CHAPTER 18

Three-dimensional echocardiography for the preoperative assessment of patients with left ventricular aneurysm

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ABSTRACT

Objectives: Surgical ventricular reconstruction has been proposed as a treatment option in heart failure patients with left ventricular (LV) aneurysm. The feasibility of this procedure has some limitations and extensive pre-operative evaluation is necessary in order to give the correct indication. For this purpose, magnetic resonance imaging (MRI) is currently considered the gold standard, providing accurate quantification of LV shape, size, global and regional function together with the assessment of myocardial scar and mitral regurgitation severity. The aim of this study was to evaluate the accuracy of real-time three-dimensional echocardiography (RT3DE) as a potential alternative to MRI for this evaluation.

Methods: A total of 52 patients with ischemic cardiomyopathy and LV aneurysm underwent a comprehensive analysis with 2D echocardiography, RT3DE and MRI.

Results: Excellent correlation (r = 0.97, p <0.001) and agreement were found between RT3DE and MRI for quantification of LV volumes, ejection fraction and sphericity index; in a segment-to-segment comparison, RT3DE showed to be accurate also for the analysis of wall motion abnormalities (k = 0.62) and LV regional thickness (k = 0.56) as a marker of myocardial scar. In turn, 2D echocardiography showed to underestimate significantly these parameters. Furthermore, mitral regurgitant volume assessed by RT3DE showed excellent correlation (r = 0.93) with regurgitant volume measured by MRI, without significant bias (= -0.7ml/beat).

Conclusions: In the management of heart failure patients with LV aneurysm, RT3DE provides an accurate and comprehensive assessment, including quantification of LV size, shape, global systolic function, regional wall motion and myocardial scar together with a precise evaluation of the severity of mitral regurgitation.
INTRODUCTION

Left ventricular (LV) remodeling after acute myocardial infarction is defined as a progressive LV dilation and dysfunction, accompanied by an expansion of myocardial scar. This process was demonstrated to be associated with a poor prognosis and several treatments are now available to attenuate or partially reverse this phenomenon. Particularly, in the presence of a LV aneurysm surgical ventricular reconstruction (SVR) has been proposed to improve LV size, shape, wall-stress and function. However, the feasibility of this procedure has some limitations and an extensive pre-operative evaluation is necessary in order to give the correct indication, to plan the operation and to estimate the peri-operative and post-operative mortality. In particular, accurate values of LV size, shape and function are crucial to evaluate the impact of surgery; precise identification of LV regional dysfunction, myocardial scar site and extent is also fundamental to determine the feasibility of the procedure. In addition, reliable quantification of mitral regurgitation is important to evaluate the possibility to perform concomitant mitral valve repair.

Magnetic resonance imaging (MRI) is currently considered the gold standard for this comprehensive assessment, providing highly accurate and reproducible data. However, this technique is not widely available and is not compatible with cardiac devices. As an alternative, conventional 2-dimensional (2D) echocardiography has been applied, although with significant inaccuracy due to assumptions about LV cavity geometry. Real-time three-dimensional echocardiography (RT3DE) is now available to overcome these limitations and showed to be more accurate than 2D echocardiography for quantification of LV volumes. The aim of this study was therefore to evaluate, in comparison with MRI, feasibility and accuracy of RT3DE for the complex assessment of patients with LV aneurysm, including LV volumes, LV shape, LV ejection fraction, LV wall motion abnormalities, identification of myocardial scar and quantification of the severity of mitral regurgitation.

METHODS

The study population consisted of 60 consecutive patients with ischemic cardiomyopathy and LV akinetic/dyskinetic aneurysm, who were referred from July 2006 to September 2008 to evaluate the possibility of a SVR. The evaluation included, in the same day, conventional 2D echocardiography, RT3DE and cardiac MRI. Using these imaging modalities, LV size and shape and LV global and regional systolic function were evaluated. The presence of a LV thrombus was also assessed. Since echocardiography can not provide a precise identification of myocardial scar, RT3DE and MRI were compared for the measure of LV regional thickness, as a well-known marker of transmural scar. Finally, these 2 imaging modalities were compared for
the assessment of mitral regurgitation severity. All the variables included in the analysis are summarized in Table 1.

All patients gave informed consent and the protocol was approved by the institutional review board.

Table 1. List of the measures and of the imaging modalities included in the study.

<table>
<thead>
<tr>
<th>Measure</th>
<th>MRI</th>
<th>RT3DE</th>
<th>2DE</th>
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<tr>
<td>Left ventricular end-diastolic volume (LVEDV)</td>
<td>X</td>
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<tr>
<td>Left ventricular end-systolic volume (LVESV)</td>
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<td>Left ventricular ejection fraction (LVEF)</td>
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<td>Left ventricular sphericity index (LVSI)</td>
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<td>Left ventricular wall motion score index (LVWMSI)</td>
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<tr>
<td>Left ventricular regional thickness</td>
<td>X</td>
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<td>-</td>
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<tr>
<td>Mitral regurgitant volume</td>
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2DE:2-dimensional echocardiography, MRI: magnetic resonance imaging, RT3DE:real-time three-dimensional echocardiography

**Standard 2D echocardiography**

Patients were imaged in the left lateral decubitus position using a commercially available system (IE33, Philips Medical Systems, N.A., Bothell, Washington, USA) equipped with a 3.5-MHz transducer. LV end-systolic volume (ESV) and LV end-diastolic volume (EDV) were determined from the conventional apical 2- and 4-chamber views and LV ejection fraction (EF) was calculated using the biplane Simpson’s technique.

As a measure of LV shape, sphericity index (SI) was calculated by dividing LVEDV by the volume of a sphere whose diameter was derived from the major end-diastolic LV long-axis. The LV long-axis was obtained as the longest distance between the centre of the mitral annulus and the endocardial apex in the 4-chamber view.

Qualitative assessment of the regional wall motion was performed according to the standard 16-segment model and was graded as follows: 1 = normal; 2 = hypokinetic; 3 = akinetic and 4 = dyskinetic. A global wall motion score index (WMSI) was calculated as the sum of each LV segment’s score divided by the number of visualized segments.

Finally, the presence of a LV thrombus, especially in the apical region, was evaluated without contrast administration, using standard and off-axis views.

**Real-time three-dimensional echocardiography**

Patients were imaged with the same system (IE33, Philips Medical Systems) equipped with an X3, fully sampled matrix transducer. Apical full-volume data sets were obtained combining,
within 1 breath-hold, 7 small real-time sub-volumes to provide a larger pyramidal volume (up to 101×104 degrees) and to ensure a complete capture of the LV. A 3D data set was considered unsuitable for analysis if >2 segments could not be visualized or if it contained visible stitch artefacts due to irregular heart rate or breathing movements. To assess the severity of mitral regurgitation, apical full-volume Color Doppler data sets were also acquired with a Nyquist limit set between 30 and 50 cm/sec. All 3D data sets were stored digitally and quantitative analysis was performed off-line using a semi-automated contour tracing algorithm (Q-Lab, version 6.0, Philips Medical Systems).

During post-processing of the 3D data set, the software automatically displays the apical 4- and 2-chamber views and the parasternal short-axis view. After initial identification of the apex and mitral annulus with 5 reference points on the end-diastolic and end-systolic frames, a preconfigured ellipse is fitted to the endocardial border for each frame. A manual adjustment of the endocardial border was performed if required. A LV 3D model is automatically generated and LV volumes and LVEF are calculated.

The SI of the LV 3D model was calculated as with 2D echocardiography; however, the use of 2 near-orthogonal cut-planes within the 3D dataset allowed for the exact location of the endocardial apex, avoiding any foreshortening (Figure 1). Furthermore, by slicing the 3D dataset, multiple LV short- and long-axes can be obtained (at the basal, mid-ventricular and apical level) and analysed to assess the 3D WMSI as for 2D echocardiography. With the same approach, the presence of a LV thrombus, particularly at the apical level, was also evaluated. From the same short-axis slices, the endocardial and epicardial contours were traced manually at end-diastole, with the papillary muscles included in the cavity. The traced contours

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**Figure 1.** Schematic example of calculation of sphericity index with RT3DE (left panel) and MRI (right panel) in a patient with LV aneurysm. The major end-diastolic LV long axis was obtained as the longest distance between the centre of the mitral annulus and the endocardial apex, identified by cropping the 3D dataset (panel A) or selecting the best slice in the MRI acquisition (panel B). Sphericity index was calculated by dividing LV end-diastolic volume by the volume of a sphere whose diameter was derived from the LV long-axis.
were then used to calculate LV regional thickness according to the standard 16-segment model \(^\text{10}\) (Figure 2). In particular as previously described \(^\text{12}\), severely thinned regions (end-diastolic thickness <6mm) were considered to be representative for transmural scar.

To evaluate the severity of mitral regurgitation, the effective regurgitant orifice area (EROA) was calculated \(^\text{13-15}\). In particular, the 3D Color Doppler dataset was manually cropped by an image plane perpendicularly oriented to the jet direction until the narrowest cross-sectional area of the jet. The EROA was measured by manual planimetry of the color Doppler signal, tilting the image in an 'en face' view (Figure 3); the regurgitant volume was estimated as EROA multiplied by the velocity time integral of the regurgitant jet on the continuous-wave Doppler.

Image acquisition required approximately 5 min, while post processing required 10 to 15 min, including the measurement of LV volumes, LVEF, LVSI and LV wall motion abnormalities, the evaluation of mitral regurgitation severity and the assessment of LV thrombus.

**Figure 2.** An example of RT3DE assessment of LV regional thickness. After slicing the 3D dataset in 9 LV short-axes (3 at the basal, 3 at the mid-ventricular and 3 at the apical level), the endocardial and epicardial contours were traced manually at the end-diastolic frame. The traced contours were then used to calculate LV regional thickness according to the standard 16-segment model. The white arrows indicate the septum at mid-ventricular level that most likely contains transmural scar tissue (end-diastolic thickness <6mm). The LV apical segments are also significantly thinned (see right bottom panel).
Three-dimensional echocardiography for the preoperative assessment of patients with left ventricular aneurysm

Figure 3. An example of RT3DE assessment of mitral effective regurgitant orifice area. The 3D dataset is manually cropped by an image plane perpendicularly oriented to the jet direction until the narrowest cross-sectional area of the jet. The effective regurgitant orifice area is measured (= 0.26 cm²) by manual planimetry of the color Doppler signal tilting the image in an ‘en face’ view.

Magnetic resonance imaging

Data acquisition

Data acquisition was performed on a 1.5 T scanner equipped with powertrack 6000 gradients (Gyrosan ACS-NT/Intera, Philips Medical Systems, Best, The Netherlands). Scout images and 2- and 4-chamber acquisitions were performed to identify the intrinsic long-axis of the heart and for further planning. A cine-set of 12-16 multi-slice images were acquired in short-axis orientation, covering the complete LV from apex to base. Segmented gradient-turbo field echo was used, with parallel imaging (Sensitivity Encoding, acceleration factor 2) and steady-state free-precession. The following imaging parameters were used: slice thickness of the imaging planes=10 mm, with no gap; Field-of-View=440 mm; 80% scan, scan-matrix=256 × 256, reconstructed voxels of 1.56×1.56×10.0 mm; α=35°; TR/TE=3.6/1.7.

To evaluate the severity of mitral regurgitation, a true 3D MRI acquisition was applied with velocity-encoding in 3 orthogonal directions (field-of-view 370 mm, 3D volume scan with slab thickness 48 mm, reconstructed into 12 slices of 4 mm, TE/TR=3.3/14, α=10°, acquisi-
tion voxel size 2.9×3.8×4.0 mm³, reconstructed into 1.4×1.4×4.0 mm³, NSA 1, with 30 phases reconstructed, EPI factor 5) 16–18.

Data analysis

Quantification of LVESV, LVEDV and LVEF was performed on the short-axis series using MASS analytical software (Medis, Leiden, The Netherlands) and manual contour tracing of the epicardial and endocardial borders, as previously described 19.

The SI was calculated from the 4-chamber acquisition as abovementioned for 2D echocardiography and RT3DE (Figure 1). Qualitative assessment of the regional wall motion was performed using both long- and short-axis acquisitions and the WMSI was based on a 16-segment model as for the echocardiographic analysis. From the same acquisitions, the presence of a LV thrombus was evaluated.

In addition, from the complete short-axis dataset 3 slices were selected representing the basal, mid-ventricular and apical level. From the epicardial and endocardial contours drawn in these slices, LV end-diastolic regional thickness was calculated according to the standard 16-segment model 10 (Figure 4). As previously described in various studies, an end-diastolic thickness <6 mm was considered as a marker of transmural scar 20,21.

Figure 4. A set of MRI short-axis slices at basal, mid-ventricular and apical level acquired for the assessment of LV wall thickness (upper panel), using gradient-echo acquisitions, and for the analysis of myocardial scar (lower panel), using delayed contrast-enhanced images. In this example, the antero-septum, the anterior wall and the apex are significantly thinned and contain transmural scar (see arrows).
To confirm the site and the extent of scar tissue, contrast-enhanced images (20-24 short-axis slices) were acquired 15 minutes after bolus injection of gadolinium diethylenetriamine pentaacetic acid (Magnevist, Schering/Berlex, Berlin, Germany; 0.15 mmol/Kg) with an inversion recovery gradient echo sequence (400x400 mm² Field-of-View; 256x256 matrix size, 5-mm slice thickness with gap of -5mm, α=15°, TE/TR=1.36/4.53) 22. Hyperenhanced regions were defined by selecting a region-of-interest inside the normal myocardium and thresholding the window setting at 5SD above the mean signal intensity 23 (Figure 4). The total extent of scar, expressed as percentage of LV mass, was quantified using QMass (Medis) and the number of segments with transmural scar was calculated.

The 3D velocity-encoded MRI acquisitions were analyzed using in-house developed image processing software. The procedure was performed as previously described 17,18. In summary, from the velocity-encoded MRI data, the 3 velocity vector components of blood flow at the level of the mitral valve plane needs to be reformatted, using the LV 4- and 2-chamber views. The velocities measured perpendicularly to the reconstructed MV plane need to be corrected for the motion of the myocardium in basal/apical direction in order to obtain the true trans-valvular velocity of the blood flow. The trans-valvular volume flow was obtained by integrating the resulting velocities over the annulus area. The regurgitant volume was obtained by calculating the Riemann sum of backward flow during systole in the flow graph. The reproducibility of this analysis was also previously reported 16–18.

**Statistical analysis**

Continuous data are presented as mean±SD; dichotomous data are presented as numbers and percentages. Comparison of data was performed using the paired Student t test. Pearson’s correlation analysis was performed to evaluate the relation between echocardiographic and MRI measurements. In addition, Bland-Altman analysis was performed to evaluate the differences between echocardiographic and MRI measurements and the mean bias±2SD are reported. Agreement between these imaging techniques was assessed using weighted κ statistics (Fleiss-Cohen weighting). The reproducibility of the RT3DE measures was assessed with Pearson’s correlation and Bland-Altman analysis. A p-value <0.05 was considered to be statistically significant. A statistical software program SPSS16.0 (SPSS Inc, Chicago, IL, USA) was used for statistical analysis.

**RESULTS**

Three patients (5%) did not undergo cardiac MRI because of major contraindications (atrial fibrillation and cardiac devices). Another 5 patients (8.5%) were excluded from further analysis because of inadequate RT3DE images. Clinical characteristics of the remaining 52 patients are
summarized in Table 2. All patients had symptoms of heart failure despite optimal medical therapy. The presence of a LV aneurysm (with at least 2 contiguous dyskinetic segments) was observed in all patients and in most of the cases (81%) involved the antero-septum, anterior and apical segments, as a result of a previous myocardial infarction in the LAD territory.

| Table 2. Clinical characteristics of the study population (n = 52). |
|-----------------------------|------------------|
| **Age (years)**             | 62±10            |
| **Male/Female**             | 37/15            |
| **NYHA class**              |                  |
| II                          | 4(8%)            |
| III                         | 40(77%)          |
| IV                          | 8(15%)           |
| **Medication**              |                  |
| ACE-inhibitors              | 48(92%)          |
| β-blockers                  | 41(79%)          |
| Diuretics and/or spironolactone | 40(94%)       |
| Amiodarone                  | 11(21%)          |
| Antiocoagulants             | 43(82%)          |
| **Myocardial infarction/aneurysm location** |                  |
| Antero-septum/anterior/apex | 42(81%)          |
| Infero-septum/inferior      | 9(17%)           |
| Postero-lateral             | 1(2%)            |
| **Previous percutaneous revascularization** |                  |
| Multi-vessel disease        | 46(88%)          |
| Single-vessel disease       | 35(67%)          |
| **Time from myocardial infarction (months)** | 19±11            |

NYHA: New York Heart Association functional class

**Left ventricular size and shape**

Mean values of LVEDV, LVESV and SI measured with 2D echocardiography, RT3DE and MRI are displayed in Table 3. According to all these techniques, a severe LV dilatation with a remodeling towards a spherical shape was observed.

Considering MRI the gold standard, RT3DE showed an excellent correlation for the measurements of LVEDV, LVESV and SI (r = 0.97, r = 0.98 and r = 0.96, respectively, p <0.001). However, Bland-Altman analysis (Figure 5) revealed a systematic bias between MRI and RT3DE of 21.6±40.4 ml for LVEDV, of 19.8±40.1 ml for LVESV and of 0.01±0.05 for SI (p <0.01), which tended to increase for larger and more spherical LV volumes.

Similarly, 2D echocardiography showed a good correlation with MRI for the measures of LVEDV, LVESV and SI (r = 0.94, r = 0.95 and r = 0.94, respectively, p <0.001). However, Bland-Altman analysis showed a significantly larger bias between these 2 techniques with a mean difference of 40.9±48.8 ml for LVEDV, of 32.7±44.9 ml for LVESV and of 0.03±0.07 for SI (p <0.001).
Three-dimensional echocardiography for the preoperative assessment of patients with left ventricular aneurysm

Table 3. Mean values of LV size and function measured by 2D echocardiography (2DE), RT3DE and MRI.

<table>
<thead>
<tr>
<th></th>
<th>MRI</th>
<th>RT3DE</th>
<th>2DE</th>
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<tbody>
<tr>
<td>LVEDV (ml)</td>
<td>288.4±87.2</td>
<td>266.8±75.3*</td>
<td>247.4±70.5*</td>
</tr>
<tr>
<td>LVESV (ml)</td>
<td>212.7±91.4†</td>
<td>192.9±70.8*</td>
<td>180.0±73.7*</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>28.0±12.2</td>
<td>29.0±10.4†</td>
<td>28.6±11.2†</td>
</tr>
<tr>
<td>LVSI</td>
<td>0.54±0.17</td>
<td>0.53±0.15†</td>
<td>0.51±0.14*</td>
</tr>
<tr>
<td>LVWMSI</td>
<td>2.0±0.6</td>
<td>2.2±0.5†</td>
<td>2.4±0.5*</td>
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</table>

*=p<0.001 compared to MRI.
†=p<0.05 compared to MRI

EDV: end-diastolic volume, EF: ejection fraction, ESV: end-systolic volume, LV: left ventricle, SI: sphericity index, WMSI: wall motion score index

Left ventricular global and regional systolic function

Mean values of LVEF and WMSI measured with 2D echocardiography, RT3DE and MRI are displayed in Table 3. Considering MRI the gold standard, RT3DE showed an excellent correlation for the measure of LVEF (r = 0.97, p < 0.001); a mean bias between MRI and RT3DE of -0.9±4.6% (p < 0.05) was found at the Bland-Altman analysis (Figure 5). Similarly, a good correlation for the measure of LVEF (r = 0.96, p < 0.001) was observed between 2D echocardiography and MRI with a mean bias of -0.7±5.2% (p < 0.05).

A significant difference in the value of WMSI was found both with RT3DE and 2D echocardiography as compared to MRI. However, in a segment-to-segment comparison (for a total of 821 segments that could be satisfactorily visualized by the 3 techniques) a better agreement was observed between RT3DE and MRI (k = 0.62) than between 2D echocardiography and MRI (k = 0.58).

Of note, a LV thrombus was detected by MRI in 4 (8%) patients. A LV thrombus was identified in the same 4 patients by RT3DE, while 2D echocardiography was not able to detect a small thrombus adjacent to the apical anterior wall in one of these patients.

Identification of LV segments with transmural scar

Using RT3DE, LV endocardial and epicardial borders could be both visualized in 779 (93%) segments and a mean of 6.0±1.7 segments per patient showed a thickness <6 mm and were considered as transmurial scar. Similarly using MRI, a mean of 5.8±2.2 segments per patient (p < 0.001) were defined as transmurual scar (thickness <6 mm). In a segment-to-segment comparison, RT3DE and MRI showed a good agreement (k = 0.56) for the identification of LV segments with transmural scar, based on the measure of LV regional thickness. A good agreement was observed also between RT3DE and contrast-enhanced MRI (k = 0.54), which showed a mean of 5.1±1.9 segments per patient with a transmural scar. Of note, using contrast-enhanced MRI mean total scar extent was 29.9±8.2%. 


From RT3DE analysis, the mean mitral regurgitant volume was 9.2±8.8 ml/beat, ranging from 2 to 37 ml/beat. Similarly from the 3D velocity encoded MRI analysis, the mean mitral regurgitant volume was 9.8±9.4 ml/beat, ranging from 2 to 42 ml/beat. RT3DE and MRI showed an excellent correlation for the assessment of mitral regurgitant volume (r = 0.93, p <0.001)

**Mitral regurgitation**

From RT3DE analysis, the mean mitral regurgitant volume was 9.2±8.8 ml/beat, ranging from 2 to 37 ml/beat. Similarly from the 3D velocity encoded MRI analysis, the mean mitral regurgitant volume was 9.8±9.4 ml/beat, ranging from 2 to 42 ml/beat. RT3DE and MRI showed an excellent correlation for the assessment of mitral regurgitant volume (r = 0.93, p <0.001)
and the Bland-Altman analysis (Figure 5) revealed a non significant bias between these techniques (RT3DE–VE MRI = -0.7 ml/beat, limits of agreement from -7.1 to 5.8 ml/beat, p = 0.71).

**Reproducibility of RT3DE measures**

Reproducibility of RT3DE measures of LVEDV, ESV and EF were previously reported by our group and were in line with other studies. Reproducibility of RT3DE assessment of mitral effective regurgitant orifice and regurgitant volume was also previously reported by our group.

Inter-observer reproducibility for SI and WMSI was obtained analyzing the 3D dataset of 15 patients at different times by 2 independent observers, each without knowledge of the results obtained by the other. The agreement was good: mean bias was 0.00±0.07 (p = 0.32) and 0.2±0.03 (p = 0.24), respectively. The correlation between the measures of the 2 observers was also excellent (both r = 0.97, p <0.001). Similarly, inter-observer variability for LV regional thickness was tested on 7 patients (112 segments): mean bias was 0.7±0.3 mm (p = 0.11, r = 0.91).

**DISCUSSION**

The main findings of the current study can be summarized as follows: 1) in patients with LV aneurysm, evaluation of LV size, shape and function by RT3DE is feasible and reproducible; 2) in this group of patients, RT3DE provides highly accurate quantification of LV volumes, EF, SI and WMSI, in a direct comparison with MRI; 3) RT3DE can be also applied for the identification of transmural scar and for the assessment of mitral regurgitation severity.

**Heart failure and LV aneurysm**

*Surgical treatment*

Surgical ventricular reconstruction, and in particular endoventricular circular patch plasty (Dor procedure), has been proposed as a treatment for heart failure patients with an extensive myocardial infarction and LV aneurysm. Aim of this procedure is to restructure the curvature of the LV wall back to its original geometric configuration, excluding the scarred portion of the ventricle from the adjacent viable myocardium. Scar exclusion prompts a return to a systolic concentric contraction and was demonstrated to decrease LV volume and to increase LV systolic function. However, the impact of this procedure on survival is still controversial and accurate patient selection should be performed. In particular, to set the
indication for SVR, accurate quantitative evaluations are necessary to determine the feasibility and the impact of surgery, considering the complicated postoperative LV geometric changes. Accurate quantification of LV size and shape is fundamental to avoid an excessive volume reduction and/or cavity deformation that lead to a progressive diastolic dysfunction and to a restrictive filling pattern. Furthermore, the precise extent of myocardial scar and the wall motion abnormalities is crucial to evaluate whether a “viable” contractile LV cavity can be reshaped. Also, the presence of a LV thrombus is often a decision point for aneurysmectomy and estimate of peri- and post-operative mortality is mainly based on a reliable assessment of LV global and regional systolic function. In addition, SVR is often accompanied by mitral valve repair and the severity of mitral regurgitation should be therefore carefully evaluated.

Use of imaging for an extensive evaluation

As mentioned above, patients with heart failure and LV aneurysm need an extensive evaluation before SVR. Currently, MRI is considered the gold standard for this comprehensive analysis. This imaging technique in fact was proven to be far more accurate than other techniques for quantification of LV shape and volumes, for the analysis of LV global systolic function and wall motion abnormalities, for identifying the precise extent of transmural scar and for the evaluation of mitral valve apparatus. However, MRI is not widely available, due to the high equipment costs and the need for special facilities, and can not be applied in the presence of cardiac devices and atrial fibrillation, often present in heart failure patients. Furthermore, MRI can not be performed at the bedside or in the operating room, where an immediate assessment of SVR results is of great importance. In a head-to-head comparison with MRI, the current study demonstrated the accuracy of RT3DE as a potential alternative technique for the study of heart failure patients with significantly abnormal LV geometry due to the presence of a LV aneurysm. In particular, excellent correlation and a good agreement were found between these 2 techniques for the calculation of LVEDV, ESV, EF and SI. Of note, a trend towards an increased disagreement between RT3DE and MRI for the measurements of larger LV volumes and for more spherical LV shape was noted, probably due to the challenges (limited sector width and lateral resolution) of obtaining an appropriate echo acquisition in the presence of a very dilated ventricle with geometrical alterations. In a segment-to-segment comparison with MRI, RT3DE showed to be accurate also for the analysis of wall motion abnormalities and identification of non-viable segments. In turn, conventional 2D echocardiography showed to be less accurate, with a significant underestimation of these LV parameters probably due to inappropriate geometric assumptions and to the difficulty of obtaining true apical views.

These findings confirmed in a large population the results of initial studies that applied the old free-hand 3D rotating probe or the novel real-time acquisition in small groups...
of patients with LV aneurysm. For the first time however, RT3DE was applied in this study also for the calculation of WMSI and the analysis of LV regional thickness, which contains crucial information for the identification of myocardial transmural scar. Several studies demonstrated that the extent of myocardial scar, more than the type of asynergy (dyskinesia versus akinesis), has an important prognostic value for SVR outcomes. Furthermore, RT3DE showed to be an accurate approach also for the assessment of the severity of mitral regurgitation, which is of great prognostic importance and is necessary to plan the surgical treatment. Mitral regurgitant volume assessed by RT3DE showed an excellent correlation with regurgitant volume measured by 3D MRI, without a significant difference between the 2 techniques. In fact, color Doppler RT3DE, allowing for an unlimited plan orientation and in particular for an “en face” view of the mitral valve, provides a direct planimetry of the regurgitant orifice, obviating the geometric assumptions not applicable in patients with functional mitral regurgitation, in which the EROA is typically elongated along the semilunar-shaped leaflet coaptation line.

This comprehensive approach makes RT3DE particularly suitable for the management of heart failure patients with LV aneurysm. Further studies are needed to demonstrate the accuracy of RT3DE measures using the transesophageal approach, in view of a potential application in the operating room for an immediate assessment of SVR results.

**Study limitations**

Although the RT3DE measures showed a good reproducibility, further multi-center studies with larger population are needed to confirm the results of the current study. Furthermore, short- and long-term follow-up data are necessary to explore the accuracy and prognostic value of RT3DE for the assessment of progressive LV remodeling or, in case of SVR, for the evaluation of the surgical outcome.

**CONCLUSIONS**

For the management of heart failure patients with LV aneurysm and in order to determine the best treatment for these patients, RT3DE provides an accurate and comprehensive assessment, including quantification of LV size, shape, global systolic function and extension of wall motion abnormalities together with the identification of transmural scar and a precise evaluation of the severity of mitral regurgitation.
REFERENCES


Three-dimensional echocardiography for the preoperative assessment of patients with left ventricular aneurysm


