Original Research

Mitral Valve Repair Results in Better Right Ventricular Remodelling Than Valve Replacement for Degenerative Mitral Regurgitation: A Three-Dimensional Echocardiographic Study

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Introduction: Right ventricular (RV) remodelling may be an important determinant of clinical outcome in patients undergoing mitral valve surgery for mitral regurgitation. In the present study we hypothesised that, compared to valve replacement, mitral valve repair for degenerative mitral regurgitation may result in better RV remodelling, as assessed by real-time, three-dimensional echocardiography (RT3DE).

Methods: Forty unselected patients with degenerative mitral valve regurgitation were recruited prospectively. Two-dimensional (2DE) and RT3DE studies were performed prior to surgery and 6 months postoperatively. RV volumes, stroke volume, ejection fraction and mass, as well as RV pressures were calculated. Regression analysis was used to demonstrate the effect of surgical mitral repair and replacement on reverse RV remodelling.

Results: Twenty-one patients underwent mitral valve repair and 19 valve replacement. Mean age was 59.5 ± 15.4 years. Five patients who underwent repair (23.8%) developed recurrent MR within 6 months postoperatively. RV systolic pressure was reduced from 39.3 ± 11.9 mmHg, to 25.4 ± 8.3 mmHg after surgery ($p=0.027$). Compared to preoperative volumes, 6 months after surgery there was a significant reduction in RV diastolic volume and stroke volume (from 106.4 ± 16.3 ml to 80.4 ± 12.1 ml and from 69.2 ± 15.4 ml to 52.2 ± 14.1 ml, respectively, $p<0.001$), and an increase in RV ejection fraction (from 54.5 ± 9.2% to 67.3 ± 8.5%, $p<0.001$). Over a 6-month follow-up period there were no deaths. Overall, the functional class was significantly improved in 39/40 patients (97.5%) but there was no difference between the repair and replacement groups. Using a multivariate regression analysis model including all parameters composing RV remodelling postoperatively, mitral valve repair was the strongest predictor of reverse RV remodelling (reduction of RV end-diastolic volume, $p<0.01$; reduction of RV mass, $p<0.01$; reduction of tricuspid regurgitant velocity, $p=0.019$).

Conclusions: Mitral valve repair leads to more favourable reverse RV remodelling, assessed by RT3DE, compared to valve replacement. This may have important clinical implications.

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Right ventricular (RV) function plays an important role in determining cardiac symptoms and exercise capacity in chronic heart failure.[1-4] The RV, together with the pulmonary circulation, is a low-resistance system, in contrast to the left ventricle (LV) and the systemic circulation.[5,6] Septal geometry and motion are affected by the difference in ventricular pressures as a result of interventricular dependence. RV pressure overload causes the septum to bulge towards the LV cavity (D-shape deformation).[4,5] When the LV becomes volume loaded, as in severe mitral regurgitation (MR), pulmonary venous hypertension will develop, which leads to RV dilatation, hypertrophy and eventually RV failure.[5,6]

The RV plays an important role, not only for survival, but also for the postoperative course and functional recovery of the patient with valvular disease.[6,7] When RV failure occurs following surgery, postoperative mortality increases significantly.[7,8] Observational studies have supported the importance of RV ejection fraction (EF) as an independent predictor of survival in patients with heart failure.[9-12] However, the determination of RV volumes and EF with conventional echocardiography is challenging, and real-time, three-dimensional echocardiography (RT3DE) has recently been proposed as a robust method for the assessment of RV volumes and function.[13-15]

While mitral valve repair has good long-term survival compared to replacement,[16-18] no studies have evaluated the effects of repair versus replacement on reverse RV remodelling. Therefore, the aim of this study was to test the hypothesis that surgical mitral valve repair, compared to valve replacement, may have a beneficial effect on reverse RV remodelling, as assessed by RT3DE.

Methods

Study population and sample size calculation

Forty unselected patients with degenerative MR, who had been referred for mitral valve surgery, were recruited prospectively and consented to participate in this study. Patients were referred for mitral valve surgery according to the current guidelines.[15] Patients with cardiomyopathy and/or concomitant coronary artery disease were excluded, as were patients with heart block (second or third degree) and/or fast atrial fibrillation (more than 100 beats per minute). Patients with slow atrial fibrillation were not excluded, but care was taken to obtain three sequences with similar RR intervals to be used for RT3DE assessment. Images were acquired over 2 seconds or for 2 heartbeats. The mean value of three different sequences was calculated.[19]

The sample size for our patient cohort was calculated as N=34 in order to achieve 80% power, with a significance of type I error $\alpha=0.05$, for detecting a difference of 1 standard deviation between the two groups in RV end-diastolic volume pre and post mitral valve surgery. Those numbers were derived from the first 20 consecutive patients undergoing mitral valve repair, where there was a reduction of RV end-diastolic volume from 121.6 ± 22 ml to 98.4 ± 17.9 ml. Therefore, a standard deviation of 18 ml was selected for the power calculation of this study.

All patients underwent preoperative right and left heart catheterisation and coronary angiography as part of their surgical workup. New York Heart Association functional class was assessed according to clinical presentation and only patients requiring surgery for mitral valve disease were recruited to the study.

The study was approved by the local research ethics committee (08/H0707/144) and all subjects gave written informed consent.

Echocardiography

A comprehensive preoperative echocardiographic examination was performed within 24 hours prior to surgery and was repeated 6 months (184 ± 17 days) after surgery, using the same protocol. The echocardiographic protocol consisted of a conventional transthoracic two-dimensional study (2DE) first, followed by an RT3DE. All examinations were performed by a single operator (JG). Intra- and interobserver reproducibility for RT3DE has previously been reported by our group.[13] RT3DE data sets were obtained using the GE Vivid 7 cardiac ultrasound system (Horton, Norway) equipped with a central ×4 transducer. Images were acquired from apical four-chamber views with the patient in the left decubitus position, during a breath hold of 7 seconds. Images were then transferred to an offline workstation (4D analysis, TomTec, Munich, Germany). Serial short-axis reconstructions of the LV and RV volumetric datasets were then obtained and the endocardial contour was traced at 7 mm intervals with cross-reference to long-axis images for identification of the mitral annulus. End-diastolic (EDV) and end-systolic (ESV) LV and RV volumes and EF were calculated offline using the method of summation of discs and semi-automated border detection. Stroke volume (SV) was calculated by subtracting ESV from EDV, while EF was calculated as EDV-ESV/EDV. For the calculation of RV mass, the myocardial volume was calculated using 1.05 g/ml.[13,19,20,22]

RV systolic pressure (RVSP) was measured from maximal tricuspid regurgitant velocity (TRv) using the formula, RVSP = $4TRv^2$ + RAP, where RAP is the right atrial pressure, estimated from the inferior *vena cava* diameter and respiratory collapse.

To summarise, the following parameters were obtained and/or calculated:

- 2DE: LV dimensions in end-systole and end-diastole, thickness of interventricular septum (IVS) and posterior wall (LVPW), RVSP, RAP and TRv.
- RT3DE: RV EDV and ESV, SV, EF and RV-mass (Figure 1).

MR was quantified using the effective regurgitant orifice area, proximal isovelocity surface area, *vena contracta* and jet area/atrial area with comprehensive 2DE. The grade of regurgitation was assessed on a standardised scale from 0 (none) to 4 (severe). Prolapsing or flailing leaflets were assessed according to standard criteria and Carpentier's functional classification, with a precise characterisation of the segments involved.[15]

Patients were consented for both mitral valve repair and replacement. While the former was first considered by the surgeon in all patients, the valve was replaced in 19 of the 40 cases due to extensive annular calcification, bileaflet prolapse (Barlow disease), or extensive leaflet disease not allowing for optimal repair. All procedures were carried out by the same experienced surgeon in order to eliminate bias. In those patients requiring valve replacement (n=19), a bioprosthesis was used in 8 (42%) and a mechanical bileaflet valve in 11 (58%).

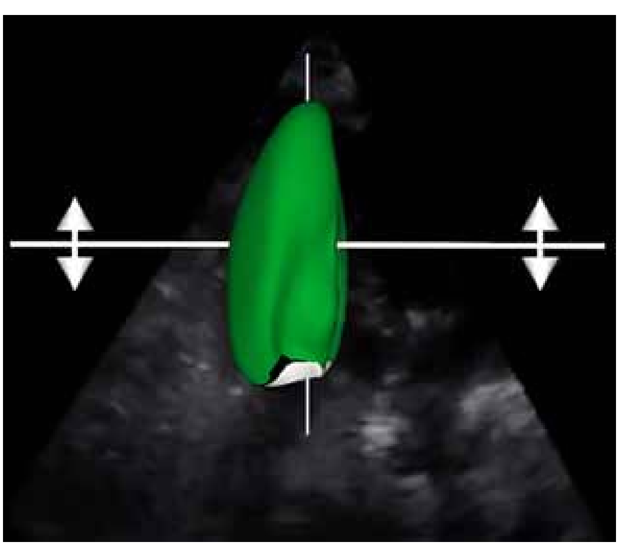

Figure 1. Calculation of right ventricular volumes and ejection fraction with real-time, three-dimensional echocardiography.

Mitral valve repair was accompanied by flexible annuloplasty ring insertion and artificial chordal implantation, with or without leaflet resection, and with concomitant radiofrequency ablation of atrial fibrillation when necessary. All patients had intraoperative transoesophageal echocardiography according to the standard practice in our institution, confirming successful mitral valve repair or mitral valve replacement without any residual MR.

Statistical analysis

Data were expressed as mean ± standard deviation for normally distributed values and median ± interquartile range when variables were not normally distributed. The normality of the distribution of each variable was assessed using the Kolmogorov-Smirnov test. For non-normally distributed variables, comparison of groups was performed with non-parametric tests and the cut-off value for significance was 0.05.

Univariate and multivariate regression analysis were further undertaken to evaluate the effect of mitral valve repair on RV remodelling (mitral valve repair = 1; mitral valve replacement = 0). The independent effect of mitral repair on RV remodelling was assessed following adjustment for the preoperative values of all RV remodelling parameters, namely RVEDV, RVESV, RVSV, RVEF, RV mass, and TRv. Statistical analysis was performed using the SPSS 17.0 (SPSS Inc., Chicago IL, USA) and Medcalc 11.1 (Medcalc, Software bvba, Belgium) software.

Results

Surgery and demographic data

Patients' demographics, comorbidities and operative data are presented in Table 1. The mean age was 59.5 ± 15.4 years. Twenty-five patients (62.5%) were in slow atrial fibrillation with a mean heart rate of 76 ± 12.7 beats per minute. Twelve hours post-surgery, only 2 patients (5%) remained in AF, while the rest were in sinus rhythm. Within 6 months of follow up, 19/40 patients were still in sinus rhythm (47.5%).

Postoperative outcome and functional class

There were no deaths for the duration of the study. Preoperatively, only one patient (2.5%) was in NYHA I, 10 patients (25%) were in NYHA II, 22 patients (55%) in NYHA III and 7 patients (17.5%) in

Table 1. Demographic data.

Variable	Mean value ± standard deviation
Age (years)	59.5 ± 15.4
BSA (m^2)	1.6 ± 0.27
BPT (minutes)	97 ± 23.7
CCT (minutes)	65.9 ± 21.8
EuroScore	5.4 ± 2.6
Mechanism of regurgitation:	
AMVLP	N=0
PMVLP	N=11
Mixed prolapse	N=29
Procedure:	
Repair	N=21
Replacement	N=19

BSA – body surface area; BPT – bypass time; CCT – cross-clamp time; AMVLP – anterior mitral valve leaflet prolapse; PMVLP – posterior mitral valve leaflet prolapse; N – number of patients.

	Pre-procedure	Post-procedure	Recurrent MR - pre	Recurrent MR - post
NYHA I	1	19		
NYHA II	10	18	1	2
NYHA III	22	2	1	2
NYHA IV	7	1	3	1

NYHA – New York Heart Association functional class.

NYHA IV. Postoperatively, 19 patients (47.5%) were in NYHA I, 18 patients (45%) in NYHA II, 2 patients in NYHA III and only one patient was in NYHA IV ($p<0.01$) (Figure 2). There were no differences in functional class between the repair and replacement groups ($p=0.65$).

Mitral valve surgery

Twenty-one patients underwent mitral valve repair: 4 patients had complete ring (CG-Future Medtronic: 2 patients 27 mm and 2 patients 29 mm) and the remaining 17 had band insertion (12 patients Duran band-Medtronic: 5 patients 25 mm, 5 patients 29 mm and 2 patients 31 mm) and 5 a Cosgrove Band (Edwards: 27 mm in 3 and 29 mm in 2).

Eleven patients (27.5%) had posterior mitral valve leaflet prolapse, involving one or two scallops, while 21 (72.5%) had bileaflet prolapse (anterior and posterior). In the repair group (n=21), the redundant tissue was excised using triangular or quadrangular resection and neo-*chordae* were inserted to allow for an improved coaptation line and to minimise billowing. In all cases the mitral annulus was reinforced with a flexible ring. In the replacement group (n=19), a bioprosthesis was selected in 8 patients (42%), while the remaining 11 (58%) received a mechanical valve.

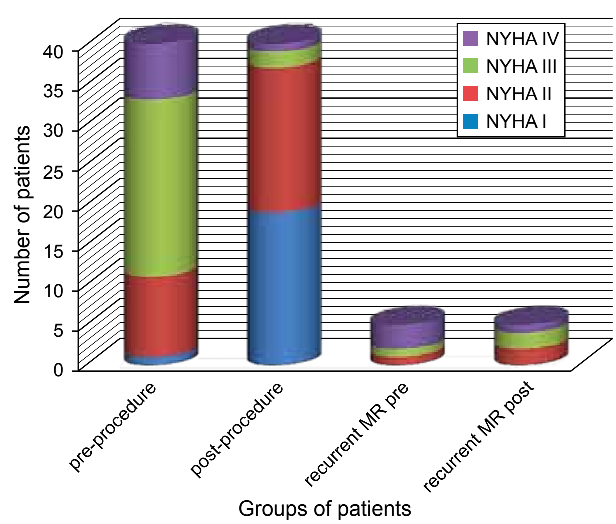

Figure 2. Functional class pre- and postoperatively. The subgroup of 5 patients who developed recurrent mitral regurgitation (MR) postoperatively is also reported. NYHA – New York Heart Association functional class.

Twenty-one patients overall had moderate or severe tricuspid regurgitation and underwent concomitant tricuspid annuloplasty.

Echocardiography - the left ventricle

The mitral regurgitant volume (from proximal isovelocity surface area) was 88 ± 13.5 ml (range: 67-108 ml) and the effective regurgitant orifice area was 0.46 ± 0.09 cm^2, prior to surgery.

LV fractional shortening (39.5 ± 7.8% vs. 40 ± 10.2%, p=0.62), IVS thickness (9 ± 1 mm vs. 9 ± 0.9 mm, p=0.8) and posterior wall (9 ± 0.9 mm vs. 9.8 ± 1.3 mm, p=0.42) were similar pre- and 6 months postoperatively. The left atrial size was, however, reduced postoperatively (from 53.1 ± 12 mm to 39.2 ± 5.8 mm, p<0.01) as were the LVEDV (from 165.2 ± 50.4 ml to 103.9 ± 34.2 ml, p<0.001) and LVSV (from 85 ± 42.6 ml to 50.8 ± 9.3 ml, p<0.05) (Table 2). LVEF was also reduced postoperatively (from 65.3 ± 9.3% to 42 ± 7.6% p<0.01), perhaps reflecting the elimination of MR.

Echocardiography – the right ventricle

There was a significant reduction in RV volumes postoperatively (RVEDV: from 106.4 ± 16.3 ml to 80.4 ± 12.1 ml, p<0.001; RVSV: from 69.2 ± 15.4 ml to 52.2 ± 14.1 ml, p=0.01), while the RVESV did not change significantly (from 37.2 ± 12.8 ml to 28.2 ± 9 ml, p=0.084). RV mass also decreased (from 68.4 ± 20 g to 53.6 ± 10.1 g, p<0.001). Overall, pulmonary pressures were, as expected, reduced following mitral valve surgery (TRv: from 3 ± 0.4 m/s to 2.3 ± 0.4 m/s, p=0.05) (Table 2). Tricuspid annular size was significantly reduced (from 46 ± 7.2 mm to 35.8 ± 4.1 mm, p<0.01).

Regression analysis following adjustment for preoperative values: repair versus replacement

According to the multivariate regression analysis, mitral valve repair had a far more favourable effect on RV reverse remodelling compared to replacement (Table 3). There was a reduction in TRv (beta coefficient=0.386, standard error=0.156, p=0.019), RVEDV (mitral valve repair: beta coefficient=0.762, standard error=0.117, p=0.001), RVSV (mitral valve repair: beta coefficient=0.562, standard error=0.128, p=0.001) and RV mass (mitral valve repair: beta coefficient=0.709, standard error=0.131, p=0.001).

Differences in RV remodelling in patients with recurrent MR

Thirty-five patients had grade 0 MR immediately postoperatively on transoesophageal echocardiography. Five patients (23.8%) from the repair group developed recurrent mild to moderate MR (grades 1-2), not related to operative factors, within 6 months following surgery.

Of those patients with recurrent MR, 2 were in functional class NYHA II, 2 in NYHA III, and only 1 in NYHA IV. Preoperatively, 3 patients were in NYHA IV, 1 in NYHA II and 1 in NYHA III. Thirty-one patients with successful mitral valve surgery were in NYHA I while 4 patients were in NYHA II.

When NYHA was added into the regression anal-

Table 2. Values of echocardiographic parameters pre- and postoperatively.

	Preoperative	Postoperative	p
RVEDV (ml)	106.4 ± 16.3	80.4 ± 12.1	<0.0001
RVESV (ml)	37.2 ± 12.8	28.2 ± 9	0.084
RVSV (ml)	69.2 ± 15.4	52.2 ± 14.1	<0.0001
RVEF (%)	54.5 ± 9.2	67.3 ± 8.5	<0.0001
RV mass (g)	68.4 ± 20	53.6 ± 10.1	<0.0001
TRv (m/s)	3 ± 0.4	2.3± 0.4	0.05
RVSP (mmHg)	39.3 ± 11.9	25.4 ± 8.3	0.027
RAP (mmHg)	7.8 ± 3.3	6.2 ± 2.5	0.43
LVFS (%)	39.5 ± 7.8	40 ± 10.2	0.62
LA diameter (mm)	53.1 ± 12	39.2 ± 5.8	<0.01
IVS (mm)	9 ± 1	9 ± 0.9	0.8
PW (mm)	9 ± 0.9	9.8 ± 1.3	0.42
LVEDV (ml)	165.2 ± 50.4	103.9 ± 34.2	<0.001
LVESV (ml)	65.2 ± 23.9	43.1 ± 12.6	0.32
LVSV (ml)	85 ± 42.6	50.8 ± 9.3	<0.05
LVEF (%)	65.3 ± 9.3	42 ± 7.6	<0.01

RV right ventricular; RVEDV – RV end-diastolic volume; RVSV – RV stroke volume; RVESV – RV end-systolic volume; TRv – velocity of tricuspid regurgitation; RVEF – RV ejection fraction; RVSP – RV systolic pressure; RAP – right atrial pressure; LA – left atrial; LV – left ventricular; LVFS – LV fractional shortening; IVS – thickness of interventricular septum; PW – thickness of posterior wall; LVEDV – LV end-diastolic volume; LVESV – LV end-systolic volume; LVSV – LV stroke volume; LVEF – LV ejection fraction.

Table 3. Effect of mitral valve repair on parameters of right ventricular reverse remodelling after adjustment for preoperative values.

Dependent value	Independent variable	B	Std error	p
	Mitral repair			
RVEDV		0.762	0.117	0.001
RVSV		0.562	0.128	0.001
RV mass		0.709	0.131	0.001
TRv		0.386	0.156	0.019

Abbreviations as in Table 2.

ysis, it was not related to recurrent MR ($p=0.43$). Nor were age ($p=0.31$), sex ($p=0.51$), preoperative atrial fibrillation ($p=0.86$), postoperative atrial fibrillation ($p=0.94$), size of ring used ($p=0.14$), or posterior leaflet repair ($p=0.18$) predictors of recurrent MR using univariate logistic regression analysis.

Comparison with patients with and without recurrent MR

Patients with and without MR had similar RVEDV (preoperative RVEDV: 86.3 ± 13.5 ml vs. 124.7 ± 24.3 ml, $p=0.06$). RVESV was smaller in patients who did not have recurrent MR (32.7 ml vs. 45.8 ml, $p=0.01$) while RVSV was higher (73.2 ml vs. 61 ml, $p=0.001$). Finally, patients with recurrent MR postoperatively (N=5) had a worse RVEF preoperatively (62.8 ± 7.2% without MR, vs. 47.5 ± 8.2% with MR, $p=0.01$).

Discussion

In this study we have shown that surgical repair of the mitral valve provides better reverse remodelling of the RV compared to mitral valve replacement.

RV remodelling post mitral valve surgery

Following successful mitral valve surgery, the most significant effect on the RV was the reduction of RVEDV and the increase in RVEF 6 months postoperatively. This is a dramatic reversal of a pathophysiological process secondary to severe MR in the absence of coronary disease. Given that the RV adapts well in time under volume loading conditions as opposed to pressure,[24-26] these findings illustrate the ability of the RV to regain its shape following correction of the increased afterload. Our population's mean age was relatively young (59.4 ± 15.4 years) and the physiological increase in pulmonary vascular resistance is still too mild at this stage[26] to contribute to increased pulmonary impedance and pressure loading, which would otherwise hinder RV recovery. Furthermore, a significant reduction in RV stroke volume (Table 2) may imply that the postoperative RV recovery is not limited to a simple reduction in length of a stretched myocardium, but represents a physiological improvement in contractility and RV performance.

Another important finding was the significant regression of RV hypertrophy following mitral valve surgery (Table 2). The RV hypertrophies in response to pressure overload[27,28] and the development of pulmonary venous hypertension (post-capillary) as a consequence of mitral valve disease. The relationship between hypertrophy and filling pressures is a complicated mechanism, which takes into consideration genetic factors such as over-expression of the gene for protein kinase C, the wall stress distribution, and the interventricular balance.[29-31]

Patients with impaired RV function after mitral valve replacement have higher 5-year mortality than patients without right heart failure.[4] While in our patient population there were no deaths, RV remodelling after mitral surgery is potentially a determinant of survival and prognosis.[32,33]

The effects of mitral repair on RV reverse remodelling: superiority over replacement

In this study we have demonstrated for the first time the benefits of mitral valve repair, compared with valve replacement, on reverse RV remodelling in patients with degenerative MR. Surgical repair led to a greater reduction in RVEDV and RVSV, and an increase in RVEF within 6 months of follow up, compared to preoperative values.

Five patients developed recurrent MR (23%), somewhat more that in other series,[17] but our patient population was not selected and involved all comers with degenerative MR. Despite the recurrence of MR, mitral repair proved to be superior to replacement as regards reverse RV remodelling.

The role of RT3DE

A robust assessment of RV function is important and RT3DE may overcome some limitations of conventional 2SE because of the cavity's crescent shape and increased trabeculation. Since RT3DE has a good agreement with cardiac magnetic resonance imaging for the assessment of RV volumes and function,[13] it could be used as the first line imaging modality for RV assessment in patients with MR. RT3DE overcomes some of the disadvantages of cardiac magnetic resonance imaging, as it can be easily used for serial imaging. When compared to cardiac magnetic resonance, RT3DE is less expensive and requires less time for acquisition, while it is widely available.

Limitations of the study

The number of patients in the present study was relatively small, but despite this the study was powered for 80% confidence. A larger patient cohort would increase the strength of our results.

The study was not randomised for the type of surgery. This however would be difficult to undertake in the current era, as valve repair is always the preferred surgical option in many centres. One could argue, therefore, that patients undergoing valve replacement had anatomically worse valves, which might have adversely affected the remodelling of the RV in the replacement group.

Given the small number of patients and the different ring diameters, the impact of the implanted valve or type of ring on RV remodelling was not assessed. However, the criteria for implantation and intention to treat were the same for all patients.

Finally, a longer follow up might show greater differences in RV remodelling between the two types of mitral valve surgery.

Conclusions

Mitral valve repair leads to improved reversed RV remodelling compared to valve replacement. This may have significant implications for a patient's outcome.

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