Original Article

Assessment of Ventricular Function in Patients of Atrial Septal Defect by Strain Imaging before and after Correction

Abstract

Background: Atrial septal defect (ASD) is a common congenital heart disease associated with volume overload of Right ventricle (RV) with variable effect on Left ventricle (LV). Two-dimensional (2D) Strain analysis is a new tool for objective analysis of myocardial function. This prospective study evaluated the systolic function of right and left ventricle by conventional 2D echo and strain echo and measured changes in cardiac hemodynamics that occurred in patients of ASD before and after correction. **Patients and Methods:** 2D echo and strain analysis of each patient before and at 48 hrs, 3 months and 6 months after correction was performed. Routine 2D echo parameters and global longitudinal strain of both ventricles were measured. **Result:** Improvement in LV ejection fraction ($P = 0.0001$) and myocardial performance index (MPI) ($P < 0.0001$) occurred at the end of 6 months, whereas decrease in RV MPI ($P < 0.0001$) and tricuspid annular plane systolic excursion ($P < 0.0001$) became statistically significant after 3 months of ASD correction. In comparison to conventional 2D echo, global longitudinal strain of RV decreased significantly only after 48 hours of ASD correction while there was no improvement in left ventricular global longitudinal strain after 6 month of correction. **Conclusion:** There was improvement in RV function with subtle change in LV function by strain imaging and most of these changes were completed within 6 months of ASD correction and nearly correlated with conventional 2DEchocardiography.

Keywords: *Atrial septal defect, global longitudinal strain, right and left ventricle*

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Introduction

Atrial septal defect (ASD) is the most common cause of chronic right heart volume overload. Over time, atrial shunts tend to increase due to a physiological ASD enlargement and an age-dependent decline of the left ventricular (LV) compliance. Natural history studies have shown that right heart volume overload caused by atrial shunt tend to increase progressively over time, thereby affecting cardiac performance even in asymptomatic patients.[1-3] Thus, one of the targets of ASD closure is the prevention of progressive cardiac enlargement in asymptomatic patients. The ideal ASD treatment should aim both to unload the right heart and also to normalize the left-to-right volumetric imbalance.

The previously mentioned studies have clearly shown the dramatic volumetric changes in both the atria and ventricles, both in adult and pediatric population with some minor differences on the timing of these changes and regarding the impact of age at closure on the speed and extent of the changes. These primarily reflect the changes in pre-load and changes occurring in right and LV function both in the presence of ASD as well as after its closure by surgical or percutaneous route, which were subsequently analyzed independent of these volumetric changes.

The reported effects of ASD on LV function are variable. In most echocardiographic studies, LV systolic function was normal despite the right ventricular (RV) volume overload.[4-7] However, a reduced ejection fraction is often found in patients with ASD with severe RV volume overload[8] Cineangiographic studies suggest abnormalities of LV function affecting the systole and diastole.[9-11] The effect of ASD on RV function appears to be more consistent. Although delayed RV contraction has been detected by radionuclide studies in the absence of conduction system defects,[12] echocardiographic assessment has shown that RV function to be normal or exaggerated.

Novel echocardiographic methods have been developed to quantify global as well

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as regional LV function and are used for diagnostic and prognostic evaluation of various cardiovascular diseases. In contrast, quantitative assessment of RV function is still challenging due to its complex anatomy and thin wall structure, and therefore not incorporated into daily clinical practice. Two-dimensional (2D) strain and strain rate (SR) analyses are Doppler-independent novel techniques that measure myocardial movement and deformation.[13] While this method has been used to assess LV function earlier, it has yet rarely been used to examine both LV and RV functions simultaneously. Since RV function is an important prognostic factor in patients with congenital heart disease, the objective of the present study is to quantify both LV as well as RV function in patients with chronic RV volume overload due to an ASD before and after its correction.

Materials and Methods

Population

After approval from the Institutional Ethics Committee, and written consent of the patient or his or her guardian, 32 consecutive patients of ostium secundum ASD with a significant left-to-right shunt and age more than 2 years who underwent correction of ASD (percutaneously or surgically) from January 2015 to July 2016 were taken into the study. The demographic details including age and sex were collected. ASD patients with any other cardiac comorbidities regardless of congenital or acquired heart diseases and patients with right-to-left shunting due to severe pulmonary hypertension were excluded.

Echocardiography

All patients with Ostium secundum ASD underwent usual clinical and transthoracic echocardiography (TTE) assessment. Those patients in whom ASD closure was indicated were assessed for suitability of percutaneous closure by TTE with 4 and/or 7 MHz probes (Vivid 6, General electronics, Horten, Norway) on outpatient basis. 2D echocardiography was performed to determine the situs, apex position, atrioventricular connections, great vessel relation and abnormalities, ventricular dimensions and functions, state of cardiac valves, venous connections, and any intracardiac shunts. M-mode echocardiography was performed to measure the cardiac chamber sizes and quantities LV wall thickness, end systolic and end diastolic diameters, and volumes and systolic function. Pulsed-Wave (PW) Doppler echocardiography: PW Doppler was performed in the apical 4-chamber view to obtain mitral inflow velocities to assess LV filling. A multitude of indices such as peak E and A velocity, their ratio, and deceleration times were derived from this velocity pattern and proposed as markers for diastolic function. A sample volume was placed between the mitral leaflet tips during diastole to record a crisp velocity profile. Tissue Doppler Echocardiography was performed to measure tissue velocities within LV myocardium and the Tei index (myocardial performance index).

Left and right atrial volume was estimated using the length-diameter ellipsoid method and were indexed to body surface area of the individual patient.

LV Tei index was measured by modified method using a built-in software by introducing the time interval from the end to the onset of the LV inflow (a) and the LV ejection time (b) by Tissue Doppler Imaging of the lateral mitral annulus and calculated automatically by following the equation (a−b)/b. In RV Tei index calculation, a = time interval between the end and onset of tricuspid annular diastolic velocity; b = RV ejection time.

RV Tricuspid Annulus Plane Systolic Excursion (TAPSE) was calculated using M-mode with cursor placed at the junction of RV-free wall and tricuspid valve. The amplitude of excursion of tricuspid annulus from the base toward the apex in systole was defined as TAPSE.

Standard echocardiographic views such as apical 4-chamber, parasternal long axis, short axis, and subcoastal bicaval were taken with TTE, and in those patients with a poor echo window, transesophageal echocardiography was done to diagnose the ASD and study the hemodynamic effects of ASD on the heart before closure. Further echocardiographic follow-up was done to detect changes in ventricular dimensions and myocardial deformations occurring at 48 h, 3 months and later at 6 months after surgical or percutaneous ASD closure. Routine postoperative echocardiography was performed at 1 month and after 12 months as per institutional protocol.

Strain imaging

Strain analysis was performed offline using customized computer software (EchoPAC, Vingmed, General electronics, Horten, Norway). For longitudinal strain analysis, gray-scale images were recorded from the apical four-, two- and three-chamber views. A frame rate of 80–100 frames/sec was used for storage and analysis. The images were optimized to visualize the myocardial walls. In brief, the endocardial border was manually traced at end systole. Tracking was automatically performed, and the analysis was accepted after visual inspection and when the software indicated adequate tracking. If tracking was suboptimal, the endocardial border was retraced. If satisfactory tracking was not accomplished within 5 min, the nontracking segments were excluded from the analysis. The end-systolic strain values were measured at aortic valve closure. The global longitudinal strain of LV (including the septum) and RV (free wall only) longitudinal strain was calculated by averaging all the measured segmental values; as shown in Figure 1a and b.

Procedural details

The ASD was assessed by TTE (transesophageal; if anatomy is not clear by TTE). In this study, patients with at least 5 mm of rim in all planes were considered for device closure. Amplatzer septal occluder (AGA Medical corp., Nathan Lane North, Plymouth, MN, USA) was used for the closure of ASD which is a self-expandable, double-disc device made from the nitinol wire mesh. The device size was at least 2 mm bigger than the size of the defect. The defect which was not suitable for device closure was closed in CTVS department under cardiopulmonary bypass. Aspirin at the dose of 5 mg/kg or clopidogrel at 3 mg/kg was given to all patients after discharge for 6 months. Routine postoperative echocardiography was performed at 1 month and after 12 months as per institutional protocol.

Statistical analysis

For statistical analysis, data were entered into a Microsoft Excel spreadsheet and then analyzed by SPSS 20.0.1(IBM, Armonk, NY, USA). Data had been summarized as mean and standard deviation (SD) for numerical variables.

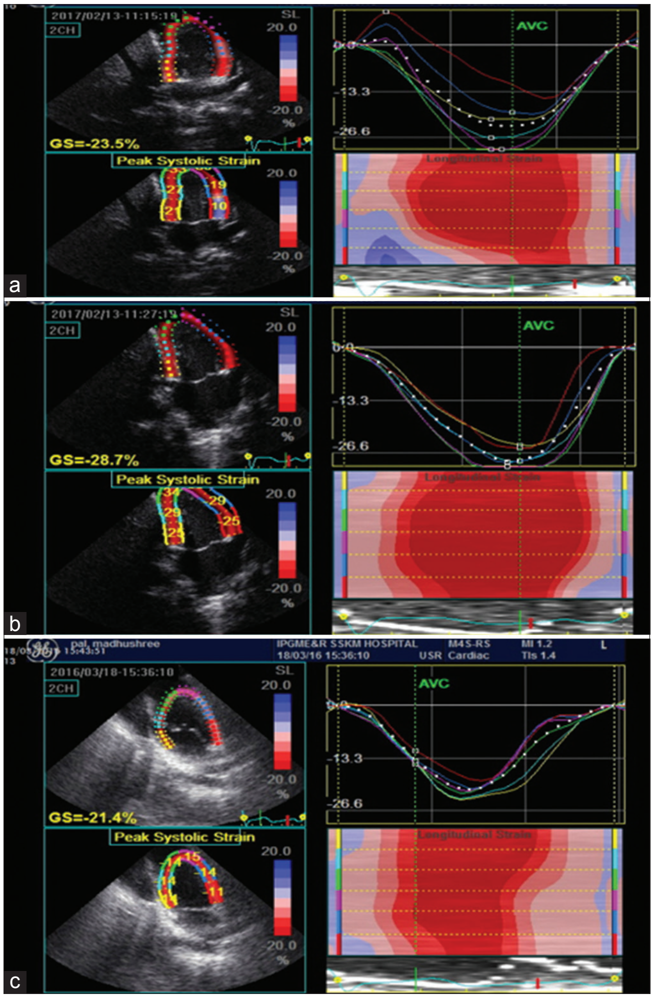

Figure 1: (a) Global longitudinal strain imaging of Left ventricle in patient of atrial septal defect before correction. Apical 4-chamber view is shown. Red, white, and blue line represent different segment of the left ventricle while dotted lines represents global longitudinal strain. (b) Global longitudinal strain imaging of right ventricle in patient of atrial septal defect before correction. Apical 4-chamber view is shown. Red, white, and blue line represent different segment of the right ventricle while dotted lines represents global longitudinal strain. (c) Global longitudinal strain imaging of right ventricle in patient of atrial septal defect after correction. Apical 4-chamber view is shown. Red, white, and blue line represent different segment of right ventricle while dotted lines represents global longitudinal strain

Where the data are normally distributed, continuous variables were presented as mean ± SD and compared using two-tailed paired Student's *t*-test. Comparison between pre-, post-, and follow-up was made by one-way ANOVA test (2-tailed) with *post hoc* analysis by Tukey test.

$P \leq 0.05$ was considered statistically significant.

Result and analyses

Age and sex distribution with regard to ASD size < or >20 mm is shown in Table 1.

Comparative changes in two-dimensional echocardiography

Changes in the LV and RV parameters are shown in Figure 2. No significant change in LA volume (23.97 ± 3.9–23.85 ± 2.81, P = 0.62) was observed, while decrease in RA volume was observed in 2D echocardiography which was statistically significant (35.85 ± 2.80–31.86 ± 3.03,

Table 1: Sex, age, Atrial septal defect size, and route of correction distribution of Atrial septal defect patients (*n*=32)

Parameters	Percentage (%)
Sex distribution (*n*=32)	
Male	10 (31.3)
Female	22 (66.8)
Age distribution (years) (*n*=32)	
>15	14 (43.8)
<15	18 (56.3)
ASD size (mm) (*n*=32)	
>20	14 (43.8)
<20	18 (56.3)
Route of correction (*n*=32)	
Surgical	14 (43.8)
Transcutaneous	18 (56.3)

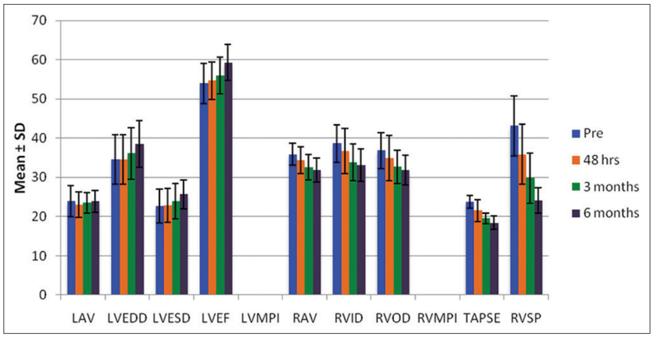

Figure 2: The echocardiographic data in patients of atrial septal defect before and after correction in subsequent follow-up. LAV: Left atrial volume, LVEDD: Left ventricular end-diastolic diameter, LVESD: Left ventricular end-systolic diameter, LVEF: Left ventricle ejection fraction, LVMP: Left ventricle myocardial performance index, RAV: Right atrial volume, RVID: Right ventricle inflow diameter, RVOD: Right ventricle outflow diameter, RVMPI: Right ventricle myocardial performance index, TAPSE: Tricuspid annulus plane systolic excursion, RVSP: Right ventricle systolic pressure

$P < 0.0001$) at 6 months. Similarly, there was significant improvement in LV end-diastolic diameter (34.57 ± 6.3–38.55 ± 5.9, $P = 0.04$), LV ejection fraction (53.91 ± 5.13–59.28 ± 4.64, $P = 0.0001$) and LV myocardial performance index (0.36 ± 0.02–0.32 ± 0.02, $P < 0.0001$) which were observed at the end of 6-month follow-up in 2D echocardiography.

In comparison to LV parameters [Figure 2], there was decrease in RV diameter (38.58 ± 4.73–33.86 ± 4.68, $P < 0.0001$), RV myocardial performance index (0.36 ± 0.01–0.32 ± 0.01, $P < 0.0001$), and TAPSE (23.71 ± 1.6–19.50 ± 1.41, $P < 0.0001$) as observed in 2D echocardiography which became statistically significant only after 3 months of ASD correction. There was also a significant fall in RV systolic pressure after 3 months of the procedure.

Comparative changes in strain imaging

The global longitudinal strain of left and RVs were compared as shown in Table 2.

Decrease in the global longitudinal strain of LV was observed after 6 months of ASD correction (−19.61 ± 1.44–−18.70 ± 6.91), but this change was statistically nonsignificant ($P = 0.814$); however, the percentage decrease in LV global longitudinal strain was 6.9% at the end of 6 months.

The result obtained in RV global longitudinal strain after correction of ASD was quite different in comparison to LV global longitudinal strain [Figure 3]. RV global longitudinal strain decreased significantly in the first follow-up at 48 h after correction of ASD (−26.10 ± 4.27–−24.33 ± 3.46, $P < 0.0001$) which was statistically significant. This observed improvement in RV global longitudinal strain persisted in subsequent follow-up with a maximum decrease (16.58%) in second follow-up at the end of 3 months and the end of 6 months as well.

Discussion

Left and RV systolic function abnormalities have been described in various congenital heart diseases especially in patients with intracardiac shunt. The complex anatomy of RV along with variability in the subjective assessment of ventricular function with TTE limits the use of this technique for routine evaluation of ventricular function in today's practice.

ASD is characterized by chronic volume overload of the RV with a progressive increase in RV dimensions and progressive pulmonary vascular changes over time which leads to pressure overload of RV. This overloading of RV leads to decreased LV filling and decreased LV preload due to shift of interventricular septum toward the left side.[14] Although volume overload of the RV is well tolerated in most of the patients[15] with ASD, it can be detrimental in some patients.[16,17]

Surgical or percutaneous closure of the defect causes reverse remodeling of the ventricles. However, such adaptation may take a long time, so the need of some functional parameters to asses reverse remodeling after percutaneous closure, or corrective surgery is well attained by newer technical modalities such as strain imaging to detect subtle changes in the ventricular function during short- and intermediate-term follow-up of patients with ASD. Speckled-derived SR echocardiography is a new modality which improves the understanding of cardiac functions, although parameters for assessment are yet to be standardized for pediatric population.[18]

The author feels that the strategies employed in the current study are novel and innovative. The global longitudinal strain is used for the assessment of both LV and RV systolic function simultaneously in patients with ASD and its comparison with conventional 2D echocardiography along with the measurement of changes that occurred after the closure of ASD (surgical or percutaneous) immediately postprocedure and after short-term follow-ups.

Changes in atrial volume

Although the RA volume in the present study was high, to begin with, it decreased to a value 35.85 ± 2.80 mm to 31.86 ± 3.03 mm, ($P < 0.0001$) which was statistically significant at the end of 6 months, which can possibly be explained by decrease in preload due to closure of left-to-right shunt.

The population in this study had a pre-closure mean LA volume of 23.9 ± 3.9 ml/m2 with nonsignificant decrease after correction of ASD. This decrease in LA volume can be explained by improved LV filling[11] and decrease in

Table 2: The left ventricular and right ventricular global longitudinal strain in patients of atrial septal defect before (pre) and after correction in subsequent follow-up at 48 h, 3 months, and 6 months with percentage change in global longitudinal strain in each follow-up

	Preoperative	48 (h)	*P* (1)	Percentage change	3 (months)	Percentage change	*P* (2)	6 (months)	*P* (3)	Percentage change	*P* (4)
LVGLS, mean±SD	−19.61±1.44	−18.61±1.44	0.600	5.18	−17.65±6.92	9.99	0.216	−18.70±6.91	0.287	4.64	0.8145
RVGLS, mean±SD	−26.10±4.27	−24.33±3.46	0.0001	6.77	−21.77±1.79	16.58	0.0001	−21.70±1.78	0.0001	16.84	0.0001

P (1): Between preoperative and 48 h, *P* (2): Between preoperative and 3 months, *P* (3): Between preoperative and 6 months, *P* (4): Overall. LVGLS: Left ventricular global longitudinal strain, SD: Standard deviation, RVGLS: Right ventricular-free wall global longitudinal strain

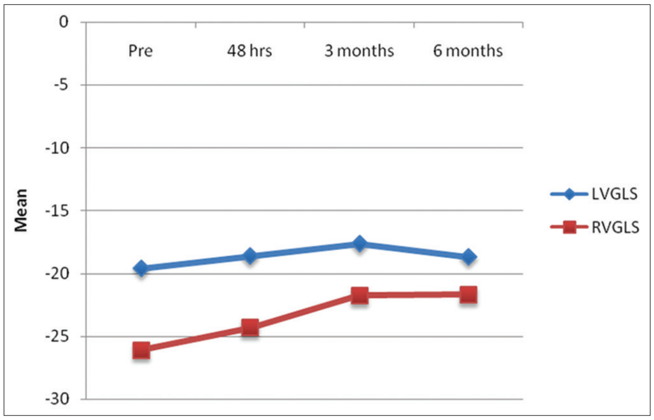

Figure 3: Graphical Description of GLS Parameter

LA preload after correction of ASD, although volume measurement may be difficult due to mass effect of the device *in situ* after correction of the defect. This decrease in LA volume might have some potential benefit in reducing the risk of atrial arrhythmias and other vascular complications like stroke probably by reducing the potentially available space for thrombus formation and organization in patients of ASD after correction of defect.[19]

Changes in left ventricular parameters

Very few studies have shown the effect of ASD correction on LV function, and among them, one study showed a significant change in LV function at each follow-up with maximum change at the end of 3 months.[20] In the present study, statistically significant and maximum improvement in LV end-diastolic diameter and LV ejection fraction occurred at the end of 6 months [Figure 1b and c]. Similarly, the authors observed a significant decrease in LV MPI (0.36 ± 0.02–0.32 ± 0.02, $P < 0.0001$) after 6 months of ASD correction. This improvement in LV function can be explained by improved LV filling.

Change in right ventricular parameters and function

RV dimensions showed a continuous fall in all studied population irrespective of the procedure used for the closure of ASD, and this change has been demonstrated in all previous studies. There was a nonsignificant fall in RV diameter after 48 h of closure which became significant at the end of 3 months with continuous fall thereafter. Similarly, there was an improvement in RV MPI and TAPSE.

Changes in strain imaging of left ventricular and right ventricular

ASD predominantly affects the right side of the heart. Here, the authors aimed to identify any subtle change in echocardiographic parameters of both the ventricles and how they evolve by reverse remodeling after correction (surgical or percutaneous, as appropriate) during serial follow-ups. Till date, no other study has shown the impact of ASD correction on LV function. Although in this study, the baseline LV strain values were within normal limits there was non-significant change in the LV global longitudinal strain observed after 6 months of follow-up, with maximum decrease of 9.38% irrespective of the type of procedure used for correction which was statistically nonsignificant.

In comparison to LV, there are some literatures related to the impact of ASD closure on RV deformation. Although there is some evidence in support of the use of RVGLS assessment for the free wall based on a limited number of single-center study (reference value >−20% was normal)[18,21,22] but accepted guidelines have not been defined for strain and SR of the RV until now. In this study, there is increase in RVGLS at the baseline because of chronic volume overload. There was statistically significant decrease in RV global longitudinal strain after 48 h of ASD correction and decrease to near normal values at 3 months of correction. Similar results have been shown by Jategaonkar *et al*. study in 2009[23] suggesting that early follow-up period after ASD correction is sufficient to have an idea about the reverse remodeling effect of ASD correction on RV.

The findings of the current study lead to the evolution that global longitudinal strain is a noninvasive tool for the objective assessment of myocardial deformation and impact of the correction of the congenital heart defects on myocardial deformation. Being an objective assessment of longitudinal strain analysis, this method is free from performance variability among echocardiographers conferring it a universally accepted tool in predicting early myocardial deformation.

Limitations of the study

Theoretically, myocardial strain can be measured in all dimensions (longitudinal, radial, and circumferential). In this study, we have only quantified the global longitudinal strain assuming that the contraction of the RV is predominantly longitudinal. Apart from this, major limitation, the number of patients included in surgical[12] and transcutaneous[20] group is different; so, it may affect the outcome after correction of ASD. Other limitations are small sample size, and lack of age- and sex-matched control population in the present study.

Conclusion

ASD causes hemodynamic alteration in RV function with subtle changes in LV function. Closure of ASD helps in improvement in ventricular systolic function due to alterations in the cardiac hemodynamics. This improvement in ventricular function occurred in all patients irrespective of the size of the defect, age of the patient, and preoperative ventricular dimensions; although it took more time in patients with a defect of larger size. Hence, 2D strain is a novel imaging technique for evaluation of global and regional myocardial function. There is an improvement of myocardial function of both the ventricles as shown by strain imaging and most of these changes are completed within 6 months of ASD correction and nearly correlates with conventional 2D Echocardiography. Such a validated tool can be used in volume overloaded conditions to predict early ventricular dysfunction and initiation of drugs to guide therapeutic remodeling on short-term basis.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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