Cardiovascular magnetic resonance of myocardial viability

Kaandorp, T.A.M.

Chapter 5

Which parameters on magnetic resonance imaging determine Q waves on the electrocardiogram?

5 Which parameters on magnetic resonance imaging determine Q waves on the electrocardiogram?

TA Kaandorp, JJ Bax, HJ Lamb, EP Viergever, E Boersma, D Poldermans, EE van der Wall, A de Roos
The American Journal of Cardiology 2005;95:925-9

Abstract

Studies have demonstrated that patients with Q wave infarctions on the electrocardiogram (ECG) frequently have non-transmural scar formation, whereas non-Q wave may have transmural scars. The precise pathophysiological substrate underlying the Q waves remains unclear. Magnetic resonance imaging (MRI) is the preferred technique to evaluate patients with myocardial infarction, since information can be obtained on function, contractile reserve (viability) and scar tissue. Consecutive patients (n=69) with coronary artery disease and history of myocardial infarction underwent MRI; the protocol included MRI at rest, low-dose dobutamine MRI and delayed contrast-enhanced MRI. Parameters included: left ventricular (LV) ejection fraction, LV volumes, end-diastolic wall thickness and contractile reserve in the infarct region, transmurality and spatial extent of scar tissue, total scar score and the quantified percentage of LV scar tissue. The MRI data were related to the presence or absence of Q waves on the ECG. Q waves were present in 39 (57%) patients. Univariate analysis identified the transmurality, the spatial extent, the total scar score and the quantified percentage scar tissue as predictors of Q waves. Multivariate analysis demonstrated that the quantified percentage scar tissue was the single best predictor. A cut off value of 17% infarcted tissue of the LV yielded a sensitivity and specificity of 90% to predict the presence or absence of Q waves. When the quantified percentage scar tissue was removed from the model, the spatial extent of infarction was the best predictor. Thus, Q waves on the ECG correlate best with the quantified percentage scar tissue on delayed contrast-enhanced MRI.

Introduction

Recently, gadolinium-enhanced cardiovascular magnetic resonance imaging (MRI) has been used for the assessment of scar tissue [1]. This technique is extremely suited to evaluate the precise relation between the circumferential extent and transmurality of left ventricular (LV) scar tissue and the presence or absence of Q waves on the electrocardiogram (ECG). Accordingly, we evaluated a consecutive series of patients with a first infarction, using delayed contrast-enhanced MRI. In addition, a variety of other parameters were derived from MRI, including the regional wall motion, the left ventricular ejection fraction (LVEF) and LV volumes, the end-diastolic wall thickness (EDWT) in the infarct region, and the presence of contractile reserve (determined during low-dose dobutamine MRI). The MRI findings were related to the presence or absence of Q waves on the ECG, and extensive analysis was performed to determine which parameter(s) correlate(s) with the presence of Q waves on the ECG.

Materials and methods

Patient population, study protocol

A total of 69 consecutive patients with chronic coronary artery disease (CAD) (angiographically documented) and history of a first myocardial infarction (>3 months before the study) were included. The region of infarction was assessed on echocardiography at rest at the time of admission. All patients had regional LV dysfunction and were in sinus rhythm. Patients with a recent infarction (<3 months), unstable angina, severe valvular disease, pacemakers and intracranial clips were excluded.

ECG at rest was first acquired to evaluate the presence or absence of Q waves. The MRI protocol consisted of a cine MRI at rest to evaluate regional and global LV function, LV volumes and EDWT in the infarct region. Next, low-dose dobutamine MRI was performed to evaluate contractile reserve in the infarct region. Thereafter, delayed contrast-enhanced MRI was performed to determine the circumferential extent and transmurality of infarcted tissue and the precise percentage of the LV with scar tissue was calculated. The MRI findings were related to presence or absence of Q waves on the ECG in the infarct region. All patients gave informed consent to the study protocol that was approved by the local ethics committee.

Electrocardiography

The surface ECGs were acquired on the day of the MRI study and read by two experienced observers without knowledge of the MRI results. Q waves were considered pathologic if they met the following criteria: (1) Q wave ≥30 ms on lead aVF, (2) Q wave ≥40 ms on leads I and aVL, (3) Q wave ≥40 ms in ≥2 on leads V4 through V6, (4) R wave ≥40 ms on lead V1, (5) any Q wave on lead V2, and (6) R wave ≤0.1 mV and of 10 ms on lead V2, according to the Selvester's QRS screening criteria for Q wave myocardial infarction [2;3].

Accordingly, pathologic Q waves were assigned to 3 LV regions: anterior (preserved R wave on lead V1 and pathologic Q wave on >1 of leads V2 to V5), lateral (pathologic Q wave on >1 of leads I, aVL, or V6), or inferior (pathologic Q wave on >1 of leads II, III, or aVF) [4].

MRI, data acquisition

A 1.5-Tesla Gyroscan ACS-NT MRI scanner (Philips Medical Systems, The Netherlands) equipped with powertrack 6000 gradients, release 9.1 scanner software and 5-element cardiac synergy coil was used. Patients were positioned in the supine position. Images were acquired during breath-holds of approximately 15 seconds using vector electrocardiographic gating. The blood pressure was continuously monitored using an external physiologic monitor.

The heart was imaged from apex to base [5] with 10 to 12 imaging levels (dependent on the heart size) in short-axis view using a sensitivity encoding balanced fast field echo sequence. Typical parameters were field of view 400 x 400 mm, matrix size 256 x 256, slice thickness 10.00 mm, slice gap 0.00 mm, flip angle 50°, time to echo 1.82 ms and time to repeat 3.65 ms. Temporal resolution was 25 to 39 ms. Geometry settings of the baseline scans were stored and repeated for low-dose dobutamine stress and delayed contrast-enhanced images, to ensure matching of the same slices (and therefore myocardial segments).

Delayed contrast-enhanced images were acquired approximately 15 minutes after bolus injection of Gadolinium-DTPA (Magnevist, Schering/Berlex, Germany, 0.15 mmol/kg) with an inversion-recovery gradient echo sequence; inversion time was determined using real time planscan. Typical parameters were the following: field of view 400 x 400 mm, matrix size 256 x 256, slice thickness 5.00 mm, flip angle 15°, time to echo 1.36 ms and time to repeat 4.53 ms.

Intravenous dobutamine infusion was started at a rate of 5 μg/kg/min and increased after 5 minutes to 10 μg/kg/min. Five minutes thereafter, low-dose dobutamine images were acquired in 2- and 4-chamber and short-axis views. The same parameters were applied as described for imaging at rest.

MRI, data analysis; LVEF, volumes, wall motion, EDWT and contractile reserve

To determine global function, endocardial borders were outlined manually on the short-axis cine images using previously validated software (MASS, Medis, The Netherlands). Papillary muscles were regarded as being part of the ventricular cavity, and epicardial fat was excluded. LV end-systolic and LV end-diastolic volumes were calculated. Subsequently, subtracting the end-systolic volume from the volume at end-diastole and dividing the result by the end-diastolic volume derived the related LVEF. The EDWT was measured quantitatively at the center of the infarct region.

To determine regional wall motion at rest, cine magnetic resonance images were visually interpreted by two experienced observers (blinded to other MRI and clinical data) using the 17-segment model [6]. Each segment was assigned a wall motion score using a 5-point scale with 0: normal wall motion, 1: mild hypokinesia, 2: severe hypokinesia, 3: akinesia, and 4: dyskinesia [7]. Summation of the individual segmental scores and divided by 17 yielded the summed wall motion score index (reflecting systolic (dys-) function per patient).

In dysfunctional segments at rest (scores 1 to 4), the presence or absence of contractile reserve was based on visual analysis of the difference in myocardial wall motion between MRI acquisitions at rest and during infusion of low-dose dobutamine. An improvement in segmental wall motion score by one grade or more was considered indicative of contractile reserve. Of note, dyskinetic segments becoming akinetic were not considered to exhibit contractile reserve [8]. Improvement of two or more segments was considered indicative of contractile reserve in the infarct region.

Assessment of scar tissue

Delayed contrast-enhanced images were scored visually by two experienced observers (blinded to other MRI and clinical data) using the 17-segment model as recently proposed [9]. Each segment was graded on a 5-point scale (segmental scar score) with 0: absence of hyperenhancement, 1: hyperenhancement of 1% to 25% of LV wall thickness, 2: hyperenhancement extending to 26% to 50%, 3: hyperenhancement

extending to 51% to 75%, and 4: hyperenhancement extending to 76% to 100% of the LV wall thickness [10].

The number of affected segments was considered to reflect the spatial (circumferential) extent of scar tissue. The number of segments with a segmental scar score of 3 or 4 was considered to reflect the transmurality of scar tissue in the infarct-zone. Summation of the individual segmental scores and divided by 17 yielded the total scar score (reflecting the damage per patient). To quantify the precise amount of infarcted tissue, hyperenhanced areas were manually traced on the short-axis images and the percentage of the LV with scar tissue was calculated. Reproducibility for visual and quantitative analysis was determined in a previous study [11]. The resulting intra- and interobserver agreements were 97% and 94% for visual analysis and 3.0 ± 5.1% and 4.2 ± 6.6% for quantitative analysis of scar tissue, respectively.

Statistical analysis

Continuous data were expressed as mean ± standard deviation and compared using nonparametric or the two-tailed Student's *t* test for (un-)paired data when appropriate. Differences in (baseline) characteristics between patients with and without Q waves were analyzed by Mann-Whitney and Fischer's exact tests, as appropriate. Comparisons of proportions for dichotomous data were performed using chi-square analysis with Yates' correction. Univariate and multivariate logistic regression analyses were performed to determine the relation between the presence or absence of Q waves on the ECG and MRI variables. The optimal cutoff value for the quantified percentage of scar tissue to predict the presence or absence of Q waves on the ECG was determined by receiver operating characteristic curve analysis. For all tests, a p-value <0.05 was considered significant.

Results

Patient characteristics, ECG results

The clinical characteristics of the study population are shown in Table 1. According to the echocardiographical findings at baseline, 24 patients were classified to have an anterior or anteroseptal infarction, 29 an inferior and 16 a lateral infarction. Pathological Q waves were present in 39 (57%) patients, the remaining 30 (43%) did not have Q waves on the ECG. All patients had significant CAD on angiography

(>70% reduction in luminal diameter of at least one major coronary artery). They had on average 2.3 ± 0.7 stenosed coronary arteries.

Table 1. Clinical characteristics of the study population.

Variable	Q wave (n=39)	Non-Q wave (n=30)
Age (years)	62 ± 11	63 ± 11
Men/Women	36/3	28/2
Number of narrowed coronary arteries	2.4 ± 0.8	2.1 ± 0.7
Locations on electrocardiogram		
Anterior	20	4*
Inferior	15	14
Lateral	4	12
Infarct therapy		
Conservative†	60%	41%‡
Thrombolysis	27%	36%
Percutaneous coronary intervention	13%	23%
Current medication		
Aspirin	97%	93%
ß-blockers	86%	90%
Angiotensin converting enzyme inhibitors	86%	83%
Diuretics	46%	53%
Nitrates	44%	40%

*Distribution of location of infarct: p<0.05, Q wave versus non-Q wave infarction.

†Conservative therapy includes anticoagulation drugs, nitrates, ß-blockers.

‡Distribution of infarct therapy: p=not significant for Q wave versus non-Q wave infarction.

Findings on MRI

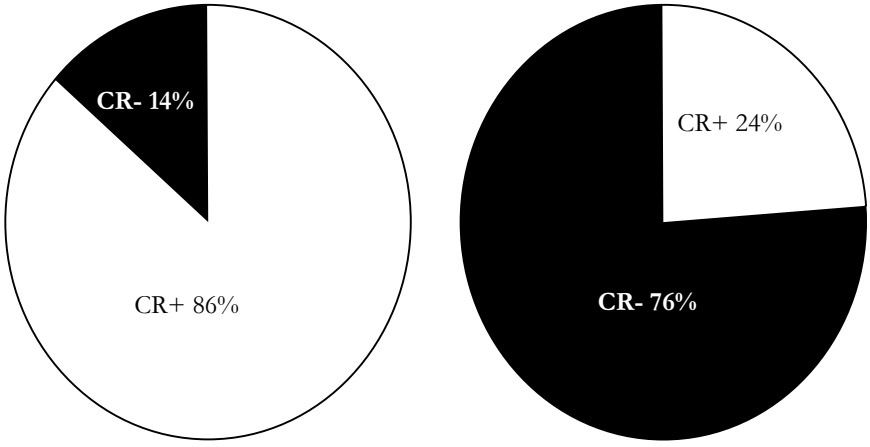
The MRI findings are summarized in Table 2. The mean LVEF was 40 ± 12% (range 14% to 64%), and was not different between patients with a Q and non-Q wave infarction. The LV end-diastolic and LV end-systolic volumes were 232 ± 53 ml (range 151 to 381 ml) and 141 ± 57 ml (range 67 to 322 ml) respectively (results were non-significant for Q wave versus non-Q wave infarction).

All patients demonstrated regional wall motion abnormalities in the infarct region, with a mean of 5.7 ± 1.5 segments per patient (range 1 to 13 segments). The

mean wall motion score index was not different between the two groups. The mean EDWT in the infarct region was comparable between patients with Q and non-Q wave infarction. Considering the proposed cutoff value of 6 mm for assessment of viability in the infarct region [12], 22 (56%) patients with a Q wave infarction had residual viable tissue in the infarct region, as compared to 22 (73%) of the patients with a non-Q wave infarction (p-value not significant). Of note, only 6 (9%) patients with an EDWT <6 mm in the infarct zone had contractile reserve, as compared to 38 (86%) patients with an EDWT ≥6 mm (p<0.01). Contractile reserve was present in 63% of all patients (60% of patients with a Q wave versus 70% with a non-Q wave infarction, Figure 1).

Of all 1173 segments, 404 (34%) demonstrated hyperenhancement; 145 with score 1, 128 score 2, 85 score 3 and 46 score 4. Accordingly, 131 segments exhibited transmural scar tissue (score 3 or 4), and the mean transmurality per patient (number of segments with score 3 or 4) was significantly larger in the patients with a Q wave infarction (Table 2). Of interest, 13 (43%) patients with a non-Q wave infarction had one or more segments with transmural scar tissue, whereas 13 (33%) patients with a Q wave did not have any segment with transmural scar tissue. Accordingly, based on the

Figure 1. Relation between contractile reserve (CR) and LV end-diastolic wall thickness (EDWT).



transmurality derived from delayed contrast-enhanced MRI, 67% of the patients with a Q wave infarction were classified as having transmural infarction as compared to 43% of the patients with a non-Q wave infarction (p-value not significant). The number of affected segments per patient (spatial extent) was 5.9 ± 3.2 (range 1 to 13), and was significantly larger in the patients with a Q wave infarction (Table 2). The total scar score (combining spatial extent and transmurality) was 0.84 ± 0.42 in

Table 2. MRI findings according to the presence or absence of Q wave infarction.

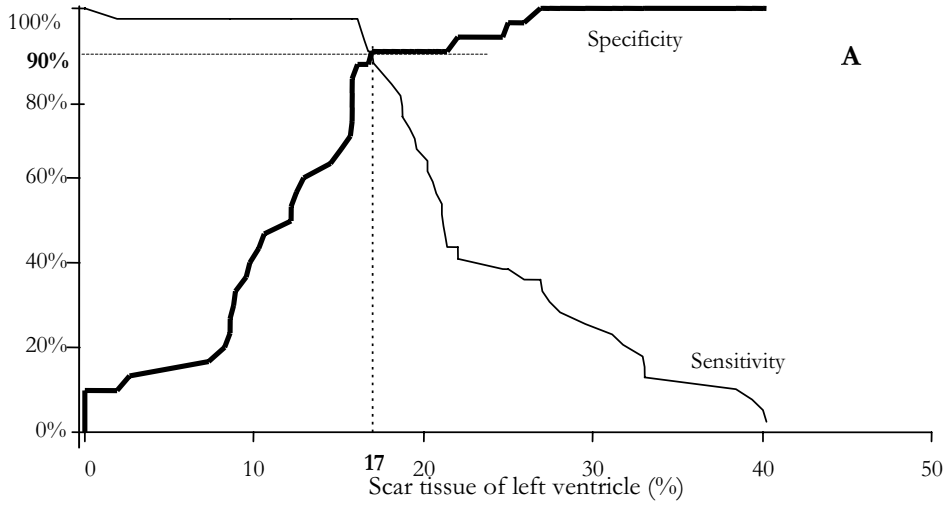
Variable	Q wave	Non-Q wave	p-value
Left ventricular ejection fraction (%)	38 ± 12	43 ± 12	NS
Left ventricular end-systolic volume (ml)	151 ± 56	130 ± 56	NS
Left ventricular end-diastolic volume (ml)	240 ± 52	220 ± 53	NS
Wall motion score index	0.67 ± 41	0.62 ± 0.48	NS
End-diastolic wall thickness (mm)	6.9 ± 2.7	7.6 ± 2.6	NS
Contractile reserve present	60%	70%	NS
Spatial extent (number of segments with any hyperenhancement)	6.7 ± 3.1	4.8 ± 3.1	<0.05
Transmurality (number of segments with hyperenhancement score 3 or 4)	2.3 ± 1.8	1.3 ± 2.2	<0.05
Total scar score (summation of individual segmental hyperenhancement scores)	0.84 ± 0.42	0.55 ± 0.48	<0.05
Quantified percentage scar tissue (%)	23 ± 8	11 ± 7	<0.05

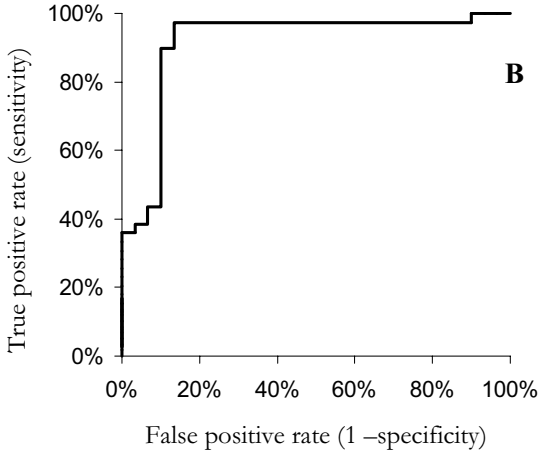
NS: not significant.

Table 3. Univariate predictors of Q wave infarction.

	Odds ratio	95% Confidence interval	p-value
Spatial extent	1.225	1.033-1.452	0.02
Transmurality	1.316	1.002-1.728	0.04
Total scar score	4.714	1.395-15.931	0.02
End-diastolic wall thickness	0.900	0.747-1.083	0.3
Contractile reserve	0.643	0.229-1.806	0.4
Quantified percentage scar tissue	1.319	1.146-1.518	0.0001

Figure 2. (A) Receiver operating characteristic curve analysis demonstrates 90% sensitivity and specificity to predict the presence or absence of Q waves on the ECG at a cutoff level of 17% for quantified infarcted tissue of the left ventricle. (B). Area under the curve is 0.92.





patients with a Q wave infarction as compared to 0.55 ± 0.48 in the patients with a non-Q wave infarction ($p<0.05$). The exactly quantified percentage of infarcted tissue (as percentage of the LV) ranged from 1% to 40% (mean 18 ± 7%). The percentage of infarcted tissue was significantly larger in the patients with a Q wave infarction (24 ± 8% versus 11 ± 7%, $p<0.05$).

Accordingly, the univariate predictors of the presence of a Q wave included the spatial extent of scar tissue, the transmurality, the total scar score, and the quantified percentage scar tissue of the LV (Table 3). In multivariate analysis, only the quantified percentage of infarcted myocardium remained significant for prediction of the presence of a Q wave on the ECG. When the quantified percentage infarcted tissue was excluded, the spatial extent was the best predictor.

To define the optimal cutoff value for the quantified percentage of infarcted tissue, receiver operating characteristic curve analysis was performed. The analysis indicated that a cutoff value of 17% infarcted tissue of the LV yielded a sensitivity and specificity of 90% to predict the presence or absence of a Q wave on the ECG (area under the curve 0.92, Figure 2).

Discussion

The results of the current study indicate that the presence or absence of a Q wave on the ECG is only correlated with the total extent of infarcted tissue, as can be quantified precisely by delayed contrast-enhanced MRI. Other MRI parameters (e.g. LVEF, EDWT in the infarct region, the presence or absence of viability, assessed by dobutamine MRI) did not contribute significantly.

Different recent studies with modern imaging technology have demonstrated that a substantial percentage of the patients with a Q wave infarction had residual viable tissue in the infarct zone, instead of a transmural scar. Schinkel et al [13] used metabolic imaging with SPECT and demonstrated that 61% of the patients with a Q wave infarct had residual glucose utilization in the infarct zone. Similar findings were reported when positron emission tomography or dobutamine stress echo were used [14]. Indeed in the current study, 60% of the infarct regions with a Q wave on the ECG had contractile reserve as assessed by dobutamine MRI. Based on these observations it was concluded that the precise pathophysiological substrate underlying the Q wave on the ECG remained uncertain [15]. More recently, delayed contrast-enhanced MRI has been introduced to precisely delineate infarct size. Fieno and coworkers [16] have

demonstrated in an animal model, that an excellent relation existed between the spatial and transmural extent of scar tissue and the ex-vivo histopathological findings. The same group showed a good correlation between enzymatically determined infarct size and the infarct size on MRI in 24 patients after acute myocardial infarction [17].

Subsequently, Wu et al [18] compared delayed contrast-enhanced MRI with ECG findings in 29 consecutive patients and highlighted the discrepancy between the MRI results and the presence or absence of Q waves on the ECG. In particular, 10 of 18 (55%) patients with a Q wave infarction did not have transmural scar formation on MRI and conversely 1 of 11 patients (9%) of the non-Q wave infarcts had transmural scar tissue on MRI. The current study confirms these observations in a large group of patients. In particular, 33% of the patients with a Q wave infarction did not have transmural scar tissue on MRI and 43% of the patients with a non-Q wave infarction had transmural scar formation on MRI. These findings are also in close agreement with the post-mortem findings presented by Raunio et al [19]. As outlined above, clinical, postmortem and imaging studies have all demonstrated that Q wave infarctions are not synonymous with transmural infarction and non-Q wave infarctions are not 100% representative of non-transmural infarctions.

The only variables that differed between patients with and without Q waves, were those reflecting the extent of scar tissue: the spatial extent of scar formation, the transmurality of scar tissue, total scar score and the quantified percentage of scar tissue on delayed contrast-enhanced MRI. Multivariate analysis demonstrated that the latter variable was the single best predictor of the absence or presence of Q waves on the ECG. When a cutoff value of 17% of infarcted tissue was used, a sensitivity and specificity of 90% were obtained to predict the absence or presence of Q waves on the ECG. However, this parameter involves transmurality as well as the spatial extent of the infarction. Interestingly, when the quantified percentage of infarcted tissue was excluded from the multivariate analysis, the spatial extent appeared the most important predictor of a Q wave. This observation suggests that the spatial extent, rather than the transmurality of infarct tissue, is the variable that determines the presence or absence of Q waves on the ECG. Preliminary data by Moon et al [20] also suggested that the regional extent rather than the transmurality of infarction determined the presence of Q waves.

Some limitations of the current study need to be addressed. First, the cutoff value of 17% to predict presence or absence of Q waves on the ECG was derived from receiver operating characteristic curve analysis. This value needs to be validated

prospectively in another patient population. Second, only patients with an infarction of more than 3 months old were included. It remains to be determined whether the findings also apply to patients with an acute myocardial infarction (<3 months). Third, the surface ECG underestimates lateral infarctions; also, the distribution of infarct locations (Table 1) was different between Q and non-Q wave patients. How these issues influence the results is not clear and should be evaluated in larger groups. Finally, only patients with one previous infarction were included, to have a homogenous study population. The observations in the current study may not be valid for patients with multiple infarctions.

Acknowledgements

This work was supported by The Netherlands Organization for Scientific Research (NWO), grant number 902-37-124 (H. J. Lamb, Leiden, The Netherlands).

References

1. Kim RJ, Wu E, Rafael A, Chen EL, Parker MA, Simonetti O *et al.* The use of contrast-enhanced magnetic resonance imaging to identify reversible myocardial dysfunction. N.Engl.J.Med. 2000;343:1445-53.
2. Anderson WD, Wagner NB, Lee KL, White RD, Yuschak J, Behar VS *et al.* Evaluation of a QRS scoring system for estimating myocardial infarct size. VI: Identification of screening criteria for non-acute myocardial infarcts. Am.J.Cardiol. 1988;61:729-33.
3. Sevilla DC, Wagner NB, Anderson WD, Ideker RE, Reimer KA, Mikat EM *et al.* Sensitivity of a set of myocardial infarction screening criteria in patients with anatomically documented single and multiple infarcts. Am.J.Cardiol. 1990;66:792-95.
4. Brunken R, Tillisch J, Schwaiger M, Child JS, Marshall R, Mandelkern M *et al.* Regional perfusion, glucose metabolism, and wall motion in patients with chronic electrocardiographic Q wave infarctions: evidence for persistence of viable tissue in some infarct regions by positron emission tomography. Circulation 1986;73:951-63.
5. Lamb HJ, Doornbos J, van der Velde EA, Kruit MC, Reiber JH, de Roos A. Echo planar MRI of the heart on a standard system: validation of measurements of left ventricular function and mass. J.Comput.Assist.Tomogr. 1996;20:942-49.
6. Cerqueira MD, Weissman NJ, Dilsizian V, Jacobs AK, Kaul S, Laskey WK *et al.* 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. Circulation 2002;105:539-42.

7. Arnese M, Fioretti PM, Cornel JH, Postma-Tjoa J, Reijs AE, Roelandt JR. Akinesis becoming dyskinesis during high-dose dobutamine stress echocardiography: a marker of myocardial ischemia or a mechanical phenomenon? Am.J.Cardiol. 1994;73:896-99.
8. 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;357:21-28.
9. Schuijf JD, Kaandorp TA, Lamb HJ, Geest RJ, Viergever EP, Wall EE *et al.* Quantification of myocardial infarct size and transmurality by contrast-enhanced magnetic resonance imaging in men. Am.J.Cardiol. 2004;94:284-88.
10. Baer FM, Theissen P, Schneider CA, Voth E, Sechtem U, Schicha H *et al.* Dobutamine magnetic resonance imaging predicts contractile recovery of chronically dysfunctional myocardium after successful revascularization. J.Am.Coll.Cardiol. 1998;31:1040-48.
11. Schinkel AF, Bax JJ, Elhendy A, Boersma E, Vourvouri EC, Sozzi FB *et al.* Assessment of viable tissue in Q-wave regions by metabolic imaging using single-photon emission computed tomography in ischemic cardiomyopathy. Am.J.Cardiol. 2002;89:1171-75.
12. Fragasso G, Chierchia SL, Rossetti E, Sciammarella MG, Conversano A, Lucignani G *et al.* Myocardial viability assessed with fluorodeoxyglucose and PET in patients with Q wave myocardial infarction receiving thrombolysis: relationship to coronary anatomy and ventricular function. Nucl.Med.Commun. 1997;18:191-99.
13. Phibbs B. Transmural versus Q wave infarction. J.Am.Coll.Cardiol. 1984;4:1332.
14. Fieno DS, Kim RJ, Chen EL, Lomasney JW, Klocke FJ, Judd RM. Contrast-enhanced magnetic resonance imaging of myocardium at risk: distinction between reversible and irreversible injury throughout infarct healing. J.Am.Coll.Cardiol. 2000;36:1985-91.
15. Choi KM, Kim RJ, Gubernikoff G, Vargas JD, Parker M, Judd RM. Transmural extent of acute myocardial infarction predicts long-term improvement in contractile function. Circulation 2001;104:1101-07.
16. Raunio H, Rissanen V, Romppanen T, Jokinen Y, Rehnberg S, Helin M *et al.* Changes in the QRS complex and ST segment in transmural and subendocardial myocardial infarctions. A clinicopathologic study. Am.Heart J. 1979;98:176-84.
17. Moon JC, Perez D, Janardhanan R, Elkington AG, Taneja AK, Senior R *et al.* The pathological basis of Q waves in myocardial infarction - Infarct extent rather than transmurality. Eur.Heart J. 2003;24 Abstract supplement:120.