



# Changes in dynamic mitral valve geometry during percutaneous edge–edge mitral valve repair with the MitraClip system

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## Abstract

**Background** The aim of this study was to quantify the acute dynamic changes of mitral valve (MV) geometry throughout the cardiac cycle—during percutaneous MV repair with the MitraClip system by 3-dimensional transesophageal echocardiography (3D TEE).

**Methods** The MV was imaged throughout the cardiac cycle (CC) before and after the MitraClip procedure using 3D TEE in 28 patients (mean age,  $77 \pm 8$  years) with functional mitral regurgitation (FMR). Dynamic changes in the MV annulus geometry and anatomical MV orifice area (AMVOA) were quantified using a novel semi-automated software.

**Results** Percutaneous MV repair decreased anterior–posterior diameter by up to 9% (at 50% of CC; from 34.5 to 31.9 mm;  $p < 0.001$ ) throughout the CC and increased the diastolic lateral–medial diameter by up to 7% (at 60% of the CC; from 39.7 to 42.3 mm;  $p < 0.001$ ), whereas the annular circumference and area were not significantly affected. Annulus sphericity index was reduced up to 13% (at 50% of the CC; from 0.89 to 0.78,  $p < 0.001$ ). The AMVOA also decreased during systole, the maximum decrease being from 0.6 to 0.2 mm<sup>2</sup> (at 0% of CC;  $p = 0.007$ ), and during diastole the maximum decrease being from 4.6 to 1.6 cm<sup>2</sup> (at 50% of CC;  $p < 0.001$ ).

**Conclusions** Percutaneous MV repair reduces the MR by an improved coaptation of MV leaflets joint with a simultaneous indirect reduction of anterior–posterior diameter. Further, the MitraClip procedure leads to a reduction of AMVOA of more than 60% during diastole.

**Keywords** Mitral valve geometry · MitraClip · Mitral regurgitation · 3D echocardiography

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## Introduction

The percutaneous edge–edge mitral valve repair using the MitraClip system is a treatment option for patients with symptomatic mitral regurgitation (MR) and high surgical risk [1–3]. Based on the surgical method by Alfieri, anterior and posterior leaflets are clipped by percutaneous mitral valve (MV) repair, which results in a double orifice mitral valve. These lead to an end-systolic reduction of anterior–posterior diameter (APD) and annular circumference and an end-systolic increase of lateral–medial diameter (AC) after percutaneous MV repair [4–6]. However, data on the changes of mitral valve (MV) geometry during percutaneous MV repair in relation to the cardiac cycle are unknown.

It is known that the MV is a dynamic structure with continuous changes of the annulus and leaflet geometry throughout the cardiac cycle [5]. With the introduction

of 3-dimensional transesophageal echocardiography (3D TEE) and the morphological quantification of MV with 3D TEE-based MV models, an improved understanding of the dynamic anatomy in healthy and pathologies is now possible [7, 8]. A newly developed 4-dimensional (4D) MV model, based on 3D TEE data, allows a comprehensive quantification of MV annulus and leaflets throughout the cardiac cycle [9]. Preliminary experiences suggest that 4D quantification of MV throughout CC is feasible, reproducible, and reliable [9, 10].

Thus, the purpose of this study is to investigate the immediate dynamic changes in the annular dimensions and shape, and the anatomical MV orifice area during percutaneous MV repair with the MitraClip device using the 3D TEE-based quantitative MV modeling approach.

## Materials and methods

### Patients

Between April 2013 and May 2014, we included consecutive patients undergoing percutaneous MV repair with MitraClip system at the Heart Center University Leipzig, Leipzig, Germany. Patients with symptomatic moderate–severe (3+) or severe (4+) functional MR [11, 12] with indication for intervention according to current guidelines [13, 14] with high surgical risk or judged as inoperable were included for this study. We excluded patients with degenerative MR, patients with mixed MV etiology of MR, and patients who underwent previous MV procedures. An interdisciplinary heart team that included a cardiac surgeon, an interventional cardiologist, and an echocardiography-experienced cardiac anesthesiologist discussed indication and echo criteria for eligibility for each patient. The study was approved by the ethics committee of the medical faculty of the Leipzig University. All patients provided written informed consent before inclusion in the study.

### Percutaneous mitral valve repair

Percutaneous MV repair with the MitraClip device (Abbott Vascular Structural Heart, Menlo Park, CA) has been described previously [15]. The procedure was performed in our hybrid operating room by an interdisciplinary heart team with echocardiographic (3D TEE) and fluoroscopic guidance according to recommendations [16]. Acute procedural success was defined as the placement of  $\geq 1$  clips resulting in a MR reduction to grade 2+ or less by echocardiography.

## Echocardiography

Echocardiographic measurements were performed according to recommendations [17, 18]. 3D TEE imaging was performed using an iE33 ultrasound system equipped with an X7-2t transesophageal echocardiography matrix transducer (Philips, Andover, MA). Electrocardiographically gated TEE full-volume and 3D zoom data sets from the MV were acquired under stable hemodynamic conditions in supine position (obtained under general anesthesia) before the start of the procedure as well as immediately after the procedure. Residual MR and diastolic MV gradient were assessed as described previously [19].

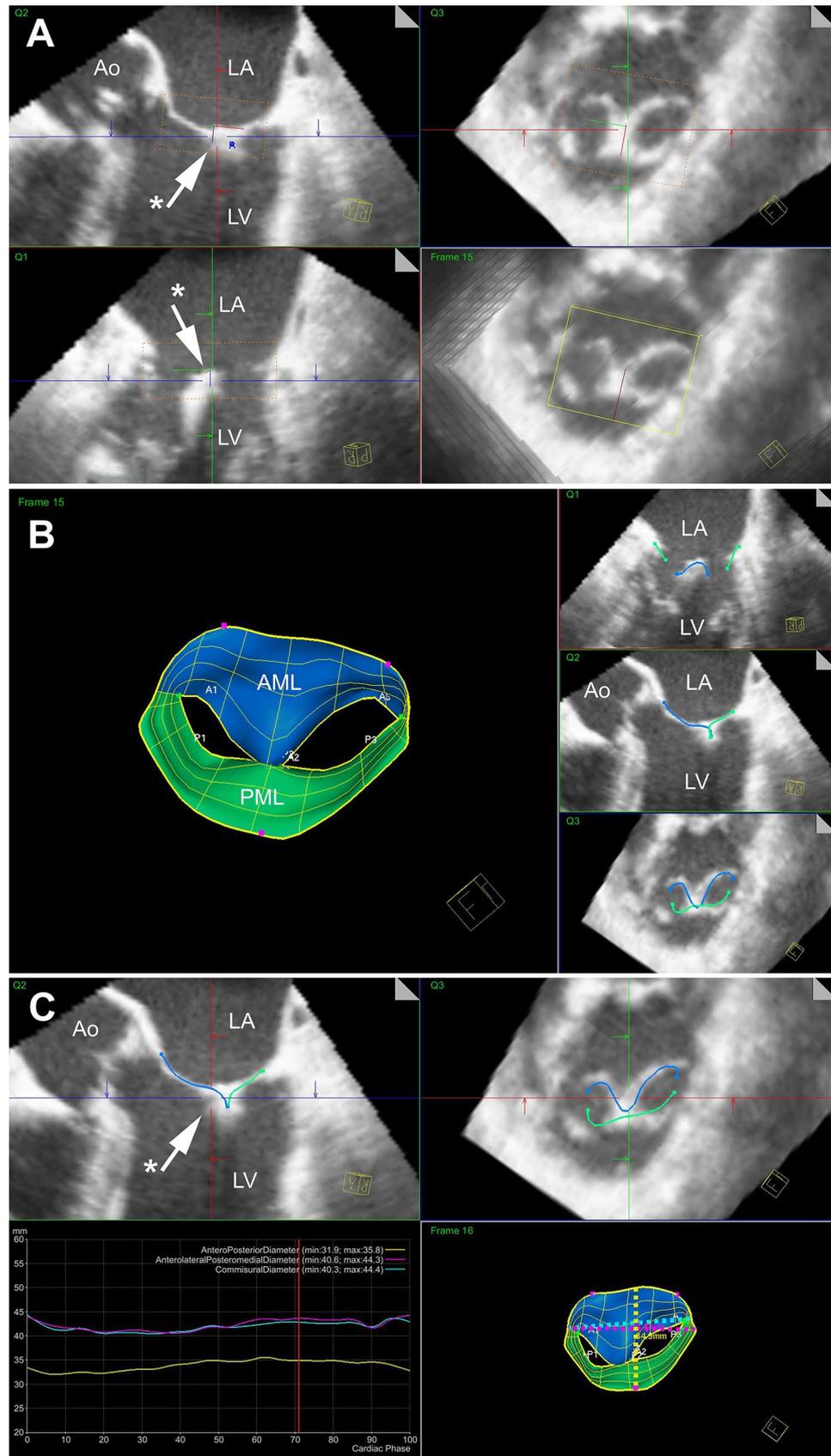
### Quantitative 3D MV analysis

For 4D quantification, we used the eSie Valves advanced analysis software (Siemens Healthcare, Mountain View, CA) as previously described (Fig. 1, Video 1) [9, 10]. Accuracy, reproducibility and reliability of the novel semi-automated 3D TEE-based 4D MV analysis software were investigated by the authors in a previous study [10]. The semi-automated software tool allows manual adjustments if necessary. The quality of all 3D TEE data sets was assessed for 4D quantification. The beginning of systole was defined as frame before aortic valve opening and the end of diastole as the frame with or after complete MV closing. Anterior–posterior diameter (AP-diameter), anterolateral–posteromedial diameter (LM-diameter), annulus sphericity index, annular height to commissural width ratio (AHCWR), annular circumference, annular area, anatomical MV orifice area (AMVOA) and non-planarity angle were measured throughout the CC. The annulus sphericity index was defined as the ratio between AP-diameter and LM-diameter. The non-planarity angle was defined as the angle between the two vectors derived from the anterior- and posterior-annular midpoints and their projection into the line between the commissures. Measured data were exported for statistical analysis per percentage of cardiac cycle duration (from 0 to 100% in steps of 10%). All measurements were done by consensus of 2 readers (TN, LM) unaware of the clinical history and the success of the percutaneous MV repair procedure.

### Statistical analysis

Data were tested for normal distribution by the D'Agostino and Pearson omnibus normality test. Normally distributed data are expressed as mean  $\pm$  SD and categorical data as proportions and percentage. A paired *t* test was used to

**Fig. 1** Quantification of mitral valve (MV) geometry by 3D echocardiography after percutaneous mitral valve repair. Exemplary quantification of different annular dimensions throughout the cardiac cycle (CC) by 3D TEE-based computational MV model. **a** Automatically detection of the global position of the MV in 3D TEE data set for one frame. Visualization in a multi-planar reconstruction. **b** Semi-automatically generated 3D surface model of MV for one frame (left). Three different cutting planes (right) visualize the accuracy of the MV model. **c** Quantification of mitral annulus diameters throughout CC computed from MV model. *AML* anterior mitral valve leaflet, *Ao* ascending aorta, *LA* left atrium, *LV* left ventricle, *PML* posterior mitral valve leaflet; \* position of the clip



**Table 1** Baseline patient characteristics

Variable	All patients ( <i>n</i> = 28)
Age, years	77 ± 8
Men	18 (64)
BMI, kg/m <sup>2</sup>	28 ± 5
EuroSCORE II, %	8 ± 6
STS score, %	7 ± 8
Hypertension	6 (93)
Hyperlipidemia	17 (60)
Diabetes mellitus	13 (45)
COPD	4 (14)
Previous stroke	2 (7)
Impaired renal function (eGFR < 60 mL/min)	14 (50)
Atrial fibrillation	19 (66)
NYHA functional class	
II	4 (7)
III	17 (61)
IV	5 (18)
MR severity grade	
3+ (moderate to severe)	26 (93)
4+ (severe)	2 (7)
Functional MR	28 (100)
LVEF	40 ± 16
EROA, mm <sup>2</sup>	34 (10–80)
PISA, mm	7 ± 3
Vena contracta, mm	8 ± 2
Coaptation length, mm	5 ± 6
Coaptation depth, mm	± 3
Annular width, mm	40 ± 7

*BMI* body mass index, *COPD* chronic obstructive pulmonary disease, *eGFR* estimated glomerular filtration rate, *EROA* effective regurgitant area, *EuroSCORE* European System for Cardiac Operation Risk Evaluation, *LVEF* left ventricular ejection fraction, *MR* mitral regurgitation, *NYHA* New York Heart Association, *PISA* proximal isovelocity surface area

evaluate for statistically significant difference between measurements. A value of  $p < 0.05$  was considered as statistically significant. Analyses were performed using IBM SPSS Statistics Version 20 (SPSS Inc., Chicago, IL) for Mac OS X.

## Results

### Patient population

Of 55 consecutive patients undergoing percutaneous MV repair, usable 3D Echo data of the MV was available in 28 patients. In 13 patients, the entire MV geometry could not be imaged throughout the cardiac cycle; in 12 patients, frame

rate was  $\leq 8$  frames/s; and in 3 patients, stitch artifacts precluded successful MV quantification. The frame rates in the data that were used for analysis were 17.5 frames/s before and 15.6 frames/s after MitraClip implantation. Patient characteristics are shown in Table 1.

### Procedural outcome

Percutaneous MV repair with the MitraClip system was successful in 27 of 28 patients (acute procedural success rate, 96%). All clips were implanted in the leaflet segments of A2 and P2 with an average of 1.6 clips per patient (1 clip in 19 patients, 2 clips in 8 patients, 3 clips in 1 patient). The reduction of MR after the procedure is presented in Fig. 2 for all patients. Post-interventional MV mean diastolic pressure gradient was  $3.1 \pm 1.3$  mmHg. There were no in-hospital deaths.

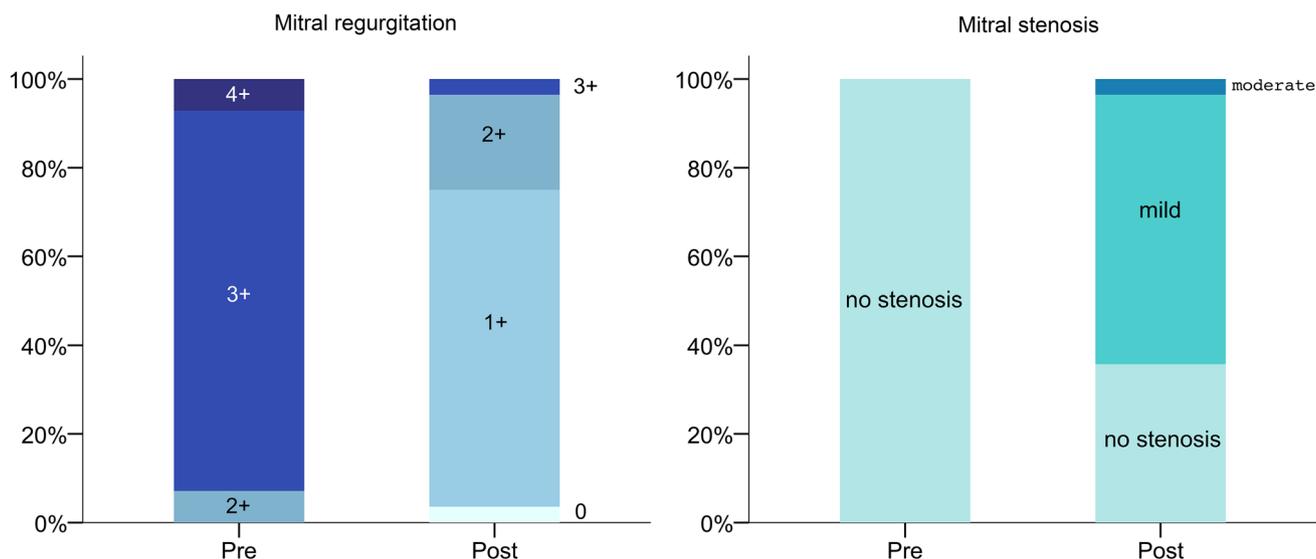
### Annular dimensions

The phasic changes in the AP-diameters pre- and post-MitraClip were similar, showing an increase during systole and a decrease during diastole. But, post-MitraClip the AP-diameter decreased significantly in all cardiac phases by 1.7–2.6 mm (5.2–7.6%,  $p$ -range from 0.003 to  $< 0.001$ ) with a maximum decrease at 50% of the cardiac cycle (34.5–31.9 mm,  $p < 0.001$ ; Table 2, Fig. 3a), compared to baseline. In contrast, LM-diameter significantly increased during diastole by 1.3–2.5 mm (3.3–6.5%,  $p$  range from 0.041 to  $< 0.001$ ; Table 2, Fig. 3b). The maximum increase of LM-diameter was identified at 60% of CC (39.7–42.3 mm,  $p < 0.001$ ). The phasic changes in the LM-diameter was comparable pre- and post-MitraClip during systole but showed a sharp increase during diastole.

Percutaneous MV repair by MitraClip does not lead to significant changes in annular circumference or annulus area immediately after the procedure (Table 2; Fig. 3c, d) although they were smaller during systole post-MitraClip. The dynamic changes were comparable pre- and post-MitraClip.

### Annular shape

The decrease of AP-diameter and increase of LM-diameter resulted in a significantly reduction of annulus sphericity index ranging from 0.07 to 0.11 (8.3–12.4%,  $p$  range from 0.003 to  $< 0.001$ ) throughout the cardiac cycle (Table 3; Fig. 3e). The MitraClip also resulted in a non-significant increase of the non-planarity angle in all cardiac phases (Table 3; Fig. 3f). The increase in the non-planarity angle during systole ranged from 3° to 6°. Percutaneous MV



**Fig. 2** Reduction in mitral regurgitation and creation of mitral stenosis by percutaneous mitral valve repair

repair shows no changes in AHCWR during systole and only showed a trend to decrease during diastole ranging from 0.01 to 0.02 (6.3–12.5%; Table 3; Fig. 3g). Both pre- and post-MitraClip AHCWR decreased during systole and increases from the middle to the end of diastole.

### Anatomical mitral valve orifice area

Percutaneous MV repair significantly reduced the mean AMVOA from 4.6 to 1.6 cm<sup>2</sup> (−65.2%,  $p < 0.001$ ) during diastole (Table 3; Fig. 3h). Furthermore, the onset of MV opening occurred at 20% of the cardiac cycle before the MitraClip and this was delayed to 30% of the cardiac cycle after the MitraClip procedure. During systole, the AMVOA was reduced by 0.4 cm<sup>2</sup> (−66.7%,  $p = 0.007$ ). The double-peaked curve of AMVOA during diastole changed to a flat curve after the procedure.

### Discussion

The present study is the first study to quantify and describe the dynamic changes in the geometry of the MV by the MitraClip procedure for MR. Our results can be summarized as follows: First, the successful percutaneous MV repair results in a decrease of AP-diameter and increase of LM-diameter throughout the cardiac cycle. Consequently, there is a reduction in annular sphericity index suggesting that the MitraClip therapy results in an indirect reduction of MV annulus in anterior–posterior direction, the latter contributing to reduction in the MR post-MitraClip. Second,

the reduction of MR was accompanied by the reduction of AMVOA during systole by up to 67%. Third, the diastolic AMVOA decreased by ~65% after the procedure. Fourth, the hemodynamic effect of percutaneous MV repair leads to a prolonged systolic and shortened diastolic phase as compared to the pre-interventional cardiac phases.

### Changes of annular dimensions

Previous investigations of the dynamic changes in the mitral annulus in FMR [5, 23] have reported a decrease in the AP-diameter by about 5% during diastole when compared to baseline and an increase back to baseline during systole. In contrast, the LM-diameter changes by only about 1% throughout the cardiac cycle. Thus, the annulus in FMR is less dynamic than the normal annulus [4, 20]. In the present study, the observed pre-interventional AP- and LM-diameters and their phasic behavior are congruent with previously reported findings [5, 6, 21].

The influence of percutaneous MV repair on the annular dynamic has been investigated in only a few studies [5, 6, 21]. Similar to these investigators, we observed a significant decrease in AP-diameter by 5–8% after percutaneous MV repair through the cardiac cycle. Thus, our data confirm that there is significant reshaping of MV annulus with reduction of the AP-diameter post-MitraClip. This change is analogous to partial annuloplasty in AP-direction, and thus contributes to a reduction of MR. But, unlike the previous reports [5, 6] which did not demonstrate significant changes in the LM-diameter, our study showed that while there was no significant change in systole, there was up to a 7% increase in diastole. These finding may be explained by fluid–structure interaction during edge–edge repair, which was described

**Table 2** Annular dimensions before and after percutaneous mitral valve repair

	CC (%)	Before	After	Difference	<i>p</i> value <sup>†</sup>
AP-diameter, mm	0	32.4	30.7	−1.7	0.003
	10	32.7	31.0	−1.7	0.002
	20	33.4	31.5	−1.9	0.002
	30	34.1	31.8	−2.3	0.001
	40	34.4	32.0	−2.4	<0.001
	50	34.5	31.9	−2.6	<0.001
	60	33.7	31.5	−2.2	<0.001
	70	33.5	31.3	−2.3	<0.001
	80	33.0	30.9	−2.0	0.002
	90	32.8	30.8	−2.0	<0.001
	100	32.4	30.7	−1.7	0.003
LM-diameter, mm	0	39.3	40.6	1.3	0.051
	10	39.6	40.2	0.6	0.290
	20	39.8	40.4	0.6	0.328
	30	40.1	40.7	0.6	0.294
	40	40.0	41.5	1.4	0.009
	50	40.0	42.1	2.1	<0.001
	60	39.7	42.3	2.5	<0.001
	70	39.7	42.1	2.4	<0.001
	80	39.6	41.5	1.9	0.007
	90	39.3	40.6	1.3	0.041
	100	39.3	40.6	1.3	0.051
Annular circumference, mm	0	119.7	118.6	−1.1	0.428
	10	119.9	118.6	−1.3	0.269
	20	121.1	119.4	−1.7	0.181
	30	122.1	120.3	−1.8	0.199
	40	121.6	122.0	0.5	0.757
	50	121.9	122.4	0.5	0.722
	60	120.7	121.7	1.0	0.357
	70	120.6	121.3	0.7	0.558
	80	120.2	120.4	0.2	0.890
	90	120.1	119.1	−0.9	0.458
	100	119.7	118.6	−1.1	0.428
Annulus area, cm <sup>2</sup>	0	10.7	10.4	−0.3	0.180
	10	10.8	10.4	−0.4	0.101
	20	11.0	10.6	−0.4	0.067
	30	11.3	10.8	−0.5	0.087
	40	11.2	11.1	−0.1	0.767
	50	11.2	11.1	−0.1	0.755
	60	11.0	10.9	−0.1	0.858
	70	10.9	10.9	−0.0	0.738
	80	10.8	10.7	−0.2	0.525
	90	10.8	10.4	−0.4	0.118
	100	10.7	10.4	−0.3	0.180

AP anterior–posterior, CC cardiac cycle, LM anterolateral–posteromedial

by Jimenez and colleagues [22]. The decreased orifice area results in an increased blood flow velocity through the double orifice MV after MitraClip. The increase in velocity during diastole will increase the force on the leaflets and,

subsequently, on the annulus. The annular force elongates the annulus only in LM-direction during diastole because an increase in AP-direction is not possible due to the clipped MV leaflets. Furthermore, Jimenez et al. [22] found that

an isolated reduction of AP-diameter (contracted annulus) increases the Alfieri stitch forces and, subsequently, the annular forces during diastole depending on whether the annulus is normal sized or dilated. During systole, the effect is reversed, which maybe explains the lack of increase in LM-diameter during systole.

The annular circumference and area were not significantly affected by the intervention. However, previous studies have demonstrated a significant decrease of annular circumference and area at end-systole [5, 6]. These results can be confirmed in the present study by the observed non-significant decrease during systole. This decrease is secondary to reduced AP-diameter after the MitraClip procedure. In contrast, no differences were found during diastole, which may be explained by the increase of LM-diameter. The reciprocal changes in annular diameters, an increase of LM-diameter and the decrease of AP-diameter during diastole, mean that there is no net change in annular circumference and annulus area during diastole. Thus, it can be concluded that percutaneous MV repair with the MitraClip system reduces the mid-portion of MV annulus, but did not downsize the MV annulus.

These findings underline the consideration of time-varying changes of MV annulus in the quantification of the mitral annulus geometry. Particularly, the quantification of diameter changes after percutaneous MV repair procedures should be performed during mid-systole and early/mid-diastole.

### Effects of percutaneous MV repair on annular shape

The reshaping of the annulus is confirmed by the reduction of the annulus sphericity index by 8–12% (from 0.89 to 0.78 at 50% of CC). Interestingly, the reduction of annulus sphericity index with the MitraClip system corresponds nearly with the results of surgical MV repair with ring in patients with FMR. Mahmood et al. found in 12 patients with ischemic MR, treated with a Carpentier-Edwards Physio ring, a decrease of the annulus sphericity index from 0.96 before repair to 0.87 after repair [23]. Both techniques are completely different and not comparable from the technical aspects, but we hypothesize that percutaneous MV repair with the MitraClip system could lead to similar morphological changes of MV annulus as the surgical MV repair with ring in patients with FMR without significant annular dilatation.

Despite the significant changes in annular diameters, percutaneous MV repair did not significantly affect the AHCWR. The AHCWR is a measure of mitral annular non-planarity and describes the 3D shape of mitral annulus. The physiological decrease during systole correlates with the increased LV pressure and the resulting elongation of the mitral annulus [22, 24]. It demonstrates a flatter annular shape during systole. The loss of mitral annular

non-planarity resulting in increased MR and the restoration of non-planarity is a central tenet of surgical MV repair [24]. The present results suggest that percutaneous MV repair did not affect the physiological 3D annular shape during systole. The observed non-significant decrease during diastole is a result of the MitraClip procedure, which leads to a flatter annular shape due to the changed fluid–structure interaction.

Independent from these findings, the effect of LA and LV geometry on the annular shape was not investigated in this study. Hypothetically, the reduction of MR itself can lead to a reduction of the LA and LV sizes, which could influence the annular shape. Further studies should investigate the post-interventional effect of the LA and LV size on the annular shape.

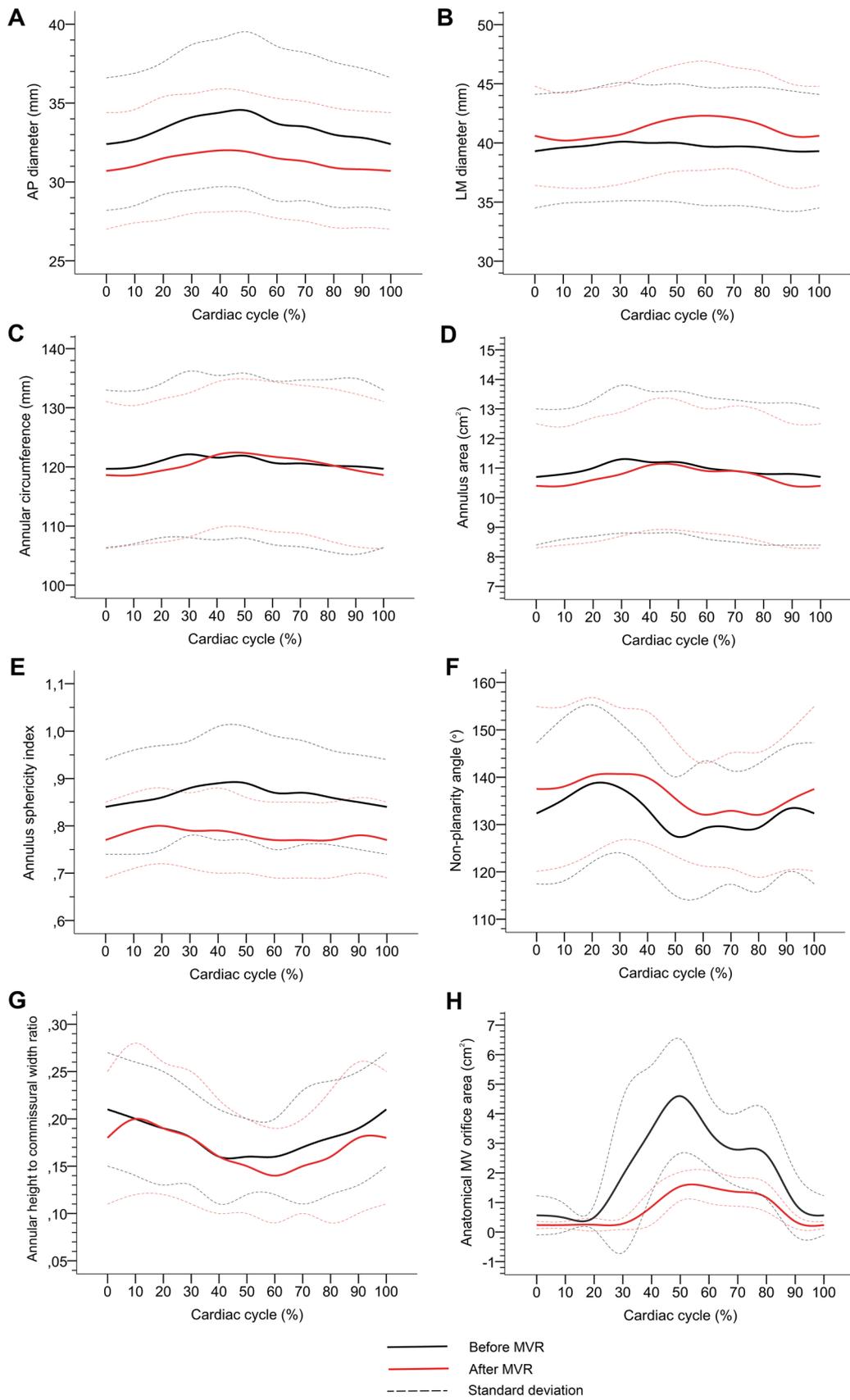
### Effects of percutaneous MV repair on anatomical MV orifice area

This study also showed that percutaneous MV repair resulted in a 67% decrease in AMVOA during systole and a 65% decrease of diastolic AMVOA. The assessment of the residual regurgitation area and MV orifice area after the MitraClip procedure is technical challenging and varies between the different measurement techniques [25]. The magnitude of decrease in systolic AMVOA is congruent with the extent of decrease in EROA shown in previous studies of MitraClip therapy [6, 26], and demonstrates the applicability AMVOA during systole as a quantitative measure of residual MR. Previous works have also shown a decrease of diastolic AMVOA ranging from 53 to 56% after the procedure [21, 25]. In both studies, the AMVOA was assessed with 3D planimetry in the proximity of the commissures. This can lead to an overestimation of the true post-interventional MV orifice area after percutaneous MV repair [25]. Our study quantified the 3D area between the leaflet tips, which would explain the larger decrease in MVOA.

Finally, percutaneous MV repair altered the temporal course of the cardiac cycle with relatively prolonged systole and shortened diastole. There is evidence from prior work that the MitraClip procedure increases the end-systolic left ventricular (LV) volume with increase of the LV pressure, and cardiac output [27], which presumably prolongs systole when compared to the duration of systole pre-MitraClip.

### Clinical implication

Prior studies have analyzed the effect of percutaneous MV repair with the MitraClip system on annular geometry alone and at predefined time points of CC [5, 6, 21]. The current report demonstrated important messages that differentiate it from existing series. First, our findings demonstrated for the first time the dynamic changes of MV geometry in relation



**Fig. 3** Changes of mitral valve geometry during percutaneous mitral valve repair. Annular dimensions (**a–d**), annular shape (**e–g**), and mitral valve orifice area (H) during percutaneous mitral valve repair. **a** Anterior–posterior diameter (AP-diameter) and **b** lateral–medial diameter (LM-diameter) of mitral annulus. **c** Annular circumference. **d** Annulus area. **e** Annulus sphericity index. **f** non-planarity angle. **g** Annular height to commissural width ration (AHCWR). **h** Anatomical MV orifice area (AMVOA)

to the AMVOA before and after percutaneous MV repair with the MitraClip system in patients with FMR. The restoration of coaptation and the indirect annular reshape in anterior–posterior direction (by 8%) with the MitraClip system has beneficial effect in patients with FMR. The clipping of anterior and posterior leaflet leads to a double orifice of the MV with substantial reduction of diastolic AMVOA. Second, the MitraClip-induced reduction of AP-diameter of 8% could limit the procedural success in patients with excessive annular dilation. Third, the most dynamic geometrically changes of annular geometry were found during mid-systole and early/mid-diastole, which should be considered in the quantification of annular morphology. Finally, the 3D TEE-based 4D MV analysis allows a fundamental improvement of the understanding of MV geometry in patients with MR, and can be used for pre- and post-interventional quantification of annular geometry and AMVOA.

### Limitations

The small number of patients in this study limits the clinical applicability. We did not perform a concrete analysis of the underlying power of the trial. However, given the novelty of the percutaneous MV repair technique and the complexity of 4D assessment of MV after the procedure, we believe that the sample size is reasonable to reach meaningful conclusions.

Furthermore, the influence of arrhythmia to the time-adjusted measurements was not investigated during the present report and should be investigated in further studies.

Finally, it is important to note that in the present study, the maximum AMVOA is a time-dependent measure dependent on the length of the cardiac cycle. The time-dependent maximum AMOVO underestimates the true maximum MV orifice area during the phase of MV opening due to the various times of MV opening between the patients. This effect is confirmed by increase of standard deviation and the difference between the minimum and maximum of AMVOA during this phase of CC (Supplementary Table 2). The assed time-independent maximum diastolic AMVOA was  $5.8 \pm 2.0$  cm<sup>2</sup> before and  $1.8 \pm 0.4$  cm<sup>2</sup> after percutaneous MV repair. The AMVOA during systole did not change between the time-independent and time-dependent analysis.

**Table 3** Annular shape and anatomic mitral valve orifice area before and after percutaneous mitral valve repair

	CC (%)	Before	After	Difference	<i>p</i> value
Annulus sphericity index	0	0.84	0.77	0.07	0.001
	10	0.85	0.79	0.06	0.003
	20	0.86	0.80	0.06	0.002
	30	0.88	0.79	0.08	<0.001
	40	0.89	0.79	0.10	<0.001
	50	0.89	0.78	0.11	<0.001
	60	0.87	0.77	0.10	<0.001
	70	0.87	0.77	0.10	<0.001
	80	0.86	0.77	0.09	<0.001
	90	0.85	0.78	0.08	<0.001
	100	0.84	0.77	0.07	0.001
Non-planarity angle, °	0	132.4	137.5	5.2	0.037
	10	135.4	138.1	2.7	0.242
	20	138.6	140.4	1.7	0.364
	30	137.8	140.7	2.9	0.167
	40	133.1	139.9	6.7	0.007
	50	127.5	135.5	8.0	<0.001
	60	129.1	132.1	3.0	0.177
	70	129.4	132.9	3.5	0.122
	80	129.3	132.1	2.7	0.197
	90	133.2	134.7	1.5	0.444
	100	132.4	137.5	5.2	0.037
AHCWR	0	0.21	0.18	−0.02	0.068
	10	0.20	0.20	0.00	0.750
	20	0.19	0.19	0.00	0.879
	30	0.18	0.18	0.00	0.663
	40	0.16	0.16	0.00	0.772
	50	0.16	0.15	−0.01	0.148
	60	0.16	0.14	−0.02	0.053
	70	0.17	0.15	−0.02	0.062
	80	0.18	0.16	−0.02	0.164
	90	0.19	0.18	−0.01	0.323
	100	0.21	0.18	−0.03	0.068
AMVOA, cm <sup>2</sup>	0	0.6	0.2	−0.3	0.007
	10	0.5	0.2	−0.2	0.008
	20	0.5	0.3	−0.25	0.013
	30	1.9	0.3	−1.6	0.003
	40	3.5	0.9	−2.6	<0.001
	50	4.6	1.6	−3.0	<0.001
	60	3.4	1.5	−1.9	<0.001
	70	2.8	1.4	−1.4	<0.001
	80	2.6	1.2	−1.4	<0.001
	90	1.0	0.4	−0.6	0.007
	100	0.6	0.2	−0.3	0.007

AMVOA anatomical mitral valve orifice area, AHCWR annular height–commissural width ratio, CC cardiac cycle

## Conclusion

The present study suggests that percutaneous MV repair reduces the mid-portion of the mitral annulus AP-dimension without a significant reduction of annular circumference or area. Further, this percutaneous treatment option reduces the MR by an improved coaptation of MV leaflets joint with a simultaneous indirect reduction of anterior–posterior diameter. Further, the MitraClip procedure leads to a reduction of AMVOA of more than 60%.

## Compliance with ethical standards

**Conflict of interest** Drs Noack and Vannan have received a speaker honorarium from Siemens Healthcare. Philipp Kiefer, Linda Mallon, Philipp Lurz, Carmine Bevilacqua, Joergen Banusch, Fabian Emrich, David M Holzhey, Holger Thiele, Friedrich-Wilhelm Mohr, Michael Andrew Borger, Joerg Ender and Joerg Seeburger declare that they have no conflict of interest.

**Research involving human participants** All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later revisions.

**Informed consent** Informed consent was obtained from all patients for being included in the study.

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