International Journal of Cardiology 159 (2012) 192–197

Contents lists available at SciVerse ScienceDirect

International Journal of Cardiology

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

Combining magnetic resonance viability variables better predicts improvement of myocardial function prior to percutaneous coronary intervention

Sharon W. Kirschbaum [a,b], Alexia Rossi [a,b], Eric Boersma [a], Tirza Springeling [a,b], Martin van de Ent [a], Gabriel P. Krestin [b], Patrick W. Serruys [a], Dirk J. Duncker [a], Pim J. de Feyter [a,b], Robert-Jan M. van Geuns [a,b,*]

[a] Department of Cardiology, Erasmus University Medical Center, Rotterdam, The Netherlands
[b] Department of Radiology, Erasmus University Medical Center, Rotterdam, The Netherlands

ARTICLE INFO

Article history:
Received 15 November 2010
Received in revised form 6 February 2011
Accepted 20 February 2011
Available online 16 March 2011

Keywords:
Magnetic resonance imaging
Chronic total occlusion
Myocardial viability
Hibernation

ABSTRACT

Objective: To optimize the predictive value of cardiac magnetic resonance imaging (MRI) for improvement of myocardial dysfunction prior to percutaneous coronary intervention (PCI).
Methods: We performed cardiac MRI in 72 patients (male 87%, age 60 years) before and 6 months after successful PCI (43/72) or unsuccessful PCI (29/72) of a chronic total coronary occlusion (CTO). Before PCI, 5 viability parameters were evaluated: transmural extent of infarction (TEI), contractile reserve during dobutamine, end diastolic wall thickness, unenhanced rim thickness and segmental wall thickening of the unenhanced rim (SWTur). Multivariate analysis was performed and based on the regression coefficient (RC) a predictive score was constructed. Diagnostic performance to predict improvement in myocardial function for each parameter and for the viability score was determined.
Results: The predictive value of a combination of contractile reserve, SWTur and TEI was incremental to TEI alone (AUROC 0.91 vs. 0.77; $p<0.001$). A viability score of ≥ 5 based on contractile reserve (RC = 4), SWTur (RC = 1) and TEI (RC = 2) was 91% sensitive and 84% specific in predicting improvement of myocardial function.
Conclusion: Combining viability parameters results in a better prediction of improvement of dysfunctional myocardial segments after a successful PCI.

1. Introduction

Myocardial dysfunction is frequently due to coronary artery stenosis in the western world. This can either be due to akinesia in transmural infarcted regions or be the results from hibernation of the myocardium as a result of chronic reduced flow. Hibernating myocardium may improve after restoration of coronary blood flow [1]. The improvement of myocardial function and the rate of recovery are related to the extent of myocardial infarction [2–4].

Contrast enhanced cardiac magnetic resonance imaging (MRI) is able to detect myocardial infarction [5,6] and can predict improvement of depressed myocardial function after revascularization [7,8]. However the diagnostic accuracy of contrast enhanced MRI as well as wall thickness [9,10], contractile reserve [9,11] and thickness of the unenhanced rim [12] is moderate. Moderate diagnostic performance of contrast enhanced MRI is caused by the limited predictive value of this technique in segments with an intermediate transmural extent of infarction [2,4]. Initial attempts to combine viability parameters suggest an improvement in diagnostic accuracy [11,13]. A structured analysis investigating the optimal combination of these 5 viability parameters has not yet been performed. The aim of the present study was to improve the diagnostic accuracy of pre-treatment MRI using combined viability assessment. We therefore studied a patient group scheduled for percutaneous coronary intervention (PCI) of a chronic total coronary occlusion (CTO) which represents the best in-vivo model of hibernation if present.

2. Methods

2.1. Patient population

Patients were recruited from April 2006 to February 2009. Patients scheduled for PCI of a CTO of a native coronary artery were prospectively selected for enrolment in this study. Sixty four percent of the patients had a positive exercise test and the remaining 36% had progressive anginal symptoms. All patients underwent a diagnostic angiogram. Inclusion criteria were (1) CTO, (2) sinus rhythm, and (3) abnormalities in wall motion in the perfusion territory of the CTO on contrast ventriculography or echocardiography. Exclusion criteria were (1) myocardial infarction within the last three months; (2) atrial fibrillation; (3) contraindications for magnetic resonance studies; (4) inability to give reliable informed consent; (5) known allergy to gadolinium based contrast material; and (6) unstable coronary artery disease.

Inclusion flow chart is presented in Fig. 1 and baseline patient characteristics are presented in Table 1. All successfully treated patients received drug eluting stents. A successful PCI was defined as the restoration of Trombolysis In Myocardial Infarction (TIMI) grade 3 flow using a drug eluting stent. The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a priori approval by the institutional review board of the Erasmus Medical Center in Rotterdam and all participating patients gave written informed consent.

* Corresponding author at: Erasmus Medical Center, room Ba 585, P.O. box 2040, 3000 CA Rotterdam, The Netherlands. Tel.: +31 10 703 3348; fax: +31 10 463 4320.
E-mail address: r.vangeuns@erasmusmc.nl (R.-J.M. van Geuns).

0167-5273/$ – see front matter © 2011 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.ijcard.2011.02.048

2.2. MRI-protocol

A 1.5 Tesla scanner with a dedicated eight-element phased-array receiver coil was used for imaging (Signa CV/*i*, GE Medical systems, Milwaukee, Wisconsin USA). Cine MRI was performed using a steady-state free-precession technique (FIESTA). Imaging parameters were reported previously [4]. Dobutamine was infused at 5 and 10-mcg/kg/min for 5 min at each dosage using an intravenous catheter, which was placed in the antecubital vein. Functional imaging was repeated using the same imaging planes as at rest. During the test the patients were monitored using electrocardiogram leads and blood pressure was measured at every 3 min interval. Criteria for ending the dobutamine-MRI examination were (1) development of a new wall motion abnormality, (2) fall of systolic blood pressure of >40 mm Hg, (3) marked hypertension >240/120 mm Hg, (4) severe chest pain, (5) ventricular arrhythmias or new atrial arrhythmias, and (6) intolerable side effects of dobutamine. Delayed enhancement imaging was performed with a gated breath hold T1-inversion recovery gradient-echo sequence 20 min after infusion of Gadoliniumdiethyltriaminepentaacetic acid (0.2 mmol/kg intravenously, Magnevist, Schering, Germany). Imaging parameters were reported previously [4]. The same slice locations and planning of the cine images were used for the acquisition of the delayed enhanced images.

2.3. Definitions and data analysis

All conventional angiograms before PCI were evaluated by two experienced observers. According to the place of occlusion and left or right dominance, the left ventricular segments were determined as being perfused by an occluded or a non-occluded vessel. A CTO was classified as a complete occlusion for more than 3 months as obtained from either the clinical history of prolonged anginal chest pain or the date of the diagnostic angiogram before PCI. All images were automatically analyzed using CAAS-MRV (version 3.2.1; Pie Medical Imaging, Maastricht, The Netherlands) [14]. Manual corrections were performed afterwards where necessary. Papillary muscles and trabeculations were considered as being part of the blood pool volume. A 17 segment-model was used to analyze the myocardial wall in each patient [15]. The 17th segment was excluded from the analysis for the reason that wall thickening analysis was not possible as on short axis images no left ventricular cavity is visible. Segmental wall thickening (SWT) was defined as a percent increase of LV wall thickness during systole as compared to diastole. To study the effect of PCI on SWT, dysfunctional segments in the perfusion territory of a CTO were analyzed. Myocardial segments were considered dysfunctional if wall thickening was less than 45% [2,16]. The predictive value of the different viability parameters were calculated with an improvement in SWT >10% after revascularization as standard for viability. Five viability indexes were evaluated before PCI; (1) end diastolic wall thickness (EDWT) [9]; (2) contractile reserve during low dose dobutamine (LDD), at either 5-mcg/kg/min or 10-mcg/kg/min dose; (3) unenhanced rim thickness [12]; (4) SWT of the unenhanced rim (SWT_{UR}); and (5) TEI. The unenhanced rim thickness was determined by subtracting the hyperenhanced area from the total area of a given segment. This area was expressed as a percentage of the total segmental area and multiplied by the EDWT. For SWT_{UR} the increase in wall thickness in the end systolic phase as compared to the end diastolic phase was assigned to the thickness of the unenhanced rim as we assume that scar tissue does not contract and expressed as a percentage of the unenhanced rim. The TEI was quantified by dividing the hyper enhanced area by the total area and expressed as a percentage. For the hyperenhanced area the minimum and maximum signal intensities of the myocardium were used and a cut-off value was visually detected for each patient individually matching the hyperenhanced area visual estimated by the observer. Using this cut-off value for hyperenhancement, contours were automatically traced. We evaluated these 5 indexes in dysfunctional myocardial segments. To compose the viability score we performed multivariate regression analysis to determine which parameter had additive predictive value. The optimal cut-off value of each individual parameter was calculated separately and the parameters were then used as binary

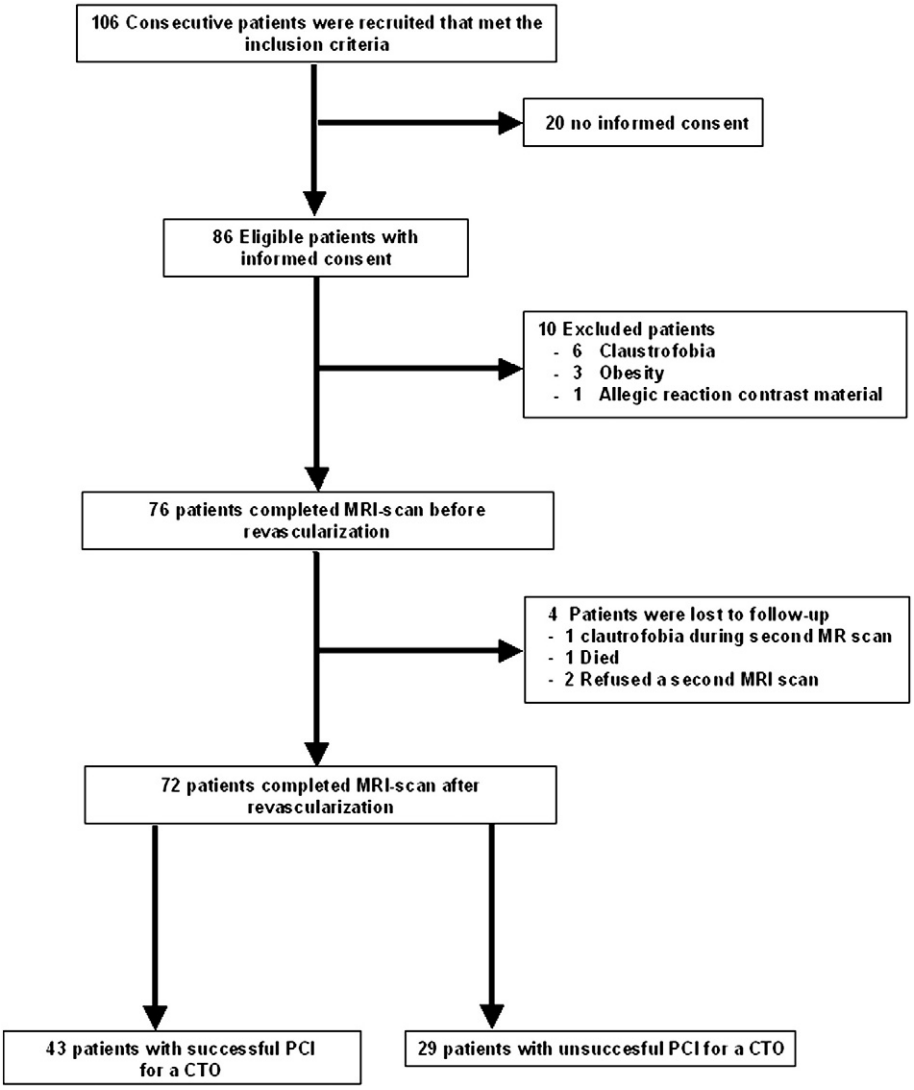

Fig. 1. Flow of patients through the study; PCI, percutaneous coronary intervention; MRI, magnetic resonance imaging; CTO, chronic total coronary occlusion.

Table 1
Baseline patient characteristics.

	Successful PCI	Unsuccessful PCI	p-value
	N = 43	N = 29	
Age (years)	60 ± 10	61 ± 10	0.32
Men	34(79)	28(93)	0.18
Previous MI	23(53)	6(21)	0.006
MI on DE-MRI	36(84)	25(86)	1.00
TEI<25%	9(21)	6(21)	0.77
TEI between 25 and 75%	20(47)	15(52)	0.63
TEI>75%	7(16)	4(13)	1.00
1-vessel disease	29(67)	24(82)	0.15
2-vessel disease	10(23)	4(14)	0.32
3-vessel disease	4(9)	1(3)	0.64
Previous PCI	10(23)	8(28)	0.79
Smoking	9(21)	7(24)	0.78
Diabetes mellitus	9(21)	8(17)	0.58
Hypertension	18(42)	15(50)	0.79
Hypercholesterolemia	34(79)	24(80)	0.75
Family history	20(47)	13(43)	0.61
Baseline ejection fraction (%)	50 ± 11	46 ± 16	0.30
End diastolic volume (ml/m^2)	93 ± 27	98 ± 38	0.46
End systolic volume (ml/m^2)	48 ± 24	58 ± 41	0.21
Infarct size on DE-MRI (g)	17 ± 15	14 ± 17	0.51
ACE inhibitor	19(44)	15(50)	0.80
β-blocker	39(91)	28(93)	0.64
Statin	39(91)	27(90)	1.00
ASA	39(91)	28(93)	1.00

Values are presented as number (%) or mean ± standard deviation. PCI, percutaneous coronary intervention; DE-MRI, delayed enhancement-cardiovascular magnetic resonance; MI, myocardial infarction; ACE, angiotensin-converting enzyme; ASA, acetylsalicylic acid.

variables. If a parameter was considered viable and reaches a certain threshold the regression coefficient (RC) was added to the sum of the viability score. The viability score was calculated as the sum of the RC of the parameters which were considered viable. All MRI data were analyzed quantitatively in a random order with the investigator blinded to the clinical information and the previous results.

2.4. Statistical analysis

Continuous data are expressed as mean values ± one standard deviation (SD), whereas dichotomous data are expressed as numbers and percentages. Differences in baseline characteristics between patients with successful PCI and non-successful PCI were evaluated using chi-square tests, Fisher's exact tests, and unpaired Student's t-tests, as appropriate. Changes in left ventricular volumes and function were evaluated by two-way analysis of variance with repeated measures over time, followed by paired Student's t-tests. Improvement was defined as an absolute change (from baseline to 6 months follow-up) in SWT of at least 10%. We applied Bonferroni's correction to adjust for the inflation of the type I error with multiple testing.

Univariable logistic regression (LR) analyses were applied to assess the power of viability parameters for the prediction of improvement in myocardial function. Results are presented as odds ratios (ORs) with corresponding 95% confidence intervals (CIs), which refers to 10 units for TEI, SWTur and LDD. Then, receiver operator characteristic (ROC) curve analyses were performed to determine the 'best' thresholds of relevant predictors, following the method of maximizing the sum of sensitivity and specificity. We present the observed area under the ROC curves (AUROC) for each of these predictors.

Subsequently, multivariable LR analyses were conducted. All variables that were significantly associated with improvement entered this multivariable stage with their values categorized at the optimal cut-off value. A backward deletion process was performed, until all variables in the model had a $p<0.05$. The RC of the variables that composed the final model was used to construct a 'viability score'. Again ROC curve analyses were applied to determine the 'best' threshold of this score for the prediction of improvement of myocardial function.

We used the segment and not the patient as the unit of our analyses. We realized that potential correlation existed between the multiple segments that were derived from the same patient. Therefore, general estimating equation (GEE) analyses were applied to construct the LR models.

We performed extensive internal validation of our results by bootstrap analyses [17,18]. A total of 1000 replications of the dataset were obtained by random sampling segments (with replacement), with the patient as cluster. All statistical tests were two sided, and a p-value <0.05 was considered statistically significant.

Additionally a per patient analysis on diagnostic accuracy was performed using both TEI and the viability score. The test was considered positive for viability when >50% of the segments in the revascularized area were viable according to the TEI or the viability score.

3. Results

3.1. Patient population

Of 106 consecutively approached patient, 72 patients completed the study protocol. The median time interval between the baseline MRI and PCI was 18 days (25th and 75th percentile, 6–31), clinical evidence of myocardial infarction did not occur during this time interval. Follow-up MRI scan was performed at a median time interval of 183 days (25th and 75th percentile, 181–190) after PCI. PCI of the CTO was successful in 43 patients and unsuccessful in 29 patients. Nineteen patients (14 with successful and 5 with unsuccessful PCI of a CTO) underwent PCI of another vessel during the same procedure.

In patients with successful PCI, the CTO was located in 19 (44%) patients in the left anterior descending artery, in 10 (23%) patients in the left circumflex artery and in 14 (33%) patients in the right coronary artery. In patients without successful PCI the CTO was located in 10 (37%) patients in the left anterior descending artery, in 6 (20%) in the left circumflex artery and in 13 (43%) patients in the right coronary artery. Nineteen patients underwent PCI of another vessel during the same procedure, 14 patients in the group with successful PCI and 5 patients in the group with unsuccessful PCI of their CTO ($p=0.12$). All patients with successful PCI for their CTO were symptom free at follow-up. Administration of dobutamine was well tolerated by all patients, no serious side effects occurred. Blood pressure and heart rate increased slightly but consistently during infusion of dobutamine. In two patients (7%) in the group with unsuccessful PCI new hyper enhancement occurred at follow-up (new infarct mass 2.1 and 3.6 g).

All 1136 segments were available for analysis. Three hundred thirty six segments were in the perfusion territory of the CTO of which 255 segments were dysfunctional (159 segments in the patient group that underwent successful PCI and 96 segments in the patient group with unsuccessful PCI).

3.2. Left ventricular function and volumes

EF increased significantly in patients that underwent successful PCI (from 50 ± 11 to 54 ± 12%; $p<0.001$). End diastolic volume index was unchanged (from 93 ± 27 to 88 ± 34 ml/m^2; $p=0.21$) and end systolic volume index decreased (from 48 ± 24 to 43 ± 29 ml/m^2; $p=0.02$). In patients with unsuccessful PCI, EF (46 ± 16 to 47 ± 13%; $p=0.41$), end diastolic volume index (98 ± 38 ml/m^2 to 92 ± 35 ml/m^2; $p=0.08$) and end systolic volume index (58 ± 41 ml/m^2 to 52 ± 35 ml/m^2; $p=0.16$) remained unchanged.

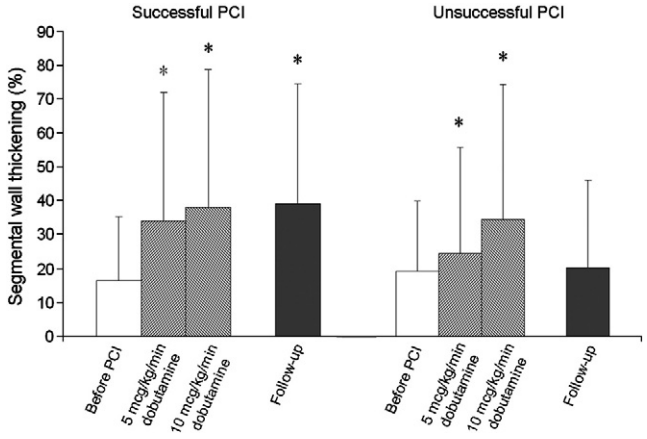

Fig. 2. In patients with successful percutaneous coronary intervention (PCI), segmental wall thickening (SWT) improved significantly during dobutamine and at follow-up as compared to SWT before PCI. In patients without successful PCI, SWT improved significantly during dobutamine but not at follow-up as compared to baseline. *$p<0.05$ vs. before PCI.

Table 2
Receiver operator characteristic curve analysis for each viability parameter.

	Cut-off value	AUROC (95% Confidence interval for AUROC)
LDD (%)	7	0.86(0.80 to 0.93)
TEI (%)	50	0.77(0.69 to 0.85)
EDWT (mm)	6	0.62(0.52 to 0.72)
Unenhanced rim thickness (mm)	3	0.76(0.68 to 0.84)
SWTUR (%)	45	0.62(0.53 to 0.72)

LDD, contractile reserve during low dose dobutamine; TEI, transmural extent of infarction; EDWT, end diastolic wall thickness; SWTur, segmental wall thickening of the unenhanced rim.

Table 3
Logistic univariate and multivariate regression analysis of the contribution of the different viability parameters for improvement in SWT.

	OR	95% confidence i nterval for OR	p-value
Univariate			
LDD	1.82	(1.49–2.22)	p<0.0001
TEI	0.68	(0.58–0.79)	p<0.0001
EDWT	1.3	(1.1–1.7)	p=0.0063
Unenhanced rim thickness	1.4	(1.2–1.5)	p<0.0001
SWTur	0.85	(0.76–0.95)	p=0.0052
Multivariate			
LDD	1.06	(1.02–1.09)	p<0.0001
TEI	0.96	(0.94–0.97)	p<0.0001
SWTur	0.98	(0.97–0.99)	p=0.0029

LDD, contractile reserve during low dose dobutamine; TEI, transmural extent of infarction; EDWT, end diastolic wall thickness; SWTur, segmental wall thickening of the unenhanced rim; OR, odds ratio. The odds ratio refers to 10 units for TEI, SWTur and LDD.

Mean SWT of dysfunctional segments in the perfusion territory of the CTO improved significantly in patients after successful PCI (16±19% to 39±35%; p<0.0001). In patients with unsuccessful PCI mean SWT remained unchanged at follow-up (19±21% to 21±25%; p=0.54). Both patient groups showed significant contractile reserve before PCI (Fig. 2).

3.3. Single assessment of myocardial viability and regional functional recovery

The optimal cut-off value and the AUROC for all parameters for the prediction of improvement are presented in Table 2. All viability parameters had significant predictive value according to the univariate logistic regression analysis (Table 3). Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) for all viability parameters to predict functional improvement of dysfunctional segments after PCI are presented in Table 4. The sensitivity, specificity, PPV and NPV of TEI for the prediction of improvement in function after PCI was 89(81–94)%, 48(36–64)%, 79(70–85)% and 67(51–82)%. LDD was a better predictor for functional improvement after PCI with sensitivity, specificity, PPV and NPV of 93(86–97)%, 77(63–87)%, 89(82–94)% and 85(71–93)%.

Table 5
Sensitivity and specificity after bootstrap analysis.

	Sensitivity (%)		Specificity (%)	
	Mean	SD	Mean	SD
LDD (>7%)	90.0	3.6	81	11.4
TEI (<50%)	92.3	3.6	45.0	13.8
EDWT (>6 mm)	92.6	3.6	27.7	11.3
Unenhanced rim thickness (>3 mm)	96.3	2.9	43.2	13.8
SWTUR (<45%)	87.2	4.1	40.2	11.9

LDD, contractile reserve during low dose dobutamine; TEI, transmural extent of infarction; EDWT, end diastolic wall thickness; SWTur, segmental wall thickening of the unenhanced rim; SD, standard deviation.

The analysis per segment was confirmed by bootstrap analysis. The mean and the standard deviation for the sensitivity and specificity are presented in Table 5.

3.4. Combined assessment of myocardial viability and regional functional recovery

Multivariate analysis including all 5 different viability parameters showed that EDWT and the thickness of the unenhanced rim did not have incremental predictive value. TEI, SWTur and LDD had incremental predictive value (Table 3). For the viability score we added the RC without decimal to the sum of the score. Receiver operator characteristic curve analysis demonstrated an optimal threshold for the viability score of 5.0 for the prediction of improvement in SWT with an AUROC of 0.91 (95%CI 0.86–0.95) (Fig. 3). Sensitivity, specificity, PPV and NPV for this cut-off value were 92(84–96)%, 83(69–91)%, 92(84–96)% and 83(69–91)% respectively. SWT improved significantly in segments with a viability score of ≥5.0 (16±20% to 49±30%; p<0.0001) and remained unchanged in segments with a viability score of <5.0 (18±16% to 18±23%; p=1.00) (Fig. 4). In segments with a viability score of ≥5.0, 92% of the segments improved. In segments with a viability score of <5.0 only 17% of the segments showed an improvement of SWT.

3.5. Myocardial viability assessment in segments with an intermediate transmural extent of infarction

In segments with an intermediate TEI (1–75%) (n=110), 85 segments were classified as viable using delayed enhancement imaging (TEI<50%) of which 61(72%) improved. Twenty-five segments were classified as not viable (TEI>50%) of which still 11 segments (44%) improved. Using the viability score with a cut-off value of 5.0, 70 segments were classified as viable of which 64 segments (91%) improved. Forty segments were classified as being not viable of which only 8 improved (20%).

Table 4
Diagnostic performance of each viability index for the prediction of improvement in SWT.

	RC	OR	Sig.	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
LDD (>7%)	4	46(17–123)	0.000	93(86–97)	77(63–87)	89(82–94)	85(71–93)
TEI (<50%)	2	8(4–18)	0.000	89(81–94)	48(36–64)	79(70–85)	67(51–82)
EDWT (>6 mm)	1	4(2–10)	0.003	92(84–96)	27(16–41)	72(64–79)	61(39–80)
Unenhanced rim thickness (>3 mm)	3	15(6–42)	0.000	94(88–98)	48(34–62)	79(71–85)	81(62–92)
SWTUR (<45%)	1	4(2–8)	0.003	88(80–93)	33(21–47)	73(64–80)	56(38–74)
Score (5)		52(19–140)	0.000	92(84–96)	83(69–91)	92(84–96)	83(69–91)

LDD, contractile reserve during low dose dobutamine; TEI, transmural extent of infarction; EDWT, end diastolic wall thickness; SWTur, segmental wall thickening of the unenhanced rim; PPV, positive predictive value; NPV negative predictive value; RC, regression coefficient; OR, odds ratio; 95% confidence interval is presented between brackets.

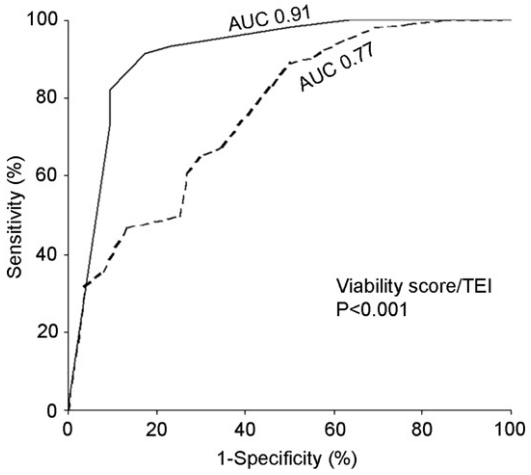

Fig. 3. Viability score (solid line) was compared to the more widely used transmural extent of infarction using delayed enhancement imaging (dotted line) alone. AUROC was significantly higher (P<0.001) for viability score as compared to TEI alone.

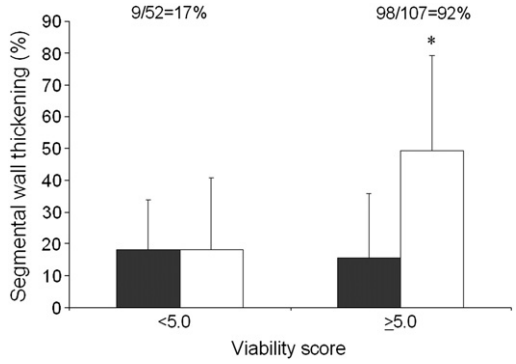

Fig. 4. Ninety-two percent of the segments with a viability score of ≥5 showed improvement of segmental wall thickening (SWT) >10% after percutaneous coronary intervention (PCI) and mean SWT improved significantly in these segments. Only seventeen percent of the segments with a viability score of <5 showed improvement of SWT >10% and mean SWT did not improve. For example if a segment shows contractile reserve, has a TEI of <50% and SWTur >45% than the viability score is; 4 + 2 + 0 = 6 which is >5. SWT is expected to improve which can be predicted with a sensitivity of 91%, specificity of 84%, PPV of 93% and NPV of 83%. Black bars = SWT before PCI and white bars = SWT at 6 months follow-up.

3.6. Per patient analysis

Using the TEI for viability assessment, 42%(5/12) of the patients that did not show improvement in myocardial function at 6 months follow-up were considered viable before revascularization and underwent percutaneous revascularization. These false positives were reduced to 8% (1/12) using the viability score. Sensitivity, specificity, PPV and NPV for the prediction of improvement in the revascularized area for TEI were 97(84–99)%, 58(32–81)%, 86(71–94)%, and 88(53–98)% and for the viability score were 97(84–99)%, 92(65–99)%, 97(84–99)% and 92(65–99)% respectively.

4. Discussion

In our study we demonstrated that successful recanalization with PCI in patients with a CTO improved myocardial function of CTO related segments that were dysfunctional. We further demonstrated that the combination of multiple MRI derived viability parameters including dobutamine contractile reserve assessment, TEI (non viable necrotic tissue) and SWT of normal remaining myocardium was a better predictor of improvement of dysfunctional segments prior to PCI for CTO than the single widely used parameter of TEI. Lastly we demonstrated that the use of multiple MRI derived viability parameters better identified patients who would benefit from PCI compared to the use of the single MRI derived variable. This would allow better use of limited resource and offers more effective management of patients with a CTO.

MRI using delayed enhancement of infarcted myocardial tissue after administration of gadolinium is helpful to assess viability of systolic dysfunctional hibernating left ventricular myocardium. Depended on the TEI, dysfunctional myocardium still maintains the capability to recover function after revascularization with CABG or PCI [11,19]. Recovery was predicted for 78% of the myocardial segments if the myocardium was fully viable (TEI = 0%) while almost no recovery may be expected if the TEI was almost transmural (>75% infarction of a myocardial segment) [7]. Similar results in improvement of dysfunctional myocardium were obtained using delayed enhancement MRI in patients with a recanalization of a CTO with PCI [2]. The likelihood of recovery was much less predictable if intermediate TEI (between 1 and 75%) was present [9,12,13]. Recently we introduced SWTur and investigated the relation of this parameter but also of TEI, EDWT and thickness of the unenhanced rim with contractile reserve by low dose dobutamine. TEI and SWTur had significant predictive value [20].

In the present study, recovery of function after revascularization was the outcome parameter and therefore it was also possible to investigate the predictive value of contractile reserve during dobutamine. Contractile reserve was a better predictor of myocardial improvement [9,11,21–23] because, unlike the other parameters, it directly unmasks the potential of the presence of contractile reserve of dysfunctional non infarcted myocardium. Using a combination of 3 viability parameters improved the prediction of viability in particular for segments with an intermediate TEI. Important to realize is that the majority (68%) of all dysfunctional segments in our study had an intermediate TEI. This is feasible in clinical practice because the versatility of current MRI allows viability assessment of multiple MRI variables that can be obtained from one MRI session. A combination of various MRI viability parameters is also useful in other patient groups [13,24] representing different aspects of viability such as the presence of contractile reserve, extent of infarction, and segmental wall thickening of epicardial non infarcted rim of myocardium which incorporated into a simple score each with a weighted factor was a reliable predictor of improvement of dysfunctional myocardium prior to recanalization of CTO.

4.1. Limitations

Sustained recanalization at follow-up was not confirmed by coronary angiography but no clinical evidence of recurrent ischemia was reported and all patients received a drug eluting stent with acknowledged low restenosis rate [3,25]. The recovery of myocardial function was assessed at 6 months and the established improvement may have been underestimated because it has been shown that the myocardial function may continue to further improve after 6 months up to a period of 3 years [4].

4.2. Conclusion

Combined viability analysis using the viability score was a better predictor than the most widely used transmural extent of infarction. This may be useful for the selection of patients where improvement of myocardial function by PCI of a CTO is desired.

Acknowledgement

The authors of this manuscript have certified that they comply with the Principles of Ethical Publishing in the International Journal of Cardiology [26].

References

[1] Cwajg JM, Cwajg E, Nagueh SF, et al. End-diastolic wall thickness as a predictor of recovery of function in myocardial hibernation: relation to rest-redistribution T1-201 tomography and dobutamine stress echocardiography. J Am Coll Cardiol 2000;35:1152–61.

[2] Baks T, van Geuns RJ, Duncker DJ, et al. Prediction of left ventricular function after drug-eluting stent implantation for chronic total coronary occlusions. J Am Coll Cardiol 2006;47:721–5.

[3] Haas F, Augustin N, Holper K, et al. Time course and extent of improvement of dysfunctioning myocardium in patients with coronary artery disease and severely depressed left ventricular function after revascularization: correlation with positron emission tomographic findings. J Am Coll Cardiol 2000;36:1927–34.

[4] Kirschbaum SW, Baks T, van den Ent M, et al. Evaluation of left ventricular function three years after percutaneous recanalization of chronic total coronary occlusions. Am J Cardiol 2008;101:179–85.

[5] Mayr A, Klug G, Schocke M, et al. Late microvascular obstruction after acute myocardial infarction: Relation with cardiac and inflammatory markers. Int J Cardiol Jan 14 2012;157(3):391–6.

[6] Thiele H, Schuster A, Erbs S, et al. Cardiac magnetic resonance imaging at 3 and 15 months after application of circulating progenitor cells in recanalised chronic total occlusions. Int J Cardiol 2009;135:287–95.

[7] Kim RJ, Wu E, Rafael A, et al. The use of contrast-enhanced magnetic resonance imaging to identify reversible myocardial dysfunction. N Engl J Med 2000;343: 1445–53.

[8] Kuhl HP, Lipke CS, Krombach GA, et al. Assessment of reversible myocardial dysfunction in chronic ischaemic heart disease: comparison of contrast-enhanced cardiovascular magnetic resonance and a combined positron emission tomography-single photon emission computed tomography imaging protocol. Eur Heart J 2006;27:846–53.

[9] Baer FM, Theissen P, Schneider CA, et al. Dobutamine magnetic resonance imaging predicts contractile recovery of chronically dysfunctional myocardium after successful revascularization. J Am Coll Cardiol 1998;31:1040–8.

[10] Schmidt M, Voth E, Schneider CA, et al. F-18-FDG uptake is a reliable predictory of functional recovery of akinetic but viable infarct regions as defined by magnetic resonance imaging before and after revascularization. Magn Reson Imaging 2004;22:229–36.

[11] Wellnhofer E, Olariu A, Klein C, et al. Magnetic resonance low-dose dobutamine test is superior to SCAR quantification for the prediction of functional recovery. Circulation 2004;109:2172–4.

[12] Ichikawa Y, Sakuma H, Suzawa N, et al. Late gadolinium-enhanced magnetic resonance imaging in acute and chronic myocardial infarction. Improved prediction of regional myocardial contraction in the chronic state by measuring thickness of nonenhanced myocardium. J Am Coll Cardiol 2005;45:901–9.

[13] Bodi V, Sanchis J, Lopez-Lereu MP, et al. Usefulness of a comprehensive cardiovascular magnetic resonance imaging assessment for predicting recovery of left ventricular wall motion in the setting of myocardial stunning. J Am Coll Cardiol 2005;46:1747–52.

[14] Kirschbaum SW, Baks T, Gronenschild EH, et al. Addition of the long-axis information to short-axis contours reduces interstudy variability of left-ventricular analysis in cardiac magnetic resonance studies. Invest Radiol 2008;43:1–6.

[15] Cerqueira MD, Weissman NJ, Dilsizian V, 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.

[16] Holman ER, Buller VG, de Roos A, et al. Detection and quantification of dysfunctional myocardium by magnetic resonance imaging. A new three-dimensional method for quantitative wall-thickening analysis. Circulation 1997;95: 924–31.

[17] Efron B, Tibshirani RJ. An introduction to the bootstrap; 1993.

[18] Zhou XH, Obuchowski NA, McClish DK. Statistical methods in diagnostic medicine; 2002.

[19] Selvanayagam JB, Kardos A, Francis JM, et al. Value of delayed-enhancement cardiovascular magnetic resonance imaging in predicting myocardial viability after surgical revascularization. Circulation 2004;110:1535–41.

[20] S.W. Kirschbaum, A. Rossi, R.T. van Domburg, et al. Contractile reserve in segments with nontransmural infarction in chronic dysfunctional myocardium using low-dose dobutamine CMR. JACC Cardiovasc, Imaging 3:614–22.

[21] Baer FM, Theissen P, Crnac J, et al. Head to head comparison of dobutamine-transoesophageal echocardiography and dobutamine-magnetic resonance imaging for the prediction of left ventricular functional recovery in patients with chronic coronary artery disease. Eur Heart J 2000;21:981–91.

[22] Cornel JH, Bax JJ, Elhendy A, et al. Biphasic response to dobutamine predicts improvement of global left ventricular function after surgical revascularization in patients with stable coronary artery disease: implications of time course of recovery on diagnostic accuracy. J Am Coll Cardiol 1998;31:1002–10.

[23] Trent RJ, Waiter GD, Hillis GS, McKiddie FI, Redpath TW, Walton S. Dobutamine magnetic resonance imaging as a predictor of myocardial functional recovery after revascularisation. Heart 2000;83:40–6.

[24] Plein S, Greenwood JP, Ridgway JP, Cranny G, Ball SG, Sivananthan MU. Assessment of non-ST-segment elevation acute coronary syndromes with cardiac magnetic resonance imaging. J Am Coll Cardiol 2004;44:2173–81.

[25] Hoye A, Tanabe K, Lemos PA, et al. Significant reduction in restenosis after the use of sirolimus-eluting stents in the treatment of chronic total occlusions. J Am Coll Cardiol 2004;43:1954–8.

[26] Shewan LG, Coats AJ. Ethics in the authorship and publishing of scientific articles. Int J Cardiol 2010;144:1–2.