Prediction of Left Ventricular Function After Drug-Eluting Stent Implantation for Chronic Total Coronary Occlusions

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OBJECTIVES We studied the effect of drug-eluting stent implantation for chronic total coronary occlusion (CTO) on left ventricular volumes and function and assessed the predictive value of magnetic resonance imaging (MRI) performed before revascularization.

BACKGROUND The effect of recanalization of CTO on long-term left ventricular function and the value of myocardial viability assessment with MRI is incompletely understood.

METHODS Twenty-seven patients underwent contrast-enhanced MRI before and five months after successful drug-eluting stent implantation for CTO. A CTO was defined as a complete occlusion of a major epicardial coronary artery existing for at least six weeks (mean, 7 ± 5 months). Myocardial wall thickening and left ventricular volumes were quantified on cine-images, and the transmural extent of infarction (TEI) was scored on delayed-enhancement images.

RESULTS A significant decrease in mean end-systolic volume index (34 ± 13 ml/m² to 31 ± 13 ml/m²; p = 0.02) and mean end-diastolic volume index (84 ± 15 ml/m² to 79 ± 15 ml/m²; p < 0.002) was observed, whereas the mean ejection fraction did not change significantly (61 ± 9% to 62 ± 11%; p = 0.54). The extent of the left ventricle that was dysfunctional but viable before revascularization was related to improvement in end-systolic volume index (R = 0.46; p = 0.01) and ejection fraction (R = 0.49; p = 0.01) but not to the end-diastolic volume index (R = 0.10; p = 0.53). Segmental wall thickening improved significantly in segments with <25% TEI (21 ± 15% to 35 ± 25%; p < 0.001), tended to improve in segments with 25% to 75% TEI (18 ± 22% to 27 ± 22%; p = 0.10), whereas segments with >75% TEI did not improve (4 ± 14% to −9 ± 14%; p = 0.54).

CONCLUSIONS Drug-eluting stent implantation for a CTO has a beneficial effect on left ventricular volumes and function that can be predicted by performing MRI before revascularization. (J Am Coll Cardiol 2006;47:721–5) © 2006 by the American College of Cardiology Foundation

Chronic total coronary occlusions (CTO) are observed in 35% to 50% of patients with significant coronary disease undergoing diagnostic angiography (1,2). Percutaneous coronary intervention (PCI) for CTO is increasingly used as treatment strategy and accounts for 10% to 15% of all angioplasties. New catheter-based techniques have led to higher success rates of PCI (3), and drug-eluting stents significantly reduce the incidence of restenosis and reocclusion (4). However, the effect of PCI on myocardial contractility and left ventricular volumes of the individual patient with CTO is incompletely understood. Previous studies used left ventricular angiography to study left ventricular function and volumes after balloon angioplasty or bare-metal stents for CTO, but results have been equivocal (5–7). These equivocal results may partly be caused by the rather crude measurements offered by left ventricular angiography in conjunction with the high restenosis and reocclusion rate after balloon angioplasty or bare-metal stent implantation. The use of contrast-enhanced magnetic resonance imaging (ce-MRI) permits refined assessment of myocardial contractility, left ventricular volumes, and the transmural extent of infarction (TEI) (8). We used ce-MRI to study the effect of drug-eluting stent implantation for CTO on left ventricular volumes and function and to evaluate the diagnostic value of ce-MRI to predict improvement in regional and global left ventricular function.

METHODS

Patient population. Patients scheduled for percutaneous revascularization of a CTO of a native coronary artery and without contraindications for MRI were prospectively selected for enrollment in this study. Of 50 selected patients, 3 patients refused to participate, 47 patients underwent MRI at 16 ± 16 days before PCI, and 27 patients underwent follow-up MRI at 5 ± 1 months after PCI. Twenty patients did not undergo follow-up MRI; in 13 patients, PCI was not successful, 1 patient gained too much weight to fit into the scanner, 1 patient had a defibrillator implanted, and 5 patients refused re-investigation. All procedures were performed by operators highly experienced in the treatment of CTO, with the interventional strategy left to the discretion of the operator. All participants gave...
written informed consent to the study protocol, which was approved by the medical ethics committee of the Erasmus Medical Center, Rotterdam. More patient characteristics are listed in Table 1.

### MRI protocol

A 1.5-T MRI scanner with a dedicated four-element phased-array receiver coil was used for imaging (Signa CV/i, GE Medical Systems, Milwaukee, Wisconsin). Cine-MRI was performed at baseline and follow-up with a steady-state free-precession technique. Sequence details have been published (9). To cover the entire left ventricle, 9 to 12 consecutive slices of 8 mm in the short-axis view were planned on the four chambers (gap of 2 mm). Delayed enhancement imaging was performed at the baseline scan 10 to 20 min after administration of gadolinium-diethytriaminepentaacetic acid (0.1 mmol/kg intravenously, Magnevist, Schering, Germany). A two-dimensional T1-weighted inversion recovery gradient-echo sequence was used as described previously (9). The inversion time was adjusted per patient to null the signal of remote myocardium. Slice locations were copied from the locations of the cine-images.

### Definitions and data analysis

All conventional angiograms before revascularization were evaluated by two experienced observers (Drs. Baks and van Geuns). Collateral function was scored on a four-point scale (10). The CTO was defined as a complete occlusion of a major coronary artery existing for at least six weeks as obtained from either the date from the previous angiogram or the clinical history of prolonged anginal chest pain or myocardial infarction. Left ventricular volumes and mass were quantified using a dedicated software package (Mass, Medis, the Netherlands). Papillary muscles were considered as part of the left ventricular volume. Regional analysis per patient was assessed using a 16-segment model excluding the apex (11). Segmental wall thickening (SWT) was calculated by (end-systolic – end-diastolic wall thickness)/end-diastolic wall thickness × 100%. Myocardial segments were considered dysfunctional if SWT was 45% or less (12). To study the effect of revascularization on SWT, segments in the perfusion territory of a CTO (defined on conventional angiogram) were analyzed for wall thickening at baseline and at five months.

Two investigators (Drs. Baks and van Geuns), blinded for the clinical data, analyzed delayed enhancement images for the TEI, and the decision was made on the basis of consensus. The TEI was calculated by dividing the hyper-enhanced area by the total area in 16 segments per patient as: 1 = 0% (TEI), 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100%. A myocardial segment with a 0% to 25% TEI was considered viable (13). The percentage of dysfunctional but viable myocardium per patient was calculated by dividing the sum of all dysfunctional but viable segments by the total amount of segments.

### Statistical analysis

Data are presented as mean ± standard deviation. Two-way analysis of variance with repeated measures over time followed by Bonferroni correction (four groups) was used to compare changes in SWT in viable segments (<25% TEI), possible viable segments (26% to 75% TEI), non-viable segments (>75% TEI), and remote segments between baseline and follow-up and to evaluate differences in SWT at baseline and at follow-up. The change in left ventricular volume indexes was tested with paired Student t tests. The relationship between the viability score per patient and the change in left ventricular volumes was analyzed with univariate linear regression analysis. All tests were performed two-sided, and significance was accepted at a p value of ≤ 0.05.

### RESULTS

#### Patient population

The CTO was located in the left anterior descending coronary artery in 14 patients, in the right coronary artery in 10 patients, and in the circumflex coronary artery in 3 patients. The mean duration of occlusion was 7 ± 5 months. The overall mean procedural time was approximately 143 ± 62 min. A total of 432 segments were available for analysis, and no segments had to be excluded because of image quality.

#### Left ventricular function and volumes

Mean end-systolic volume index decreased significantly from 34 ± 13 ml/m² to 31 ± 13 ml/m² (p = 0.02; 66 ± 29 ml to 60 ± 28 ml, p = 0.02), and mean end-diastolic volume index...
decreased significantly from 84 ± 15 ml/m² to 79 ± 15 ml/m² (p < 0.002; 162 ± 38 ml to 153 ± 36 ml, p = 0.002). Overall mean ejection fraction remained unchanged from 61 ± 9% to 62 ± 11% (p = 0.54) (Fig. 1). The extent of the left ventricle that was dysfunctional but viable before revascularization was related to improvement in end-systolic volume index (R = 0.46; p = 0.01) and ejection fraction (R = 0.49; p = 0.01) but not to the end-diastolic volume index (R = 0.10; p = 0.53) (Fig. 2).

In dysfunctional but viable segments (<25% TEI), mean SWT improved significantly from 21 ± 15% to 35 ± 25% (p < 0.001), whereas mean SWT tended to improve from 18 ± 22% to 27 ± 22% (p = 0.10) in segments with 25% to 75% TEI and did not improve (4 ± 14% to −9 ± 14%; p = 0.54) in segments with >75% TEI (Fig. 3). Improvement of more than 10% in absolute SWT was observed in 76% of dysfunctional segments (16 of 21) with TEI 0%, in 67% (4 of 6) with TEI 1% to 25%, 35% (6 of 17) with TEI 26% to 50%, 35% (5 of 14) with TEI 51% to 75%, and 0% (0 of 4) with TEI >75%. The sensitivity, specificity, and positive and negative predictive values of MRI for predicting segmental improvement were 65% (20 of 31), 77% (24 of 31), 74% (20 of 27), and 69% (24 of 35), respectively, using <25% TEI as the threshold for viability. Left ventricular mass index did not change significantly from 64 ± 13 g/m² to 63 ± 11 g/m² (p = 0.25; 127 ± 27 g to 122 ± 22 g, p = 0.26).

**DISCUSSION**

We showed the beneficial effect of successful drug-eluting stent implantation for CTO on end-systolic and end-diastolic volumes and SWT. Furthermore, we showed that the extent of dysfunctional but viable myocardium before revascularization was related to improvement in end-systolic volume, ejection fraction, and SWT.

Previous studies investigated the effect of successful PCI for CTO on left ventricular function (5,14–18). Overall, the average of left ventricular improvement is not overwhelming and is likely to escape detection by crude measurements of global left ventricular ejection fraction, and seems to be limited to fairly recent occlusions. In the current study, we used up-to-date methodology to study a well-defined group of patients with a duration of occlusion of more than six months.

![Figure 1](image1.png)

**Figure 1.** The change in left ventricular volume indexes between baseline and five months of follow-up measured with magnetic resonance imaging (MRI). The mean ejection fraction remained unchanged, but end-systolic and end-diastolic volume index decreased significantly.

![Figure 2](image2.png)

**Figure 2.** Improvement in end-systolic volume index (ESVI) and ejection fraction (EF) was related to the extent of dysfunctional but viable myocardium before revascularization. No relationship was found for end-diastolic volume index (EDVI).
weeks and well-developed collars making PCI feasible. All patients received a drug-eluting stent with a CTO, but other beneficial effects such as prevention of arrhythmias and prevention of recurrent myocardial ischemia were not assessed.

**Study limitations.** Angiography at follow-up was not performed, but no clinical evidence of recurrent myocardial ischemia was noted and all patients received a drug-eluting stent with very low numbers of restenosis reported (4). The definition for CTO was arbitrarily set at six weeks in the present study, whereas previous studies defined CTO as seven days until three months of occlusion time. Delayed enhancement patterns at follow-up were not studied, but might provide further insight in the pathophysiological mechanisms underlying recovery of function of viable myocardium.

**CONCLUSIONS**

Implantation of a drug-eluting stent in patients with a CTO has a beneficial effect on myocardial contractility and left ventricular volumes. Improvement in regional and global left ventricular function after revascularization is related to the extent of dysfunctional but viable myocardium assessed with MRI before revascularization.

**REFERENCES**


