Role of speckle tracking echocardiography in assessing right ventricle function after percutaneous closure of atrial septal defect

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Abstract

Background: Atrial septal defect (ASD) is one of the most common congenital heart diseases. Right ventricular (RV) dysfunction is closely related to patient outcome in open and closed ASD closure.

Aim of work: to quantify RV function in patients with chronic RV volume overload due to an ASD before and after its percutaneous closure.

Subjects & methods: In this prospective study which included 40 patients with secundum type ASD and normal sinus rhythm who underwent successful percutaneous ASD closure procedure at Cardiology Department, Faculty of Medicine, Benha University; and Cardiology Department, national-heart-institute. All patients underwent full history taking, clinical examination, ecg & echocardiography including assessment of LA, LV, RA & RV functions & dimensions with special emphasis on TAPSE, RV MPI & 2D speckle tracking.

Result: LA diameters (mm) were decreased significantly after ASD closure; Antero-posterior, Medio-lateral, and Apico-basal. RA diameters (mm) were decreased significantly after ASD closure; PASP was decreased significantly after ASD closure. LVEF% was increased significantly after ASD closure. TAPSE was increased significantly after ASD closure. RV end diastolic diameters were decreased significantly after ASD closure. Pulsed Doppler RV MPI was decreased significantly after ASD closure. RV longitudinal strain (%) was increased significantly after ASD closure. there was a positive correlation among delta RVSTE and delta RV MPI, RV end diastolic diameter, RA diameters, and PASP.

Conclusion: Our study demonstrated significant improvements in multiple echocardiographic measures of cardiac structure and function including reduced LA/RA diameters, decreased PASP, increased LVEF, higher TAPSE, reduced RVEDD, lower RV MPI, and increased RV longitudinal strain at one month post-procedure. These changes indicate reversal of the chronic volume and pressure overload on the right heart caused by the left-to-right shunt, resulting in measurable reverse remodeling and improved mechanics of the right ventricle.

Keywords
Speckle Tracking Echocardiography, Right Ventricle Function, Percutaneous Closure of Atrial Septal Defect.

INTRODUCTION

Atrial septal defect (ASD) accounts for 25-30% of congenital heart defects, which are typically diagnosed during adulthood (1). Trans catheter occlusion of ASD is performed worldwide and has become one of the most practiced interventional procedures for structural heart disease. Percutaneous closure of ASDs is associated with improvement in right ventricle (RV) dimension, morphology, function, exercise physiology, and positive remodeling of the RV (2). However, such adaptation may take a long time. Also, this adaptation can be inadequate in adult ASD patients. Left and right atrial diameters and volumes are increased in ASD patients due to volume overload (3).

New echocardiographic methods have been developed to quantify global and regional left and RV function. These new echocardiographic methods are important for diagnostic and prognostic evaluation in various cardiovascular diseases (4). The echocardiographic technique known as two-dimensional speckle tracking echocardiography (2D-STE) is a reliable technique for angle-independent tracking of myocar-
dial deformation. This echocardiographic technique allows noninvasive and quantitative assessment of global or regional myocardial function (5).

Myocardial speckle tracking echocardiography measures tissue deformation within the myocardium expressed as a fraction or percentage change. Myocardial tissue shortening provides a positive and myocardial tissue shortening and gives a negative strain value. Strain rate (SR) measures the local rate of myocardial deformation per time unit. The myocardial global strain and strain rate are measured by averaging the values computed at the segmental values (6).

RV myocardial function is very important to determine a prognosis in patients with congenital heart disease (6 & 7).

The aim of this work was to quantify RV function in patients with chronic RV volume overload due to an ASD before and after its percutaneous closure.

PATIENTS AND METHODS

This was a prospective study which included 40 patients with secundum type ASD and normal sinus rhythm underwent successful percutaneous ASD closure procedure at cardiology department, faculty of medicine, Benha University; and cardiology department, national-heart-institute during the period from September 2021 to December 2022. Informed consent was obtained from the patients before enrollment of the study. The protocol was applied for approval of Benha Research Ethics Committee.

• Inclusion criteria:
  1. Adult patients were eligible if they had the secundum type of ASD and normal sinus rhythm who underwent successful percutaneous ASD closure procedure.
  2. Clinical indication for ASD closure was haemodynamically significant left-to-right shunt (Qp/Qs > 2.0) or echocardiographic signs of right heart dilatation or shunt related symptoms.

• Exclusion criteria:
  Patients who were excluded:
  1. Patients with a stretched secundum ASD larger than 36 mm,
  2. Patients with inadequate atrial septal rims to permit stable device deployment
  3. Patients with proximity to the defect to the atrioventricular valves, the coronary sinus, or the vena cavae, sinus venosus.
  4. Patients with premium type ASD.
  5. Pulmonary vascular resistance greater than 8 Woods despite 100 % oxygen inhalation.
  6. Other concomitant congenital heart disease, valvular heart disease, coronary artery disease, LV systolic dysfunction, atrial fibrillation, or hypertension.

The secundum ASD patients were evaluated by clinical and echocardiographic examinations before and 1 month after the percutaneous closure ASD procedure.

• Operational design: patients were subjected to the following:
  A-History taking regarding: Demographic data: age, gender.
  B-General and Local examination: Including heart rate & blood pressure measurements.
  C-Transthoracic echocardiographic examination: All patients underwent comprehensive trans-thoracic echocardiography examinations at rest, according to the American Society of Echocardiography guidelines (8).
  1. ECG was recorded continuously.
  2. Pulmonary artery systolic pressure (PASP) was calculated by measuring maximal tricuspid regurgitation velocity, and applying the modified Bernoulli equation to convert this value into pressure values. Estimated right atrial pressure (RAP) was added to this obtained value [PASP = tricuspid regurgitation gradient + RA-pressure (RAP)].
  3. 2D echocardiographic images of the RA and RV were obtained in the apical four-chamber view at the end of expiration.
  4. These echocardiographic images were obtained while taking care to capture the entire RA, allowing for more reliable delineation of the atrial endocardial border.
  5. The frame rate was set at between 40 and 80 Hz. At least three consecutive cardiac cycles of 2D echocardiographic images recorded at each plane were stored in order to select the images with the best quality for off-line speckle tracking analysis (9).

D- Calculation of RV myocardial performance index (MPI).
  1. The RV inflow was recorded with the transducer in the apical 4chamber view, aligning the Doppler beam as perpendicular as possible to the plane of the tricuspid annulus.
  2. The sample volume was placed at the tips of the tricuspid leaflets during diastole.
3. The RV outflow velocity curve was recorded from the parasternal short-axis view, with the Doppler sample volume positioned just below the pulmonary valve.

4. There were time intervals used for calculating the Doppler index, which was measured from the tricuspid inflow and RV outflow recordings.

5. The RV MPI was calculated as \((a – b/b)\). The interval “a” from cessation to onset tricuspid valve inflow. Ejection time “b” is derived from the duration of RV outflow Doppler velocity profile.

6. Three consecutive beats were measured and averaged for each measurement (10).

7. Tricuspid annular plane systolic excursion (TAPSE) is measured as the displacement of the lateral tricuspid annulus toward the apex during systole. E-Two-dimensional speckle tracking analysis.

1. Speckle tracking analysis was performed by a single experienced and independent investigator, who was blinded to the clinical data.

2. To assess the RV myocardial function with 2D-STE, RV basal septal, basal lateral and apical borders was manually traced in the four-chamber view, followed by automatic tracing of the endocardial and epicardial borders, thus delineating a region of interest composed of six segments.

3. After analysis of segmental tracking quality and manual adjustment of the region of interest, longitudinal strain curves were generated for each atrial segment by the software.

4. A cine loop preview feature will allow visual confirmation that the internal line will follow the RV endocardium movements throughout the cardiac cycle.

5. If tracking of the RV endocardium was unsatisfactory, manual adjustments of the region of interest size was performed to ensure optimal tracking.

6. RV longitudinal strain (RVLS) was measured in six segments of the RV.

   Once approved by the reading analyst, the software display longitudinal strain [peak systolic strain (PSS)].

   - **Statistical Analysis:** Data were checked, entered and analyzed using version 25 (SPSS Inc. Chicago, IL, U.S.A) for data processing. The following statistical methods were used for analysis of results of the present study. Data were expressed as number and percentage for qualitative variables and mean ± standard deviation (SD) for quantitative one.

   - **Analytic statistics:**

     - **Paired Samples Student t-test:** was used for pairwise comparison of the quantitative variables with normal distribution (for parametric data)

     - **Pearson correlation coefficient:** was used to assess the Correlation between RV longitudinal strain (%) with delta value of other echocardiographic parameters in patients with ASD.

     - A **P-value** of < 0.05 was considered statistically significant & <0.001 for high significant result for two tailed tests.

**RESULTS**

Our study included 40 patients with ASD, they included 17(42.5%) males, and 23(57.5%) females, with mean age (36.95±0.821) ranging from 35 to 39, and their BMI was 25.25±3.05, ranging from 19 to 34 (Table 1).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>N</th>
<th>%</th>
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<td>Sex</td>
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</tr>
<tr>
<td>Male</td>
<td>17</td>
<td>42.5</td>
</tr>
<tr>
<td>Female</td>
<td>23</td>
<td>57.5</td>
</tr>
<tr>
<td>Age in years</td>
<td></td>
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<tr>
<td>Min.-Max.</td>
<td>35-39</td>
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</tr>
<tr>
<td>Mean ±SD.</td>
<td>36.95±0.821</td>
<td></td>
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<tr>
<td>BMI (Kg/m²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.-Max.</td>
<td>19-34</td>
<td></td>
</tr>
<tr>
<td>Mean ±SD.</td>
<td>25.25±3.05</td>
<td></td>
</tr>
</tbody>
</table>

LV end diastolic diameters remained unchanged before and after ASD closure (50.48±2.882 vs. 51.33±3.198 mm, p > 0.05). LV end systolic diameter remained unchanged before and after ASD closure (28.98±2.655 vs. 29.68±3.133 mm, p > 0.05). LVEF% was increased significantly after ASD closure (59.45±3.186 vs. 61.35±3.401, p < 0.05). LA diameters (mm) were decreased significantly after ASD closure; Antero-posterior (39.15±3.83 vs. 36.93±1.98, p < 0.05), Medio-lateral (42.68±5.10 vs. 40.65±4.73, p < 0.05), and Apico-basal (48.20±3.19 vs. 46.58±5.01, p < 0.05) (Table 2).

RA diameters (mm) were decreased significantly after ASD closure; Medio-lateral (43.43±4.545 vs. 41.58±4.193, p < 0.05), and Apico-basal (49.25±3.754 vs. 47.83±3.727, p < 0.05). RV end diastolic diameters were decreased significantly after ASD closure (43.13±4.027 vs. 41.45±3.573 mm, p < 0.05).
PASP was decreased significantly after ASD closure (50.10±8.869 vs. 45.15±11.432 mmHg, p < 0.05). TAPSE was increased significantly after ASD closure (18.86±3.653 vs. 20.33±3.957 mm, p < 0.05). Pulsed Doppler RV MPI was decreased significantly after ASD closure (0.389±0.077 vs. 0.315±0.074, p < 0.05). RV longitudinal strain (%) was increased significantly after ASD closure (23.13 ±2.49 vs. 30.18±2.82, p < 0.05) (Table 3).

There was a positive correlation among delta RVSTE and delta LVEF and TAPSE. Also, there was a negative correlation among delta RVSTE and delta RV MPI, RV end diastolic diameter, RA diameters, and PASP (Table 4).

Table 2. Comparison between patients’ pre-procedure and 1 month’s post-procedure as regards RA & RV echo parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Pre-procedure</th>
<th>Post-procedure</th>
<th>t</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA diameter (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min – Max</td>
<td>45 – 57</td>
<td>45 – 57</td>
<td>-2.012</td>
<td>0.051</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>50.48 ± 2.882</td>
<td>51.33 ± 3.198</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV end systolic diameter (mm)</td>
<td>25 – 35</td>
<td>24 – 35</td>
<td>-1.924</td>
<td>0.062</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>28.98 ± 2.655</td>
<td>29.68 ± 3.133</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV EF %</td>
<td>54 – 70</td>
<td>54 – 72</td>
<td>-3.936</td>
<td>0.002*</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>59.45 ± 3.186</td>
<td>61.35 ± 3.401</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LA diameter (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antero-posterior</td>
<td>30 – 44</td>
<td>30 – 40</td>
<td>3.444</td>
<td>0.0013*</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>39.15 ± 3.83</td>
<td>36.93 ± 1.98</td>
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</tr>
<tr>
<td>Medio-lateral</td>
<td>33 – 53</td>
<td>31 – 52</td>
<td>2.704</td>
<td>0.010*</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>42.68 ± 5.10</td>
<td>40.65 ± 4.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apico-basal</td>
<td>41 – 53</td>
<td>38 – 53</td>
<td>2.950</td>
<td>0.0053*</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>48.20 ± 3.19</td>
<td>46.58 ± 5.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV end diastolic diameter (mm)</td>
<td>45 – 57</td>
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<td>-2.012</td>
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</tr>
<tr>
<td>TAPSE (mm)</td>
<td>18.86±3.653</td>
<td>20.33±3.957</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>42.68±5.10</td>
<td>40.65±4.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RV end diastolic diameter (mm)</td>
<td>33 – 50</td>
<td>33 – 48</td>
<td>2.089</td>
<td>0.043*</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>43.13 ± 4.027</td>
<td>41.45 ± 3.573</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PASP (mmHg)</td>
<td>33 – 67</td>
<td>29 – 66</td>
<td>2.732</td>
<td>&lt;0.0094*</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>50.10 ± 8.869</td>
<td>45.15 ± 11.432</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAPSE (mm)</td>
<td>13 – 27</td>
<td>14 – 29</td>
<td>-2.926</td>
<td>0.0062*</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>18.86 ± 3.653</td>
<td>20.33 ± 3.957</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulsed Doppler RV MPI</td>
<td>0.23 – 0.53</td>
<td>0.21 – 0.48</td>
<td>4.531</td>
<td>0.0054*</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>0.389 ± 0.077</td>
<td>0.315 ± 0.074</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RV longitudinal strain (%)</td>
<td>18.1 – 26.7</td>
<td>22.7 – 33.9</td>
<td>-19.63</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>23.13 ± 2.49</td>
<td>30.18 ± 2.82</td>
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Table 3. Comparison between patients’ pre-procedure and 1 month’s post-procedure as regards PASP, TAPSE, Pulsed Doppler RV MPI, and RV longitudinal strain (%)

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<tr>
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<td>RA diameter (mm)</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Min – Max</td>
<td>32 – 50</td>
<td>32 – 50</td>
<td>2.544</td>
<td>0.015*</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>43.43 ± 4.545</td>
<td>41.58 ± 4.193</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RV end diastolic diameter (mm)</td>
<td>33 – 67</td>
<td>29 – 66</td>
<td>2.732</td>
<td>&lt;0.0094*</td>
</tr>
<tr>
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<td>RV longitudinal strain (%)</td>
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<td>&lt;0.001**</td>
</tr>
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</table>

Table 4. Correlation between RV longitudinal strain (%) with delta value of other echocardiographic parameters in patients with ASD

<table>
<thead>
<tr>
<th>Studied Parameters</th>
<th>RV longitudinal strain (%)</th>
<th>Correlation</th>
<th>p-value</th>
</tr>
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<tbody>
<tr>
<td>LV end diastolic diameter</td>
<td>0.284</td>
<td>0.076</td>
<td></td>
</tr>
<tr>
<td>LV end systolic diameter</td>
<td>0.172</td>
<td>0.289</td>
<td></td>
</tr>
<tr>
<td>LV EF %</td>
<td>0.980</td>
<td>0.000**</td>
<td></td>
</tr>
<tr>
<td>Studied Parameters</td>
<td>RV longitudinal strain (%)</td>
<td>Correlation</td>
<td>p-value</td>
</tr>
<tr>
<td>--------------------</td>
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<td>---------</td>
</tr>
<tr>
<td>LA diameter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Antero-posterior</td>
<td>-0.048</td>
<td>0.769</td>
<td></td>
</tr>
<tr>
<td>• Medio-lateral</td>
<td>0.001</td>
<td>0.997</td>
<td></td>
</tr>
<tr>
<td>• Apico-basal</td>
<td>-0.271</td>
<td>0.091</td>
<td></td>
</tr>
<tr>
<td>RA diameter</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>• Medio-Lateral</td>
<td>-0.853</td>
<td>0.000**</td>
<td></td>
</tr>
<tr>
<td>• Apico-basal</td>
<td>-0.768</td>
<td>0.000**</td>
<td></td>
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<tr>
<td>RV end diastolic diameter</td>
<td>-0.820</td>
<td>0.000**</td>
<td></td>
</tr>
<tr>
<td>PASP</td>
<td>-0.876</td>
<td>0.000**</td>
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</tr>
<tr>
<td>TAPSE</td>
<td>0.868</td>
<td>0.000**</td>
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<tr>
<td>Pulsed Doppler RV MPI</td>
<td>-0.856</td>
<td>0.000**</td>
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</table>

**P-value ≤ 0.001 highly significant

**DISCUSSION**

Atrial septal defect (ASD) is one of the most common congenital heart diseases. Right ventricular (RV) dysfunction is closely related to patient outcome in open and closed ASD closure. Two-dimensional echocardiography has been widely used in the assessment of RV systolic function in ASD. However, there are certain limitations in two-dimensional methods considering the complicated anatomy and irregular chamber shape of the right ventricle (10).

Two-dimensional speckle tracking echocardiography (2D-STE) is a relatively new echocardiography technique for myocardial deformation evaluation (11).

The objective of the present study was to quantify RV function in patients with chronic RV volume overload due to an ASD before and after its percutaneous closure.

The study included 40 patients, 17(42.5%) were males, and 23(57.5%) females, with mean age (36.95±0.821) ranging from 35 to 39, and their BMI mean was 25.25±3.05, ranging from 19 to 34.

Choi et al., (13) analyzed the clinical characteristics and LA strain rate before and six months after ASD closure. They reported that, the mean age was 42.6±9.9 years, and six (54.5%) were females.

In our study, LA diameters (mm) were decreased significantly after ASD closure; Antero-posterior (39.15±3.83 vs. 36.93±1.98, p < 0.05), Medio-lateral (42.68±5.10 vs. 40.65±4.73, p < 0.05), and Apico-basal (48.20±3.19 vs. 46.58±5.01, p < 0.05). RA diameters (mm) were decreased significantly after ASD closure; Medio-lateral (43.43±4.545 vs. 41.58±4.193, p < 0.05), and Apico-basal (49.25±3.754 vs. 47.83±3.727, p < 0.05).

This is in harmony with Ozturk et al. (12) who reported that, an improvement of multiple echocardiographic parameters such as the right atrial diameter, left atrial diameter, was noted in the first month post-procedure period.

On the other hand, El-Sherbeny and Elhefnawy (14) reported that left atrium (LA) diameter significantly increased after ASD closure; and peak longitudinal strain of RA increased significantly one day and one month after ASD closure (48.77±4.40, vs.55.36±3.70 and, vs. 62.13±3.81%, p=0.001). LA longitudinal strain significantly decreased after ASD closure (42.55±4.57, vs. 34.79±3.20%, p=0.001). Right-sided diameters were reduced early on due to elimination of volume overload and left ventricular diameters increased due to relief of RV septum deviation and increase in preload which was similar to Saedi et al. (15).

Kucinska et al. (16) studied 42 children who underwent ASD device closure; echocardiographic measurement of RA and RV dimensions and area (indexed to body surface area) were obtained one day and 1, 3, and 12 months after percutaneous ASD closure and compared with control group; they found that measurements decreased rapidly during first 24 h, and most of them normalized within 3 months.

Suzuki et al. (17) who studied 34 children with ASD and 13 controls, and the LA strain was measured using 2D-STE; twelve of the patients had surgery (ASD-S) and thirteen had device closure (ASD-D). They found that following ASD-D, LA strain was significantly reduced, however, not significantly changed following ASD-S.

Cakal et al. (18) followed 20 ASD patients and 20 age-matched controls for 24 h prior to the operation and for one month after the percutaneous closure. Peak longitudinal strain (S) and strain rate (SR) were measured during the LA reservoir, passive emptying, and atrial contraction phases. Peaks S and SR were found to be similar to controls in ASD patients. Instantly after the defect was closed, all of these parameters increased. But one month following closure, LA S and SR have been decreased. This delay in the changes at LA strain may be due to the older age of the studied patients. Since the LA adaptation to chronic volume
overload, redistribution of raised intravascular volume with transient rise in LA filling following ASD closure results in a quick rise in LA pressure; however, the LA did not instantly adapt to the new situation, but after one month the LA was more adapted to the new volume distribution.

On the contrary of our finding, the results of Thilen et al. (19) found that cardiac remodeling begins within the first week of closure and is completed four months later, who discovered that the LA remained unchanged, may be due to older age that reduced the potential to normalized LA size after ASD closure.

In our study, PASP was decreased significantly after ASD closure (50.10±8.869 vs. 45.15±11.432 mmHg, p < 0.05).

This is in accordance with Ozturk et al. (12) who reported that, an improvement of PASP was noted in the first month post-procedure period.

In our study, LVEF% was increased significantly after ASD closure (59.45±3.186 vs. 61.35±3.401, p < 0.05). TAPSE was increased significantly after ASD closure (18.86±3.653 vs. 20.33±3.957 mm, p < 0.05).

This is in line with Ozturk et al. (12) who reported that, LVEF and TAPSE were significantly increased in the first month post-procedure period.

Pascotto et al. (20) performed a study on outcomes of percutaneous ASD closure using echocardiography for function assessments. They presented similar outcomes as EF improved while LV functions improved following intervention but not significantly.

Eroglu et al. (21) who aimed to assess the regional RV function in ASD patients, to evaluate the extent and time course of RV remodeling following ASD closure, and to investigate whether any regional difference exists in RV remodeling. They reported that, LVEF increased immediately at 24 hours, and decreased back to normal values 1 month after the closure. All of the global RV systolic function parameters including TAPSE, was worsened immediately after the procedure, and improved again at first month follow-up.

Differences in RV regional EF measured by RT3DE have also been reported in patients with tetralogy of Fallot and pulmonary hypertension (22).

Our finding of improvement of RV systolic function (TAPSE) is consistent with the research of Atashband et al. (23) which discovered that right heart morphology improves rapidly after percutaneous ASD closure within one month.

Furthermore, Kumar et al. (24) who aimed to evaluate 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. They reported improvement in LV ejection fraction (P = 0.0001) occurred at the end of 6 months.

In our study, RV end diastolic diameters were decreased significantly after ASD closure (43.13±4.027 vs. 41.45±3.573 mm, p < 0.05). Pulsed Doppler RV MPI was decreased significantly after ASD closure (0.389±0.077 vs. 0.315±0.074, p < 0.05).

This agrees with Ozturk et al. (12) who aimed to evaluate RV function using STE in patients with atrial septal defect (ASD) before and the first month after percutaneous closure. They observed significantly improved RV function with speckle tracking and RV MPI.

RV function is difficult to assess because of its complex structures. MPI does not depend on any geometric assumption. Also, MPI is not age or heart rate dependent. In previous studies, MPI has been used to assess RV function in patients with congenital heart disease. Ding et al. (25) found that MPI increased significantly in patients with ASD compared to the control subjects. Also, they found that after transcatheter closure, MPI decreased markedly in patients with ASD. Also, study results of Ding et al. are similar to our study findings.

Ghaderian et al. (26) reported that, comparison of indices postoperatively showed better RV function indices after the procedure. Following the ASD closure, volume load on both ventricles changes, and this unloading of RV is the absolute benefit of ASD closure that can improve its function and prevent long-term further complications.

Our results are similar to the study conducted by Agha et al. (27) which demonstrated that remodeling of both RV and LV was reversible after percutaneous ASD closure; however, their study was performed in older children.

Bussadori et al. (28) performed a similar study on older population following ASD closure. They presented significant improvement of RV functions as the fluid volume decreased but immediately it got worse after closure. They presented this improvement in six-month follow-up as well which may be attributed to the chronic long-term effects of ASD on cardiac function (the mean age of patients was in the third decade).
However, benefit of ASD closure on LV function was not statistically significant.

Furthermore, in another study by Kowalik et al., (29) there was no difference in RV deformation indices between ASD patients and control group in adults. Standard echocardiographic studies in ASD patients showed higher RV dimensions with lower LV dimensions, indicating an interventricular independence (29). Also higher global RV systolic function indices such as TAPSE and RVEF were reported in ASD patients (20).

Eroglu et al. (21) their standard echocardiographic data demonstrated larger RV diameters, and higher RV global systolic function indices in ASD patients. RVMPI was worsened immediately after the procedure, and improved again at first month follow-up.

Kumar et al. (24) reported improvement in myocardial performance index (MPI) (P < 0.0001) occurred at the end of 6 months, whereas decrease in RV MPI (P < 0.0001) became statistically significant after 3 months of ASD correction.

In our study, RV longitudinal strain (%) was increased significantly after ASD closure (23.13 ±2.49 vs. 30.18±2.82, p < 0.05).

This came in agreement with Ozturk et al. (12) who demonstrated that peak RVLS was shown to be significantly increasing after percutaneous closure of ASD.

Kumar et al. (24) reported that, global longitudinal strain of RV decreased significantly only after 48 hours of ASD correction.

However, Elsheikh et al. (30) found that volume overload induced by ASD is associated with increased strain values, which return to normal after closure.

On the other hand, Teo et al. (31) found that a significant reduction in RV volumes at 6 months after ASD closure and RV ejection fraction (RVEF) was significantly increased in cardiovascular magnetic resonance (CMR). CMR is an accurate and reproducible imaging modality for the assessment of cardiac function and volumes. Study results of Teo et al. are similar to our study findings.

Xu et al (32) evaluated RV myocardial strains by STE after percutaneous ASD closure in children. They reported that RV strains were significantly higher in children before device closure. At 1 day after closure, all these measures decreased accordingly. This discrepancy between their findings and ours can be due to the differences in ages and ASD dimensions before procedure though they concluded that transcatheter device closure of ASDs improved RV strain indices, so its function recovered to normal over 3 months.

The other study conducted by Vitarelli et al. (33) evaluated the efficacy of three-dimensional (3D) and 2D speckle tracking on assessing outcomes of ASD closure and its ability in prediction of further paroxysmal atrial fibrillation (AF) progression. Their study findings were consistent with our findings regarding RV function improvement. Furthermore, they presented that speckle tracking could successfully predict paroxysmal AF progression among patients with ASD.

Moradian et al. (34) compared global longitudinal strain and strain rate of RV free wall of ASD patients in two groups who underwent surgically versus percutaneous device closure before and after procedures. Fifty-seven ASD 2 patients were enrolled in the study. Their deformation indices in two groups of surgical ASD closure and device closure had no meaningful different based on the age and sex of the patients. ASD closure reduced cardiac chambers size in both groups. However, tricuspid annular size reduction was more significant in percutaneous ASD closure group. The study shows that echocardiographic RV function indices improved after percutaneous ASD2 closure but deformational indices of RV reduced after surgical closure.

Eroglu et al. (21) observed higher RV longitudinal S both in lateral and septal walls in ASD patients when compared with controls. Importantly, the difference was more prominent in RV lateral wall strain. The difference between the septal and lateral wall deformation can be explained with the fact that 2D speckle tracking could not distinguish between right and left sided components of the septum.

Increased contraction in RV lateral wall measured by two-dimensional echocardiographic methods was noted in previous studies (35).

Kong et al. (10) reported that, when compared with controls, RV global was decreased in preclosure patients (P < 0.001). After closure, RV systolic function parameters were all reduced (P < 0.001).

In our study, there was a positive correlation among delta RVSTE and delta LVEF and TAPSE. Also, there was a negative correlation among delta RV MPI, RV end diastolic diameter, RA diameters, and PASP.

In accordance, Ozturk et al. (12) found a positive correlation among delta RVSTE and delta LVEF and TAPSE. Also, they found a negative correlation among delta RVSTE and RV MPI.
delta RVSTE and delta RV MPI, RV diameter, RA diameter, and PASP.

Previous studies have also demonstrated similar findings of decreased right atrial and ventricular dimensions after percutaneous ASD closure. Akula et al. (36) showed that RV volumes decreased significantly in the first month after ASD device closure and continued up to 6 months.

Atashband et al. (23) showed that percutaneous ASD closure in adults is effective with reverse remodeling and better functional capacity.

El-Sherbeny and Elhefnawy (14) reported that negative correlation was found between the size of the ASD and delta LA systolic strain and strain rate.

Kong et al. (10) reported that, Preclusion TAPSE and S were positively correlated with ASD diameter in patients without pulmonary hypertension, but there was no significant relationship between RT3DE parameters and RV preload. These results suggest RT3DE-derived systolic function parameters are less preload dependent when compared with conventional two-dimensional ones. RV global and regional EF in the inflow compartment were negatively correlated with PVR in patients after closure (r = −0.601, −0.543, P < 0.001).

CONCLUSION

Our study demonstrated significant improvements in multiple echocardiographic measures of cardiac structure and function including reduced LA/RA diameters, decreased PASP, increased LVEF, higher TAPSE, reduced RVEDD, lower RV MPI, and increased RV longitudinal strain at one month post-procedure. These changes indicate reversal of the chronic volume and pressure overload on the right heart caused by the left-to-right shunt, resulting in measurable reverse remodeling and improved mechanics of the right ventricle. Further, correlations between enhanced RV strain and other indices of positive remodeling confirm the utility of advanced speckle tracking to quantify physiological benefits of ASD correction.

Further large-scale studies could help better characterize the duration of remodeling changes, compare to age-matched peers, and correlate echo findings with patient outcomes over an extended period to better establish clinical benefits of percutaneous ASD closure.

Limitations

Potential limitations of this study include a small sample size from only two centers without longer-term follow-up, lack of a control group, and reliance on echocardiography which can have substantial measurement variability. Additionally, this study did not explore effects on functional status or exercise capacity after ASD closure.

REFERENCES

11. Ali YA, Hassan MA, El Fiky AA. Assessment of left ventricular systolic function after VSD trans catheter