Assessment of acute changes in ventricular volumes, function, and strain after interventional edge-to-edge repair of mitral regurgitation using cardiac magnetic resonance imaging

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Aims
Whereas haemodynamic and echocardiographic studies suggest benefits for left ventricular (LV) function and cardiac output following reduction in LV preload by interventional edge-to-edge repair for mitral regurgitation (MR), there is limited data on volumetric and functional LV and right ventricular (RV) changes using cardiac magnetic resonance (CMR) imaging.

Methods and results
Patients with moderate to severe MR and high surgical risk underwent MitraClip™-implantation and CMR imaging before and within 7 days after the procedure. In addition to volumetric and flow studies, myocardial feature tracking (FT) technology for quantification of myocardial strain was applied. Twenty patients (age: 76 ± 8 years) with functional (n = 15) or degenerative MR (n = 5) with a mean logistic Euroscore I of 33 ± 16 underwent both successful MitraClip™ implantation and CMR imaging. MR fraction (36 ± 10 vs. 19 ± 12%; P < 0.001) and LV end-diastolic volume (115 ± 36 vs. 105 ± 41 mL/m²; P = 0.002) decreased significantly, whereas LV ejection fraction (42 ± 15 vs. 41 ± 16%, P = 0.8) and cardiac index (1.7 ± 0.5 vs. 1.8 ± 0.4 L/min/m², P = 0.4) remained unchanged. MitraClip™ implantation resulted in a significant impairment of circumferential (−12.8 ± 4.8 vs. −8.2 ± 3.3; P = 0.002) and radial strain (15.4 ± 7.7 vs. 9.6 ± 5.3; P = 0.02) on basal short-axis view. On RV level, there were no significant changes in end-diastolic volume (83 ± 19 vs. 84 ± 18 mL/m², P = 0.8), ejection fraction (42 ± 9 vs. 43 ± 11%, P = 0.8), or tricuspid regurgitation fraction (24 ± 17 vs. 25 ± 19%, P = 0.7). MitraClip™ implantation led to a significant improvement in New York Heart Association functional class (patients in functional class III–IV pre 100% vs. post 45%; P < 0.001).

Conclusion
In severely compromised patients, marked reduction in MR by MitraClip™ implantation might not result in immediate improved cardiac output and effective biventricular forward flow.

Keywords
Magnetic resonance imaging • MitraClip • Mitral insufficiency • Strain imaging

Introduction
Interventional edge-to-edge repair by MitraClip™ implantation has been shown to significantly reduce mitral regurgitation (MR) in patients with high surgical risk.1–4 Haemodynamic and echocardiographic studies suggest a reduction in left ventricular (LV) volumes and an increase in cardiac output following the intervention.5 Albeit, a significant number of patients experience no symptomatic improvement despite

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a successful MitraClip procedure. From a physiological point of view, reduction in MR results in an increase in LV afterload. The impact of this afterload increase on LV performance remains under discussion. A more sound understanding of changes in biventricular physiology following MitraClip™ implantation might help to improve patient selection and thereby outcome in this population. In patients with systolic heart failure, acute echocardiographic studies have shown a trend towards improvement in LV function, whereas recordings of pressure-volume-loops suggested an acute impairment in LV systolic function. In contrast, an acute invasive haemodynamic study reported a significant improvement in cardiac output following MR reduction by MitraClip™ implantation. However, these studies are limited by the fact that haemodynamic parameters were recorded under general anaesthesia. Likewise, the reproducibility and accuracy of echocardiographic volumetric assessments can be tempered by inadequate imaging windows.

Cardiac magnetic resonance (CMR) imaging is the considered method of choice for biventricular volumetric and functional assessment and allows for true quantification of valvular regurgitations as well as cardiac output. Aim of this study was therefore to assess the impact of MitraClip™ implantation in patients with significant MR on biventricular volumes and global function as well as on changes in mitral and tricuspid regurgitation and cardiac output. In addition, myocardial feature tracking (FT) technology for detection of potential subtle changes in regional and global LV systolic function by quantification of myocardial wall mechanics was applied.

Methods

In this prospective study, consecutive patients fulfilling the inclusion criteria were recruited. Patients were recruited at the Heart Center, University of Leipzig, Leipzig, Germany. Patients were included if they had severe symptomatic MR, high surgical risk, and therefore scheduled transcatheter mitral valve repair. Patients were classified into New York Heart Association of Echocardiography recommendations. Patients with contraindications to CMR or anatomical unsuitability for MitraClip™-implantation were excluded.

The pre-procedural diagnostic work-up included transthoracic and transoesophageal echocardiography as well as CMR imaging. Transthoracic echocardiography and CMR imaging were repeated within 7 days post procedure. Patients were classified into New York Heart Association (NYHA) functional class pre and post MitraClip™-implantation. The study was approved by the local ethics committee, and all patients provided written informed consent.

Echocardiographic assessment

Echocardiographic studies were performed on Vivid 7 system (General Electrics Healthcare, Chalfont St Giles, UK) by an experienced cardiologist. The origin and degree of MR were graded according to European Association of Echocardiography recommendations. At follow-up, MR severity was assessed with the technique reported by Foster et al as appropriate. As an estimate of right ventricular (RV) systolic pressure, the RV to right atrium pressure gradient was calculated from the tricuspid regurgitant jet (without addition of right atrial pressure) before and after MitraClip™ implantation. Furthermore, the presence of relevant intra-cardiac shunting or pulmonary regurgitation was excluded in all patients. The change in MR severity and the mean gradient across the mitral valve from pre- to post procedure was assessed on transthoracic and transoesophageal echocardiography prior to and by transthoracic echocardiography within 7 days after MitraClip™ implantation.

MitraClip™ procedure

Technical aspects of the MitraClip™ procedure have been described in detail previously. All procedures were performed under general anaesthesia in a dedicated hybrid operating room. In brief, the clip was positioned using 3D transoesophageal echocardiographic (iE33, Philips, The Netherlands) and fluoroscopic guidance. Multiple clip implantations were performed in case of insufficient MR reduction. Procedural success was defined as a reduction of MR to grade ≤2. Blood pressure was monitored invasively. After the procedure, patients were treated with acetylsalicylic acid (100 mg/day) for 6 months and clopidogrel (75 mg/day) for 30 days or in case of atrial fibrillation acetylsalicylic acid was substituted by phenprocoumon (target international normalized ratio 2.0–3.0).

CMR imaging

CMR imaging was performed within 2 days before and 7 days after the edge-to-edge mitral valve repair. Patients were examined with a 1.5 T scanner (Intera, Philips Medical Systems, Best, The Netherlands). All examinations were performed using a four-element phased-array coil setup.

Retrospective gated steady-state free-preccession cine magnetic resonance images of the heart were acquired in the vertical long-axis view, four-chamber view, short-axis views that included the entirety of both ventricles (9–12 slices), and two long-axis planes of the LV outflow tract for positioning of through-plane flow quantification. The cine steady-state free-precession sequence parameters were as follows: repetition time: 3.6 ms; echo time: 1.8 ms; flip angle: 60°; slice thickness: 8–10 mm (no gap in short-axis stack); matrix size: 240 × 236; field of view: 280–380 mm.

Aortic flow data were acquired with a flow-sensitive gradient echo sequence during free breathing. The flow-sensitive gradient echo sequence parameters were as follows: repetition time: 8 ms; echo time: 3.8 ms; flip angle: 30°; slice thickness: 5 mm; matrix size: 256 × 192; field of view: 280–380 mm, with a temporal resolution of ~30 ms reconstructed to 30 phases per cardiac cycle.

Assessment of LV and RV volumes was performed by manually defining the endocardial outline at end-diastole and end-systole in each of the short-axis cine images (cmr42, Circle Cardiovascular Imaging Inc., Calgary, Alberta, Canada). The end-diastolic and end-systolic phase for each ventricle was identified by visual inspection of the largest (end-diastolic) and smallest (end-systolic) blood pool area for each slice and manually segmented. The papillary muscles and, if present, coarse trabeculae were excluded from the blood pool. LV and RV end-diastolic volume (EDV) and end-systolic volume (ESV) were calculated using the slice summation method. The stroke volume (SV) was the difference between EDV and ESV, and EF was SV divided by EDV expressed as a percentage.

An effective LV SV was calculated to reflect the net forward blood flow into the aorta as follows: effective LV SV = total aortic forward flow – aortic backward flow. Mitral regurgitation fraction was calculated as follows: [(total LV SV – total aortic forward flow)/total LV SV] × 100. Effective RV SV was assumed to be equal to effective LV SV. To allow for this indirect measurement of effective RV SV, intra-cardiac shunting and relevant pulmonary regurgitation were excluded on echocardiography in these patients. Furthermore, tricuspid regurgitation was calculated as: [(total RV SV – effective RV = LV SV)/total RV SV] × 100. Aortic regurgitant fraction was calculated as the percentage of backward flow over forward flow. All volumes and flow measurements were indexed for body surface area and expressed in mL/m².

CMR strain assessment

Strain analyses by CMR FT analysis of strain were performed using dedicated software (Diogenes MRI, version 3.0; TomTec Imaging Systems, Germany). A steady-state free-precession cine magnet resonance imaging (SSFP) sequence during free breathing was used to acquire the CMR images. A cine sequence was performed using a four-element phased-array coil setup.

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Germany). The four-chamber view was used to calculate LV longitudinal (ELL4CH) and radial (ERR4CH) strain, LV short-axis circumferential (ECCSA4W) and radial (ERRSAW) strains were derived at an apical level, at the level of the papillary muscles and at basal level just below the mitral valve. Endocardial contours were drawn manually and analysed in all slices by one observer. Strain parameters are expressed as an average of all segments within one slice.8–10

Statistical analysis

Normally distributed data are expressed as mean ± SD, not normally distributed data as median and inter-quartile range (IQR). Proportions are expressed as number of patients and percentages. Two-paired samples were analysed with paired Student’s t-test for normally distributed data and with the Mann–Whitney U test for non-normally distributed data. All statistical tests were two-sided, and a P-value < 0.05 was considered statistically significant. Statistical testing and data analysis were performed with GraphPad Prism version 5.0b (Graphpad Software, San Diego, CA, USA).

The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agreed to the manuscript as written.

Results

Patient characteristics

Patients were recruited within a time period of 8 months. Out of 55 patients undergoing MitraClip™ implantation at the Heart Center Leipzig during this period, 22 patients had contraindications due to previous pacemaker or ICD implantation, 10 patients refused to undergo pre- and post-procedural CMR and in 3 patients, CMR imaging could not be analysed due to severe artefacts caused by motion and/or arrhythmia. The final study cohort comprised 20 patients at high risk for conventional heart surgery by heart-team assessment reflected by an advanced age (76 ± 9 years) and a logistic EuroSCORE I of 33 ± 16% with significant MR. All patients were symptomatic with 85% in NYHA Class III and 15% in NYHA Class IV. The mean LV EF was 42 ± 15%, in 15/20 patients the origin of MR was classified as secondary vs. 5/20 with organic primary in 5/20 of patients. A detailed summary of patient characteristics is given in Table 1.

Procedural results

The procedural success rate, as defined by a reduction in MR to <3+, was 96%. In one patient, no noteworthy reduction of MR could be achieved. Device time was 51 ± 25 min and operation time 78 ± 33 min. Overall, 23 clips were implanted in 20 patients with a maximum of two clips in three (15%) patients. There were no relevant intra-procedural complications.

Functional outcome

MitraClip™ implantation led to a significant improvement in NYHA functional class (patients in functional class III–IV pre 100 vs. post 45%; P < 0.001; Figure 1).

Echocardiographic parameters

MR severity could be reduced from a median of 3 (IQR 3; 3) to 1 (IQR 1; 1); P < 0.001. The mean gradient across the mitral valve rose from 1.9 ± 1.5 to 3.3 ± 1.7 mmHg (P < 0.001). In addition, there was a significant reduction in estimated pulmonary artery pressure (from 44.7 ± 11 to 38.0 ± 6.3 mmHg; P = 0.01; n = 19, in one patient pulmonary artery pressure could not be estimated in absence of any tricuspid regurgitation).

Results of CMR imaging

The results of CMR imaging before and after MitraClip™-procedure are summarized in Table 2 (see also Figure 2). Volumetric assessment as well as aortic flow calculation showed a significant reduction in MR fraction by 47%. This reduction in LV preload was accompanied by a decrease in LV EDV. However, there was no significant change in LV ESV, resulting in a lower total LV SV post procedure at unchanged LV

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Patient characteristics</th>
<th>n = 20</th>
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<tbody>
<tr>
<td>Age (year)</td>
<td>76 ± 9</td>
<td></td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>6 (30)</td>
<td></td>
</tr>
<tr>
<td>NYHA III, n (%)</td>
<td>17 (85)</td>
<td></td>
</tr>
<tr>
<td>NYHA IV, n (%)</td>
<td>3 (15)</td>
<td></td>
</tr>
<tr>
<td>Secondary mitral regurgitation, n (%)</td>
<td>15 (75)</td>
<td></td>
</tr>
<tr>
<td>Left ventricular ejection fraction, CMR imaging (%)</td>
<td>45 ± 15</td>
<td></td>
</tr>
<tr>
<td>Logistic EuroSCORE I (%)</td>
<td>33 ± 16</td>
<td></td>
</tr>
<tr>
<td>Arterial hypertension, n (%)</td>
<td>20 (100)</td>
<td></td>
</tr>
<tr>
<td>(Ex-)Smoker, n (%)</td>
<td>5 (25)</td>
<td></td>
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<tr>
<td>Diabetes mellitus, n (%)</td>
<td>6 (30)</td>
<td></td>
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<tr>
<td>Hypercholesterolaemia, n (%)</td>
<td>14 (70)</td>
<td></td>
</tr>
<tr>
<td>Body mass index &gt; 30 kg/m², n (%)</td>
<td>3 (15)</td>
<td></td>
</tr>
<tr>
<td>Coronary artery disease, n (%)</td>
<td>14 (70)</td>
<td></td>
</tr>
<tr>
<td>Previous heart surgery, n (%)</td>
<td>4 (20)</td>
<td></td>
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<tr>
<td>Persistent atrial fibrillation, n (%)</td>
<td>12 (60)</td>
<td></td>
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NYHA, New York Heart Association functional class; CMR, cardiac magnetic resonance.

Figure 1 Change in NYHA functional class from pre to post MitraClip™ implantation. NYHA functional class improves following MitraClip™ implantation.
EF. The effective LV SV and cardiac output were unaffected by reduction in MR. Furthermore, there were no significant changes in RV EDV, ESV, SV, EF, and tricuspid regurgitation fraction.

Strain analyses by FT demonstrated no significant changes in LV radial and circumferential strain at apical and papillary muscle levels. In contrast, radial and circumferential strain at the level just below the mitral valve was significantly impaired following MitraClip™ implantation. In addition, there was a significant reduction in LV radial strain as assessed on the four-chamber view, whereas longitudinal strain remained unchanged (Table 3).

Discussion

The main findings of our study can be summarized as follows: the reduction in MR by MitraClip™ implantation is associated with an immediate significant reduction in LV preload and thereby LV EDV; these changes did not lead to an acutely improved LV EF, effective SV, or cardiac output in this markedly compromised patient cohort; RV volumes and function as well as the degree of tricuspid regurgitation remained unaffected; strain analyses by CMR suggest some impairment of the basal, mitral valve near segments of the LV. Irrespective of CMR results, there was a significant symptomatic improvement after MitraClip™ implantation.

Changes in LV parameters

CMR was performed early after MitraClip™ implantation to assess the impact of altered LV and RV loading condition on cardiac performance without the confounding effects of open heart surgery and cardiopulmonary bypass. In this respect, MitraClip™ implantation represents an ideal physiological model. On LV level, reduction in MR leads to an increase in afterload as previously shown with conductance catheter methods.7 According to Frank–Starling law, this can result in an increase in ESV, as shown in a population with preserved LV EF.7 In our population with markedly reduced LV EF, however, ESV remained unchanged. The decrease in LV preload due to MR reduction might attenuate unfavourable LV fibre stretch prior to treatment in these impaired and dilated LVs and thereby compensate for the rise in LV afterload. As a consequence, LV EF was found to be unaffected by MitraClip™ implantation. Accordingly, Radunski et al.16 have documented an unchanged LV EF in 12 patients undergoing CMR imaging before and 6 months after MitraClip™ implantation. In contrast to our finding of reduced total LV SV post procedure, two previous CMR studies16,17 demonstrated no decrease in that parameter. This discrepancy might be explained by varying degrees of MR reduction within different studies. Only our study included flow measurements, meaning that the true degree of MR reduction in the two previous CMR studies remains unknown. Interestingly, Krum et al. found only a minor

<table>
<thead>
<tr>
<th>Volumetric and flow assessment on CMR</th>
<th>Pre</th>
<th>Post</th>
<th>P-value</th>
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<tbody>
<tr>
<td>LV end-diastolic volume, mL/m²</td>
<td>115 ± 36</td>
<td>105 ± 41</td>
<td>0.002</td>
</tr>
<tr>
<td>LV end-systolic volume, mL/m²</td>
<td>70 ± 37</td>
<td>70 ± 45</td>
<td>1.0</td>
</tr>
<tr>
<td>LV stroke volume, mL/m²</td>
<td>45 ± 14</td>
<td>35 ± 7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LV ejection fraction, %</td>
<td>42 ± 15</td>
<td>41 ± 16</td>
<td>0.8</td>
</tr>
<tr>
<td>Effective LV stroke volume, mL/m²</td>
<td>26 ± 6</td>
<td>26 ± 6</td>
<td>0.9</td>
</tr>
<tr>
<td>Mitral regurgitation fraction, %</td>
<td>36 ± 10</td>
<td>19 ± 12</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Aortic regurgitation fraction</td>
<td>9 ± 8</td>
<td>8 ± 9</td>
<td>0.6</td>
</tr>
<tr>
<td>RV end-diastolic volume, mL/m²</td>
<td>83 ± 19</td>
<td>84 ± 18</td>
<td>0.3</td>
</tr>
<tr>
<td>RV end-systolic volume, mL/m²</td>
<td>49 ± 17</td>
<td>49 ± 17</td>
<td>0.9</td>
</tr>
<tr>
<td>RV stroke volume, mL/m²</td>
<td>35 ± 8</td>
<td>35 ± 8</td>
<td>0.8</td>
</tr>
<tr>
<td>RV ejection fraction, %</td>
<td>42 ± 9</td>
<td>43 ± 11</td>
<td>0.8</td>
</tr>
<tr>
<td>Tricuspid regurgitation fraction, %</td>
<td>24 ± 17</td>
<td>25 ± 19</td>
<td>0.7</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>69 ± 17</td>
<td>73 ± 14</td>
<td>0.24</td>
</tr>
<tr>
<td>Cardiac index, L/min/m²</td>
<td>1.7 ± 0.5</td>
<td>1.8 ± 0.4</td>
<td>0.4</td>
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</table>

LV, left ventricle; RV, right ventricle.
Interventional edge-to-edge repair by MitraClip™ implantation

Table 3  Results of CMR feature tracking for strain analyses

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>Post</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERRaxx apical level</td>
<td>14.0</td>
<td>13.0</td>
<td>0.53</td>
</tr>
<tr>
<td>ECCaxx apical level</td>
<td>−14.8</td>
<td>−15.5</td>
<td>0.81</td>
</tr>
<tr>
<td>ERRaxx papillary muscle</td>
<td>15.1</td>
<td>14.4</td>
<td>0.67</td>
</tr>
<tr>
<td>ECCaxx papillary muscle</td>
<td>−12.8</td>
<td>−11.3</td>
<td>0.27</td>
</tr>
<tr>
<td>ERRxx mitral valve level</td>
<td>15.4</td>
<td>9.6</td>
<td>0.02</td>
</tr>
<tr>
<td>ECCxx mitral valve level</td>
<td>−12.8</td>
<td>−8.3</td>
<td>0.002</td>
</tr>
<tr>
<td>ERRch</td>
<td>15.5</td>
<td>10.9</td>
<td>0.02</td>
</tr>
<tr>
<td>ELIchn</td>
<td>−11.5</td>
<td>−10.7</td>
<td>0.54</td>
</tr>
</tbody>
</table>

ERRaxx, radial strain on short-axis images; ECCaxx, circumferential strain on short-axis images; ERRch, radial strain on four-chamber view; ELIchn, longitudinal strain on four-chamber view.

Changes in RV parameters

Impaired RV function and tricuspid regurgitation are common in patients with chronic MR and can be attributed to long-standing pressure overload caused by the increase in left atrial pressure and changes in the pulmonary vasculature. Surgical series have demonstrated that RV function is an important predictor for the postoperative course and is often markedly impaired in the early postoperative phase. Therefore, we were also interested in immediate changes in RV function as well as degree of tricuspid regurgitation after MitraClip™ implantation. Despite reduction in RV afterload (reduced estimated RV systolic pressure), there was no immediate improvement in RV size or function. Likewise, the degree of tricuspid regurgitation was found to be unaffected by MitraClip™ implantation. Although somehow against expectations, these results are in line with recent echocardiographic series on this subject and have to be interpreted in light of the fact that surgical mitral repair results in deterioration of RV function acutely, which recovers only partially during follow-up. The lack of improved RV function or tricuspid valve competence suggests that, at least acutely, the reduction in afterload might not be sufficient in these RVs with chronic adverse loading condition. Alternatively, this reduction in afterload might be partially counterbalanced by a slight increase in preload due to new atrial left-to-right shunting. Within a previous study, a high prevalence of iatrogenic atrial septal defects following MitraClip™ implantation could be demonstrated and was estimated to result in a pulmonary to systemic artery flow of 1.2:1. The potential contribution of existing atrial shunting post procedure on acute changes in RV size and function as well as the potential for late remodelling of the RV needs to be addressed in further studies.

It should be noted that despite no significant improvement in biventricular function, we observed a marked improvement in symptoms in our patients treated by MitraClip™ implantation. Although this study focused on changes in biventricular size and function, it should be underlined that biventricular performance assessed at rest is only one of several measures of potential benefits of MitraClip™ implantation, which could influence the long-term outcome and management of these patients. The impact of this procedure on biventricular performance during physical activity however remains unknown and might explain the discrepancies in altered symptoms and MR parameters.

**Limitations**

The most relevant limitation of this study is the relatively small sample size. This prohibits any further exploratory linear regression analyses and therefore more insights into the mechanisms of altered symptoms despite no improvement in biventricular performance. Larger trials including more patients with predefined subgroups such as functional vs. degenerative MR are needed to address these issues.

Since patients with pulmonary regurgitation or evidence for intra-cardiac shunting prior to Mitraclip™ implantation were not included in this study, it seems reasonable to calculate tricuspid regurgitation based on the assumption that pulmonary artery forward flow equals net aortic forward flow. However, following MitraClip™ implantation, some degree of intra-cardiac shunting across the atrial septum can be expected, which could have masked a mild reduction in tricuspid regurgitation fraction. However, this mild reduction in tricuspid regurgitation is unlikely to be of clinical relevance and would not have altered the overall interpretation of this study.

CMR myocardial FT is a relatively new technique with no data on inter-study reproducibility in such a patient population. Morton et al. assessed the reproducibility of FT in healthy subjects and demonstrated the best reproducibility for circumferential strain analyses. In fact, they calculated a sample size of 11 to be sufficient to demonstrate a 5% difference with a 90% power and an α-error of 0.05. Given the fact that we have observed a reduction in circumferential strain of −4.5 (35%), this change is unlikely to be by chance. However, since reproducibility of longitudinal and radial strain has been shown to be worse, the described changes in these strain parameters should be interpreted with caution. Likewise, although subjectively not relevant...
for analyses, some error caused by device-related artefacts cannot be excluded.

CMR imaging was performed early after MitraClip™ implantation, since the aim of our study was to assess the impact of acutely altered biventricular loading condition. We previously have shown that in the setting of acutely altered RV load, load-dependent changes are apparent within 5 minutes after the procedure (as assessed in X-ray/MR hybrid laboratory) and do not differ from assessments performed within 1 month post procedure.29 We therefore believe that an early assessment is a reliable reflect of changes accompanied by altered RV loading. Nevertheless, the potential for late remodelling and changes in ventricular contractility remain unaddressed in our work.

Conclusions

In severely compromised patients, marked reduction in MR by MitraClip™ implantation does not result in acutely improved cardiac output and effective biventricular forward flow.

These to some extent unexpected findings underline that the acute effects of LV volume overload reduction on biventricular physiology are still poorly understood. Further studies are needed to enhance our understanding of these effects, which bare the hope that this could help in judging procedural success and refine patient selection for MR reduction therapies in markedly compromised patients in the future.

Conflicts of interest: P.L., A.L., and J.S. have received speaker honoraria from Abbott Vascular.

References


