Left ventricular reconstruction in ischemic cardiomyopathy

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Chapter 8

Transcatheter and minimally invasive surgical left ventricular reconstruction for the treatment of ischaemic cardiomyopathy: preliminary results

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ABSTRACT

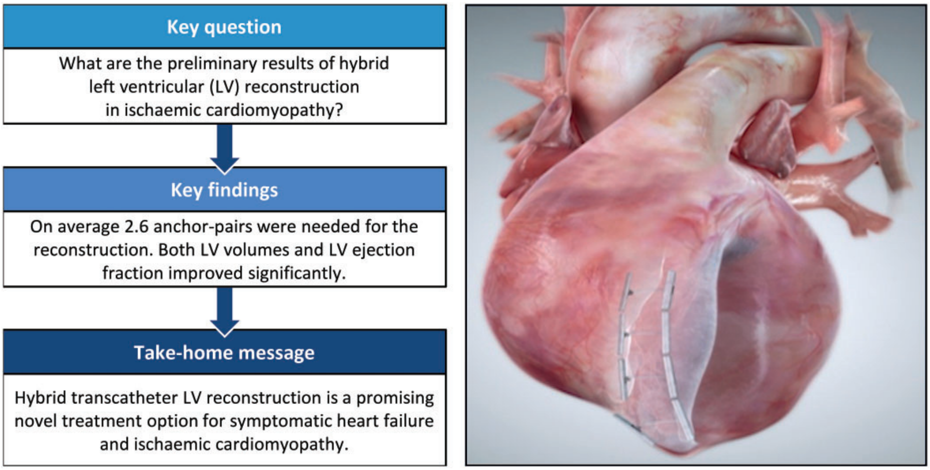
Objectives: Adverse remodelling of the left ventricle (LV) after myocardial infarction (MI) results in a pathological increase in LV volume and reduction in LV ejection fraction (EF). We describe the preliminary results of a novel, multicentre, combined transcatheter and minimally invasive technique to reconstruct the remodelled LV by plication and exclusion of the scar, and to reduce the excess volume, resulting in decreased wall stress and increased EF.

Methods: A novel hybrid transcatheter technique that relies on microanchoring technology (Revivent TC™ System, BioVentrix Inc., San Ramon, CA, USA) was used. The LV is reconstructed without the use of extracorporeal circulation by plication of the fibrous scar. This is achieved by implantation of a series of internal and external microanchors brought together over a PEEK (poly-ether-ether-ketone) tether to form a longitudinal line of apposition between the LV free wall and the anterior septum. Internal anchors are deployed by a transcatheter technique on the right side of the ventricular septum through the right internal jugular vein. Paired external anchors are advanced through a left-sided minithoracotomy and deployed on the LV epicardium. A specialized force gauge is used to bring these 'right ventricle (RV)-LV' anchors together under measured compression forces. LV-LV' anchor pairs through the LV apex beyond the distal tip of the RV complete the reconstruction. Patients who were considered eligible for the procedure presented with symptomatic heart failure (New York Heart Association class >II) and ischaemic cardiomyopathy (EF <40%) after anteroseptal MI. All patients had a dilated LV with either an a- or dyskinetic scar in the anteroseptal wall and apex of ≥50% transmurality.

Results: Between October 2016 and April 2017, 9 patients (8 men, 1 woman; mean age 60 ± 8 years) were operated on in 2 Dutch centres. Procedural success was 100%. On average, 2.6 anchor pairs were used to reconstruct the LV. Comparing echocardiographic data preoperatively and directly postoperatively, LV ejection fraction increased from 28 ± 8% to 40 ± 10% (change +43%, $P < 0.001$) and LV volumes decreased LV end-systolic volume index 53 ± 8 ml/m^2 to 30 ± 11 ml/m^2 (change -43%, $P < 0.001$) and LVEDVI 75 ± 23 ml/m^2 to 45 ± 6 ml/m^2 (change -40%, $P = 0.001$). In 1 patient, an RV perforation occurred which necessitated conversion to full sternotomy. One patient underwent a postoperative revision because of RV restriction. After the removal of 1 'RV-LV' anchor pair, the patient recovered completely. Hospital mortality was 0%. The median duration of intensive care unit stay was 2 days [interquartile range (IQR) 1–46 days], and the median length of hospital stay was 9 days (IQR 3–57 days).

Conclusions: Hybrid transcatheter LV reconstruction is a promising novel treatment option for patients with symptomatic heart failure and ischaemic cardiomyopathy after anteroseptal MI. The early results demonstrate that the procedure is safe and results in a significant improvement in EF and reduction in LV volumes in the early postoperative period.

Keywords: Hybrid left ventricular reconstruction • Ischaemic heart failure • Ischaemic cardiomyopathy • Left ventricular remodelling



INTRODUCTION

Remodelling of the left ventricle (LV) after myocardial infarction (MI) results in an increase in volume and a reduction in ejection fraction (EF). Transmurality of the infarction determines whether or not a true LV aneurysm will result. Surgical ventricular reconstruction (SVR) reduces the LV volume and reconstructs the shape of the remodelled LV leading to improvement in systolic function. Consensus from expert centres for SVR is that appropriately selected patients could benefit from a well-conducted procedure sufficiently reducing the LV end-systolic volume (LVESV) and reconstructing the elliptical shape of a normal LV [1–4]. Conventional SVR relies on full median sternotomy, the use of extracorporeal circulation, cardioplegic arrest and ventriculotomy, which inflicts a considerable physical burden on often vulnerable patients with ischaemic heart failure. A less invasive procedure able to achieve the same results as conventional SVR is appealing, and we report our preliminary results of a novel hybrid procedure which is a combination of a transcatheter intervention with a minimally invasive surgical procedure. The remodelled LV is reconstructed by plication of the anteroseptal and apical LV scar using microanchoring technology without the use of extracorporeal circulation.

METHODS

Patient characteristics

Patients considered eligible for the procedure presented with symptomatic heart failure [New York Heart Association (NYHA) class ≥II] and ischaemic cardiomyopathy (EF <40%) after anteroseptal MI. All patients had a dilated LV with either an a- or dys-kinetic scar in the anteroseptal wall and apex with ≥50% transmurality. None of the patients in this study were contraindicated to surgery, and in case of a conversion to full sternotomy, it was also an option to perform a conventional SVR as was described before [5]. The exclusion criteria were previous sternotomy and significant valvular pathology, necessitating concomitant valvular repair or replacement. The institutional medical ethics committees of both centres approved the study, and written informed consent was obtained from all participating patients.

Preoperative workup

Preoperative planning requires Gadolinium-enhanced magnetic resonance imaging (or contrast computed tomography in the presence of ICD/pacemaker) to clearly define the scar morphology. Scarred regions must comprise at least 50% of the wall thickness to enable a safe anchor implantation. Additionally, preoperative echo is adopted to define wall motion abnormalities, identify areas of viable myocardium, measure LV volumes and determine valvular dysfunction and EF.

Hybrid transcatheter procedure

The hybrid transcatheter technique relies on microanchoring technology (Revivent TC™ System, BioVentrix Inc., San Ramon, CA, USA) and is called less invasive ventricular enhancement (LIVE). The procedure is performed under general anaesthesia and 'off-pump', e.g. without the use of extracorporeal circulation. Transvenous excess for the reconstruction is through the right internal jugular vein. The surgical approach is through a left-sided minithoracotomy in the 4th, 5th or 6th intercostal space depending on the location of the apex of the LV. For safety reasons, in these first patients, arterial and venous sheaths are inserted in the common femoral artery and vein, respectively. Through these sheaths, guidewires can be readily inserted over which cannulas can be inserted for emergent institution of extracorporeal circulation. The LV is reconstructed by plication of the fibrous scar. This is achieved by implantation of a series of internal and external microanchors (Fig. 1) brought together over a PEEK (poly-etherether- ketone) tether to form a longitudinal line of apposition between the LV free wall and the anterior septum (Figs 2 and 3). Internal anchors are deployed by a transcatheter technique on the right side of the ventricular septum through a delivery catheter inserted in the right internal jugular vein. Paired external anchors are advanced through a left-sided minithoracotomy and deployed on the LV epicardium. The surgeon punctures the anterolateral scar, and thereafter, the (anterior) septum with an 18-Gauge needle, through which a guidewire is advanced into the RV. After the introduction of a 6-F introducing sheath over this wire, an angulated catheter (8-F internal mammary artery (IMA) or multipurpose) is advanced through this introducing sheath and directed towards the pulmonary artery. A 0.018 inch guidewire is now advanced into the direction of the pulmonary artery. In the meantime, the interventional cardiologist has deployed a snare in the pulmonary artery. The guidewires can be snared, and now over the guidewires, the 8-F IMA or multipurpose catheter can be pulled into the 14-F introducing sheath, which has been inserted through the internal jugular vein. In this way, a transseptal catheter is in place from the internal jugular vein to the anterolateral surface of the LV. Through this 'delivery canal', the PEEK tether with the microanchors can be placed 'over the wire'. A specialized force gauge (Fig. 4) is used to bring these 'RV-LV' anchors together under measured compression forces (1–2 Newtons of force). 'LV-LV' anchor pairs through the LV apex beyond the distal tip of the RV to complete the reconstruction (Figs 5 and 6). A combination of LV and RV angiograms and fluoroscopy transoesophageal echocardiography guide the reconstruction. Postoperatively, the patients are maintained on coumadins or warfarin for 3 months.

Figure 1: Internal and external anchors.

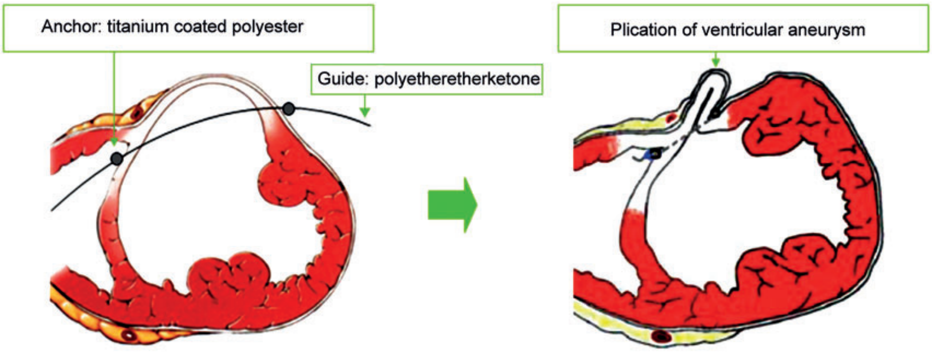


Figure 2: An illustration of a plicated anterolateral scar onto the interventricular septum.

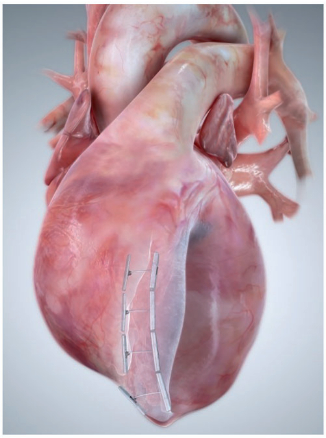


Figure 3: An illustration of the results.

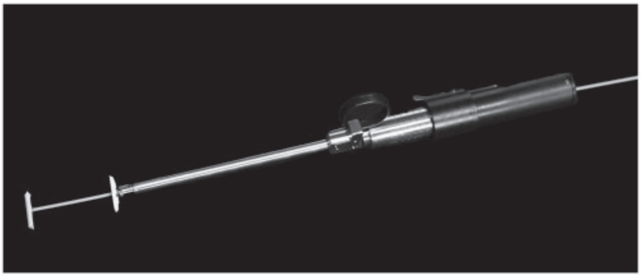


Figure 4: A specialized Forge gauge with the tether inserted and pushing on the external anchor.

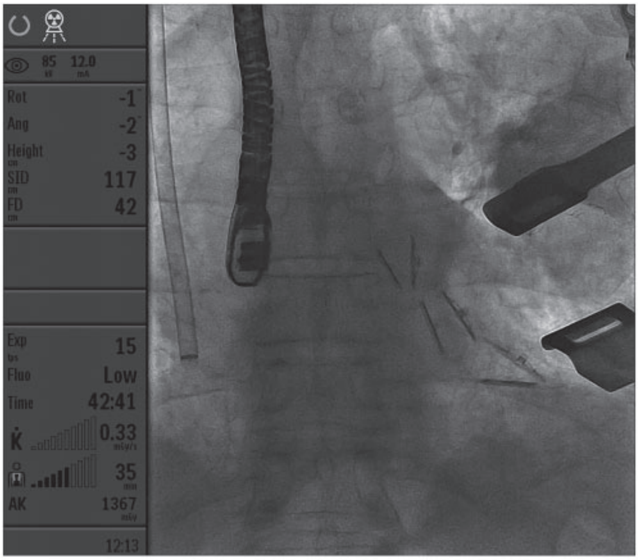


Figure 5: Intraprocedural fluoroscopy with anchor pairs in place.

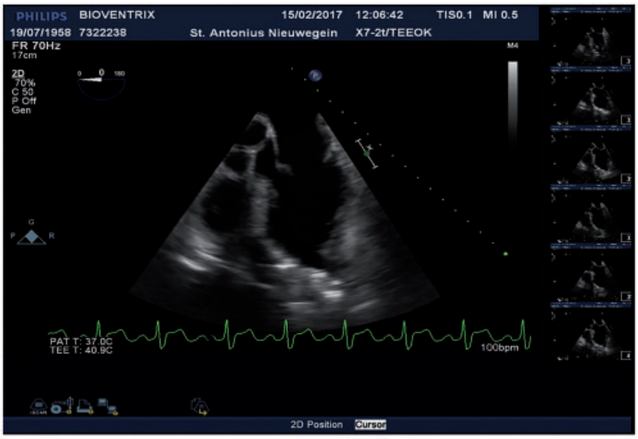


Figure 6: Intraprocedural transoesophageal echocardiography with completed reconstruction.

Clinical and echocardiographic examinations

Patients were given optimal medical treatment for heart failure after surgery. Functional status was assessed using the NYHA classification for symptoms of heart failure at discharge. Transthoracic echocardiograms were performed after surgery, just prior to hospital discharge. From these examinations, LV ejection fraction, LV dimensions and volumes and the presence of MR and TR were assessed. The sphericity index (SI) was calculated as the ratio between the greater cross-sectional diameter and the greater longitudinal diameter of the LV in end-systolic apical 4-chamber view. This index was used as an indicator of geometry change.

Statistical analysis

Statistical analysis was performed using the SPSS 16.0 statistical software (SPSS Inc., Chicago, IL, USA). Categorical variables are described as frequencies and percentages and compared using the χ^2 test with Yates's correction. Continuous data are expressed as mean ± standard deviation or median with ranges and compared using the Wilcoxon signed-rank test for paired data. A *P*-value <0.05 was considered statistically significant.

Table 1: Preoperative patient characteristics (*n*= 9)

Age (years), mean ± SD	60 ± 8
Male gender, *n* (%)	8 (89)
Height (cm), mean ± SD	177 ± 8
Weight (kg), mean ± SD	83 ± 17
BSA (m^2), mean ± SD	2.0 ± 0.3
ICD, *n* (%)	3 (33)
Diabetes, *n* (%)	2 (22)
Atrial fibrillation, *n* (%)	2 (22)
COPD > GOLD Class II, *n* (%)	1 (11)
LVEF (%), mean ± SD	28 ± 8
LVESD (mm), mean ± SD	44 ± 7
LVEDD (mm), mean ± SD	56 ± 5
LVESVI (ml/m^2 BSA), mean ± SD	53 ± 8
LVEDVI (ml/m^2 BSA), mean ± SD	75 ± 23
Mitral regurgitation ≥ Grade 2, *n* (%)	1 (11)
Tricuspid regurgitation ≥ Grade 2, *n* (%)	1 (11)
NYHA class	2.7 ± 0.4

BSA: body surface area; COPD: chronic obstructive pulmonary disease; GOLD: global initiative on obstructive lung disease; ICD: internal cardioverter defibrillator; LVEDD: left ventricular end-diastolic dimension; LVEDVI: left ventricular end-diastolic volume index; LVEF: left ventricular ejection fraction; LVESD: left ventricular end-systolic dimension; LVESVI: left ventricular end-systolic volume index; NYHA: New York Heart Association; SD: standard deviation.

RESULTS

Between October 2016 and April 2017, 9 patients (8 men and 1 woman; mean age 60 ± 8 years) were operated on in 2 Dutch centres (Table 1).

Procedural success was 100%. In all patients, a reconstruction with complete exclusion of the aneurysmatic part of the LV was achieved. On average, 2.6 anchor pairs were used to reconstruct the LV. The average skin-to-skin time for the procedure was 217 ± 100 min (Table 2). Comparing echocardiographic data preoperatively and directly postoperatively, LV ejection fraction increased from 28 ± 8% to 40 ± 10% (change +43%, $P < 0.001$) and LV volumes decreased from left ventricular end-systolic volume index (LVESVI) 53 ± 8 ml/m^2 to 30 ± 11 ml/m^2 (change -43%, $P < 0.001$) and LVEDVI 75 ± 23 ml/m^2 to 45 ± 6 ml/m^2 (change -40%, $P = 0.001$). The SI remained unchanged from 0.5 ± 0.1 to 0.5 ± 0.1 ($P = 0.7$). One patient had a moderate–severe functional mitral regurgitation prior to surgery, which decreased to moderate after the reconstruction. In 2 patients, a mild increase in tricuspid regurgitation was observed after surgery (mild increase to moderate in both patients).

Table 2: Procedural data (*n*=9)

Internal anchors (*n*), mean ± SD	1.3 ± 0.5
External anchors (*n*), mean ± SD	1.2 ± 0.7
Total anchors (*n*), mean ± SD	2.6 ± 0.7
Procedural success (%)	100
Skin-to-skin (h, min), mean ± SD	21 ± 100
Fluoroscopy time (mm:s), mean ± SD	50:50 ± 31:26
Dosage (mGy/cm^2), mean ± SD	2277 ± 2379

SD: standard deviation.

In 1 patient, an RV perforation occurred which necessitated conversion to full sternotomy. After the conversion, the bleeding was controlled and the reconstruction completed. Additionally, a single venous graft to the right coronary artery was constructed on the beating heart. A percutaneous coronary intervention was also an option to treat this lesion. One patient underwent a postoperative revision because of RV restriction. Initially, 4 anchor pairs were placed. During the postoperative course, a clinical condition resembling diastolic failure with tachycardia and low output was observed. Transoesophageal echocardiography showed a small right ventricular cavity (~50% of the preoperative volume) with an improved left ventricular systolic function when compared preoperatively (left ventricular ejection fraction postoperatively 36% compared to left ventricular ejection fraction (LVEF)

25% preoperatively). The interventricular septum seemed to bulge into the right ventricular cavity due to the reconstruction. The decision was made to remove 1 'RV-LV' anchor pair during a revision surgery. Patient was reoperated through the initial left anterior thoracotomy. The RV-LV anchor pair could easily be released: the external anchor was removed, and the bleeding from the puncture site of the anchor was controlled temporally by manual compression with a gauze. The internal anchor stayed fixed with the tether in the septum. At follow-up, the position of this detached internal anchor remained unchanged. After the revision, the patient recovered completely. Hospital mortality was 0%. The median duration of intensive care unit stay was 2 days [interquartile range (IQR) 1–46 days], and the median length of hospital stay was 9 days (IQR 3–57 days). Average NYHA class at discharge was 2.3 ± 0.7 (2, 3 and 3 patients in NYHA Classes I–II, II and III, respectively), compared to 2.7 ± 0.4 preoperatively ($P = 0.58$; 1, 3 and 5 patients in NYHA Classes II, II–III and III, respectively). A detailed summary of the pre- and postoperative echocardiographic data and follow-up duration of all 9 patients is provided as Supplementary Material.

DISCUSSION

Postinfarction ventricular remodelling leading to ischaemic heart failure is an important cause for morbidity and mortality. Efforts to improve ventricular function, symptoms and survival have included medical therapy such as neurohormonal inhibition and cardiac resynchronization therapy. Although these treatments have demonstrated clinical effect, they do not address the underlying pathology: coronary artery disease and dysfunction of the remodelled myocardium [4]. Revascularization can improve contractile function in ischaemic but viable myocardial segments, but both non-ischaemic dysfunctional myocardium and areas of scar tissue will not improve. SVR procedures have demonstrated—in selected patients—that the dysfunctional myocardium can be favourably remodelled. Usually, these procedures are performed in adjunct with coronary artery bypass surgery [6]. The Hypothesis 2 arm of the multicentre, randomized controlled Surgical Treatment for Ischaemic Heart Failure (STICH) trial compared coronary artery bypass grafting (CABG) alone with a combined procedure CABG and SVR. No difference was demonstrated for the primary outcome of death from any cause or rehospitalization for heart failure [2]. Also, both procedures were evenly effective in a reduction of symptoms and an improvement of the 6-min walk test. Obviously, a greater reduction in LVESVI was achieved with the combined procedure of CABG and LV reconstruction. Michler *et al.* [7] analysed the subgroup of patients from the STICH trial who had left ventricular volumes examined at baseline and at 4 months postoperatively (555 of 1000 patients) to determine whether any magnitude of postoperative end-systolic volume reduction affected survival. They found that a survival benefit was realized in patients after CABG and LV reconstruction compared to CABG alone when a postoperative LVESVI of 70 ml/m^2 BSA was achieved. They also found that a reduction in LVESVI of 30% could only be realized in 45% of the patients. Interestingly, in 17% of the patients after combined CABG and LV reconstruction, no change or even an increase in LVESVI at 4 months was observed.

We evaluated the preliminary results of a novel hybrid transcatheter technique also called less invasive ventricular enhancement (LIVE) to reconstruct the remodelled LV after an anteroseptal MI by plication of the anteroseptal LV scar using microanchoring technology. Compared to conventional LV reconstruction, the hybrid technique does not rely on a full median sternotomy, the use of extracorporeal circulation, cardioplegic arrest and ventriculotomy. All of which inflicts a considerable physical burden on vulnerable and sometimes frail patients. So far, only a case report of this technique has been published [8]. Our early results in a small series of patients demonstrated that the procedure is both safe and results in a significant improvement in EF and reduction in LV volumes. Di Donato *et al.* [7, 9] suggested that one of the goals of LV reconstruction is an LVESVI of less than 60 ml/m^2. The results of the subanalysis of the STICH trial confirm this idea, but the cut-off closer to 70 ml/m^2 for the benefit of the reconstruction. We found an average reduction in LVESVI of 43%, and moreover, in all patients, a postoperative LVESVI of <60 ml/m^2 body surface area was achieved. A generally accepted fact is that surgical reduction in LV volume is beneficial; however reduced wall stress and improved systolic function are counterbalanced by a reduction in the diastolic function (less distensibility) [4]. Whether this negative impact on the diastolic function is of the same magnitude with this hybrid transcatheter technique as the conventional surgical procedure has to be evaluated in future studies. Also, longer follow-up studies are needed to evaluate the clinical effect and stability over time. Concerning the reshaping of the LV, we found no change in the SI. This was also previously described in the article by Di Donato *et al.* [11] and the RESTORE group in 2006. We consider this as an indicator that the hybrid reconstruction has an effect on the global shape of the ventricle, as both LV long-axis and basal LV dimensions have to be reduced to maintain the same SI. If only the apex was amputated in this procedure, the sole reduction in LV long axis would lead to an increase in the SI. Furthermore, this procedure is a standalone LV reconstruction, so should revascularization be indicated, a percuteneous coronary intervention (PCI) procedure could be performed either preoperatively or postoperatively. Theoretically, important functional mitral regurgitation could be reduced because of the improvement in LV systolic function and reduction in LV volumes.

Although our preliminary results are very promising, we would like to emphasize that the patients were highly selected. A sufficient transmural anteroseptal scar should be present for safe transseptal anchor placement and plication. The extent of the scar in both the interventricular septum and the anterolateral wall also dictates the amount of volume reduction that can be achieved. We also demonstrated that care has to be taken not to create a too-restrictive RV implantation of internal anchors on the RV septum far posterior and external anchors on the same time far lateral, may lead to bulging of the septum in between after plication. In a pre-existing relatively small RV, this can lead to a restriction. Fortunately, revision of the reconstruction is possible but most likely reduces the efficacy of the reconstruction.

LIMITATIONS

The present study is an observational study of the early results of a small number of patients operated on in 2 Dutch centres. However, apart from a case report and an experimental paper of the technique in an ovine model, this is the first article describing the clinical results of this novel technique. These findings should be confirmed in other, larger studies with a longer follow-up. Because this technique requires that all anchors should be placed well into the scar tissue, possibly not all the aneurysmatic tissues might be excluded for this technique. We have demonstrated, however, that this does not lead to an inferior anatomical reconstruction of the LV.

CONCLUSIONS

Hybrid transcatheter LV reconstruction is a promising novel treatment option for patients with symptomatic heart failure and ischaemic cardiomyopathy after anteroseptal MI. Early results demonstrate that the procedure is safe and results in a significant improvement in EF and reduction in LV volumes in the early postoperative period.

SUPPLEMENTARY MATERIAL

Supplementary material is available at ICVTS online.

Conflict of interest: Patrick Klein acts as a proctor and consultant for BioVentrix Inc.

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