ORIGINAL ARTICLE

Changes in right ventricular morphology and function in patients undergoing cardiac surgery: A 3D echocardiographic study

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Editorial
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ABSTRACT

Background: An impairment of standard echocardiographic parameters of right ventricular (RV) function is a known phenomenon in patients undergoing cardiac surgery, but its significance remains unclear.

Aims: This study aimed to assess changes in RV function in patients undergoing cardiac surgery using speckle tracking and 3D echocardiography.

Methods: The study population comprised 122 patients referred for cardiac surgery. Transthoracic echocardiographic (TTE) examinations were performed: before the surgery (TTE1), 1 week after surgery (TTE2), and 1 year after surgery (TTE 3). Parameters measured during these examinations included both standard and advanced indices of the RV size and function, as well as a new parameter introduced by our team — RV shortening fraction (RV SF).

Results: TTE1 was performed on average (standard deviation [SD]) 24 (15) hours before surgery, whereas TTE2 and TTE3 were performed on average 7.2 (3) days and 346 (75) days after the surgery, respectively. A postoperative impairment of parameters of RV longitudinal function was observed (P <0.001). However, neither the RV size assessed by both 2D and 3D techniques changed, nor the global RV function measured with the use of fractional area change and ejection fraction. Additionally, during the postoperative period, an increase in the value of an RV SF by 12.9% was observed. After 12 months we observed an improvement in the parameters of the longitudinal RV function.

Conclusions: Uncomplicated cardiac surgery causes transient impairment of the longitudinal systolic RV function, with no influence on the global RV function. The preservation of global function results from increased RV SF. After 12 months, an improvement of the longitudinal function can be observed.

Key words: 3D echocardiography, cardiac surgery, right ventricular function

INTRODUCTION

The right ventricular (RV) function is recognized as an important factor influencing the course of numerous cardiovascular pathologies. It has been proved that preoperative RV dysfunction is a strong risk factor for death in patients undergoing cardiac surgery; it is also associated with an increased risk of perioperative complications [1–4]. This underlines the importance of accurate preoperative assessment of RV function to improve risk stratification and the need for early accurate postoperative monitoring to optimize treatment [5, 6]. Currently, tricuspid annular longitudinal excursion (TAPSE) and RV S' (systolic velocity of the tricuspid annulus measured by tissue Doppler) are the most frequent echocardiographic parameters. Studies based

WHAT'S NEW?

An impairment of standard echocardiographic parameters of right ventricular (RV) function is a known phenomenon in patients undergoing cardiac surgery. However, little is known about the significance of these alterations for global RV function. In our study, we clarify this issue using novel echocardiographic techniques: 3D assessment of RV volume and function, as well as a speckle tracking technique. In the postoperative period after uncomplicated cardiac surgery, we observed transient changes in the geometry of the right ventricle, as well as impairment of its longitudinal function with a simultaneous compensatory increase in other components of the RV function, which enable to maintain global RV function at the unchanged level. This observation was possible owing to the introduction of a new parameter: RV shortening fraction (RV SF) by our team. In the follow-up examination, an improvement of parameters reflecting the function of the RV longitudinal fibers can be observed.

on these indices suggested RV functional impairment following cardiac surgery [1, 7, 8]. However, these parameters provide insight into the longitudinal function of the RV free wall and do not necessarily reflect global RV function [9]. The development of novel echocardiographic techniques, including 3D echocardiography, allows accurate evaluation of RV volume and function [10, 11].

The purpose of this study was to assess the impact of cardiac surgery on the morphology and function of the right ventricle assessed by both standard echocardiographic parameters, as well as advanced echocardiographic techniques including speckle tracking and 3D echocardiography.

METHODS

Study group

One hundred twenty-two consecutive adult patients (92 [75.4%] men), mean (standard deviation [SD]) age 65 (11) years with coronary artery disease and/or significant left-sided valvular disease referred for cardiac surgery in our center were included in this prospective study. The referrals were based on heart-team decisions.

The exclusion criteria included RV enlargement or dysfunction at baseline, a history of RV infarction, severe chronic disease significantly affecting prognosis, atrial fibrillation, previous cardiac surgery, planned tricuspid valve repair, pulmonary artery systolic pressures >40 mm Hg, perioperative myocardial infarction, poor quality of echocardiographic views excluding the possibility of analysis.

Concomitant diseases present in our study group were diabetes (26.2%), hypertension (73.8%), and hypercholesterolemia (79.5%). Twenty-six patients (21.3%) had a history of myocardial infarction.

Cardiac surgery

Coronary artery bypass surgery (CABG) was performed in 81 (66.4%) patients, out of whom 71 (58.2%) patients underwent bypass surgery on a beating heart (off-pump coronary artery bypass grafting, OPCAB). In the remaining group, isolated valve surgery was performed in 32 (26.2%) patients, whereas concomitant valvular surgery and CABG were performed in 9 (7.4%) patients.

Table 1. Surgical procedures in the studied group of patients (n = 122)

Procedure, %	Number of patients (n)	Prevalence
OPCAB	71	58.2
On-pump CABG	9	7.4
CABG + AVR	4	3.3
CABG + MV annuloplasty	2	1.62
CABG + aortic aneurysm surgery (Bentall procedure)	3	2.5
MV annuloplasty	2	1.62
MVR	6	4.92
AVR	22	18
AVR + aortic aneurysm surgery (Bentall procedure), aortic root/aneurysm surgery	2	1.62
AV + MV plastic surgery	1	0.82

Abbreviations: AVR, aortic valve replacement; CABG, coronary artery bypass grafting; MV, mitral valve; MVR, mitral valve replacement; OPCAB, off-pump coronary artery bypass grafting

The majority of surgeries were performed by a full midline sternotomy. Only 9 (7.4%) patients underwent minimally invasive surgery. More detailed characteristics for surgical procedures are presented in Table 1.

Study protocol

Transthoracic echocardiography (TTE) was performed before cardiac surgery (TTE1), 1 week after surgery (TTE2), and 1 year after surgery (TTE3).

The study protocol was approved by the local Ethics Committee, and all study participants signed written informed consent.

Echocardiography

Transthoracic echocardiographic studies were performed by a single experienced echocardiographer with the use of the GE Vivid 9 ultrasound system (General Electric Healthcare, Boston, MA, US). The imaging protocol included full echocardiographic examination according to current guidelines [12, 13].

Numerous RV dimensions listed in Table 2 were measured using 2- and 3-dimensional echocardiography (Figure 1). Moreover, the following parameters of RV function were measured: tricuspid annular longitudinal excursion (TAPSE), systolic tissue Doppler velocity of the tricuspid annulus (RV S'), and fractional area change (FAC)

Table 2. Right ventricular dimensions measured during echocardiographic examinations

Parameter	Echocardiography			*P* pre- vs. postoperative	*P* preoperative vs. follow-up
	Pre-operative mean (SD)	Post-operative mean (SD)	Follow-up mean (SD)		
RV D1, mm	35 (5)	34 (6)	36 (5)	0.03	0.08
RV D2 diast, mm	25.6 (4)	24.5 (5)	25.9 (4)	0.02	0.4
RV D2 syst, mm	18.4 (3.4)	17 (4)	18.2 (4)	<0.001	0.8
RV D3, mm	66.7 (7.5)	69 (8)	67.8 (7.6)	0.01	0.2
RVOT 1, mm	28 (3)	26.9 (3)	27.5 (3)	0.001	0.2
RVOT 2, mm	29.3 (4)	27.4 (3)	28.6 (3)	<0.001	0.6
RVOT 3, mm	23.7 (3.5)	21.6 (3)	23.4 (2.5)	<0.001	0.3
TV annulus, mm	29.3 (4)	28.9 (5)	31 (5)	0.3	0.08
RV wall thickness, mm	4.5 (0.6)	4.6 (0.8)	4.6 (0.8)	0.8	0.6
RV EDA, cm^2	15.4 (4)	15.8 (4)	16,6 (4)	0.7	0.08
RV EDAI, cm^2/m^2	8.2 (2)	8.4 (2)	8.8 (2)	0.6	0.1
RV ESA, cm^2	9.8 (3)	10 (3)	10.3 (3)	0.3	0.06
RV ESAI, cm^2/m^2	5.2 (1.6)	5.3 (1.6)	5.5 (1.6)	0.3	0.08
RV EDV, ml	114 (27)	116 (24)	116.5 (18)	0.7	0.4
RV EDVI, ml/m^2	61 (14)	62 (13)	62 (10)	0.7	0.3
RV ESV, ml	61.6 (19)	63.6 (15)	62 (11)	0.8	0.4
RV ESVI, ml/m^2	32 (10)	34 (8)	33 (6)	0.8	0.3
RA, mm	34.6 (6)	32 (7)	35.7 (5)	<0.001	0.1
RAA, cm^2	14 (4)	13.5 (4)	15 (3.5)	0.09	0.09

Abbreviations: EDA, end-diastolic area; EDAI, end-diastolic area indexed to BSA; ESA, end-diastolic area; ESAI, end-systolic area indexed to BSA; RA, right atrium; RAA, right atrium area; RV, right ventricular; RVD1, basal RV linear dimension; RVD2 diast, mid-cavity RV linear dimension in diastole; RVD2 syst, mid-cavity RV linear dimension in systole; RVD3, long-axis RV linear dimension; RVOT, right ventricular outflow tract; RVOT 1-PLAX, RVOT measured in parasternal long-axis LV view; RVOT 2, proximal RVOT measured in parasternal short-axis view; RVOT 3, distal RVOT measured in parasternal short-axis view; TV, tricuspid valve

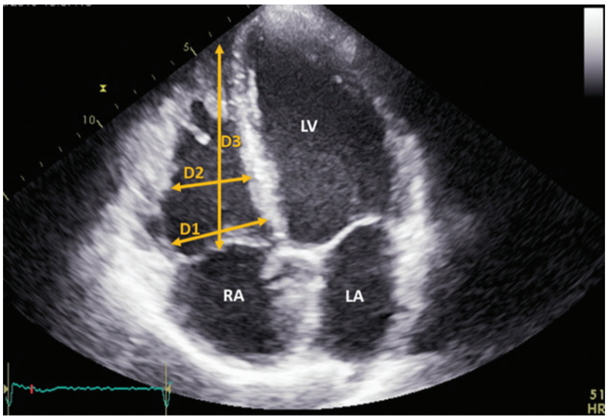

Figure 1. Apical 4-chamber view focused on the right ventricle. Example of measurement of basal (D1) and mid-cavity (D2) transverse dimensions, as well as a linear dimension (D3). The measurements of D2 in end-systole and end-diastole were used for the calculation of the right ventricular shortening fraction = (D2 diast – D2 syst)/ /D2 diast

Abbreviations: LA, left atrium; LV, left ventricle; RA, right atrium

[14, 15]. The echocardiographic quantitative assessment of the RV systolic function also included RV free wall longitudinal strain (RV FWSL) measurement based on the speckle tracking technique [16]. Additionally, we acquired 3D datasets enabling off-line calculation of RV volumes and ejection fraction (3D RV EF) using EchoPAC SW 202 (GE Healthcare, Boston, MA, US) [17]. Furthermore, the newly introduced parameter was assessed — RV shortening fraction (RV SF), calculated as the percentage shortening of the mid-cavity linear dimension of the right ventricle in the 4-chamber apical view.

Statistical analysis

All quantitative variables were initially subjected to an analysis of compliance with the normal distribution assessed in Kolmogorov-Smirnov's test. Normally distributed variables are expressed as mean (SD). Categorical variables are presented as percentages (%). A paired 2-tailed Student's t-test was used to test for difference in each of the echocardiographic variables between TTE1 and TTE2 and between TTE1 and TTE3. After a Bonferroni correction based on comparing the two primary echocardiographic endpoints, statistical significance was assumed when $P = 0.025$. All analyses were performed using MedCalc Software, Frank Schoonjans, Belgium.

RESULTS

Five patients died during the perioperative period (between the 3rd and the 14th day after cardiac surgery). Within one year of follow-up, no patient underwent myocardial infarction or developed new congestive heart failure. One patient died one month after hospital discharge.

TTE1 was performed on average (SD) 24 (15) hours before cardiac surgery (range 4–48 hours), whereas TTE2 and TTE 3 were performed on average (SD) 7.2 (3) days (range 3–17 days) and 346 (75) days after cardiac surgery.

Preoperative echocardiography was performed in all patients (n = 122), the postoperative examination was available in 117 patients, whereas follow-up examinations

Table 3. Values of parameters assessing the right ventricular function recorded during echocardiography performed preoperative, postoperative, and control (after one year)

Parameter	Echocardiography			*P* pre- vs. postoperative	*P* preoperative vs. follow-up
	Pre-operative mean (SD)	Post-operative mean (SD)	Follow-up mean (SD)		
RV FWSL, %	−23.4 (5)	−12.2 (4)	−19 (8)	<0.001	<0.001
TAPSE, mm	24 (4)	13.4 (2.5)	20.4 (4)	<0.001	0.001
RV S', cm/s	11.7 (2.3)	8 (2)	10.6 (2)	<0.001	<0.01
RV SF, mm	28 (7.6)	31.6 (10)	29.7 (8)	0.005	0.09
RV FAC, %	37 (10)	35.7 (11)	37.6 (6)	0.1	0.6
3D RV EF, %	46.4 (8)	45.3 (6)	46.2 (7)	0.2	0.2
RVSVI, ml/m^2	27.7 (7)	28 (6)	28.6 (6)	0.5	0.8

Abbreviations: RV, right ventricular; FAC, fractional area change; 3D EF, 3-dimensional ejection fraction; FWSL, free wall longitudinal strain; RV S', systolic velocity of the tricuspid annulus; SF, shortening fraction; SVI, stroke volume indexed to BSA; TAPSE, tricuspid annular longitudinal excursion

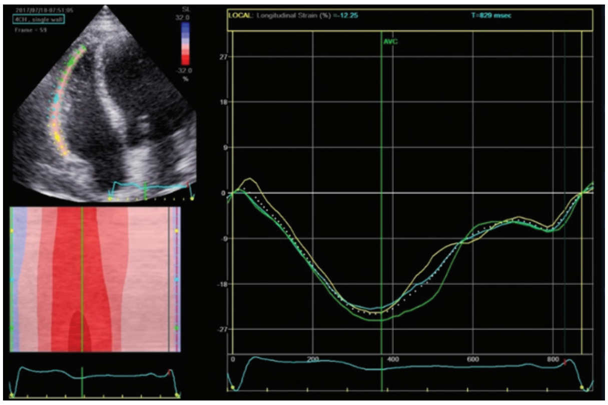

Figure 2. Quantitative evaluation of right ventricular function using speckle tracking echocardiography in apical 4-chamber view

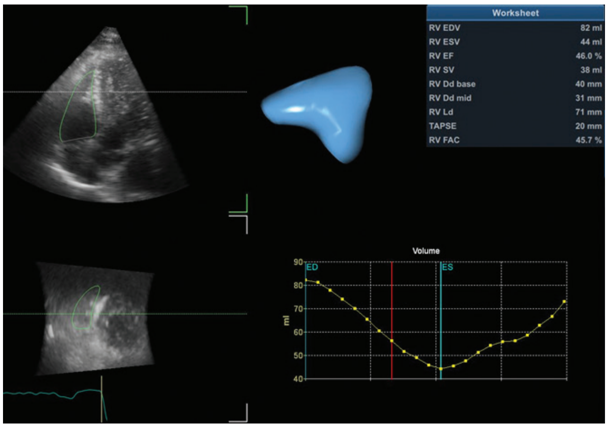

Figure 3. The RV model based on 3D echocardiography allowing measurement of RV volumes and ejection fraction

Abbreviations: RV, right ventricular

were performed in 116 patients. Due to the suboptimal image quality, 9.3% of segments were excluded from the RV FWSL analysis, and 11 (9%) patients were excluded from 3D assessment in the preoperative study. In the post-operative examination, 14% of the segments were excluded from the RV FWSL assessment and 25 (20.5%) patients from the 3D assessment. Eleven percent of segments and 12 (10%) patients were excluded from the study after one year.

Changes in RV morphology

Preoperative examination showed normal RV dimensions in all patients (Table 2). In the postoperative echocardiographic examination, a decrease in the diameter of the RV outflow tract and mid-cavity transverse dimension of the right ventricle (D2) was noted, while the mean longitudinal dimension (D3) increased (Figure 1). For the other parameters reflecting the RV size, including systolic and diastolic area, as well as 3D end-systolic volume and 3D en-diastolic volume, no significant difference was found between pre- and postoperative examination (Table 2).

The follow-up echocardiography showed a withdrawal of postoperative changes and return to baseline ranges.

Changes in RV function

In preoperative examination parameters of RV systolic function were within the normal range in all patients.

In the postoperative examination, a reduction in the mean values of TAPSE, RV S' and RV FWSL (Figure 4) was observed (Table 3, *P* <0.001). However, there were no significant changes in the mean FAC, 3D RV EF, and the 3D stroke volume index. In the postoperative study the RV SF value increased compared to preoperative examination (from 28% [7.6%] to 31.6% [10%]; *P* = 0.005).

The follow-up echocardiography showed improvement of RV longitudinal systolic function — TAPSE, RV S', RV FWSL, but their values were still slightly lower than at baseline, yet within the normal range. There were no significant changes in RV FAC, 3D RV EF, or 3D RV stroke volume indexed (Table 3). Figure 4 shows the TAPSE, RV FAC, and 3D RV EF plots assessed at three time points.

The mean (SD) left ventricular EF in the studied group of patients in the preoperative, postoperative, and control studies at one year was 49% (9%), 50.5% (8%), and 52.5% (7.4%), respectively.

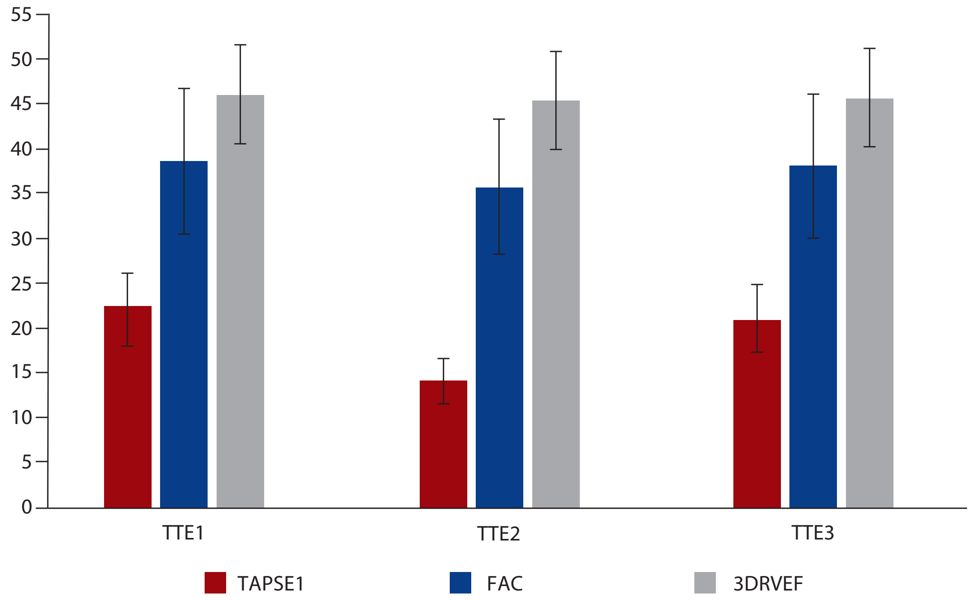

Figure 4. Plots demonstrating mean values and standard deviations of TAPSE, RV FAC, and 3D RV EF, assessed at 3 time points: before cardiac surgery (TTE1), during the postoperative period (TTE2), and after one-year follow-up (TTE3)

Abbreviations: RV FAC, right ventricular fractional area change; TAPSE, tricuspid annular longitudinal excursion; TTE, transthoracic echocardiography

DISCUSSION

We have demonstrated that RV shape and geometry, but not volume, undergo complex changes after uncomplicated cardiac surgery. We observed transient impairment of RV longitudinal function, which did not result in the impairment of global function assessed by both 2D and 3D echocardiography. This was due to a compensatory increase in circumferential and transverse function, as demonstrated by a new proposed parameter — the RV shortening fraction. These findings highlight the need for using more detailed parameters than TAPSE and RV S′ in all patients undergoing cardiac surgery to properly diagnose perioperative RV global dysfunction.

The transient changes in the RV shape observed after cardiac surgery are expressed by a decrease in the diameter of the RV outflow tract and the mid-cavity RV transverse dimension with simultaneous RV elongation (an increase in the value of long-axis RV linear dimension — D3). It should be noted that the change in the values of the linear parameters was not accompanied by changes in the RV systolic and the diastolic surface area or its volume determined by the 3D method.

These observations add to currently existing scarce data on the RV size in patients undergoing cardiac surgery. In a group of 35 patients, Alam et al. [18] showed that the linear RV dimension decreased from 29 (4) mm to 28 (3) mm one month after the surgery and returned to baseline one year after the procedure. Tamborini et al. [19] compared RV volume before and after 3, 6, and 12 months following the cardiac surgery in a group of 40 patients. They did not observe a change in RV volume at any of the time points despite the post-operative reduction of RV performance along the long axis suggested by TAPSE and RVS′. The results of this study are consistent with our observations on a larger group — we did not notice a significant change in RV volume (or area) in the examination performed in the postoperative period.

The decrease in TAPSE and RV S′ after cardiac surgery has been well documented [20, 21]. Yadav et al. [22] described selective RV impairment in 20 patients found on the basis of RV S′ 3 months post CABG. Similarly, Diller et al. [23] evaluated the effect of CABG on ventricular function in a group of 32 patients. In the postoperative period (5 days after surgery), impairment of RV S′ was observed without deterioration of left ventricular function. These observations were interpreted as isolated impairment of RV function, without changes in left ventricular function parameters or impairment of clinically assessed exercise capacity.

Similar to our findings, Bitcon and Tousignant [24] showed in a small group of 21 patients no effect of cardiac surgery on RV function measured with the use of FAC, whereas TAPSE, RV S′, and RV free wall strain significantly deteriorated. Also, Khani et al. [25], who analyzed 30 patients undergoing coronary artery bypass grafting, observed postoperative deterioration of TAPSE, RV S′ and longitudinal deformation of the RV free wall, while in the control examination, after three months, there was a slight improvement of these parameters.

Importantly, the analysis of 3D echocardiography in patients operated on in our center did not show any significant effect of cardiac surgery on the RV function.

The RV ejection fraction and indexed RV ejection volume remained unchanged in the study performed 7 days after cardiac surgery compared to the preoperative study. Similar results were described in a previous smaller study, where 40 patients were examined using transthoracic 2D and 3D echocardiography pre- and 3, 6, and 12 months after surgery. The 3D assessment of RV function showed unchanged 3D RV EF throughout the entire observation period despite a decrease in RV longitudinal fiber function parameters [17].

Rösner et al. [26] described similar observations on echocardiography and magnetic resonance imaging in a group of 57 patients undergoing cardiac imaging in the perioperative period and at 8–10 months after surgery. The authors postulated a slightly different etiology of changes observed in TAPSE — they observed the increase in RV sphericity in the post-CABG period and attributed this change to altered constraint and pressures caused by the opening of the pericardium during surgery. Rösner et al. [26] also found that despite the more spherical shape of the RV, there was no loss in systolic function based on various parameters including RVEF and SV by magnetic resonance imaging. The etiology of the decrease in TAPSE was interpreted as secondary to the morphologic changes present after differences in constraint of the RV by the pericardium in the early postoperative period.

All these data indicate the deterioration of the function of longitudinal fibers in patients undergoing cardiac surgery without impairment of global RV function. In an attempt to characterize this phenomenon, we introduced a new echocardiographic parameter — RV SF, which describes the shortening of the mid-cavity RV dimension in a 4-chamber apical view. It is a simple indicator enabling the assessment of the presence of a compensatory increase in non-longitudinal components of the RV systolic function. In the postoperative examination, the RV SF value increased significantly, thus compensating for impaired longitudinal function.

Limitations of the study

Compared to previous studies on this subject, we enrolled a large group of patients, but they were all operated in one center using standard access. Therefore, we believe that the described phenomena should be confirmed in a multicenter study. A larger group of patients and inclusion of cardiac surgeries complicated with RV infarction would allow us to determine the criteria for RV longitudinal function impairment indicative of global function impairment.

When using the speckle tracking technique, we measured only the longitudinal deformation of the RV free wall. Theoretically, it would be possible to assess transverse strain, but such measurements are not well validated.

CONCLUSIONS

In the postoperative period after uncomplicated cardiac surgery, we observe transient changes in the geometry of the right ventricle, as well as impairment of its longitudinal function with a simultaneous compensatory increase in other components of the RV function, which leads to the maintainance of global RV function at the unchanged level. In the follow-up examination (one year after surgery), an improvement of parameters reflecting the function of the RV longitudinal fibers can be observed.

Article information

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