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A study of right ventricular function in pre- and post-valvular surgeries

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Abstract: *Aims:* The aim of this study is to compare tricuspid annular plane systolic excursion (TAPSE) in pre- and postoperative valvular heart surgery patients using M-mode imaging, to determine changes in tissue Doppler parameters among patients undergoing valvular heart surgery, and to analyze tissue deformation parameters of right ventricle (RV) and RV strain in pre- and postoperative patients. *Materials and methods:* This was an observational, cross-sectional, single-center study that included 24 patients who underwent echocardiographic assessment prior to surgery, after surgery, and at 1-month follow-up. Assessment of left and right ventricles by M-mode echocardiography, evaluation of RV by 2D Doppler echocardiography, tissue Doppler imaging, and strain imaging were performed. *Results:* The TAPSE was significantly reduced immediately after surgery (14.8 ± 0.37 vs. 10.9 ± 0.26 mm), which was then improved on follow-up assessment (17.8 ± 34 mm) ($p = 0.001$). Tricuspid valve diastolic velocity was increased after surgery and then gradually declined at 1-month follow-up ($p = 0.003$). Presurgery RV free wall strain was found to be reduced, which was then improved during post-procedure analysis as well as on follow-up ($p = 0.001$). *Conclusions:* After cardiac valvular surgery, RV myocardial deformation showed a gradual improvement after 1 month, although there was an immediate decline in RV function postsurgery. The pattern of RV contraction, as showed by RV strain, varied postsurgery, which was remarkably increased in postoperative patients at the time of follow-up. Tissue deformation imaging being an emerging technique helps in the assessment of minute, subtle changes that occur in the RV myocardial function in cardiac patients undergoing valve surgery.

Keywords: echocardiography, heart valve, right ventricle, surgery, tissue Doppler imaging

Introduction

Right ventricle (RV) is a crucial predictor of outcome in patients with heart failure and valvular disease. Yet, the physiological significance of RV has been trivialized. The RV maintains suitable pulmonary perfusion pressure to develop gas exchange membrane of lungs and also facilitates to sustain a low systemic venous pressure to prevent tissue and organ congestion [1]. The RV dysfunction affects the functioning of left ventricle (LV) not only by limiting preload but also by adverse systolic and diastolic interaction through ventricular septum [2].

Assessment of RV function ameliorates risk stratification and leads to timely management of RV failure. Echocardiography has become vital in the assessment of preoperative RV structure and function, as it presents useful information on RV size, shape, and function [3]. The indices of RV systolic function demonstrate the extent of RV contraction [4]. Moreover, it provides assistance in the management for anesthetic, surgical approach, and hemodynamically unstable patients.

The two-dimensional (2D) guided M-mode measurements have been useful in estimating various essential parameters, such as systolic long axis motion of the RV free wall, ejection fraction, RV end-diastolic (ED) diameter from the parasternal projection, tricuspid annular plane systolic excursion (TAPSE), etc. It has also been shown to be useful in assessing ischemic heart disease and cardiomyopathy [5].

The 2D Doppler measurement, tissue Doppler imaging (TDI), and strain rate (SR) imaging techniques have led to appropriate estimation of global and regional

systolic and diastolic RV function. Altogether, the measurements of these echocardiographic parameters lead to proper assessment of the RV for optimizing the management of disease and for diagnosing the disease. RV failure after cardiac surgery has been a major cause of morbidity and mortality. Thus, a complete assessment of RV function may improve early management of RV failure. Nowadays, echocardiography is becoming a mainstay in the assessment of pre- and postoperative RV functions [6]. Hence, this study was aimed to compare TAPSE in pre- and postoperative valvular heart surgery patients using M-mode imaging, to determine changes in tissue Doppler parameters among patients undergoing valvular heart surgery, and to analyze tissue deformation parameters of RV and RV strain in pre- and postoperative patients.

Materials and Methods

Study population and study design

This was an observational, cross sectional, single-center study that included 24 patients who underwent echocardiographic assessment before and after valvular heart surgery. Patients undergoing open-heart surgery for valve repair or replacement were included in the study. Patients with previous heart surgery, those who are undergoing emergency cardiac surgery, those of age <20 years, and those who are undergoing intra/extracardiac repair in complex congenital heart disease were excluded. Various echocardiographic parameters were assessed for each patient 1 day prior to surgery, 3–5 days after surgery, and at 1-month follow-up. Medications including

angiotensin-converting enzyme inhibitor and beta-blockers were adjusted as per the decision of the physician and the surgeon who are treating. Postoperatively, all patients with a prosthetic valve received oral anticoagulation.

Procedure

Echocardiography

Individuals were subjected to complete clinical examination and transthoracic echocardiography using Philips Epiq 7, an echocardiography system with a 2.5-MHz adult transducer. Echocardiographic parameters were evaluated and measurements of right heart chambers were taken according to established criteria [7, 8]. RV ED area and end-systolic area were assessed by manual planimetry, and then RV fractional area (RVFA) change was derived using the formula [9]:

$$RVFA = (RVED\ area - RVES\ area)/RVED\ area \times 100.$$

Using M-mode technique, RV ED dimension (Fig. 1), IVC diameter, and LV internal dimensions were obtained. TAPSE was measured in apical 4-chamber (A4CH) view. Trans-tricuspid valve Doppler flow velocities, i.e., peak early and late diastolic velocities were recorded from A4CH view, deceleration time, isovolumic relaxation time (IVRT), isovolumic contraction time (IVCT), and ejection time (ET) were measured with the additional recording of transpulmonary valve Doppler flow velocity. Pulmonary artery systolic pressure was estimated by continuous wave Doppler as four times square of peak regurgitation velocity and
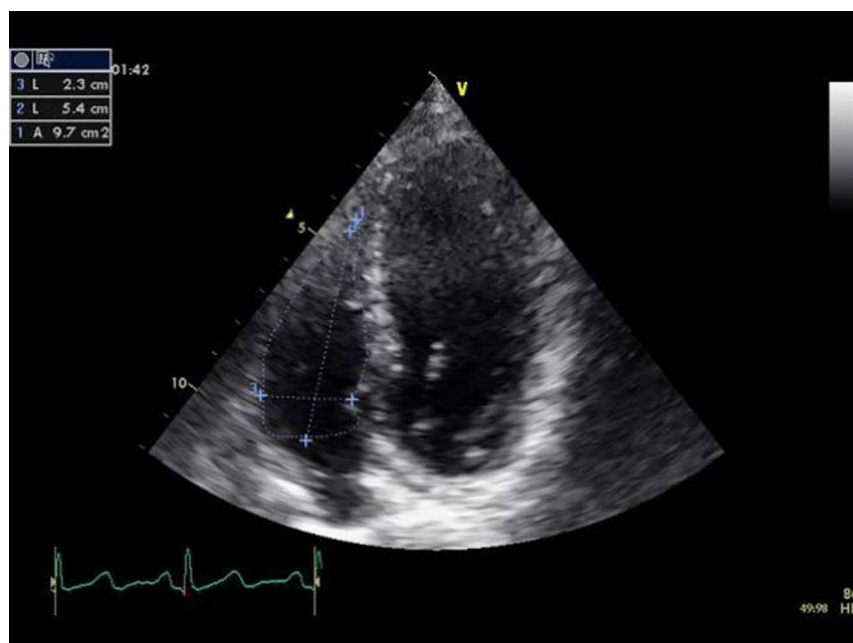

Fig. 1. Right ventricular end-diastolic and -systolic area measurement from 2D apical 4-chamber view

assumed right atrial pressure of 10 mmHg (fixed value method) [9]. For the analysis of global RV function, Doppler parameters were used to derive the Tei index, i.e., (IVCT + IVRT)/ET.

Tissue Doppler imaging (TDI)
Recordings were stored digitally as 2D cine loops and were transferred to an optical disk medium work station for offline analysis. The images showing the tissue motion velocity were superimposed on the 2D echocardiographic images for real-time color display. TDI annular velocities during systole *(Fig. 2)*, early relaxation (Ea), and atrial systole (Aa) were possessed from RV free wall and interventricular septum (IVS) at basal site in the A4CH view *(Fig. 3)*.

The strain (change in length per unit length) in each segment is defined as the relative magnitude of segmental deformation [10]. From tissue Doppler data, SR was estimated by calculating the velocity gradient. The time integral of incremental SR yields logarithmic strain:
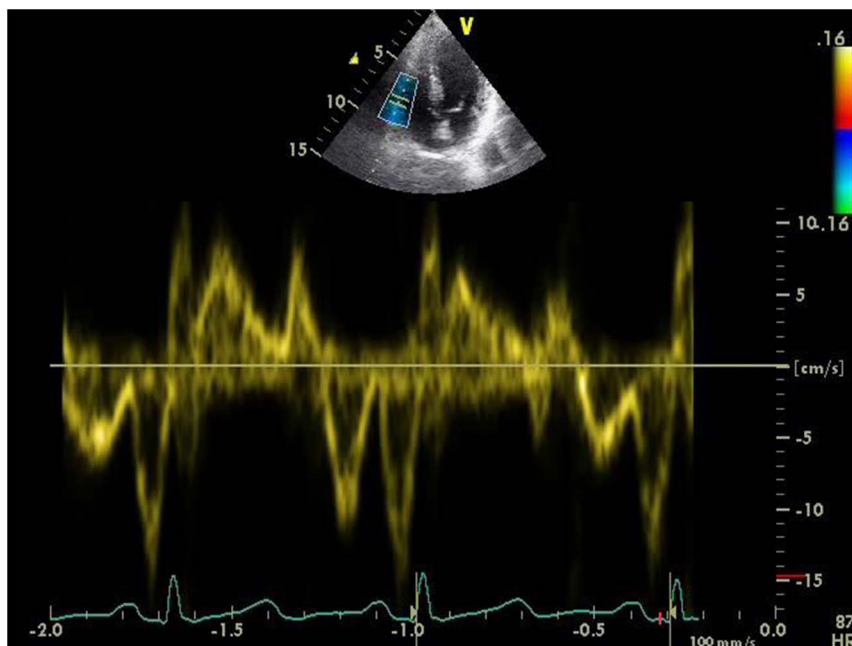

Fig. 2. Tissue Doppler imaging showing right ventricular tissue annular velocity
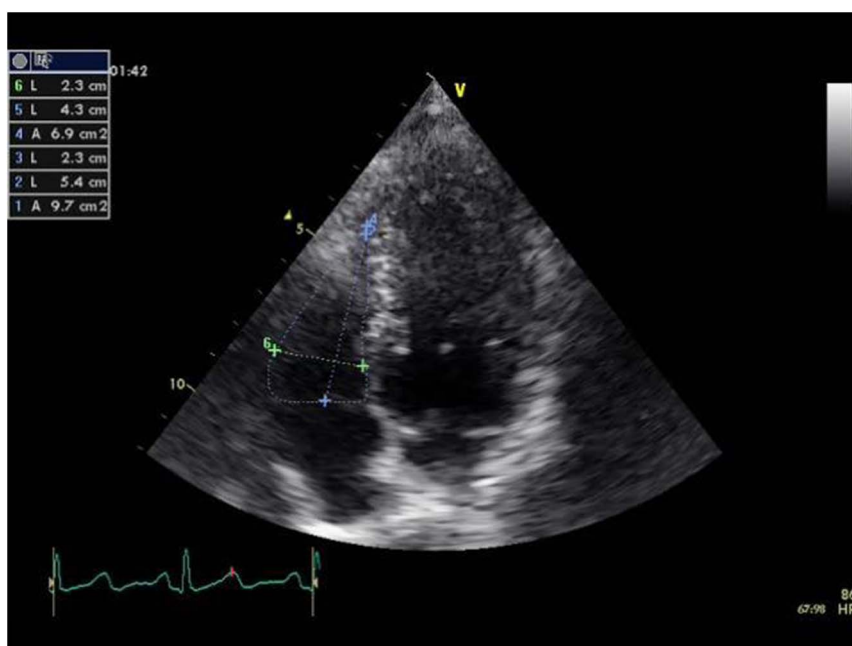

Fig. 3. Right ventricular free wall thickness in end diastole in subcostal 4-chamber view

$E = \log(L/L_0)$. In this study, the logarithmic strain was converted to Lagrangian strain: $e = (L - L_0)/L_0$. The 2D speckle-tracking echocardiography was performed to estimate RV strain (*Figs 4 and 5*).

This spatial offset was selected as a compromise between acceptable signal-to-noise ratio and longitudinal spatial resolution. SR is determined during systole (S), early diastole (E), and late diastole (A). Systolic strain was measured from the same wall site in the same views. TDI wall velocities at the tricuspid annulus level during systole, early relaxation, and atrial systole were also obtained.

Statistical analysis

Continuous variables are presented as mean ± standard deviation and categorical variables as counts and percentages.
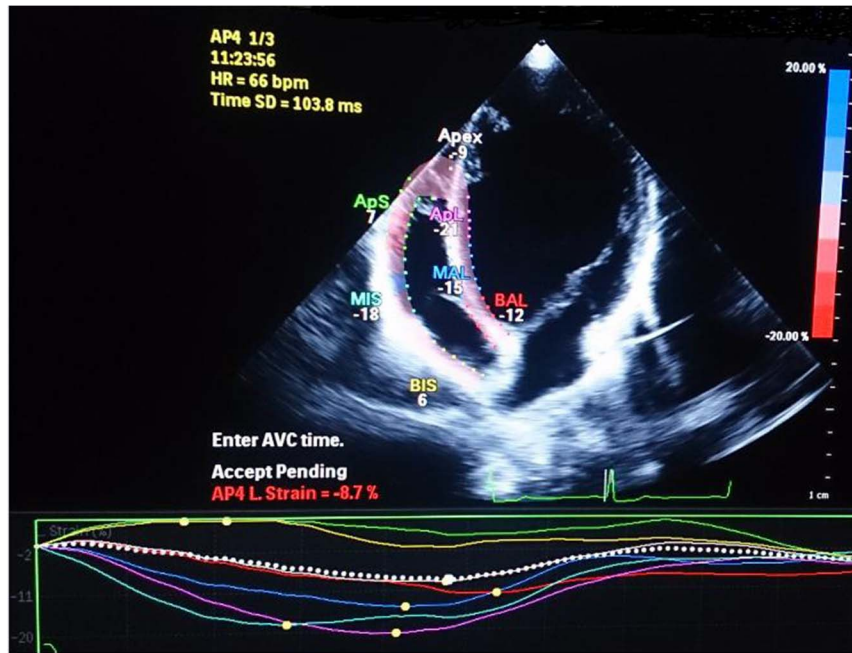

Fig. 4. 2D speckle-tracking echocardiography revealing right ventricle strain
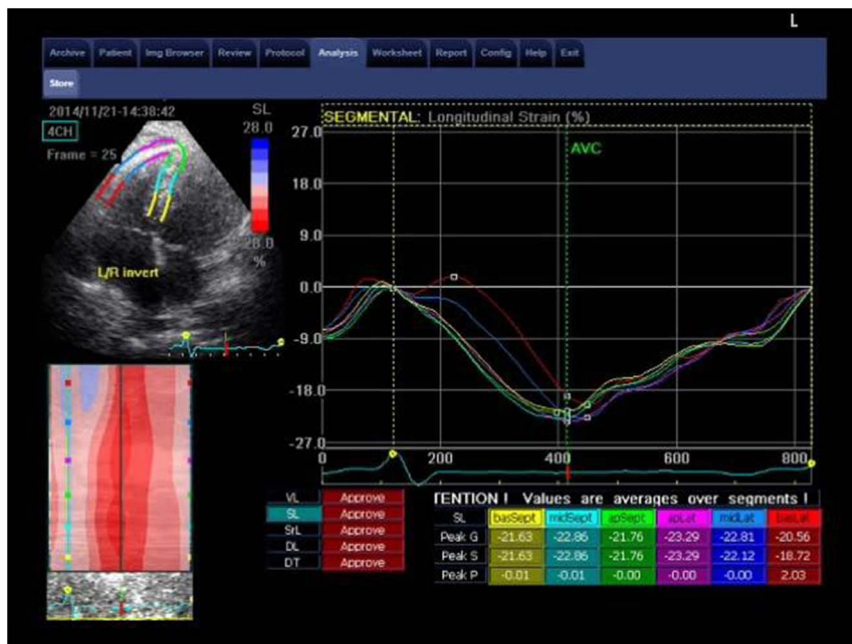

Fig. 5. 2D speckle-tracking echocardiography revealing global right ventricle strain

Sample size was calculated, using 80% power at 5% level of significance. For normally distributed variables, one-way analysis of variance with repeated measures was used for evaluating the difference between the consecutive observations. Since most of the continuous variables were not following normal distribution, the readings were analyzed using Friedman's non-parametric test to find the difference in consecutive observations. All data were analyzed using the Statistical Package for Social Sciences program (SPSS, version 15; Chicago, IL, USA).

Results

A total of 24 patients had undergone echocardiographic assessment pre- and post-valvular heart surgery. Mean age was found to be 48 ± 13.39 years. Among 8 female patients, 2 were hypertensive and among 16 males, 9 were found to be hypertensive. There were four patients with diabetes and two smokers in the study population.

This study had higher mitral valve replacement (MVR) cases than aortic valve replacement (AVR) and double valve replacement (DVR). Patients who underwent MVR were 12, AVR 8, and DVR 5. About 16 patients received the TTK Chitra valve and 8 patients received the St. Jude valve.

Echocardiography findings

Left ventricular M-mode echocardiography
There were changes in all parameters of LV after surgery. The left ventricular ED dimension and posterior wall in systole dimension were found to be significantly increased after a month of surgery (Table I).

Right ventricular M-mode echocardiography
As RV being the most sensitive chamber for loading condition, this study showed significant gradual decrease in RV free wall thickness (RVFWT) on postoperative follow-up. Consistent decrease in RVFWT was observed in both immediate postoperative assessment (0.70 ± 0.19 vs. 0.6 ± 0.12 mm) and at 1-month follow-up (0.56 ± 0.91 mm), which was statistically significant ($p = 0.001$).

RVFA change was decreased immediately after surgery; however, this change was found to be transient, as follow-up echo showed improvement with significant p value of 0.004.

TAPSE was significantly reduced immediately after surgery, which was then improved on follow-up assessment. As far as RV geometry is considered, there was also significant change in the values of RV internal dimensions and RVFWT in postoperative state. The M-mode echocardiographic parameters assessing RV geometry are detailed in Table II.

Doppler echocardiography

Doppler echocardiographic findings showed that right ventricular systolic pressure (RVSP) and tricuspid valve early diastolic forward flow were found to be gradually reduced after valve surgery, which was statically significant ($p = 0.002$). However, trans-tricuspid E/A ratio did not alter significantly throughout the study (Table III).

Tissue Doppler imaging (TDI)

Systolic tricuspid annular velocity was significantly altered in these three consecutive readings in the study ($p = 0.001$); it showed immediate decrease in tissue annular velocity of RV in predischarge assessment and further it decreased during follow-up (Table IV). However, tissue annular velocity measured in basal IVS during systole did not show significant change.

Table I | Left ventricular M-mode echocardiographic parameters

Parameters	Preoperative (mean ± SD)	Postoperative (mean ± SD)	At 1-month follow-up (mean ± SD)	p value
IVSS (mm)	8.35 ± 1.12	9.28 ± 1.59	9.19 ± 1.33	NS
IVSD (mm)	1.15 ± 0.97	1.095 ± 0.06	1.13 ± 0.08	NS
LVEDD (mm)	4.1 ± 0.64	4.7 ± 0.6	5.6 ± 0.47	0.001
LVESD (mm)	3.28 ± 0.66	3.54 ± 0.56	4.0 ± 0.56	0.001
PWD (mm)	0.99 ± 0.10	0.97 ± 0.072	1.0 ± 0.13	NS
PWS (mm)	1.03 ± 0.16	1.05 ± 0.88	1.10 ± 0.10	0.001
EF (%)	48.96 ± 8.92	53.33 ± 9.74	59.42 ± 8.93	0.001
FS (%)	26.13 ± 4.32	26.96 ± 4.46	26.54 ± 4.55	NS
HR (bpm)	104.17 ± 8.58	107.08 ± 16.10	97.46 ± 10.85	0.002

IVSD: interventricular septum in diastole; IVSS: interventricular septum in systole; LVEDD: left ventricular end-diastolic dimension; LVESD: left ventricular end-systolic dimension; PWD: posterior wall in diastole; PWS: posterior wall in systole; EF: ejection fraction; FS: fractional shortening; HR: heart rate; SD: standard deviation

Table II | Right ventricle M-mode echocardiographic parameters

Parameters	Preoperative (mean ± SD)	Postoperative (mean ± SD)	At 1-month follow-up (mean ± SD)	p value
RVFWT (mm)	0.70 ± 0.19	0.6 ± 0.12	0.56 ± 0.91	0.001
RVEDD (mm)	5.73 ± 0.36	6.108 ± 0.38	5.88 ± 0.37	NS
RVED SAX (mm)	25.53 ± 4.0	26.14 ± 4.91	28.03 ± 7.31	NS
RVED LAX (mm)	3.62 ± 0.70	3.93 ± 0.74	3.74 ± 0.6	NS
RVES SAX (mm)	20.32 ± 2.84	23.0 ± 5.86	23.97 ± 6.6	0.004
RVES LAX (mm)	37.85 ± 5.01	40.11 ± 6.28	41.11 ± 0.76	NS
RVFA (%)	53.71 ± 2.86	47.42 ± 4.87	55.46 ± 4.3	0.004
TAPSE (mm)	14.8 ± 0.37	10.9 ± 0.26	17.8 ± 0.34	0.001

RVFWT: right ventricular free wall thickness; RVEDD: right ventricular end-diastolic dimension; SAX: short axis; LAX: long axis; RVED: right ventricular dimension in end-diastole; RVES: right ventricular dimension in end-systole; RVFA: right ventricular fractional area change; TAPSE: tricuspid annular plane systolic excursion; SD: standard deviation

Table III | Right ventricular two-dimensional Doppler echocardiographic parameters

Parameters	Preoperative (mean ± SD)	Postoperative (mean ± SD)	At 1-month follow-up (mean ± SD)	p value
RVSP (mmHg)	49.83 ± 14.42	45.04 ± 04.97	39.13 ± 5.00	0.002
TV-E (cm/s)	56.68 ± 13.83	58.25 ± 15.71	46.38 ± 15.03	0.003
TV-A (cm/s)	45.74 ± 15.3	59.64 ± 15.03	55.56 ± 18.27	NS
TV-E/A	1.31 ± 0.24	1.00 ± 0.3	1.05 ± 0.31	NS
IVRT (ms)	93.75 ± 11.91	101.92 ± 10.312	96.21 ± 5.116	0.002

RVSP: right ventricular systolic pressure; TV-E: tricuspid valve early diastolic velocity; TV-A: late diastolic velocity; IVRT: isovolumic relaxation time; SD: standard deviation

Table IV | Right ventricular tissue Doppler imaging parameters

Parameters	Preoperative (mean ± SD)	Postoperative (mean ± SD)	At 1-month follow-up (mean ± SD)	p value
RV E′ (m/s)	8.67 ± 7.07	11.64 ± 8.95	9.2 ± 7.30	NS
RV A′ (m/s)	3.96 ± 2.94	4.17 ± 3.15	3.75 ± 3.26	0.002
RV S (m/s)	0.18 ± 0.02	0.14 ± 0.03	0.10 ± 0.04	0.001
IVS E′ (m/s)	0.11 ± 0.02	0.08 ± 0.02	0.06 ± 0.02	0.001
IVS A′ (m/s)	0.09 ± 0.02	0.10 ± 0.02	0.10 ± 0.02	NS
IVS S (m/s)	0.09 ± 0.01	0.08 ± 0.01	0.08 ± 0.02	NS

RV: right ventricle; IVS: interventricular septum; E′: early diastolic tissue annular velocity; A′: late diastolic tissue annular velocity; S: systolic annular velocity; SD: standard deviation

Right ventricular strain imaging

Presurgery RV free wall strain was found to be reduced, which was then improved during post-procedure analysis as well as on follow-up. Strain measured in basal IVS showed decreased value in postoperative predischarge assessment ($-24.62\% \pm 1.76\%$ vs. $-14.80\% \pm 1.88\%$), whereas it was higher in follow-up state ($-21.06\% \pm 3.65\%$). However, basal and distal IVS did not show significant change with these series of observations (Table V).

Discussion

This study showed that in the patients who are undergoing valvular surgery, echocardiographic parameters including 2D TDI and tissue deformation imaging can detect RV dysfunction and changes in RV structure and function after valvular surgery. The study demonstrated significant gradual decrease in RV thickness and the chamber dimension at follow-up after 1 month of surgery, although the predischarge evaluation did not show significant alteration in RV geometry.

Table V | Right ventricular strain imaging parameters

Parameters	Preoperative (mean ± SD)	Postoperative (mean ± SD)	At 1-month follow-up (mean ± SD)	p value
RVSS B (s^{-1})	−11.9 ± 1.3	−19.04 ± 0.8	−15.0 ± 1.04	0.001
RVSS M (s^{-1})	−18.4 ± 2.4	−22.83 ± 3.66	−20.67 ± 4.7	0.001
RVSS D (s^{-1})	−22.46 ± 7.08	−22.29 ± 4.46	−21.29 ± 4.8	NS
IVSS B (%)	−24.62 ± 1.76	−14.80 ± 1.88	−21.06 ± 3.65	NS
IVSS M (%)	−17.9 ± 1.3	−29.04 ± 0.8	−10.95 ± 12.16	0.001
IVSS D (%)	−19.4 ± 2.4	−22.83 ± 3.66	−20.67 ± 4.7	NS

RV: right ventricle; IVS: interventricular septum; SI: systolic strain imaging; IVSS: interventricular systolic strain; B: basal; M: mid; D: distal; SD: standard deviation

Similar alterations in RV geometry were found in the study conducted by Schuuring et al. [6], which revealed that the effect of valvular surgery may be long lasting. The TAPSE measured after valve surgery depicted drastic decrease in its valve; however, it was evident that on follow-up TAPSE was significantly improved. Similarly, the study by Tamborini et al. [11] revealed reduced TAPSE reading on postsurgery analysis, then showed gradual improvement on series of echocardiography analysis over 1 year ($p < 0.01$). In accordance with these results, Grønlykke et al. [12] had also reported similar changes in TAPSE but there was no major increase seen at 12-month follow-up, i.e., prior to treatment, the TAPSE was 2.4 ± 0.52 cm, at 3 months follow-up 1.6 ± 0.42 cm, and at 12-months follow-up 1.7 ± 0.42 cm. Various hypotheses, such as RV geometrical changes in relation to interventricular septal paradoxical motion and poor RV protection during cardiopulmonary bypass causing reduction of RV performance along the long axis, have been proposed to explain the drastic reduction in TAPSE following cardiac surgery [11]. A decline in TAPSE alone or along with peak systolic velocity of tricuspid annulus subsequent to cardiac surgery has been previously reported in both congenital and acquired diseases [13–16].

Post-valvular surgery assessment of RVSP showed reduction in consecutive values compared with presurgery evaluation. This can be supported by the result obtained in the study conducted by Grapsa et al. [17]. The RVFA change in this study was found to be significantly declined immediately after surgery but was increased at 1 month follow-up. Parallel to our results, recently, Grønlykke et al. [12] had assessed the RV functions after transcatheter versus surgical AVR upto 12 months after procedure. The RVFA change was initially observed to be decreased at 3-month follow-up (39% ± 10%) when compared with presurgery (44% ± 11%) and was gradually increased to 43% ± 10% at 12-month follow-up [12].

RV strain showed gradual decrease in its value after the surgery and also at the time of follow-up depicting that impact of valve surgery on RV was long lasting but further studies with longer follow-up would confirm these findings. This study also showed the changes in tissue deformation parameters of IVS, which reduced immediately after valve surgery, but gradually improved later on as assessed on follow-up.

Study limitations

Study was not randomized for the type of surgery performed. Number of patients included in the study was less. The study included only short-term follow-up of patients.

Conclusions

After cardiac valvular surgery, RV myocardial deformation showed a gradual improvement after 1 month, although there was an immediate decline in RV function postsurgery. The pattern of RV contraction, as showed by RV strain, varied postsurgery, which was remarkably increased in postoperative patients at the time of follow-up. Tissue deformation imaging being an emerging technique helps in the assessment of minute, subtle changes that occur in the RV myocardial function in cardiac patients who are undergoing valve surgery.

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