Is right ventricular systolic function reduced after cardiac surgery? A two- and three-dimensional echocardiographic study

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Aims A reduction in tricuspid annular plane systolic excursion (TAPSE) and peak systolic velocity (PSV) of tricuspid annulus after cardiac surgery is a well-known phenomenon, even though its origin is not well established. Recently, a new three-dimensional (3D) echocardiographic software adapted for right ventricular (RV) analysis has been validated. Aims of this study were to evaluate RV function in patients with mitral valve prolapse undergoing surgical valvular repair and to compare and correlate 3D RV ejection fraction (RVEF) with TAPSE and PSV before and after surgery.

Methods and results Forty patients were studied by transthoracic 2D and 3D echocardiography pre- and 3, 6, and 12 months post-surgery. TAPSE (15.5 ± 3, 16.5 ± 3, and 18.5 ± 4 mm at 3, 6, and 12 months, respectively) and PSV (11.9 ± 2, 12 ± 2, and 12.8 ± 3 cm/s at 3, 6, and 12 months, respectively) were significantly (P < 0.001) lower after surgery in comparison with pre-surgical values (TAPSE: 25.3 ± 4 mm; PSV: 17.8 ± 4 cm/s). On the contrary, pre-operative RVEF (58.4 ± 4%) did not change after surgery (56.9 ± 5, 59.5 ± 5, and 58.5 ± 5% at each step).

Conclusion Despite the post-operative reduction of RV performance along the long axis suggested by TAPSE and PSV, the absence of a decrease in 3D RVEF leads to caution in the interpretation of these 2D and Doppler parameters after cardiac surgery, supporting the hypothesis of geometrical rather than functional changes in the right ventricle.

KEYWORDS Three-dimensional echocardiography; Cardiac surgery; Right ventricular function; Mitral valve prolapse

Introduction

The importance of the right ventricle as a determinant of exercise capacity and the prognostic value of right ventricular (RV) function in heart failure, as well as in cardiac surgery outcome, have been largely proved.1–4 Due to the peculiar RV morphology, two-dimensional (2D) transthoracic echocardiography has several limitations in RV evaluation. However, tricuspid annular plane systolic excursion (TAPSE) and peak systolic velocity (PSV) of tricuspid annulus have been widely used as simple indexes for RV performance.5–11 Recently, a new software for RV quantification applied to three-dimensional (3D) echocardiographic images has been introduced and validated in a large population of normal subjects and patients. As shown by magnetic resonance or angiographic estimated ejection fraction, also 3D RV ejection fraction (RVEF) is positively correlated with both TAPSE and PSV.12–16

The reduction in TAPSE and PSV after cardiac surgery is a well-known phenomenon, even though its origin is not well established.17–20 Several hypotheses have been proposed, such as RV geometrical changes in association with interventricular septal paradoxical motion or poor RV protection during cardiopulmonary bypass causing reduction of RV performance along the long axis. However, the reduction in RV function assessed by TAPSE was not associated with a decrease in either exercise capacity or left ventricular (LV) function. Thus, the depressed RV function measured from TAPSE after surgery was interpreted as not clinically significant.20 As this reduction does not seem set completely right 1 year after cardiac surgical procedure,19 the investigation of TAPSE as RV function parameter in patients who underwent cardiac surgery is intriguing.

Aims of this study were (i) to evaluate the 2D and 3D echocardiographic parameters of RV function in patients with...
mitral valve prolapse (MVP) undergoing surgical valvular repair and (ii) to compare and correlate 3D RVEF with TAPSE and PSV pre- and 3, 6, and 12 months post-surgery.

Methods

Population and study protocol

The study population consisted of 40 consecutive patients (mean age 60 ± 11 years; 25 males/15 females) with severe mitral regurgitation due to degenerative MVP. All patients were scheduled for surgical mitral valve repair. Exclusion criteria were atrial fibrillation, inadequate echocardiographic acoustic apical window, severe tricuspid regurgitation candidate for tricuspid annuloplasty, history of coronary artery disease or of previous cardiac surgery. Both 2D and 3D transthoracic echocardiography were performed pre- and 3, 6, and 12 months post-mitral valve repair. The local Ethics Committee approved the study and informed consent was obtained from each enrolled patient.

Echocardiographic measurements

All echocardiographic examinations were performed with a Philips ultrasound system (iE33, Andover, MA, USA). A complete standard M-mode and 2D echocardiographic examinations were performed according to the clinical laboratory practice using an S5-1 sector array probe. LV end-diastolic and end-systolic volumes, as well as biplane ejection fraction were measured from apical four- and two-chamber views by the area-length method. Systolic pulmonary arterial pressure (SPAP) was non-invasively obtained using Doppler echo method from the systolic RV–right atrial gradient, calculated by means of the inferior vena cava collapsibility index measured from the subcostal view.21 To evaluate TAPSE, defined as the difference in the displacement of the RV base from end-diastole to end-systole, from the apical four-chamber view, the M-mode cursor was positioned at the junction of the tricuspid valve plane with the RV free.3,6 For tissue Doppler analysis, previously reported modifications of settings were applied, to record wall motion low velocities.8-10 From the apical four-chamber view, the pulsed-Doppler sample volume was positioned within the lateral margin of the tricuspid annulus, with the cursor parallel to the movement of the annular motion. The low Doppler shift frequencies produced by the moving wall were recorded and the PSV measured.

Real-time 3D transthoracic echocardiography was performed immediately following the 2D examination, by utilizing an X3-1 matrix array probe. The 3D datasets were acquired in the ‘full volume’ mode from the apical view, adapted to improve the visualization of the RV chamber. Two datasets per patient were obtained and stored. The offline post-processing and 3D reconstruction were performed with a commercially available dedicated system (Echo View, Tom Tec Imaging Inc., Munich, Germany) equipped with a four-dimensional RV analysis software. This software is based on the manual tracing of the RV endocardial contours in the end-diastolic and end-systolic frames performed in the sagittal, four-chamber, and coronal views, obtained by slicing the acquired 3D dataset.13 Once manual initialization was completed, a semi-automated endocardial border detection algorithm was applied throughout the heart cycle. After manual correction, RV end-diastolic and end-systolic volumes were automatically calculated. Then, RV stroke volume and RVEF were measured as the difference and the percentage of change of the volumes, respectively.

Table 1  Two-dimensional, Doppler, and three-dimensional echocardiographic parameters measured at pre- and 3, 6, and 12 months post-surgery

<table>
<thead>
<tr>
<th></th>
<th>Pre-surgery</th>
<th>Third month</th>
<th>Sixth month</th>
<th>Twelfth month</th>
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<tbody>
<tr>
<td>Tricuspid annular plane systolic excursion (mm)</td>
<td>25.3 ± 4</td>
<td>15.5 ± 3*</td>
<td>16.5 ± 3*</td>
<td>18.5 ± 4*</td>
</tr>
<tr>
<td>Peak systolic velocity of tricuspid annulus (cm/s)</td>
<td>17.8 ± 4</td>
<td>11.9 ± 2*</td>
<td>12 ± 2*</td>
<td>12.8 ± 3*</td>
</tr>
<tr>
<td>2D Left ventricular end-diastolic volume (mL)</td>
<td>142 ± 50</td>
<td>111 ± 34*</td>
<td>105.6 ± 28*</td>
<td>103.8 ± 25*</td>
</tr>
<tr>
<td>2D Left ventricular end-systolic volume (mL)</td>
<td>45.8 ± 20</td>
<td>45.1 ± 22</td>
<td>39.8 ± 15</td>
<td>39.2 ± 13*</td>
</tr>
<tr>
<td>2D Left ventricular ejection fraction (%)</td>
<td>68.5 ± 6</td>
<td>60.6 ± 7*</td>
<td>62.6 ± 6*</td>
<td>63 ± 6*</td>
</tr>
<tr>
<td>Systolic pulmonary arterial pressure (mmHg)</td>
<td>34 ± 4</td>
<td>25.8 ± 3*</td>
<td>25.1 ± 4*</td>
<td>26.7 ± 5*</td>
</tr>
<tr>
<td>3D Right ventricular end-diastolic volume (mL)</td>
<td>95.8 ± 23</td>
<td>91.8 ± 22</td>
<td>92.4 ± 20</td>
<td>96 ± 23</td>
</tr>
<tr>
<td>3D Right ventricular end-systolic volume (mL)</td>
<td>39.8 ± 11</td>
<td>39.7 ± 10</td>
<td>37.6 ± 10</td>
<td>40 ± 10</td>
</tr>
<tr>
<td>3D Right ventricular ejection fraction (%)</td>
<td>58.4 ± 4</td>
<td>56.9 ± 5</td>
<td>59.5 ± 5</td>
<td>58.6 ± 5</td>
</tr>
</tbody>
</table>

*P < 0.01 vs. pre-surgery data.

Results

All patients underwent surgery for mitral valve repair without significant complications. In three patients, mitral valve repair was accompanied by coronary artery bypass grafting of anterior descending coronary artery, without associated stenosis of right coronary or circumflex arteries. At least one good quality, 3D RV dataset was acquired in all patients, at each step of the study. Image acquisition took an average time of 3 ± 1 min, whereas offline analysis of the RV datasets was performed in 5 ± 2 min, including the time spent in uploading the dataset (3 ± 1).

Table 1 and Figure 1 show the mean values of the 2D, 3D, and Doppler parameters for each step of the study.
Two-dimensional and Doppler measurement

When compared with pre-surgery values, TAPSE, PSV, and SPAP were found significantly decreased at 3, 6, and 12 months follow-up. A trend of increase towards recovery in TAPSE at 12 months after surgery was also observed.

Pulmonary systolic pressure and LV end-diastolic volume were reduced after surgery at each step. On the contrary, LV end-systolic volume was similar to pre-surgery values at 3 months, and decreased significantly only at 6 and 12 months. LV ejection fraction was reduced at 3 and 6 months and recovered to basal values at 12 months after surgery.

Three-dimensional measurements

No differences in RV dimensions were observed during the follow-up compared with pre-surgery values, accordingly the 3D RVEF did not change.

Figure 2 shows an example of M-mode, tissue Doppler, and RV volume curve throughout the cardiac cycle obtained in one patient at pre- and at 3, 6, and 12 months post-surgery. A reduction in TAPSE and PSV after surgery can be noted, despite RVEF was unchanged.

Inter- and intra-observer variability

Results for inter- and intra-observer variability are reported in Table 2. All parameters showed minimal bias (P: n.s.) with narrow limits of agreement, in particular for TAPSE and PSV, demonstrating good reproducibility of the obtained measurements.

Discussion

Our study confirmed that the evaluation of RV systolic function after cardiac surgery by TAPSE results in reduced motion of tricuspid annulus movement. However, when RV global systolic function is estimated through real-time 3D echocardiography, RVEF does not change after surgery.

The evaluation of the RV performance is very important for its clinical and prognostic value, in several conditions, as like as after cardiac surgery. The vulnerability of the right ventricle due to poor RV protection during cardiopulmonary bypass is widely recognized.1–4,22,23 RV echocardiographic evaluation has been limited in the past due to the complex structure and anatomy of this ventricle. However, the measurement of tricuspid annulus movement by M-mode or tissue Doppler analysis has been proved to be accurate, feasible, simple, and reproducible in both normal and pathological patients.11 A reduction in TAPSE and/or PSV after cardiac surgery has been previously reported in both congenital and acquired diseases.17–20

Possible hypotheses to explain this reduction in RV performance detected along the long-axis function included geometrical changes of the RV chamber (in association with interventricular septal paradoxical motion), intra-operative ischaemia, extra myocardial causes (pericardium, changes in fossa ovale, and post-operative adherence of RV to the thoracic wall). Recently, a new 3D echocardiographic quantification software adapted for the analysis of the RV chamber has been introduced and validated in both normals and patients.13–16 As 3D echocardiography overcomes the limitations of 2D imaging methods, the computation in 3D space of the RV volume and function throughout the cardiac cycle, without any geometrical assumption, appears promising and more accurate than that available from 2D images. Accordingly, the 3D echo-derived RVEF could be considered as a parameter of global RV performance, not limited to the individual systolic aspect, such as that described by the tricuspid annulus or by the ventricular free wall movements.
In this study, patients undergoing surgical repair of MVP for chronic severe regurgitation associated with mild pulmonary hypertension or symptoms, before the onset of LV or RV dysfunction, were studied. All surgical procedures were performed in stable clinical and haemodynamic conditions. When compared with pre-surgery values, LV ejection fraction at 3 and 6 months follow-up was found expectedly reduced due to afterload increase resulting from the elimination of valve insufficiency, without any symptoms or sign of cardiac failure. Also, pulmonary pressures were found reduced after surgery. In all the examined patients, no sign or symptom of RV failure was present both before and after surgery. Moreover, 3D RVEF was found similar in pre- and post-surgery evaluation, in spite of a significant reduction in TAPSE and PSV. Consequently, 3D RVEF, and not TAPSE or PSV, was coherent to the clinical conditions of our valvular patients. In fact, the interpretation of post-surgery TAPSE and PSV evaluation would lead to an underestimation of RV performance, thus losing the accuracy of these indexes in defining the ‘true’ systolic function of the RV.

Our study could not add any additional data in terms of the aetiology of this phenomenon, but clearly demonstrates that only the long-axis function of the RV is impaired in surgical patients, thus leading to caution in the interpretation of TAPSE and PSV after cardiac surgery. In fact, in patients undergoing cardiac surgery with a RV pre-operative

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### Table 2 Inter- and intra-observer variability for the computed parameters

<table>
<thead>
<tr>
<th></th>
<th>Bias</th>
<th>95% Limits of agreement</th>
<th>Percentage error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>−2 SD</td>
<td>+2 SD</td>
</tr>
<tr>
<td><strong>Inter-observer variability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D Right ventricular end-diastolic volume (mL)</td>
<td>−3.2</td>
<td>−11.0</td>
<td>17.3</td>
</tr>
<tr>
<td>3D Right ventricular end-systolic volume (mL)</td>
<td>−0.6</td>
<td>−15.9</td>
<td>14.0</td>
</tr>
<tr>
<td>Tricuspid annular plane systolic excursion (mm)</td>
<td>0.2</td>
<td>−2.6</td>
<td>2.9</td>
</tr>
<tr>
<td>Peak systolic velocity of tricuspid annulus (cm/s)</td>
<td>0.1</td>
<td>−2.9</td>
<td>2.9</td>
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<tr>
<td><strong>Intra-observer variability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D Right ventricular end-diastolic volume (mL)</td>
<td>1.2</td>
<td>−6.8</td>
<td>9.2</td>
</tr>
<tr>
<td>3D Right ventricular end-systolic volume (mL)</td>
<td>0.2</td>
<td>−13</td>
<td>13</td>
</tr>
<tr>
<td>Tricuspid annular plane systolic excursion (mm)</td>
<td>0.2</td>
<td>−2.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Peak systolic velocity of tricuspid annulus (cm/s)</td>
<td>0.2</td>
<td>−2.6</td>
<td>3</td>
</tr>
</tbody>
</table>

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**Figure 2** Example of M-mode with changes in tricuspid annular motion (TAPSE, upper panels), tissue Doppler with changes in peak systolic velocity of tricuspid annulus (PSV, mid panels), and 3D RV volume curve throughout the cardiac cycle with ejection fraction (RVEF, lower panels) obtained in one patient at pre- and 3, 6, and 12 months post-surgery. EDV, right ventricular end-diastolic volume; ESV, right ventricular end-systolic volume.
dysfunction or with the suspicion of RV dysfunction after surgery, the use of annular movement evaluation alone could be insensitive and even dangerous, although the measurement of 3D RVEF improves the understanding of RV performance in these critical conditions.

Limitation of the study
As only one acquisition was recorded for TAPSE and PSV measurements, test re-test repeatability evaluation was not performed. However, both intra- and inter-observer variability showed good reproducibility for both 2D- and 3D-derived parameters, in agreement with previous results.5,9–11

Conclusions
3D echocardiography allows an easy measurement of RV volumes and systolic function before and after cardiac surgery. Despite the reduction in RV performance measured post-surgery along the ventricular long axis by TAPSE and PSV, the absence of an associated decrease in 3D RVEF leads to caution in the interpretation of these 2D and Doppler parameter, supporting the hypothesis of geometrical rather than functional changes in the RV chamber after uncomplicated cardiac surgery.

Conflict of interest: none declared.

References