



**University of  
Zurich**<sup>UZH</sup>

**Zurich Open Repository and  
Archive**

University of Zurich  
Main Library  
Strickhofstrasse 39  
CH-8057 Zurich  
[www.zora.uzh.ch](http://www.zora.uzh.ch)

---

Year: 2011

---

## **Prediction of the annuloplasty ring size in patients undergoing mitral valve repair using real-time three-dimensional transoesophageal echocardiography**

Ender, J ; Eibel, S ; Mukherjee, C ; Mathioudakis, D ; Borger, M A ; Jacobs, S ; Mohr, F W ; Falk, V

**Abstract:** Aims We sought to investigate the additional value of real-time three-dimensional transoesophageal echocardiography (RT 3D TOE)-guided sizing for predicting annuloplasty ring size during mitral valve repair. Methods and results In 53 patients undergoing elective mitral valve repair, an RT 3D TOE was performed pre- and post-operatively. The digitally stored loops were imported into a software for mitral valve assessment. The annuloplasty ring size was predicted by superimposing computer-aided design (CAD) models of annuloplasty rings onto Live 3D zoom loops, measurement of the intercommissural distance, or the height of the anterior mitral leaflet. The surgeon implanted the annuloplasty ring according to the usual surgical technique and was blinded to the echocardiographic measurement results. Pre-operative correlation between the selected ring size with mitral valve assessment and the actual implanted annuloplasty ring size was 0.91. The correlation for measurement of the intercommissural distance was 0.55 and for measurement of the height of the anterior mitral leaflet 0.75. The post-operative correlation with the actual implanted ring size was 0.96 for mitral valve assessment, 0.92 for intercommissural distance, and 0.79 for the anterior mitral leaflet height. Conclusion Superimposition of annuloplasty ring CAD models on the Live 3D zoom loops of the mitral valve using mitral valve assessment is superior to two-dimensional measurements of the intercommissural distance or the height of the anterior mitral leaflet in predicting correct annuloplasty ring size.

DOI: <https://doi.org/10.1093/ejechoard/jer042>

Posted at the Zurich Open Repository and Archive, University of Zurich

ZORA URL: <https://doi.org/10.5167/uzh-52412>

Journal Article

Published Version

Originally published at:

Ender, J; Eibel, S; Mukherjee, C; Mathioudakis, D; Borger, M A; Jacobs, S; Mohr, F W; Falk, V (2011). Prediction of the annuloplasty ring size in patients undergoing mitral valve repair using real-time three-dimensional transoesophageal echocardiography. *European Journal of Echocardiography*, 12(6):445-453. DOI: <https://doi.org/10.1093/ejechoard/jer042>

# Prediction of the annuloplasty ring size in patients undergoing mitral valve repair using real-time three-dimensional transoesophageal echocardiography

J. Ender<sup>1\*</sup>†, S. Eibel<sup>1†</sup>, C. Mukherjee<sup>1</sup>, D. Mathioudakis<sup>1</sup>, M.A. Borger<sup>2</sup>, S. Jacobs<sup>3</sup>, F.W. Mohr<sup>2</sup>, and V. Falk<sup>3</sup>

<sup>1</sup>Department of Anaesthesiology and Intensive Care Medicine II, Leipzig Heart Center, University of Leipzig, Struempellstrasse 39, 04289 Leipzig, Germany; <sup>2</sup>Department of Cardiac Surgery, Leipzig Heart Center, University of Leipzig, Leipzig, Germany; and <sup>3</sup>Clinic for Cardiac Surgery, University of Zurich, Zurich, Switzerland

Received 21 December 2010; accepted after revision 22 March 2011; online publish-ahead-of-print 4 May 2011

## Aims

We sought to investigate the additional value of real-time three-dimensional transoesophageal echocardiography (RT 3D TOE)-guided sizing for predicting annuloplasty ring size during mitral valve repair.

## Methods and results

In 53 patients undergoing elective mitral valve repair, an RT 3D TOE was performed pre- and post-operatively. The digitally stored loops were imported into a software for mitral valve assessment. The annuloplasty ring size was predicted by superimposing computer-aided design (CAD) models of annuloplasty rings onto Live 3D zoom loops, measurement of the intercommissural distance, or the height of the anterior mitral leaflet. The surgeon implanted the annuloplasty ring according to the usual surgical technique and was blinded to the echocardiographic measurement results. Pre-operative correlation between the selected ring size with mitral valve assessment and the actual implanted annuloplasty ring size was 0.91. The correlation for measurement of the intercommissural distance was 0.55 and for measurement of the height of the anterior mitral leaflet 0.75. The post-operative correlation with the actual implanted ring size was 0.96 for mitral valve assessment, 0.92 for intercommissural distance, and 0.79 for the anterior mitral leaflet height.

## Conclusion

Superimposition of annuloplasty ring CAD models on the Live 3D zoom loops of the mitral valve using mitral valve assessment is superior to two-dimensional measurements of the intercommissural distance or the height of the anterior mitral leaflet in predicting correct annuloplasty ring size.

## Keywords

Real-time three-dimensional echocardiography • Transoesophageal echocardiography • Mitral valve repair • Intercommissural distance • Anterior mitral leaflet • Annuloplasty ring

## Introduction

Mitral valve repair for mitral regurgitation is the treatment of choice due to the disappointing results of medical treatment.<sup>1</sup> Surgical treatment for mitral regurgitation secondary to mitral valve

prolapse consists mainly of implantation of artificial neochords<sup>2</sup> or resection of the involved tissue.<sup>3</sup> For good long-term results, additional implantation of an annuloplasty ring is also necessary.<sup>4</sup> Determination of the annuloplasty ring size is usually performed in the cardioplegic-arrested heart under the surgeon's direct

\* Corresponding author. Tel: +49 341 865 1438, Fax: +41 341 865 1820, Email: joerg.ender@medizin.uni-leipzig.de

† J.E. and S.E. both have equally contributed to the manuscript.

Published on behalf of the European Society of Cardiology. All rights reserved. © The Author 2011. For permissions please email: journals.permissions@oup.com.

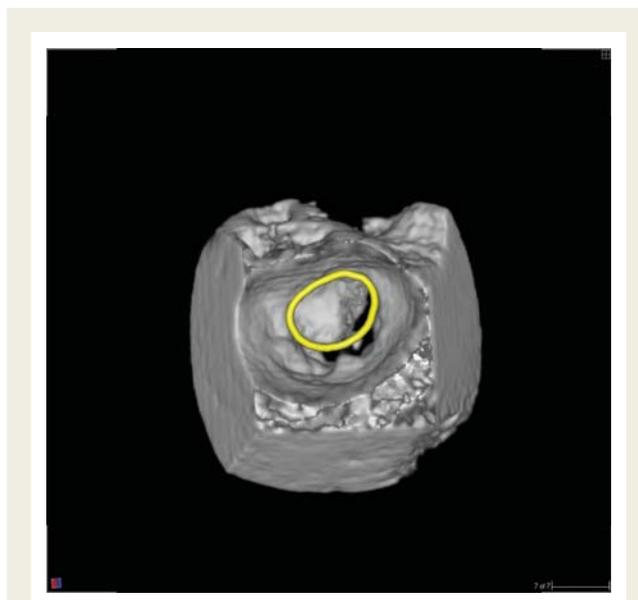
The online version of this article has been published under an open access model. Users are entitled to use, reproduce, disseminate, or display the open access version of this article for non-commercial purposes provided that the original authorship is properly and fully attributed; the Journal, Learned Society and Oxford University Press are attributed as the original place of publication with correct citation details given; if an article is subsequently reproduced or disseminated not in its entirety but only in part or as a derivative work this must be clearly indicated. For commercial re-use, please contact journals.permissions@oup.com

vision, with the help of commercial annuloplasty ring sizers. The use of perioperative transoesophageal echocardiography (TOE) during mitral valve (MV) repair is strongly recommended as a Class I indication according to the ASE/SCA guidelines.<sup>5</sup> TOE not only quantifies the severity of the mitral valve disease,<sup>6,7</sup> but also helps identify the precise valvular morphology and pathophysiology. The latter information can be critical in determining the operative technique to be employed by the surgeon in order to achieve a successful mitral valve repair. Cook *et al.*<sup>8</sup> stated that the measurement of only one single echocardiographic variable, such as the intertrigonal distance, does not accurately predict the annuloplasty band size. Three-dimensional (3D) reconstruction of the mitral valve based on multiple two-dimensional (2D) TOE slices with the use of computer-aided design (CAD) models of annuloplasty rings have been recently described.<sup>9</sup> Real-time (RT) 3D TOE is now available and may offer new possibilities and advantages compared with 2D TOE and 3D reconstruction techniques.<sup>10</sup> The purpose of the current study was to evaluate the feasibility of RT 3D TOE in predicting the annuloplasty ring size in patients undergoing elective mitral valve repair for mitral regurgitation.

## Methods

Upon approval by the local Ethics Committee and written informed consent, 53 patients undergoing elective mitral valve repair were included in this prospective study. We tested the feasibility of predicting the annuloplasty ring size based on different 2D and 3D echocardiographic measurements pre-operatively, as well as determining the actual implanted annuloplasty ring size post-operatively.

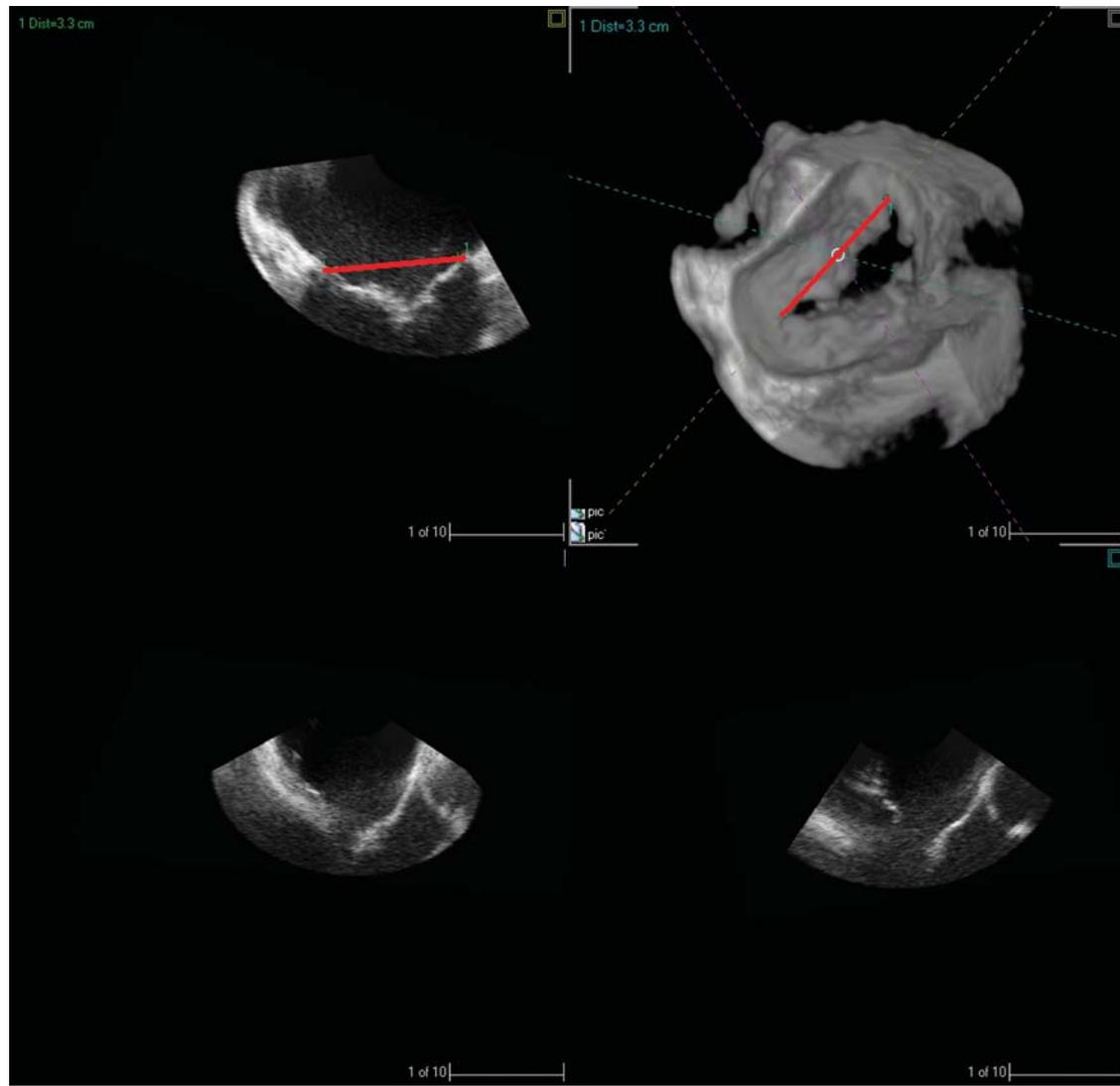
After routine induction of anaesthesia and placement of the central venous lines, a 3D probe was inserted and connected to the TOE console (IE33, Philips; Netherlands). After completion of a comprehensive 2D TOE examination, a 3D assessment of the mitral valve was performed. Data were acquired in Live 3D zoom in all patients and additionally in full volume modes in 20 patients. We used the mid-oesophageal four-chamber view and adjusted the region of interest for the Live 3D zoom to cover the whole mitral valve. Two heartbeats were digitally recorded with optimal settings of gain and compression in order to visualize the mitral valve leaflets, as well as the commissures, with the best possible image quality using Live 3D zoom. Four consecutive heartbeats were used for the full volume mode. These 3D loops were reviewed off-line on a laptop with the use of a prototype of the 4D Valve Assessment<sup>®</sup> software called Ring Tool<sup>®</sup> (TomTec, Munich, Germany). The Ring Tool<sup>®</sup> software modification consisted of a digital database of Carpentier–Edwards Physio<sup>®</sup> annuloplasty rings (Edwards Lifesciences, Irvine, CA, USA) ranging in size from 28 to 36. The creation of these CAD models, as well as the modified software, was described previously in detail by Ender *et al.*<sup>9</sup> In short, the CAD models were generated using computed tomography imaging of annuloplasty rings. Geometries of the artificial rings were defined by triangular meshes stored in a polygon (PLY) file format. With the help of Ring Tool<sup>®</sup>, an automated ring adjustment algorithm, the CAD models could be superimposed on the 3D loops of the mitral valve. In the current study, all patients received a complete, rigid Carpentier–Edwards Physio<sup>®</sup> annuloplasty ring because it is the device of choice for MV repair at our institution. Ring Tool<sup>®</sup> enables the echocardiographer to use a CAD model out of the database and to overlay the CAD model with the 3D loop of the mitral valve (Figure 1). In addition, the software programme offers the



**Figure 1** Computer-assisted design model of an annuloplasty ring (yellow) superimposed on the three-dimensional loop of the native mitral valve.

possibility to move the selected ring into different possible directions (see Supplementary data online, Video S1). The ring can be adjusted upwards and downwards, rotated around its own axes, moved to the right or left, as well as backwards and forwards. If position adjustment results in an unsatisfactory location, however, the database can be used to return to the last ring location. It is also possible to change the selected ring size (see Supplementary data online, Video S2). Optimal ring sizing prior to mitral valve repair was determined using a combination of three techniques. First, the 3D loop was examined visually in order to determine the best fit of the virtual ring to the native mitral valve (i.e. 'eyeballing'). Secondly, Ring Tool<sup>®</sup> was used to simultaneously view three 2D planes (coronal, sagittal, and transverse; Figure 2), resulting in a repeated measurement of the mitral valve inter-commissural distance. Lastly, we measured the maximum height of the anterior leaflet in the 2D planes (Figure 3). The cardiac surgeon chose the appropriate annuloplasty ring size according to standard surgical techniques. These techniques consisted of assessment of the intertrigonal distance and the area of the anterior mitral valve leaflet using a commercial ring sizer (Figure 4), in addition to assessment of the height of the anterior mitral leaflet. The surgeon was blinded to the annuloplasty ring size selection based on the Ring Tool<sup>®</sup> software, as well as for the 2D measurement of the intercommissural distance.

After the annuloplasty ring was implanted, a validation protocol was performed post-cardiopulmonary bypass. A second 3D examination was performed, and the echo investigator was blinded to the actual size of the implanted ring. The modified 4D Valve Assessment<sup>®</sup> software was used to determine the size of the annuloplasty ring by superimposing the computerized ring models over the actual implanted ring. The implanted annuloplasty ring was visualized either in a 3D loop or in three 2D planes derived from the 3D model. In addition, the size of the annuloplasty ring based on the 2D measurements of the outer ring diameter as well as the height of the anterior mitral leaflet was compared with the actual implanted ring size (Figure 5). The size of the selected computerized annuloplasty ring was compared afterwards with the size of the actual implanted ring (Figure 6).



**Figure 2** Measurement of the intercommissural distance (red line) in the two-dimensional plane (left upper corner) guided by orientation in the three-dimensional loop (right upper corner).

### Image quality

Image quality was assessed as follows: images that showed commissures and both leaflets very well without artefacts were classified as 'excellent = 1'. Images that showed commissures and both leaflets well but having insignificant artefacts were classified as 'good = 2'. Images with poorly defined, albeit identifiable commissures and leaflets, were classified as 'poor = 3'. Moreover, we analysed the influence of the heart rhythm on the image quality.

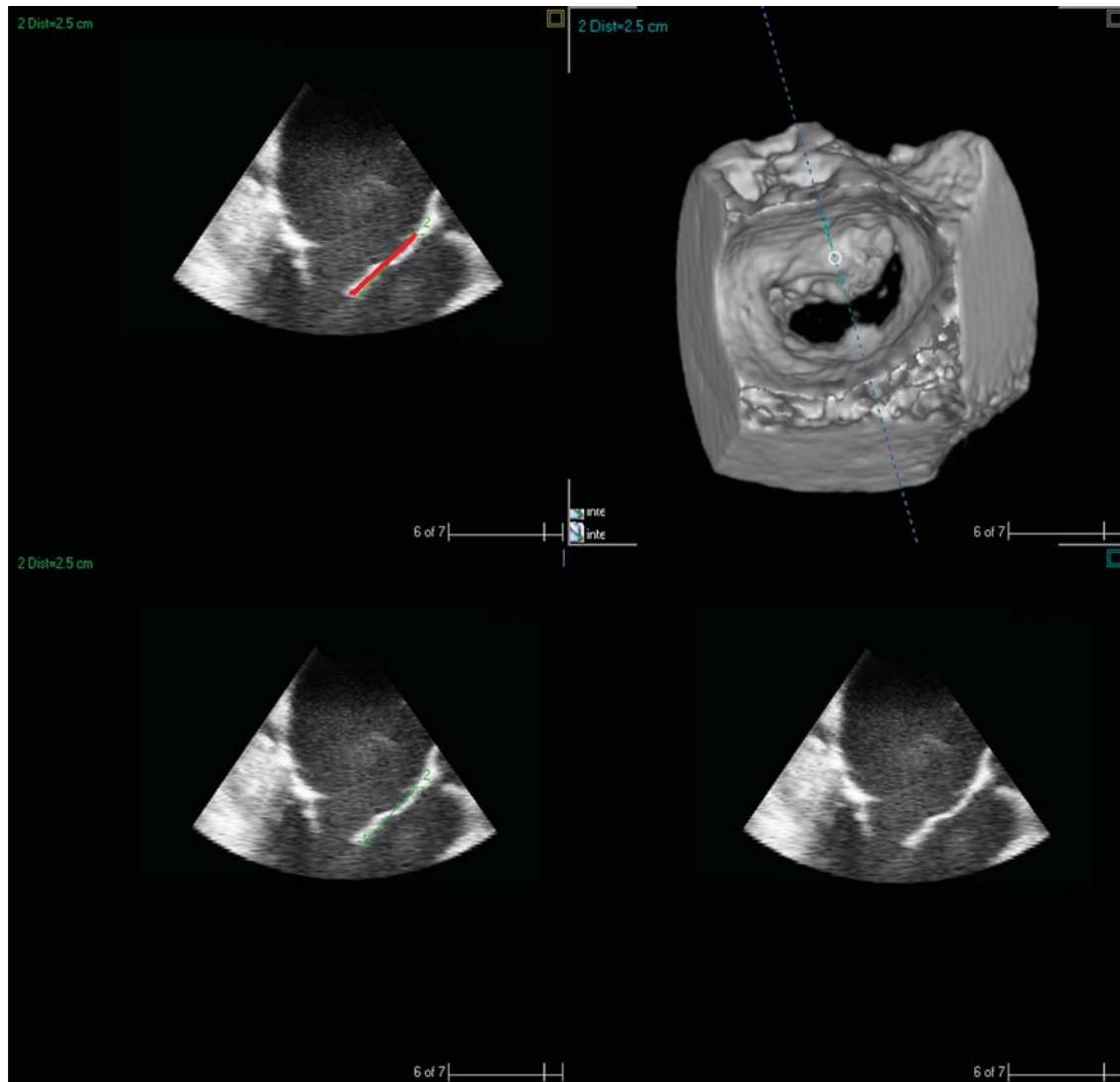
### Comparison of zoom mode vs. full volume mode

In 20 out of the 53 patients, the Live 3D zoom mode (low frame 8 Hz, real time) was compared with the full volume mode (higher frame rate 22 Hz, summation of four heartbeats) regarding the prediction of the correct ring size and image quality.

### Inter-observer and intra-observer variability

Inter-observer and intra-observer variability for sizing of the annuloplasty ring pre- and post-mitral valve repair was determined in 20 patients. Measurements were performed in the same 3D video frames by two different observers.

Statistical analyses were performed using SPSS 17.0 software (SPSS Inc., Chicago, IL, USA). Categorical variables are expressed as proportions and continuous variables as mean  $\pm$  standard deviation (or 95% confidence intervals where appropriate) throughout the manuscript. Significance testing was performed with the Pearson test. The paired t-test was used to analyse statistical significance of pre- and post-repair continuous variables within patients. Inter- and intra-observer correlation was analysed with two-tailed intra-class correlation coefficients. The analysis of the image quality depending on the stable or instable heart rhythm was performed with the Jonckheere–Terpstra trend test.



**Figure 3** Measurement of the height of the anterior mitral leaflet (red line) in the two-dimensional plane (left upper corner) guided by orientation in the three-dimensional loop (blue line in the right upper corner).

## Results

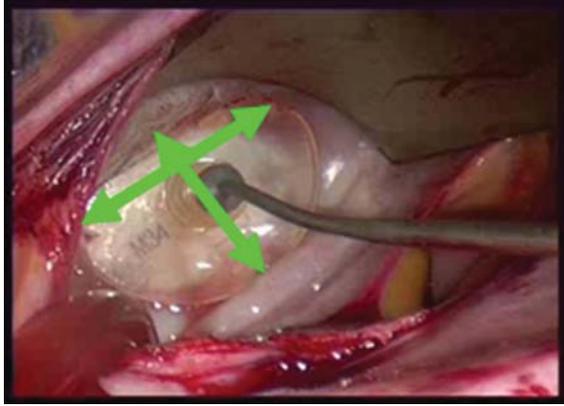
A total of 53 patients (14 female, 39 male) with a mean age of  $58.2 \pm 13.8$  years were consecutively included in the study. The pre-operative mitral regurgitation severity was  $3.1 \pm 0.6$  on a grading scale from 0 to 4. Mitral valve regurgitation was quantified with measurement of the vena contracta. The pre-operative New York Heart Association functional class was  $2.3 \pm 0.7$ . All 53 patients received a Carpentier–Edwards Physio<sup>®</sup> annuloplasty ring for mitral valve repair. Table 1 shows the different mitral valve pathologies and the surgical treatment of the study population.

### Type of repair

In 36 patients, mitral regurgitation was corrected by implantation of an annuloplasty ring and artificial Gore-Tex neochordae (i.e. the ‘Loop technique’).<sup>2</sup> In six patients, mitral regurgitation was

corrected with ring implantation alone. Six patients received ring implantation and partial leaflet resection, while the remaining five patients required ring implantation, artificial Gore-Tex neochordae, and partial leaflet resection.

Post-operative residual mitral regurgitation was not present in 46 patients (87%), trace in 3 (6%), and mild in 4 patients (7%). In the three patients with trace regurgitation, Ring Tool<sup>®</sup> recommended the same ring size in one patient, a larger ring in one patient, and a smaller ring in one patient. In the four patients with mild regurgitation, Ring Tool<sup>®</sup> recommended the same ring size in two patients (Vena contracta 3 and 4 mm, respectively), a larger ring in one patient (Vena contracta 4 mm), and a smaller ring size in one patient (Vena contracta 4 mm). In these seven cases, the surgeon determined that no further surgical revision was required. Transthoracic echocardiography at discharge in these seven patients showed no residual mitral regurgitation in one patient, trace in four patients, and mild regurgitation in two



**Figure 4** Surgical sizer for determining the annuloplasty ring size, as used by the surgeon (green lines indicate the intercommissural length and the height of the anterior mitral leaflet).

patients. Ring Tool<sup>®</sup> recommended for the patient without residual regurgitation the same ring size. In the four patients with trace regurgitation, Ring Tool<sup>®</sup> recommended the same ring size in one patient, a smaller ring size in one patient, and a larger ring size in two patients. In the two patients with mild regurgitation, Ring Tool<sup>®</sup> recommended the same ring size for one patient (Vena contracta 4 mm) and a larger ring size for one patient (Vena contracta 3–4 mm). The mean pressure gradient was  $3 \pm 1.4$  mmHg in these patients.

Relative mitral valve stenosis was not observed after the repair in any patient. For details of the mean pressure gradient according to the predicted ring size based on Ring Tool<sup>®</sup> for all patients, see Table 2.

### Real-time three-dimensional Ring Tool<sup>®</sup> visual assessment

The correlation coefficient between the predicted pre-operative annuloplasty ring size and that of the actual implanted ring was 0.91 ( $P < 0.01$ ), with a mean difference of 0.0 mm ( $-0.3$  to  $+0.3$ ,  $P = 1.0$ ). Of the 53 ring templates, 37 (70%) were of the same size as the actual implanted ring, while 8 (15%) templates deviated by  $-2$  mm and 8 (15%) templates deviated by  $+2$  mm. Mean pressure gradient pre- and post-operatively are listed in Table 2. The correlation coefficient between the post-operative Ring Tool<sup>®</sup> measurement and the size of the actual implanted ring was 0.96 ( $P < 0.01$ ) with a mean difference of 0.2 mm ( $0.0$ – $0.4$  mm,  $P = 0.096$ ). For differences in predicted ring size to the actual implanted annuloplasty ring, see Table 3.

### Real-time three-dimensional intercommissural distance and outer ring diameter measurements

The correlation coefficient between the pre-operative 2D intercommissural distance measurements and the inner ring diameter of the actual implanted ring was 0.55 ( $\rho < 0.01$ ) in end-diastole, with a mean difference of 3.3 mm ( $2.6$ – $4.1$  mm,  $P < 0.001$ ), and 0.54 ( $\rho < 0.01$ ) in end-systole, with a mean difference of 3.6 mm

( $2.8$ – $4.3$  mm,  $P < 0.001$ ). The post-operative correlation coefficient of the outer ring diameter compared with the outer ring diameter of the actual implanted ring was 0.92 ( $\rho < 0.01$ ) in end-diastole, with a mean difference of 0.3 mm ( $0.0$ – $0.6$  mm,  $\rho = 0.091$ ), and 0.95 ( $\rho < 0.01$ ) in end-systole, with a mean difference of 0.2 mm ( $0.0$ – $0.4$  mm,  $\rho = 0.096$ ). For the level of agreement between echocardiographic measurements and actual implanted ring size, see Table 3.

There was no statistical difference in the accuracy of measurements between patients with stable and unstable rhythm.

### Three-dimensional height of anterior mitral leaflet measurements

A correlation coefficient of 0.75 ( $\rho < 0.01$ ) was found between the measurements of the height of the anterior mitral leaflet and the actual implanted ring size pre-operatively, with a mean difference of 4.3 mm ( $3.8$ – $4.8$ ,  $\rho < 0.001$ ). Post-operatively, the anterior–posterior (AP) diameter of the implanted ring had a correlation coefficient in end-diastole of 0.79 ( $\rho < 0.01$ ), with a mean difference of 0.2 mm ( $-0.19$  to  $+0.6$  mm,  $P = 0.3$ ), and a correlation coefficient in end-systole of 0.77 ( $\rho < 0.01$ ) with a mean difference of 0.4 mm ( $-0.0$  to  $+0.8$  mm,  $\rho = 0.064$ ) in comparison with the AP diameter of the actual implanted ring.

### Image quality

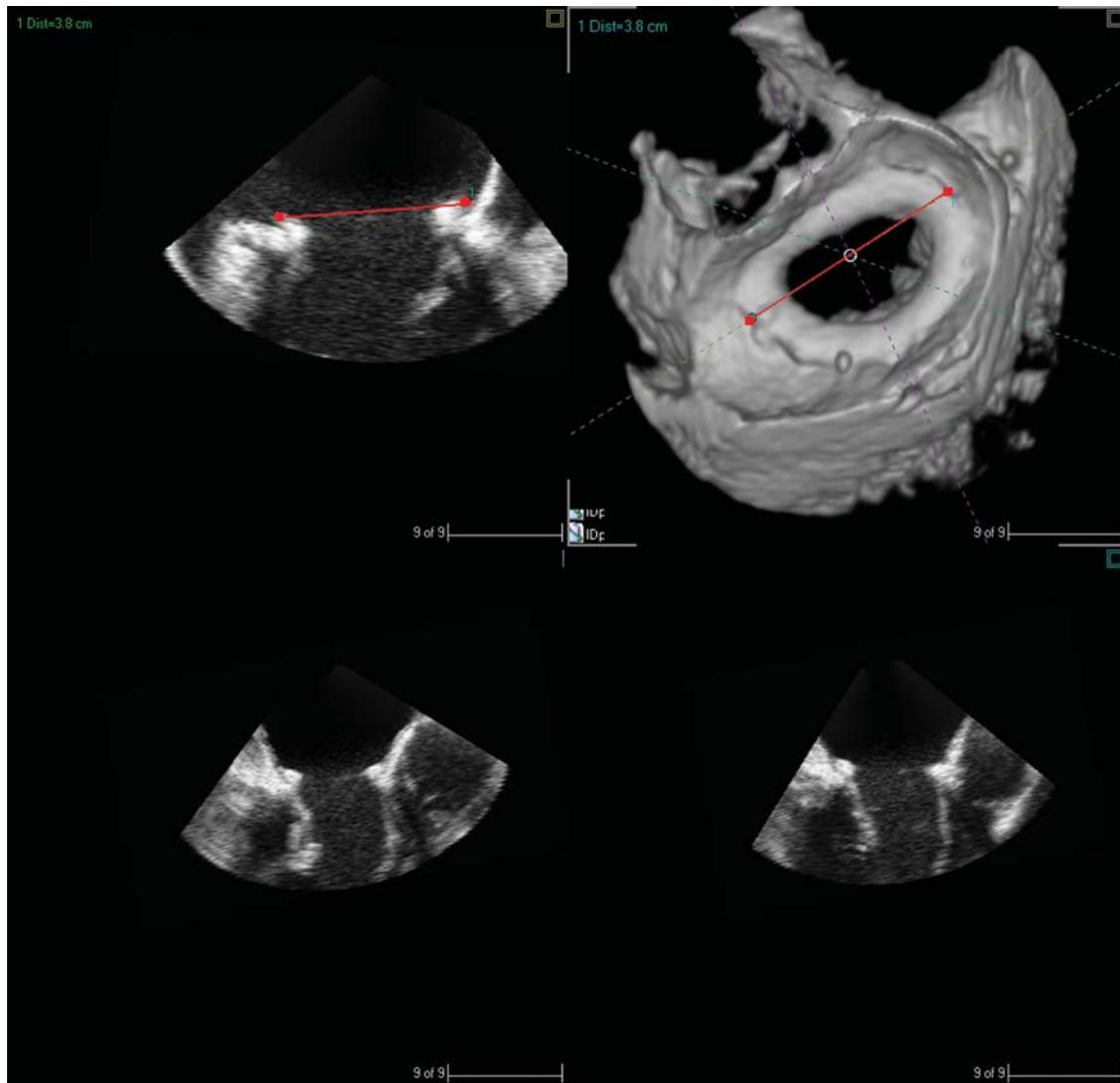
For a description of image quality, see Table 4. Pre-cardiopulmonary bypass, 72% of patients were in sinus rhythm and 28% in atrial fibrillation. Post-cardiopulmonary bypass, 57% of patients were in sinus rhythm, 36% required temporary dual chamber pacing, and 7% were in atrial fibrillation. Analysis of image quality according to cardiac rhythm described as stable (i.e. sinus rhythm or pacing) or unstable (i.e. atrial fibrillation) showed no statistically significant relationship.  $P$ -value was 0.76 pre-operatively and 0.16 post-operatively. We found no relationship between the heart rhythm and image quality.

### Time for off-line analysis

Post-acquisition evaluation of images was performed off-line using Ring Tool<sup>®</sup>. The length of time required to perform all measurements with Ring Tool<sup>®</sup> was  $7.3 \pm 2.0$  min. Specifically, an average of 2 min was required for landmark tracking, 2.3 min for sizing in 3D and 2D planes (with visual assessment), 1.4 min for measurement of the intercommissural distance, and 1.1 min for measurement of the AP leaflet distance and anterior mitral leaflet height.

### Comparison of Live three-dimensional zoom mode vs. full volume mode

The pre-operative correlation between the actual implanted ring size and the ring size measured in the Live 3D zoom mode was 0.92 with a mean difference of 0.1 mm ( $-0.4$  to  $+0.6$  mm,  $\rho = 0.66$ ), in comparison with a correlation of 0.91 in full volume with a mean difference of 0.2 mm ( $-0.3$  to  $+0.7$  mm,  $\rho = 0.42$ ). Post-operatively, the correlation of the Live 3D zoom mode measurements was 0.95 with a mean difference of 0.2 mm ( $-0.2$  to  $+0.6$  mm,  $\rho = 0.33$ ) compared with 0.96 with a mean difference of 0.4 mm ( $0.1$ –



**Figure 5** Measurement of the outer intercommissural diameter (red line) of the implanted annuloplasty ring in two-dimensional plane (left upper corner) guided by orientation in the three-dimensional loop (right upper corner).

0.8 mm,  $\rho = 0.04$ ) in the full volume mode. See *Table 5* for image quality information of the full volume and Live 3D zoom modes on the 20 selected patients. The trend test for the relationship between image quality in the full volume or the Live 3D zoom mode and stable (sinus rhythm or pacing) or unstable (atrial fibrillation) heart rhythm showed no significance. The *P*-value for the full volume mode was 0.15 pre-operatively and post-operatively 0.76. The Live 3D zoom mode had a *P*-value of 0.98 pre-operatively and 0.63 post-operatively. There was no relationship between the image quality in the full volume or the Live 3D zoom and the heart rhythm.

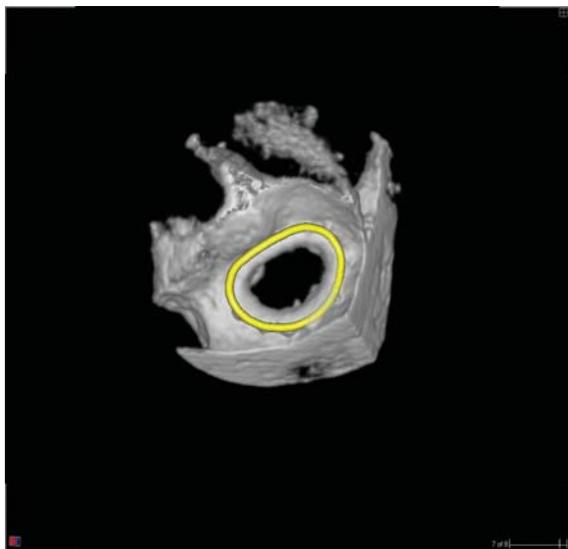
### Inter-observer and intra-observer variability

A subgroup of 20 patients was analysed by two different observers with a time interval of 1 week between each measurement.

Inter-observer correlation was 0.94 pre-operatively with a mean difference of 0.1 mm ( $-0.2$  to  $+0.6$  mm,  $\rho = 0.66$ ) and 0.96 post-operatively with a mean difference of 0.3 mm, ( $-0.0$  to  $+0.6$  mm,  $\rho = 0.083$ ). Intra-observer correlation was 0.94 with a mean difference of 0.1 mm ( $-0.4$  to  $+0.6$ ,  $\rho = 0.66$ ) pre-operatively and 0.95 with a mean difference of 0.2 mm ( $-0.0$  to  $0.6$ ,  $P = 0.33$ ) post-operatively.

### Discussion

Surgical sizing of the height of the anterior mitral leaflet and the intercommissural distance with commercially available sizers during cardioplegic arrest is the current gold standard for ring sizing for mitral valve repair. Sizing under direct vision is sometimes challenging however, particularly in patients among whom good exposure of the mitral valve is difficult to achieve. In addition,



**Figure 6** Superimposed computer-assisted design model (yellow) on a post-operative three-dimensional loop of the native mitral valve along with the implanted annuloplasty ring.

**Table 1** Mitral valve pathology

Mitral valve pathology	n = 53 (%)	Surgical treatment
Anterior leaflet prolapse	9 (17)	Ring: 2 Ring + loops: 4 Ring + resection: 2 Ring + resection + loops: 1
Posterior leaflet prolapse	33 (62)	Ring + loops: 25 Ring + resection: 4 Ring + resection + loops: 4
Bileaflet prolapse	7 (13)	Ring + loops: 7
Ring dilatation	2 (4)	Ring: 2
Restrictive posterior leaflet	2 (4)	Ring: 2

Ring, annuloplasty ring implantation alone; Ring + loops, annuloplasty ring and artificial Gore-Tex neochordae; Ring + resection, annuloplasty ring and partial leaflet resection; Ring + resection + Loops, annuloplasty ring, artificial Gore-Tex neochordae and partial leaflet resection.

sizing during cardioplegic arrest may be error prone as the mitral ring assumes a non-physiological shape; that is, the surgeon assesses the immobile valve in an empty heart, whereas the echocardiographer evaluates the dynamic valve in a beating heart.<sup>11</sup>

### Real-time three-dimensional Ring Tool<sup>®</sup> visual assessment

Our study results show a better correlation regarding annuloplasty ring sizing with visual assessment (0.91 pre- and 0.96 post-operatively) in the Live 3D zoom loops, when compared with the 2D measurements of the intercommissural distance (0.55 pre- and 0.92 post-operatively) or the height of the anterior mitral leaflet (0.75 pre- and 0.79 post-operatively).

Disparities in annuloplasty ring sizes in the current study could be explained by the different haemodynamic circumstances during sizing. The surgeon, our gold standard in this study, performs sizing on a cardioplegic-arrested heart, whereas our echocardiographic measurements were taken under beating heart conditions.

However, there was residual mitral valve regurgitation after surgery in seven cases. In these cases, the echocardiographer recommended the same ring size in three cases, a larger ring in two cases, and a smaller ring in two cases in comparison with the actual implanted ring. Further studies should be performed to clarify this issue.

### Image quality

RT 3D TOE provides excellent imaging and accurate pre-surgical and post-surgical evaluation of native mitral valve pathology and anatomy, as well as mitral valve prostheses.<sup>10,12</sup> In the current study, image quality was rated as excellent in over 50% of cases. The improved imaging most likely contributed to better ring size prediction than that observed in our prior study,<sup>9</sup> in which excellent image quality was observed in only 14% of patients. Mitral valve commissures and leaflets are well defined in most RT 3D studies using the Live 3D zoom or the full volume mode. Our observed better image quality for the Live 3D zoom mode when compared with the full volume mode can be explained by less rhythm-related artefacts. However, we did not observe any statistically significant differences for measurements obtained between the two techniques in the current study. We agree with Sugeng *et al.*<sup>12</sup> that Live 3D zoom should be the preferred mode since it is real time and insensitive to electrocardiogram and ventilator artefacts.

**Table 2** Mean pressure gradient

	n = 37 predicted and implanted ring size were equal		n = 8 deviation from predicted and implanted ring size by -2 mm		n = 8 deviation from predicted and implanted ring size by +2 mm	
	Pre-OP	Post-OP	Pre-OP	Post-OP	Pre-OP	Post-OP
Mean pressure gradient (mmHg)	0.7 ± 0.5	2.1 ± 1.0	0.6 ± 0.5	2.3 ± 0.8	0.5 ± 0.5	1.5 ± 0.7

Mean pressure gradient (mmHg) of the mitral valve was measured pre- and post-operatively. n = 37, no difference between predicted and implanted ring size; n = 8, templates deviated by -2 mm from the actually implanted ring; n = 8, templates deviated by +2 mm from the actually implanted ring size.

**Table 3** Differences between implanted ring and predicted annuloplasty ring size (n = 53, proportions in parentheses)

Diff. in mm	3D pre-OP	3D post-OP	ID pre-OP dias	ID pre-OP sys	OD post-OP dias	OD post-OP sys	AML pre-OP	AP post-OP dias	AP post-OP sys
0	37 (70)	44 (83)	5 (9.4)	4 (7.5)	34 (64.2)	41 (77.4)	–	22 (41.5)	23 (43.4)
–2	8 (15)	7 (13.2)	11 (20.8)	11 (20.8)	12 (22.6)	9 (17)	–	5 (9.4)	14 (26.4)
+2	8 (15)	2 (3.8)	2 (3.8)	1 (1.8)	7 (13.2)	3 (5.6)	4 (7.5)	19 (36)	7 (13.2)
–4	–	–	–	–	–	–	–	6 (11.3)	7 (13.2)
+4	–	–	15 (28.3)	16 (30.2)	–	–	19 (36)	1 (1.8)	2 (3.8)
+6	–	–	12 (22.6)	11 (20.8)	–	–	22 (41.5)	–	–
+8	–	–	7 (13.2)	8 (15)	–	–	6 (11.3)	–	–
+10	–	–	1 (1.8)	2 (3.8)	–	–	1 (1.8)	–	–
+12	–	–	–	–	–	–	1 (1.8)	–	–

3D, measurements in 3D loop (visual estimation method); ID, measurements of intercommissural distance pre-operatively in 2D end-diastolic and end-systolic; OD, measurements of outer ring diameter postoperatively in 2D end-diastolic and end-systolic; AML, measurements of the maximum height of the anterior leaflet in 2D; AP, measurements of anterior–posterior leaflet distance in 2D end-diastolic and end-systolic.

**Table 4** Image quality

Quality	Pre-operative	%	Post-operative	%
Excellent	30	56.6	24	45.3
Good	17	32.1	23	43.4
Poor	6	11.3	6	11.3

Excellent, visualization of commissures and both leaflets very good; no artefacts; Good, visualization of commissures and both leaflets good; artefacts present but not relevant; Poor, commissures and both leaflets visible, but with significant artefacts.

**Table 5** Differences in image quality between full volume and zoom mode (n = 20)

Quality	Zoom pre-OP	Zoom post-Op	Full volume pre-OP	Full volume post-Op
Excellent (1)	13	9	2	1
Good (2)	6	8	11	8
Poor (3)	1	3	7	11
Mean score	1.4	1.7	2.2	2.5

Excellent (1), visualization of commissures and both leaflets very good; no artefacts; Good (2), visualization of commissures and both leaflets good; artefacts present but not relevant; Poor (3), commissures and both leaflets visible, but with significant artefacts.

## Inter-observer and intra-observer variability

Our low inter-observer (0.94 pre- and 0.96 post-operatively) and intra-observer (0.94 pre- and 0.95 post-operatively) variability strongly suggest the value of the Ring Tool<sup>®</sup> in predicting the annuloplasty ring size independent from the user.

Our study showed that the reality enhanced RT 3D TOE with Ring Tool<sup>®</sup> software correlates well with conventional surgical sizing of the annuloplasty ring in patients undergoing mitral valve repair. Such an observation may play an important role in further facilitating the performance of minimally invasive, robotic, and percutaneous mitral valve repair procedures in centres around the world, however, a prospective randomized study is needed to clarify this issue.

## Supplementary data

Supplementary data are available at *European Journal of Echocardiography* online.

## Acknowledgements

There is full disclosure of any potential relationship with industry.

**Conflict of interest:** none declared.

## Funding

This article was supported by institutional funding.

## References

- Enriquez-Sarano M, Avierinos JF, Messika-Zeitoun D, Detaint D, Capps M, Nkomo V et al. Quantitative determinants of the outcome of asymptomatic mitral regurgitation. *N Engl J Med* 2005;**352**:875–83.
- Seeburger J, Kuntze T, Mohr FW. Gore-tex chordoplasty in degenerative mitral valve repair. *Semin Thorac Cardiovasc Surg* 2007;**19**:111–5.
- Carpentier A, Deloche A, Dauptain J, Soyfer R, Blondeau P, Piwnica A et al. A new reconstructive operation for correction of mitral and tricuspid insufficiency. *J Thorac Cardiovasc Surg* 1971;**61**:1–13.
- David TE, Ivanov J, Armstrong S, Christie D, Rakowski H. A comparison of outcomes of mitral valve repair for degenerative disease with posterior, anterior, and bileaflet prolapse. *J Thorac Cardiovasc Surg* 2005;**130**:1242–9.
- Shanewise JS, Cheung AT, Aronson S, Stewart WJ, Weiss RL, Mark JB et al. ASE/SCA guidelines for performing a comprehensive intraoperative multiplane transesophageal echocardiography examination: recommendations of the American Society of Echocardiography Council for Intraoperative Echocardiography and the Society of Cardiovascular Anesthesiologists Task Force for Certification in Perioperative Transesophageal Echocardiography. *Anesth Analg* 1999;**89**:870–84.
- Lambert AS, Miller JP, Merrick SH, Schiller NB, Foster E, Muhiudeen-Russell I et al. Improved evaluation of the location and mechanism of mitral valve regurgitation

- with a systematic transesophageal echocardiography examination. *Anesth Analg* 1999;**88**:1205–12.
7. Troianos CA, Konstadt S. Evaluation of mitral regurgitation. *Semin Cardiothorac Vasc Anesth* 2006;**10**:67–71.
  8. Cook RC, Nifong LW, Lashley GG, Duncan RA, Campbell JA, Law YB et al. Echocardiographic measurements alone do not provide accurate non-invasive selection of annuloplasty band size for robotic mitral valve repair. *J Heart Valve Dis* 2006;**15**:524–7.
  9. Ender J, Koncar-Zeh J, Mukherjee C, Jacobs S, Borger MA, Viola C et al. Value of augmented reality enhanced transesophageal echocardiography (TEE) for determining optimal annuloplasty ring size during mitral valve repair. *Ann Thorac Surg* 2008;**86**:1473–8.
  10. Kronzon I, Sugeng L, Perk G, Hirsh D, Weinert L, Fernandez MA et al. Real-time 3-dimensional transesophageal echocardiography in the evaluation of post-operative mitral annuloplasty ring and prosthetic valve dehiscence. *J Am Coll Cardiol* 2009;**53**:1543–7.
  11. Agricola E, Oppizzi M, Pisani M, Maisano F, Margonato A. Accuracy of real-time 3D echocardiography in the evaluation of functional anatomy of mitral regurgitation. *Int J Cardiol* 2008;**127**:342–9.
  12. Sugeng L, Shernan SK, Weinert L, Shook D, Raman J, Jeevanandam V et al. Real-time three dimensional transesophageal echocardiography in valve diseases: comparison with surgical findings and evaluation of prosthetic valves. *J Am Soc Echocardiogr* 2008;**21**:1347–54.

## IMAGE FOCUS

doi:10.1093/ejehocard/jer038

Online publish-ahead-of-print 22 April 2011

# Biopptome injury to the tricuspid valve in a cardiac allograft recipient visualized by three-dimensional echocardiography

Emir Karacaglar, Leyla Elif Sade\*, Alp Aydınalp, Cihan Altın, and Haldun Müderrisoğlu

Department of Cardiology, Baskent University, Ankara Hospital, Fevzi Cakmak Caddesi, 10. sokak, No. 45, Ankara, Turkey

\*Corresponding author. Tel: +903122126868, Email: elifsade@baskent-ank.edu.tr

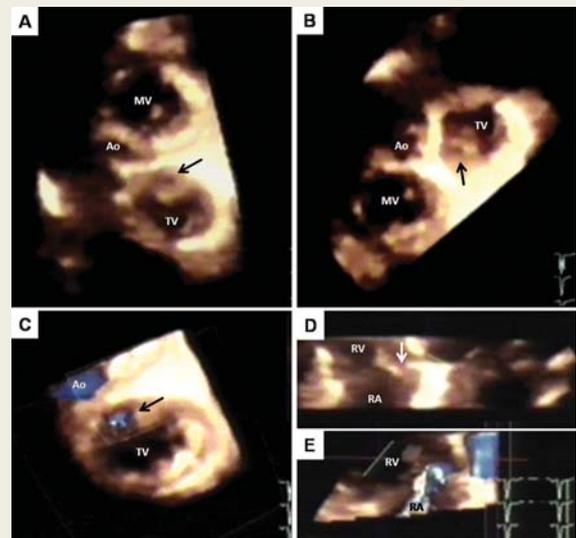
Tricuspid regurgitation (TR) is the most commonly seen valvular pathology after orthotopic heart transplantation (OHT). The reported incidence ranges from 47 to 98%, depending on the definition of significant regurgitation and the surgical method. Multiple aetiologies are implicated in the development of TR after OHT; percutaneous transvenous endomyocardial biopsy (EMB), performed to detect rejection, is the most important contributor to significant TR by causing anatomic disruption of the valvular structure.

A 38-year-old man with ischaemic cardiomyopathy, underwent orthotopic biatrial cardiac transplantation 6 years ago. During his follow-up, acute rejection occurred at the second month and first year, which were successfully treated. The patient had been undergoing regular echocardiographic examinations according to our institutional echocardiography follow-up protocol for OHT patients. On these follow-up visits, echocardiography revealed only mild TR until his sixth post-operative year.

At the 6th year cardiac catheterization, coronary angiography and EMB were performed at the same time. The procedure was apparently uneventful, and the patient was discharged from the hospital the day after with no rejection. However, on his next transthoracic echocardiogram examination, we noticed an increase in the TR. Two separate TR jets were visualized: mild central jet accompanied by another more eccentric jet (see Supplementary data online, *Figure S1*). There was no damage on the chordae and no flail leaflet on two-dimensional images. When we performed three-dimensional echocardiography, we found out a hole at the basal portion of the septal leaflet, possibly caused by the biopptome.

### Supplementary data

Supplementary data are available at *European Journal of Echocardiography* online.



**Figure 1.** 3D (A) and color 3D (C) views from the ventricles showing the perforation (arrow) on the base of the septal leaflet of the tricuspid valve, view from the atria of the same defect (B), 3D and color 3D coronal plane views of the tricuspid valve showing the perforation (arrow) and the regurgitant jet.