 patients who met the following criteria: 1) first MI; 2) no confounders for Q-wave analysis on the ECG (left or right bundle branch block, LV hypertrophy with strain or paced rhythms); and 3) both ECG tracings and CMR studies available in the first week (baseline) and at 4 months, 1 year, and 5 years after the acute event (12). Two patients were excluded: 1 who had experienced in-stent thrombosis 11 months after MI and 1 who had an MI in a different coronary territory during follow-up. The local ethics review board approved the protocol, and written informed consent was obtained from each patient.

CMR data acquisition. CMR studies were performed on a 1.5-T unit (Intera-CV, Philips, Best, the Netherlands) using commercially available cardiac software, electrocardiographic triggering, and cardiac-dedicated surface coils. CMR included cine imaging, T2-weighted imaging, and LGE-CMR, as previously described in detail (12).

CMR data analysis. CMR studies were analyzed blinded to the clinical and electrocardiographic data. Functional parameters included LV volumes at end-diastole and end-systole, ejection fraction, and myocardial mass. The area at risk (AAR) was determined by T2-weighted imaging. LGE-CMR was used to quantify microvascular obstruction and infarct mass and its relative extent (normalized LV mass). The salvage index was calculated as the difference between AAR and baseline infarct size normalized to AAR. A 5-grade score (0 = no LGE; 1 = 0 to 25%; 2 = 26% to 50%; 3 = 51% to 75%; and 4 = 76% to 100% LGE) was used to express infarct transmurality using the 17-segment model as recommended by the American Heart Association. Per patient, a transmurality score was obtained by adding the segmental grades (13). A transmural infarct was defined as a transmural score of 4 in at least 1 segment.

Electrocardiograms. Standard 12-lead ECGs obtained at the time of CMR were recorded at a speed of 25 mm/s and a voltage of 10 mm/mV. Studies were randomly analyzed by 2 cardiologists blinded to clinical and CMR data. Any disagreement was resolved by a consensus reading. The ESC/ACCF/AHA/WHF criteria for previous MI were used to assess patterns of necrosis on the ECG as follows: 1) Q waves were considered pathological (Q) if $\geq$0.02 s (or QS complex) in leads V_2,V_3, and $\geq$0.03 s and 0.1 mV deep (or QS complex) in leads I, aVL, V_6, V_4 to V_6, II, III, aVF; and 2) R waves were considered pathological if $\geq$0.04 s and R/S $\geq$1 in leads V_1 and/or V_2 with a concordant positive

Table 1. Demographic, Clinical, and Infarct-Related Characteristics

	All (n = 46)	Anterior (n = 23)	Nonanterior (n = 23)	p Value*
Age, yrs	54 ± 9	52 ± 9	56 ± 10	0.20
Men	41 (89)	20 (87)	21 (91)	1.00
Cardiovascular risk factors				
Hypertension	17 (37)	6 (26)	11 (48)	0.20
Diabetes mellitus	5 (11)	3 (13)	2 (9)	1.00
Current smoker	28 (61)	14 (61)	14 (61)	1.00
High cholesterol	30 (65)	15 (65)	15 (65)	1.00
Obesity	6 (13)	2 (9)	4 (17)	0.70
Time to PCI, h	4.4 ± 2.5	4.0 ± 1.9	4.7 ± 2.9	0.40
TIMI flow-grade pre-PCI				0.40
0/1	32 (70)	14 (61)	18 (78)	
2/3	14 (30)	9 (39)	5 (22)	
TIMI flow-grade post-PCI				
0/1	1 (2)	1 (4)	0	
2/3	44 (98)	22 (96)	23 (100)	
Infarct-related artery				
LAD	27 (59)	23 (100)	4 (17)	
RCA	17 (37)		17 (74)	
CX	2 (4)		2 (9)	
Max troponin I, ng/ml	78 ± 72	95 ± 89	60 ± 43	0.10
Max CK-MB, U/l	177 ± 109	200 ± 137	156 ± 72	0.19

Values are mean ± SD or n (%). *Anterior versus nonanterior.
CK-MB = creatine kinase myocardial band; CX = circumflex artery; LAD = left anterior descending coronary artery; LCX = left circumflex coronary artery; Max = maximum; PCI = percutaneous coronary intervention; RCA = right coronary artery; TIMI = thrombolysis in myocardial infarction.

T-wave in the absence of right-axis deviation ≥100° (1,2,5). In the anterior precordial leads, an R-wave was considered the initial positive deflection of >0.1-mV amplitude. The presence, location, and number of Q waves were noted for each tracing. To better characterize the relationship between the number of pathological Q waves and infarct size on CMR, isolated Q waves in any of the above-mentioned lead groupings were counted in the total number of Q waves of a patient.

Localization of MI. Infarct location was attributed to the LV walls, as determined by LGE-CMR, and not to a specific coronary artery territory. Thus, anterior MI was defined if LGE was present in at least 1 of the following segments: basal anteroseptal, midanterior, midanteroseptal, or apical anterior (i.e., anterior MI group). Inferior MI was defined if LGE involved at least 1 of the basal and midventricular inferior segments, whereas lateral MI was considered if there was LGE in at least 1 of the lateral segments (14). Inferior and lateral MIs were considered as the nonanterior MI group. On an ECG, anterior MI was defined if Q waves were present in V_1 to V_6 leads, inferior MI if Q waves were present in any 2 inferior leads (II, III, aVF), and lateral MI if Q waves were present in any 2 of the leads I, aVL, or V_6, or if pathological R waves were present in leads V_1 to V_2. Pathological R waves in leads V_1 and/or V_2 were considered lateral Q-wave equivalents. The presence of a Q wave in aVL ± I and in V_2 to V_3 but not in V_6 was considered anterior MI (15).

Statistical analysis. Continuous variables were expressed as mean ± SD. Skewed variables were expressed as median and interquartile range. Categorical variables were expressed as frequency with percentage. Student *t* test was used to compare baseline patient characteristics expressed as continuous variables. Repeated-measures analysis of variance with a post hoc Bonferroni test was used to assess timely changes in CMR parameters in and between patients groups. Nonparametric tests were used for not normally distributed variables (i.e., Mann-Whitney *U* test and Friedman test for repeated measurements). For the time changes in relative infarct size in anterior/nonanterior groups, where sphericity was violated (Mauchly test), analysis of variance with repeated measures with a Greenhouse-Geisser correction was used. The chi-square test was used to compare noncontinuous variables, expressed as proportions. Pearson correlation (r) was used to assess the relationship between infarct extent on CMR and the number of Q waves. Receiver-operating characteristic curve anal-

ysis was used to determine the best cutoff value of infarct size to predict the presence of a diagnostic ECG. The cutoff was identified as the point on receiver-operating characteristic curve closest to the upper left corner. Statistical analysis was performed using SPSS software for Windows (version 18, SPSS Inc., Chicago, Illinois). A p value <0.05 was considered statistically significant.

RESULTS

Baseline findings. Baseline CMR studies and ECG tracings were obtained at day 4 (range 3 to 5 days) and at day 7 (range 5 to 9 days) post-PCI, respectively. Patients were equally distributed between anterior and nonanterior MIs (Table 1). In 36 of 46 patients (78%), Q waves were present (Fig. 1). Patients with a nondiagnostic ECG (i.e., 6 anterior, 4 nonanterior) had a significantly smaller AAR and infarct size and smaller LV volumes and mass than patients with Q waves (Table 2). Q waves developed in none of these patients on their ECG at follow-up. In patients with a diagnostic ECG, the infarct was anterior (n = 17), inferior (n = 14), lateral (n = 1), and mixed inferior/lateral (n = 4) on LGE-CMR. Although the ECG correctly located all anterior MIs, in 4 of 14 inferior MIs, Q waves were also present in the lateral leads. The patient with the lateral MI had an ECG diagnostic of inferior MI. Finally, an ECG/LGE-CMR match was found in 2 of 4 patients with a mixed inferior/lateral MI (Fig. 2).

Table 2. Baseline Parameters Characterizing Infarct Size in Patients With Diagnostic and Nondiagnostic ECGs at Baseline

ECG	Nondiagnostic (n = 10)	Diagnostic (n = 36)	p Value*
LVEDV, ml	144 ± 35	165 ± 26	0.04
LVESV, ml	69 ± 19	87 ± 20	0.012
LV mass, g	101 ± 19	124 ± 30	0.02
EF, %	52 ± 5	47 ± 8	0.08
Absolute MI size, g	8.6 ± 7.0	22.5 ± 15.9	<0.0001
Relative MI size, % of LV mass	9.2 ± 6.3	17.9 ± 11.7	0.03
Transmurality score	10.4 ± 6.2	17.7 ± 8.3	0.009
AAR, g	25.8 ± 11.9	40.1 ± 21.0	0.015
Salvage index	0.6 ± 0.1	0.4 ± 0.5	0.16
MVO	4 (36.4)	24 (67.0)	0.09
Max troponin I, ng/ml	44 ± 47	86 ± 75	0.09
Max CK-MB, U/l	127 ± 58	234 ± 148	0.03

Values are mean ± SD or n (%). *Nondiagnostic versus diagnostic.
AAR = area at risk; ECGs = electrocardiograms; EF = ejection fraction; LV = left ventricular; LVEDV = left ventricular end-diastolic volume; LVESV = left ventricular end-systolic volume; MVO = microvascular obstruction; other abbreviations as in Table 1.

Anterior infarcts exhibited a significantly larger infarct size than nonanterior infarcts (Table 3). A transmural MI was present in 15 and 17 of anterior and nonanterior infarcts, respectively. The median number of Q waves was 3 (range 0 to 7) and 3 (range 0 to 5) for anterior and nonanterior infarcts, respectively (p = 0.5). No correlation was found between number of Q waves and infarct size.

Follow-up findings. The same distribution of LGE as at baseline, except in 2 patients with a inferior/lateral MI in whom LGE was limited to the inferior

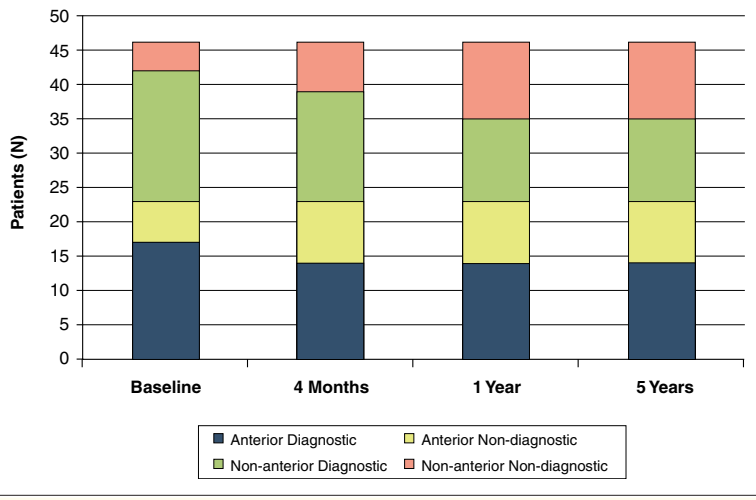

Figure 1. Evolution in the Number of Diagnostic Versus Nondiagnostic ECGs Over Time

At baseline, nondiagnostic electrocardiograms (ECGs) are present in both the anterior and nonanterior infarct groups. The number of patients with nondiagnostic ECGs increases at 1 year post-infarction but then remains stable until 5-year follow-up.

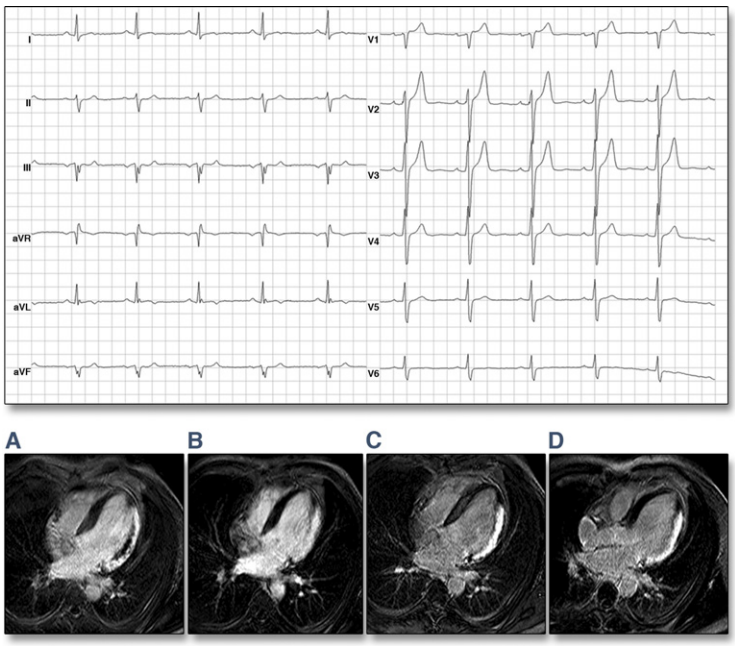

Figure 2. ECG Versus LGE-CMR in Extensive Lateral MI

Extensive lateral myocardial infarction (MI) caused by proximal dominant circumflex occlusion. Successful percutaneous coronary intervention at 6.5 h after onset. Electrocardiogram (ECG) tracing 1 year post-infarction shows pathological Q waves in 2 inferior leads, III and aVF (similar appearance at 4 months and 5 years). Horizontal long-axis LGE images at baseline **(A)**, 4 months **(B)**, 1 year **(C)**, and 5 years **(D)** show extensive, transmural hyperenhancement in the lateral wall. Presence of an extensive microvascular obstruction at baseline **(A)**. LGE-CMR = late gadolinium enhancement cardiac magnetic resonance.

wall at 1 year. Both patients showed subendocardial LGE at baseline, and the lateral wall was only partially involved. Infarct size significantly decreased at follow-up (i.e., from 20 ± 12 g at baseline to 12 ± 9 g, 10 ± 8 g, and 9 ± 7 g at 4 months, 1 year, and 5 years, respectively [$p = 0.001$ for trend]). Anterior infarcts remained significantly larger than nonanterior infarcts (Table 3). Transmural MI was found at 5 years in 14 of 15 anterior and 12 of 17 nonanterior infarcts with a baseline transmural MI.

Ten patients (21%) developed nondiagnostic ECG, 6 patients at 4 months (3 anterior, 3 nonanterior), and 4 patients at 1 year (all nonanterior) (Figs. 1, 3, and 4). Three patients with an inferior/lateral infarct on the baseline ECG demonstrated an inferior infarct on the 1-year ECG. In 2 of them, baseline CMR showed a pure inferior infarct. Two inferior infarcts on the baseline CMR/ECG appeared on the 1-year ECG as an inferior/lateral infarct and lateral infarct, respectively. The number of Q waves did not differ significantly over time. In anterior infarcts, a moderate correlation was found between relative infarct size and number of Q waves (i.e., $r = 0.56$ [$p = 0.006$] at 4 months; $r = 0.58$ [$p = 0.005$] at 1 year, and $r = 0.56$ [$p = 0.019$] at 5 years).

CMR versus ECG for previous MI detection. The frequency of patients with nondiagnostic ECGs increased from 22% at baseline to 43% at 5 years. By receiver-operating characteristic curve analysis, relative infarct size predicted a diagnostic ECG with an area under the curve of 0.76 (95% confidence interval: 0.61 to 0.91) at baseline, which increased to 0.84 (95% confidence interval: 0.71 to 0.96) at 5 years. A cutoff value with 6.2% of relative infarct size at 1 year yielded the highest sensitivity (89%) and specificity (74%), with an area under the curve of 0.85 (95% confidence interval, 0.75 to 0.97) (Fig. 5). In nonanterior infarct patients having a nondiagnostic ECG over time, the baseline relative infarct size was significantly smaller than in patients with a diagnostic ECG (Fig. 6). The degree of infarct shrinkage was similar among groups. Although patients with a nondiagnostic ECG at 5 years had higher ejection fractions and lower end-systolic volumes, no statistical significance was reached, except for end-systolic volume at 4 months (Fig. 7).

Table 3. CMR Parameters in Anterior and Nonanterior MI Patients at Baseline and Follow-Up

	Baseline	4 Months	1 Year	5 Years	p Value*
LVEDV, ml					
Anterior	163 ± 26	168 ± 43	192 ± 44	176 ± 50	0.08
Nonanterior	159 ± 29	165 ± 40	177 ± 42	170 ± 38	0.40
LVESV, ml					
Anterior	87 ± 22	85 ± 33	100 ± 34	93 ± 43	0.40
Nonanterior	79 ± 19	78 ± 32	85 ± 34	82 ± 32	0.90
EF, %					
Anterior	47 ± 8	50 ± 9	49 ± 7	49 ± 9	0.50
Nonanterior	50 ± 7	54 ± 11	53 ± 10	53 ± 10	0.50
LV mass, g					
Anterior	123 ± 30	107 ± 20	113 ± 19	105 ± 22	0.10
Nonanterior	114 ± 27	109 ± 26	107 ± 22	107 ± 20	0.70
MVO					
Anterior	14 (61)				
Nonanterior	14 (61)				
Absolute MI size, g					
Anterior	25 ± 15	15 ± 10	13 ± 8†	12 ± 8†	0.007
Nonanterior	14 ± 14‡	8 ± 8‡	8 ± 7‡	7 ± 6‡	0.10
Relative MI size, % of LV mass					
Anterior	20 ± 12	14 ± 10	12 ± 7†	12 ± 7†	0.01
Nonanterior	12 ± 9‡	8 ± 6‡	7 ± 6‡	6 ± 5†‡	0.02
Transmurality score					
Anterior	19.3 ± 8.6	17.3 ± 9.9	16.9 ± 8.0	19.5 ± 10.2	0.70
Nonanterior	13.4 ± 6.5‡	11.8 ± 6.4‡	10.3 ± 7.0‡	13.3 ± 7.9	0.40
Transmural segments, n					
Anterior	3 (0–9)	3 (0–9)	2 (0–7)	2 (0–7)	0.20
Nonanterior	2 (0–6)	2 (0–5)	1 (0–6)†	2 (0–7)	0.02
Transmural MI, %					
Anterior	15 (65)	15 (65)	14 (62)	14 (62)	0.99
Nonanterior	17 (74)	15 (64)	14 (61)	12 (53)	0.55

Values are mean ± SD, n (%), or n (range). *Repeated-measures analysis of variance. †$p < 0.05$ versus baseline. ‡$p < 0.05$ versus anterior.
CMR = cardiac magnetic resonance; other abbreviations as in Table 2.

DISCUSSION

Although the 12-lead surface ECG is the frontline tool in the diagnosis of acute and healed MI (2), the present study shows that the current ESC/ACCF/AHA/WHF ECG consensus criteria for previous MI frequently fail to depict MI in patients with a first-time STEMI treated by primary PCI. Moreover, the number of nondiagnostic ECGs increases over time after the acute event. In particular, small infarcts and infarcts in nonanterior locations at baseline are those more commonly associated with nondiagnostic ECGs at mid- and long-term follow-up.

In the absence of QRS confounders, abnormal Q waves are usually diagnostic of myocardial necrosis. Using LGE-CMR as in vivo validation technique, the presence or absence of Q waves on the ECG is primarily determined by total infarct size (i.e., endocardial infarct extent and not by transmural extent) (5–10,16,17). Moreover, ECG-derived estimates of infarct size correlate only modestly with those with LGE-CMR, especially in lateral infarcts, which are often electrically silent (11,18,19).

The novelty of our approach is that patients with MI were studied at 4 time points post-infarction, providing insight into short-, intermediate-, and long-term infarct and ventricular remodeling. Although all patients had a well-documented acute STEMI, only 36 of 46 of the analyzable patients (78%) had a diagnostic ECG early post-infarction. Similar findings were reported by Engblom et al. (10), using the Minnesota ECG criteria for MI detection, with nondiagnostic ECGs in 11 of 29 patients 1 week after primary PCI. In particular, there is a risk that smaller infarcts remain undiagnosed, most likely because they generate insufficiently large Q waves to be transmitted to the body

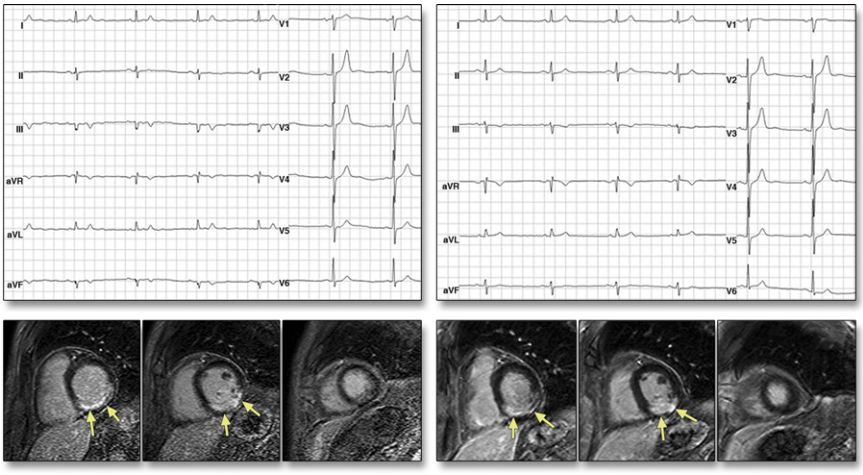

Figure 3. ECG Versus LGE-CMR in Inferior MI

Electrocardiogram (ECG) tracings recorded at 4 months **(left)** and 1 year **(right)** in a patient with an inferior myocardial infarction (MI). Pathological Q waves in inferior leads III and aVF disappeared at 1 year. Short-axis late gadolinium enhancement cardiac magnetic resonance (LGE-CMR) at basal, midventricular, and apical levels at 4 months **(lower left)** and 1 year **(lower right)** show 75% transmural enhancement in basal/midinferior wall **(arrows)**. Infarct size decreased from 8% at 4 months to 6% at 1 year post-infarction.

surface. An ECG is excellent for locating anterior infarcts, but it not infrequently fails to accurately locate nonanterior infarcts. Lateral infarcts or inferior infarcts extending to the lateral wall are difficult to depict on an ECG (20). As suggested by Rovai et al. (18), several factors may contribute to a lower sensitivity of an ECG to detect infarcts in this part of the ventricle (21). Additionally, the number of Q waves (or Q-wave equivalents), as a measure of infarct severity, correlates poorly in the acute phase with LGE measures (such as infarct size and transmurality), whereas a moderate positive correlation is found at long-term phases for anterior infarcts. Ibrahim et al. (22) showed significant changes in LGE extent in the first week post-infarction, which may explain the lack of agreement between ECG and CMR findings early post-infarction.

Figure 4. ECG Versus LGE-CMR in Anterior MI

ECG tracings recorded at 1 week **(left)** and 4 months **(right)**. Presence of small (1-mm) R waves in anterior leads V_2 and V_3, making the 4-month ECG nondiagnostic for previous MI. Horizontal **(A and D)**, vertical **(B and E)** long-axis, and midventricular level short-axis **(C and F)** LGE-CMR at 1 week **(lower left)** and 4 months **(lower right)** show transmural enhancement in anterior wall, midseptum, and apical segments **(arrows)**. Infarct size decreased from 23% at 1 week to 14% at 4 months post-infarction. Abbreviations as in Figure 3.

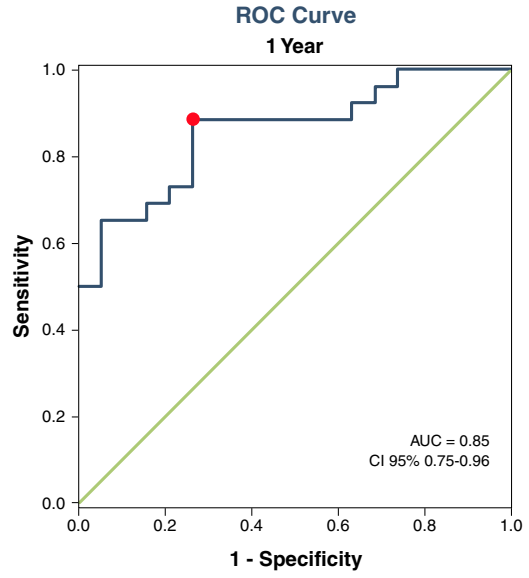

Figure 5. ROC Curve Analysis for the Association Between Relative Infarct Size and Presence/Absence of a Diagnostic ECG at 1 Year Post-MI

Receiver-operating characteristic (ROC) curve analysis shows an area under the curve (AUC) of 0.85 (95% confidence interval [CI], 0.75 to 0.96 and a 6.2% cutoff with optimal sensitivity and specificity **(red dot)** to predict a diagnostic ECG. Abbreviations as in Figure 3.

Remarkably, the number of patients with nondiagnostic ECGs for previous MI doubled at 5 years post-infarction. A new nondiagnostic ECG always occurred in the first year post-infarction. Taking into account the significant reduction in infarct size in the first months post-infarction (as measured by LGE-CMR), infarct size may drop below a critical threshold to yield a diagnostic ECG. In particular, most of the new nondiagnostic ECGs at follow-up occurred in the nonanterior group, and this is likely explained by the fact that nonanterior infarcts had smaller baseline infarct size than anterior infarcts; the diagnostic performance of ECG is also reduced when depicting infarcts in this region of the ventricle.

Our study results indicate that a cutoff (relative) infarct size of 6.2% (at 1 year) yields good sensitivity and moderate specificity to predict the presence/absence of Q waves. This cutoff is considerably lower than the cutoff value (i.e., 17%) previously reported by Kaandorp et al. (6), suggesting that an ECG is able to depict smaller infarcts. This discrepancy can be explained by a difference in treatment strategies because in the study of Kaandorp et al. (6), half of the patients were treated conservatively. Accordingly, the relative infarct size was larger in their study (11 ± 9% vs. 8 ± 7% at 4 months in our study).

Putting our findings in a clinical perspective, it is important to realize that normalization of the ECG post-infarction is frequent (23), even in patients with a well-documented acute STEMI, and confirms what was already suggested by Cox more than 4 decades ago (24). However, with the advent of LGE-CMR as an in vivo validation technique, it has become clear that it concerns a pseudo- and not

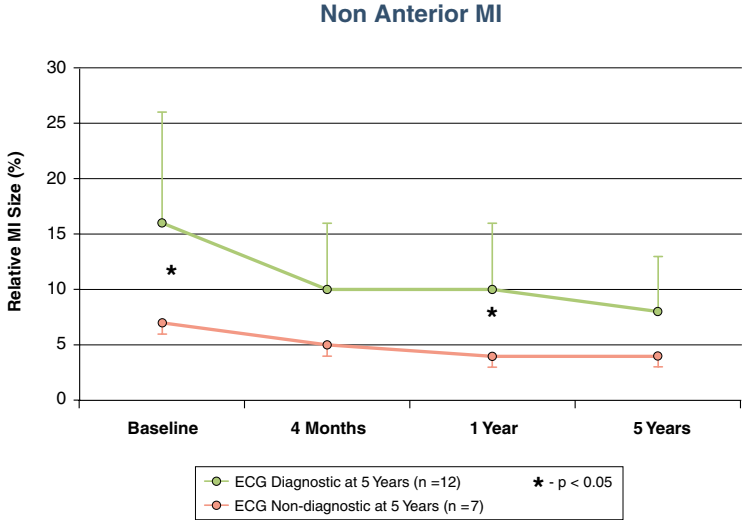

Figure 6. Evolution of Relative Infarct Size Over Time in Nonanterior MI Patients With Diagnostic Versus Nondiagnostic ECG

Significant decrease in relative infarct size of the nonanterior MIs over time. At baseline and at 1-year follow-up, MIs yielding nondiagnostic ECGs are significantly smaller than infarcts with diagnostic ECGs. Results shown as mean ± SD. Abbreviations as in Figure 3.

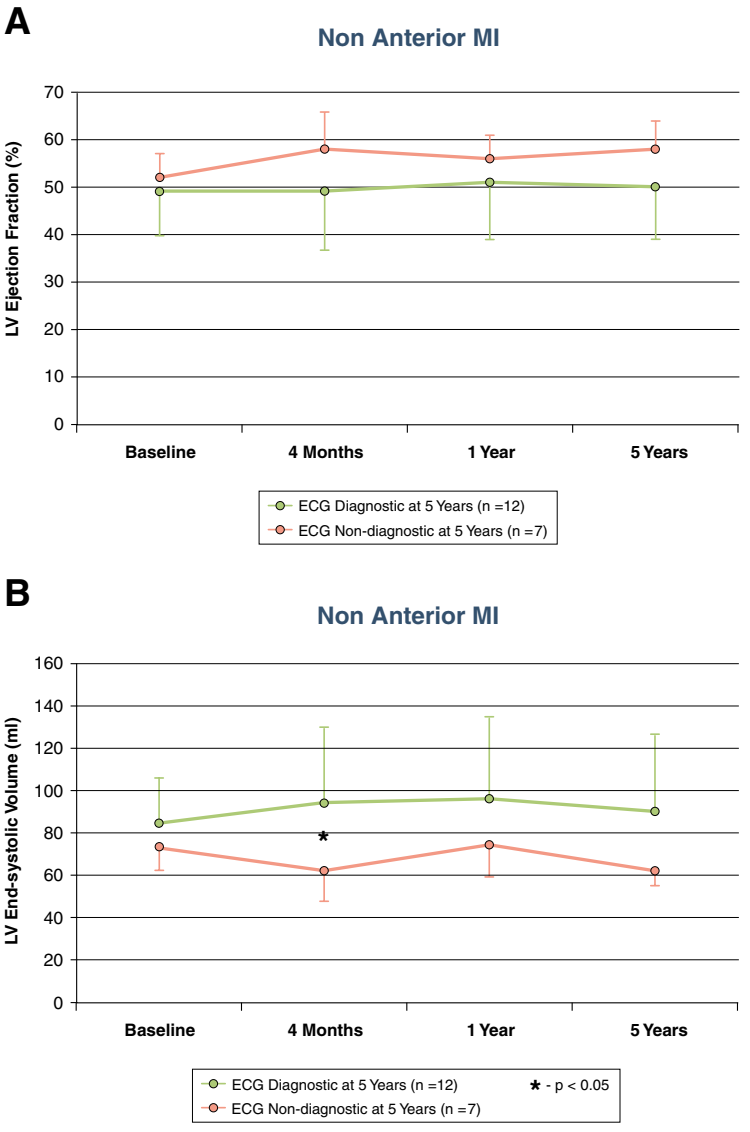

Figure 7. Evolution in Ejection Fraction and End-Diastolic Volume Over Time in Nonanterior Infarct Patients With Diagnostic Versus Nondiagnostic ECGs

(A) Although left ventricular (LV) ejection fractions in patients with nondiagnostic ECGs are higher than in patients with diagnostic ECGs, no statistical significance was reached. **(B)** LV end-systolic volume at 4-month follow-up in the nondiagnostic ECG group is significantly smaller than in patients with diagnostic ECGs. Results shown as mean ± SD.

a true normalization because irreversible myocardial damage continues to persist at late follow-up. Because these electrically silent infarcts have a prognosis similar to that of overt ones, use of more accurate techniques such as LGE-CMR may be indicated to depict myocardial damage in patients with suspected previous MI (25–27).

Study limitations. The small number of patients is an important limitation of the study. Nonetheless, the design is unique because all patients were investigated at 4 time points post-infarction using LGE-CMR, the current noninvasive reference of MI detection, thereby providing distinctive data regarding the MI evolution over a period of 5 years. Second, we considered only the criteria for previous MI, without taking into consideration the pre-PCI ECG tracings and other parameters as ST-segment shifts in the acute phase. Thus, no inferences can be made regarding the influence of ST-segment shifts post-PCI on the further Q-wave expression. Third, patients with ECG confounders such as

the presence of bundle branch blocks were excluded from the analysis. We can only assume that if these patients had been included, the accuracy of ECG in diagnosing and localizing MI would have been less. Last, a qualitative approach rather than a scoring system was used to evaluate the Q-wave changes over time post-infarction. We opted for this approach because it is better suited to daily clinical practice. Moreover, in the "era of reperfusion therapy," these time-consuming scoring systems, like the Sylvester score, have proved to be less accurate compared with CMR-LGE (11).

CONCLUSIONS

The electrocardiographic appearance of Q waves in patients with a previous MI is mainly determined by infarct size. The ESC/ACCF/AHA/WHF consensus criteria frequently fail to depict small size STEMIs in nonanterior locations. Post-infarction electrical Q-wave remodeling parallels infarct remodeling, resulting in nearly double the nondiagnostic ECGs at 5 years post-infarction.

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REFERENCES

1. Surawicz B, Knilans TK. Myocardial infarction and electrocardiographic patterns simulating myocardial infarction. In: Surawicz B, Knilans TK, editors. Chou's Electrocardiography in Clinical Practice. Philadelphia, PA: WB Saunders, 2008:162–204.
2. Thygesen K, Alpert JS, White HD, Joint ESC/ACCF/AHA/WHF Task Force for the Redefinition of Myocardial Infarction. Universal definition of myocardial infarction. J Am Coll Cardiol 2007;50:2173–95.
3. Voon WC, Chen YW, Hsu CC, Lai WT, Sheu SH. Q-wave regression after acute myocardial infarction assessed by Tl-201 myocardial perfusion SPECT. J Nucl Cardiol 2004;11:165–70.
4. Kim HW, Farzaneh-Far A, Kim RJ. Cardiovascular magnetic resonance in patients with myocardial infarction. Current and emerging applications. J Am Coll Cardiol 2010;55;1–16.
5. Moon JC, De Arenaza DP, Elkington AG, et al. The pathologic basis of Q-wave and non-Q-wave myocardial infarction: a cardiovascular magnetic resonance study. J Am Coll Cardiol 2004;44:554–60.
6. Kaandorp TA, Bax JJ, Lamb HJ, et al. Which parameters on magnetic resonance imaging determine Q waves on the electrocardiogram? Am J Cardiol 2005;95:925–9.
7. Engblom H, Hedström E, Heiberg E, Wagner GS, Pahlm O, Arheden H. Size and transmural extent of first-time reperfused myocardial infarction assessed by cardiac magnetic resonance can be estimated by 12-lead electrocardiogram. Am Heart J 2005; 150:920.
8. Bodí V, Sanchis J, Guillem MS, et al. Analysis of the extension of Q-waves after infarction with body surface map: relationship with infarct size. Int J Cardiol 2006;111:399–404.
9. Plein S, Younger JF, Sparrow P, Ridgway JP, Ball SG, Greenwood JP. Cardiovascular magnetic resonance of scar and ischemia burden early after acute ST elevation and non-ST elevation myocardial infarction. J Cardiovasc Magn Reson 2008;10:47.
10. Engblom H, Carlsson MB, Hedström E, et al. The endocardial extent of reperfused first-time myocardial infarction is more predictive of pathologic Q waves than is infarct transmurality: a magnetic resonance imaging study. Clin Physiol Funct Imaging 2007;27:101–8.
11. Geerse DA, Wu KC, Gorgels AP, Zimmet J, Wagner GS, Miller JM. Comparison between contrast-enhanced magnetic resonance imaging and Selvester QRS scoring system in estimating changes in infarct size between the acute and chronic phases of myocardial infarction. Ann Noninvasive Electrocardiol 2009;14:360–5.
12. Janssens S, Dubois C, Bogaert J, et al. Autologous bone marrow-derived stem cell transfer in patients with ST-segment elevation myocardial infarction, double-blind, randomised controlled trial. Lancet 2006;367:113–21.
13. Cerqueira MD, Weissman NJ, Dilsizian V, et al., American Heart Association Writing Group on Myocardial Segmentation and Registration for Cardiac Imaging. Standardized myocardial segmentation and nomenclature for tomographic imaging of the heart. A statement for healthcare professionals from the Cardiac Imaging Committee of the Council on Clinical Cardiology of the American Heart Association. Int J Cardiovasc Imaging 2002;18:539–42.
14. Ortiz-Pérez JT, Rodríguez J, Meyers SN, Lee DC, Davidson C, Wu E. Correspondence between the 17-segment model and coronary arterial anatomy using contrast-enhanced cardiac magnetic resonance imaging. J Am Coll Cardiol Img 2008;1:282–93.
15. Bayés de Luna A, Wagner G, Birnbaum Y, et al; International Society for Holter and Noninvasive Electrocardiography. A new terminology for left ventricular walls and location of myocardial infarcts that present Q waves based on the standard of cardiac magnetic resonance imaging: a statement for healthcare professionals from a committee appointed by the International Society for Holter and Noninvasive Electrocardiography. Circulation 2006;114:1755–60.
16. Wu E, Judd RM, Vargas JD, Klocke FJ, Bonow RO, Kim RJ. Visualisation of presence, location, and transmural extent of healed Q-wave and non-Q-wave myocardial infarction. Lancet 2001;357:21–8.
17. Sievers B, John B, Brandts B, Franken U, van Bracht M, Trappe HJ. How reliable is electrocardiography in differentiating transmural from nontransmural myocardial infarction? A study with contrast magnetic resonance imaging as gold standard. Int J Cardiol 2004;97:417–23.
18. Rovai D, Di Bella G, Rossi G, et al. Q-wave prediction of myocardial infarct location, size and transmural extent at magnetic resonance imaging. Coron Artery Dis 2007;18:381–9.
19. Smalling RW. Ischemic time: the new gold standard for ST-segment elevation myocardial infarction care. J Am Coll Cardiol 2009;54:2154–6.
20. Cino JM, Pujadas S, Carreras F, et al. Utility of contrast-enhanced cardiovascular magnetic resonance (CE-CMR) to assess how likely is an infarct to produce a typical ECG pattern. J Cardiovasc Magn Reson 2006;8:335–44.

21. Blanke H, Cohen M, Schlueter GU, Karsch KR, Rentrop KP. Relation between electrocardiography and coronary angiography findings in the infarct stage. Z Kardiol 1985;74:157–64.
22. Ibrahim T, Hackl T, Nekolla SG, et al. Acute myocardial infarction: serial cardiac MR imaging shows a decrease in delayed enhancement of the myocardium during the 1st week after reperfusion. Radiology 2010;254:88–97.
23. Kannel WB, Abbott RD. Incidence and prognosis of unrecognized myocardial infarction. An update on the Framingham study. N Engl J Med 1984;311:1144–7.
24. Cox CJ. Return to normal of the electrocardiogram after myocardial infarction. Lancet 1967;1:1194–7.
25. Barbier CE, Bjerner T, Johansson L, Lind L, Ahlström H. Myocardial scars more frequent than expected: magnetic resonance imaging detects potential risk group. J Am Coll Cardiol 2006;48:765–71.
26. Krittayaphong R, Maneesai A, Chaithiraphan V, Saiviroonporn P, Chaipet O, Udompunturak S. Comparison of diagnostic and prognostic value of different electrocardiographic criteria to delayed-enhancement magnetic resonance imaging for healed myocardial infarction. Am J Cardiol 2009; 103:464–70.
27. Kwong RY, Sattar H, Wu H, et al. Incidence and prognostic implication of unrecognized myocardial scar characterized by cardiac magnetic resonance in diabetic patients without clinical evidence of myocardial infarction. Circulation 2008;118: 1011–20.

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