Multislice computed tomography-guided surgical repair of acquired posterior left ventricular aneurysms: demonstration of mitral valve and left ventricular reverse remodelling

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Abstract

OBJECTIVES: Involvement of the mitral valve (MV) apparatus represents a challenge in surgical ventricular repair (SVR) of posterior left ventricular (LV) aneurysms. This study sought to investigate whether multislice computed tomography (MSCT) assessment can be used to optimize the surgical procedure for posterior LV aneurysms.

METHODS: Thirty patients (m : w = 24 : 6, age 38–78, median 66 years; mean New York Heart Association class 2.98) with posterior LV aneurysm were operated upon. MSCT was performed in 24 patients before and after surgery. End-diastolic and end-systolic volumes of LV and aneurysm were indexed to body surface area (LVEDVI/LVESVI, AEDVI/AESVI). The MV apparatus was characterized by coaptation distance (CD), tenting area (TA), MV closure angle (MVCA), MV annulus area (MV AA) and interpapillary muscle distance (IMD).

RESULTS: Thirty-day mortality was 10% and 5-year survival rate was 83%. After surgery, LVEDVI decreased from 151.2 ± 84.1 to 85.7 ± 28.3 ml/m² (P = 0.001) and LVESVI from 110.6 ± 88.8 to 50.2 ± 22.9 ml/m² (P = 0.001). LV ejection fraction increased from 31.5 ± 15.1 to 43.4 ± 9.9% (P = 0.001). Preoperative MSCT showed significantly higher values of MV AA, CD and TA in patients who needed MV repair or replacement. Postoperative reduction of mitral regurgitation in patients without MV surgery corresponded with significant reduction in intercommissural diameter, anteroposterior diameter, MV AA, TA, CD, MVCA and IMD.

CONCLUSIONS: MSCT represents an excellent diagnostic tool for the assessment of MV and LV geometry. MSCT-guided SVR of submitral LV aneurysms leads to excellent mid-term results. On the basis of the MSCT assessment, we propose an algorithm for surgical planning in posterior LV aneurysms.

Keywords: Myocardial infarction • Aneurysm • Mitral valve • Heart failure • Imaging

INTRODUCTION

Surgical repair of posterior left ventricular (LV) aneurysms poses a technical challenge because of their localization in myocardial segments adjacent to the mitral valve (MV), and especially so in cases of involvement of the MV apparatus. To approach the aneurysm safely and to decide on the surgical strategy, the critical issue of reconstruction is resection of the aneurysm with preservation and restoration of the shape and function of the LV/MV complex, and—in cases of mitral apparatus involvement with severe mitral regurgitation (MR)—additional MV repair or replacement.

The underlying pathology in these cases is more frequently LV pseudoaneurysm than true aneurysm. While pseudoaneurysms are the result of acute free wall rupture (which as a complication of acute myocardial infarction has an incidence of 3.7% and causes 4% mortality [1]) and are contained by overlying adherent pericardium, true ventricular aneurysms present in thinned dyskinetic areas of scarred myocardium. Whereas pseudoaneurysms require urgent surgical resection because of the danger of rupture, true aneurysms can be operated upon electively or sometimes treated conservatively. Posterior and lateral localization is found in ~11% of all surgically treated true LV aneurysms, as reported by Jeganathan et al. [2] and Mickleborough et al. [3, 4].

Concomitant ischaemic MR signifies an increased operative risk with higher perioperative morbidity and mortality in patients undergoing surgical ventricular repair (SVR). A stepwise algorithm was recently proposed by Jeganathan et al. [2] for the planning of combined MV and ventricular reconstructive surgery in anterior
LV aneurysms. On the other hand, remodelling and distortion of the LV play a key role in the pathogenesis of ischaemic MR, whereby posterolateral localization of myocardial infarction and involvement of the posterior papillary muscle are associated with increased severity of ischaemic MR [5]. In the attempt to decipher the characteristics of patients who developed recurrent MR, in the subanalysis of the recently published prospective trial from the Cardiothoracic Surgical Trials Network [6], Kron et al. [7] identified the presence of basal inferior aneurysm/dyskinesis as an independent predictor of recurrent ischaemic MR after MV repair.

Owing to the limited surgical experience in single institutions, the literature on the planning of operative approaches and outcome of surgical repair of posterior LV aneurysms is sparse [8–12].

Recent technical advances in multislice computed tomography (MSCT) enable the analysis of a primary three-dimensionally acquired dataset, detailed study of cardiac anatomy with free choice of view planes and ventricular functional assessment with very high accuracy [13].

This study aimed to investigate the potential of ECG-triggered MSCT in the evaluation of aneurysm morphology and changes in LV and mitral geometry and function, and to analyse our single-centre early and mid-term results of surgical reconstruction of posterior LV aneurysms using preoperative MSCT assessment (Video 1).

METHODS

Study design

The diagnosis of posterior LV true or pseudoaneurysm was made by echocardiography, computed tomography and angiography. The surgeons made the decision regarding the operative approach and patch size on the basis of MSCT data. Echocardiography and MSCT were repeated during the first postoperative week. The data evaluated before and after surgery were analysed and compared retrospectively.

Study population

Data of all consecutive patients with coronary artery disease who underwent SVR for LV aneurysms of posterior medial, posterior or posterior lateral localization in our hospital between February 2006 and May 2014 were retrospectively analysed. The written informed consent for surgery was obtained from all patients or their representatives. This study was approved by our Institutional Review Board with waiver of need for patient consent.

Operative procedures

All LV repairs were performed through a median sternotomy approach under cardiopulmonary bypass. The definite diagnosis of a true or pseudoaneurysm was made by direct surgical inspection with the assessment of aneurysm localization, the presence of pericardial adhesions, myocardial disruption and thrombotic masses. After coronary artery bypass grafting (CABG), LV repair and MV repair or replacement were performed (Video 2).

Intraoperative transoesophageal echocardiography was routinely performed to assess the adequacy of LV and MV repair. Mitral surgery was performed in patients with aneurysm defect area larger than 20 cm², MSCT morphological signs of MV tethering and echocardiographically proven MR grade >2. All surgeons had access to the complete preoperative MSCT assessment.

Multislice computed tomographic measurements

Contrast-enhanced ECG-triggered cardiac scanning was performed using a first- or second-generation dual-source scanner (Somatom Definition, Somatom Definition Flash, Siemens AG, Erlangen, Germany). To study the anatomy and geometry of the LV and MV apparatus, the dataset was reconstructed with a slice...
thickness of 0.75 mm and reconstruction increment of 0.4 mm, from early systole (0% of cardiac cycle) to end diastole (90% of cardiac cycle) in steps of 10%.

LV end-diastolic volume (LVEDV) and end-systolic volume (LVESV) were obtained (syngo.via Cardiac Function, Siemens AG) (Fig. 1). The systolic and diastolic LV sphericity index was calculated as short to long LV axis ratio. Morphological characteristics of the aneurysm in terms of myocardial disruption, aneurysm defect area, apposition of thrombotic masses and pericardial effusion were evaluated.

Additionally, the aneurysm's end-systolic and end-diastolic volumes (AEDV and AESV) and end-diastolic aneurysm defect area (ADA) were estimated using the same software tool with manually defined 2D aneurysm borders to the remaining part of the left ventricle (Fig. 1).

MV geometry was studied in the reconstructed mid-systolic phase, when the valve is closed. Using the two- and four-chamber view and the reconstructed LV short-axis view, a plane coaxial to the MV was reconstructed. At the level of the MV annulus, the annulus area was quantified by planimetry; anteroposterior and intercommissural diameters (APD, ICD) were measured on the level of MV segments A2/P2 (Fig. 2).

The corresponding three-chamber view representing the anteroposterior plane through the MV segments A2/P2 was used for the measurements of coaptation distance (CD) as the distance between the leaflet coaptation point and mitral annulus plane, tenting area (TA) as the area between the two mitral leaflets below the mitral annulus plane and MV closure angle (MVCA) as the angle between the leaflets at the coaptation point (Fig. 2).

The severity of corresponding MR was estimated by echocardiography. Measurements of the submitral apparatus, including interpapillary muscle distance (IMD) and distances and angles between the MV annulus and anterior and posterior papillary muscle head (AnAPMD, AnPMD, AnAPMA, AnPPMA), were also made in the reconstructed mid-systolic phase using the same planes. CT morphological characteristics of other elements of the submitral apparatus—chordae, papillary muscle—and load-bearing LV wall dysfunction were analysed semi-qualitatively.

**Statistical analysis**

Continuous variables are presented as mean ± SD. Categorical variables are presented as numbers with percentages. Means were compared with the paired, two-tailed Student’s t-test. Actuarial survival curves were calculated using the Kaplan–Meier method. P < 0.05 was considered statistically significant. The data were analysed with SPSS 20 (SPSS, Chicago, IL, USA).

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Figure 1: Assessment of left ventricular and aneurysmatic volume. (A and B) MSCT reconstruction of four-chamber view and two-chamber view for semi-automatic measurement of LV volume including aneurysm in diastole (pink area). (C and D) Short-axis view and two-chamber view for measurement of separate aneurysm volume in diastole (pink area). MSCT: multislice computed tomography; LA: left atrium; LV: left ventricle; An: aneurysm; Ao: aorta.
RESULTS

Thirty patients with aneurysms of the posterior medial, posterior and posterior lateral LV wall due to myocardial infarction underwent SVR. The median age of the patients was 66 years (range: 38–78 years). There were 6 (20%) female and 24 (80%) male patients. Mean New York Heart Association (NYHA) class was 2.98 ± 0.16. The mean preoperative LV ejection fraction (LVEF), estimated with echocardiography, was 34.7 ± 10.2%. Seven patients had concomitant MR of grade ≥2. There were 17 patients with heart failure of NYHA class III and 8 patients in NYHA class IV. Preoperative patient characteristics are presented in Table 1.

The median overall survival period was 52.2 ± 5.1 months (range: 0.47–98.4 months). Overall 30-day mortality was 10% (3/30). One- and 5-year actuarial survival rates estimated by the Kaplan–Meier method were 90.0 ± 0.1 and 83.1 ± 0.1%, respectively (Supplementary Figure 1).

Procedural outcome

For posterior ventricular reconstruction in the population of 30 patients, patch ventriculoplasty was performed in 15 patients (50%) and linear repair in 15 (50%). Sixteen patients (53%) had associated myocardial revascularization. Six patients (20%) underwent concomitant MV surgery. MV repair was performed in three (10%) and MV replacement also in three (10%) patients. One patient needed reoperation due to the secondary covered LV perforation after 9 months. Three patients (10%) died in hospital due to septic shock (n = 2) or multiorgan failure (n = 1). All of them had had combined surgery (one—SVR and CABG, two—SVR, CABG and MV replacement). Operative and postoperative data are summarized in Table 2.

Changes in left ventricular geometry and function

Postoperative echocardiographically measured LVEF had increased from 34.7 ± 10.2 to 40.2 ± 9.2% (P = 0.091) and mean LVEDD had decreased from 57.5 ± 6.9 to 52.7 ± 6.7 mm (P = 0.028).

LV volumetric parameters measured in MSCT in 24 patients were also significantly decreased. LVEDVI decreased from 151.2 ± 84.1 to 85.7 ± 28.3 ml/m² (P = 0.001) and LVESVI from 110.6 ± 88.8 to 50.2 ± 22.9 ml/m² (P = 0.001). There was a statistically significant increase in LVEF from 31.5 ± 15.1 to 43.4 ± 9.9% (P = 0.001) after posterior SVR. The diastolic LV SI was significantly decreased from 0.60 ± 0.13 to 0.53 ± 0.07 (P = 0.007), showing reverse remodelling of the LV towards a more normal shape (for full comparison of LV parameters, see Table 3).
Left ventricular aneurysm characteristics before ventricular restoration

Aneurysms were localized in posterior myocardial segments in 9 patients, in posterior medial segments in 7 patients and in posterior lateral segments in 8. Aneurysm morphology was analysed using such criteria as myocardial disruption, thrombotic opposition, pericardial adhesion and pericardial effusion, based on 4D reconstructions of MSCT data. LV pseudoaneurysm according to these criteria was suspected in 19 patients (79%) and verified intraoperatively in 17 patients (71%). ADA was smaller than 10 cm² in 9 patients, 10–20 cm² in 9 patients and larger than 20 cm² in 6 patients (5 of these 6 patients needed MV surgery). The ADA was used to estimate the required patch size and as one of the criteria to select patients needing MV surgery. Preoperative aneurysm end-diastolic volume index (AEDVI) showed a systolic increase of >10 ml/m² only in the 5 patients with AEDVI higher than 42.9 ml/m², demonstrating volume shift during systole of potential adverse haemodynamic significance. LV aneurysm characteristics are summarized in Supplementary Tables 1a and b.

Mitrail geometry and function

In our series, only 6 patients (20% of the whole population) needed concomitant mitral surgery; all of them received a preoperative MSCT assessment. Postoperative reduction of MR (from grade 0.84 ± 0.15 to 0.25 ± 0.09, P = 0.003) in 18 patients from the MSCT analysis group (n = 24) without concomitant MV surgery corresponded with a significant improvement of MV geometry: significant reduction in ICD, APD, MV annulus area (MVAA) and TA, shortening of leaflet CD and flattening of MVCA. Measurements of the submural apparatus that characterize MV tethering showed significant changes in such parameters as IMD from 33.4 ± 6.3 to 28.9 ± 6.0 mm (P < 0.001) and in AnAPMD and AnPPMD (anterior and posterior papillary muscle tethering length) from 23.6 ± 4.1 to 21.8 ± 3.7 (P = 0.027) and from 27.1 ± 3.9 to 23.9 ± 6.8 mm (P = 0.033), respectively. The complete data are reported in Table 4.

The preoperatively measured MVAA, TA and CD were significantly higher in 6 patients who needed MV repair/replacement (MVAA: 10.7 ± 1.7 vs 8.7 ± 1.5, P = 0.013; TA: 3.1 ± 1.4 vs 1.9 ± 0.5, P = 0.009; CD: 12.7 ± 2.6 vs 10.1 ± 2.0, P = 0.020), representing parameters potentially predictive for the necessity of concomitant MV surgery. Volumetric parameters of the LV and aneurysm as well as aneurysm localization showed no significant differences between the SVR and SVR + MV repair/replacement groups, whereas ADA was markedly higher in the SVR + MV repair/replacement group.

The comparison of clinical variables between these two groups shows higher prevalence of patients with severe MR, LVEF <20%, NYHA IV symptoms and high hospital mortality in the SVR + MV repair/replacement group, however, without statistical significance (Supplementary Tables 2a–c).
Linear versus patch repair

Patch ventriculoplasty was performed in 11 (46%) and linear repair in 13 (54%) of 24 analysed cases. The differences between these two groups in patient age (61 vs 65 years, P = 0.22), presence of NYHA IV symptoms (27 vs 8%, P = 0.51) or severe impairment of LV function (18 vs 8%, P = 1.0) and hospital mortality (9 vs 8%, P = 1.0) were not statistically significant. The differences in CT morphological variables—LV and aneurysm volumes, aneurysm defect area and localization and geometrical parameters of the MV and submitral apparatus—did not reach statistical significance (Supplementary Tables 3a–c).

DISCUSSION

SVR is currently considered an effective therapeutic strategy in the management of patients with ischaemic heart failure.

Surgical procedures for the more common anterolateral LV aneurysms are well developed, studied and standardized [4, 14, 15]. Posterior LV aneurysms are much more heterogeneous because of the variability of their localization, from posterior medial to posterior lateral, and of their morphological presentation, from acute wall necrosis with a very small defect to pseudoaneurysms with adherence to the pericardium, to true scar aneurysms. Our institutional results show that the majority in this mixed group are patients with pseudoaneurysms (71%), which require prompt surgical intervention because of potential danger of rupture or thrombotic complications. Restoration of LV shape and function and preservation of the mitral geometry need to be achieved in such an operation. This task requires quick and at the same time precise planning using all available diagnostic tools before surgery.

Diagnostic testing

Accurate assessment of the MV, LV and aneurysm morphology and their spatial relations is key for successful surgical ventricular restoration [14]. The questions that should be answered with the available imaging modalities concern the localization and size of aneurysm, size of basic wall defect, spatial relationship to and potential involvement of the mitral apparatus, morphological features of the aneurysm in the proper sense of true or pseudoaneurysm, assessment of global LV function, MR and potential adverse haemodynamic effects of the aneurysm.

The most widely available imaging modality remains echocardiography, but its utility depends highly on the patient’s anatomy and the operator’s skill. Cardiac magnetic resonance (CMR) is now considered the ‘gold standard’ technique for preoperative non-invasive diagnostic evaluation of ventricular aneurysms [14, 16]. Localization, depth and extension of the myocardial scar, asynergic areas, ventricular wall disruption and thrombus formation can be excellently recognized by CMR. However, implanted pacemaker devices or acute cardiac decompensation with the need for full intensive care equipment restrict the feasibility of CMR.

MSCT without technical contraindications, with short examination time and the possibility of unrestricted reconstructions of primarily acquired three-dimensional data, has become increasingly used. Former studies [13, 17, 18] demonstrated that MSCT is a valuable tool to study LV and MV geometry and function. Delgado’s group showed very high suitability of MSCT for studying MV anatomy and provided a concept of geometric indices of clinical interest for the functional MV/LV complex [18].

For our study, we developed a combined measurement protocol comprising LV volumetric and functional parameters, geometric parameters of the mitral apparatus, and localization, morphological characteristics and volumetric assessment of the aneurysm. Precise analysis of LV and MV dimensions and reliable distinction between true and pseudoaneurysm were possible, based on CT data. Complementary to MSCT, we used echocardiography for the evaluation of myocardial viability and severity of MR pre- and postoperatively.

Surgical approaches and results

As stated above, restoration of LV shape and function with preservation of the mitral geometry is the aim of surgical treatment in posterior LV aneurysms. The parameters of aneurysm localization and morphology, size of the aneurysm neck and extension of the perfused pseudoaneurysm allow precise planning of the operative steps. LV and aneurysm volumes, measured in MSCT, allow exact estimation of the required volume reduction of the LV, the possibility of linear repair and precise sizing of the Dacron patch for patch repair.

Efficient LV volume reduction towards a physiological range of LVESVI of <60–70 ml/m² is essential to improve survival after surgical repair. Di Donato et al. [19] showed that a postoperative LVESVI of >60 ml/m² is an independent predictor of mortality. The latest analysis of the STICH trial data [20] shows that a statistically significant reduction in mortality was achieved in those patients attaining an LVESVI of <70 ml/m². In our study group, the LVESVI was markedly reduced from 110.6 ± 88.8 to 50.2 ± 22.9 ml/m² (P = 0.001) accompanied by a statistically significant increase in LVEF from 31.5 ± 15.1 to 43.4 ± 9.9% (P = 0.001) and improvement of LV shape, with a significant decrease in diastolic LV sphericity index from 0.60 ± 0.13 to 0.53 ± 0.07 (P = 0.007), showing reverse remodelling of the LV towards more normal shape.

Concomitant correction of severe MR is an essential part of the surgical procedure for the following reasons: MR is highly relevant for haemodynamic stability immediately after surgery, for the severity of postoperative heart failure and for clinical prognosis and survival [2, 21, 22]. Severe MR was present in 7 patients (23% of the whole population). Six patients (20%) needed concomitant mitral repair or replacement; this subgroup shows a markedly higher quota of NYHA IV symptoms (33%), LVEF <20% (17%) and hospital mortality (33%). We identified MSCT morphological variables of potential predictive relevance for the necessity of concomitant mitral surgery—ADA, MVAA, CD and TA—which differ with statistical significance between patients who needed SVR alone and those who needed SVR with concomitant MV surgery.

A remarkable result of our study is that SVR alone led to a reduction in mild MR (from grade 0.84 ± 0.15 to 0.25 ± 0.09, P = 0.003), with concomitant improvement in MV geometry as shown by the statistically significant reduction of mitral annulus diameters, mitral annulus area and TA, shortening of CD, flattening of MVCA and reduction of IMD (Table 4). These changes reveal a geometric remodelling effect towards a more physiological shape of the MV by SVR alone through improved LV geometry, realignment of papillary muscles and reduced wall tension.

We, therefore, propose an MSCT-based algorithm for structured planning of the surgical procedure (Fig. 3) that allows not only identification of the mechanism of severe MR as related to LV distortion due to aneurysm but also performance of the LV repair
applying an undersized patch and consequent approximation of papillary muscles with the recovery of mitral function (Fig. 4).

Surgical outcome

In our series, three patients died in hospital, accounting exclusively for the overall 30-day mortality of 10%. All of them died due to septic shock or multiorgan failure and all of them had had combined surgery (one—SVR and CABG, two—SVR, CABG and MV replacement). Jeganathan et al. [2] reported hospital mortality of 13.3% in patients who underwent combined SVR and MV surgery, 27% of whom had an aneurysm with posterior localization. His group identified NYHA class IV symptoms, preoperative atrial fibrillation, previous cardiac surgery and presence of ischaemic MR as significant risk factors for increased operative mortality.

One- and 5-year actuarial survival rates were 90 and 83% in our study population. Mickleborough et al. [4] reported 1-, 5- and 10-year actuarial survival of 92, 82 and 62% in patients who underwent SVR for anterior and posterior LV aneurysms. Dor et al. [14] found hospital mortality rates of 8.1 and 4.8% and 5-year survival rates of 82 and 85% in early and late series of patients who underwent SVR for both localizations, respectively, partially combined with mitral surgery. Garatti et al. [22] reported a 30-day mortality of 8.3% in patients after SVR for anterior aneurysm and 5.4% after SVR for posterior aneurysm, with 5-year survival rate of 80 and 75% and 10-year survival of 60 and 58%, respectively. Our institutional hospital mortality and survival rates are absolutely comparable with those of other groups, although our patient collective presumably had substantially higher morbidity and despite the larger proportion of patients with pseudoaneurysms.

Limitations

It is to be acknowledged that the current study has certain limitations. First, by its nature, it is subject to the restrictions of a retrospective study of prospectively collected datasets. Second, the study cohort is relatively small.
CONCLUSION

This study reports one of the largest series of patients undergoing SVR for aneurysm of the posterior LV wall, in which a surgical procedure was accompanied with systematic analysis of morphological and functional data.

With valuable information about aneurysm localization, its extent and effect on LV and MV geometry, obtained with MSCT, the reconstruction of posterior LV aneurysms can be performed with good early and mid-term results.

MSCT also reveals a marked reduction in LV volumes and improved LV and MV function after surgery, shows a reverse remodelling effect on the MV apparatus achieved by posterior SVR alone and provides predictive parameters for necessity of concomitant mitral surgery. We propose an MSCT-based algorithm that allows identification of the mechanism of severe MR as related to LV distortion and performance of the LV repair applying an undersized patch to improve the MV geometry.

The MSCT imaging approach described here can be successfully used to design new strategies for interventional and surgical treatment of LV and MV pathology.

SUPPLEMENTARY MATERIAL

Supplementary material is available at ICVTS online.

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