The Egyptian Journal of Hospital Medicine (July 2024) Vol. 96, Page 3371-3377

Assessment of Atrial Function and Rhythm after Percutaneous Closure of Atrial Septal Defect

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ABSTRACT

Background: Secundum atrial septal defect (ASD) is one of the most common congenital heart conditions. Transcatheter device closure of secundum ASD has become the preferred treatment for patients with suitable anatomy. While, the impact on ventricular function and volume post-closure has been widely studied, data on atrial performance following percutaneous ASD closure remains limited. **Objective:** This study aimed to assess atrial function using echocardiographic modalities and atrial rhythm through Holter monitoring early after percutaneous ASD closure.

Patients and Methods: The study included 40 patients with secundum ASD, evaluated before and shortly after percutaneous closure. Atrial performance was assessed using two-dimensional echocardiography, tissue Doppler imaging (TDI) velocities, and speckle-tracking echocardiography (STE) to measure reservoir, conduit, and contractile functions. Electrical function was monitored with electrocardiograms (ECG) and Holter monitoring to detect heart rate (HR) rhythms and heart rate variability (HRV) before and after ASD closure.

Results: Right atrial diameters, volumes, and TDI velocities significantly decreased post-closure. RA reservoir function dropped from 34.58 ± 11.69 before closure to 28.73 ± 11.52 after closure (p<0.001). Similarly, LA reservoir function decreased from 31.4 ± 7.28 to 27.08 ± 6.93 (p<0.001). Average HR decreased from 98.08 ± 13.51 bpm to 92.05 ± 13.23 bpm (p<0.001). The incidence of supraventricular arrhythmia increased significantly post-closure (0.41 ± 0.46%) compared to pre-closure (0.08 ± 0.19%; p<0.001). **Conclusion:** Atrial diameters and volumes decreased early after ASD device closure, along with reductions in atrial reservoir, conduit, and contractile functions. Supraventricular arrhythmias increased, but there was an improvement in HR and HRV parameters post-closure.

Keywords: Atrial septal defect, Left atrium, Right atrium, Tissue Doppler imaging, Speckle tracking echocardiography.

INTRODUCTION

Atrial septal defects represent the second most common type of congenital heart disease and account for 7% to 10% [1]. Worldwide, ASDs are noted to be 1.64 per 1000 live births with a female-to-male ratio of 2:1 [2]. Trans-catheter device closure of secundum type ASD has now become the treatment of choice in those with suitable rims (Deaconu *et al.*, 2024). Although, ventricular functions or volumes after percutaneous closure of ASD have been studied, information about the effects of percutaneous closure on atrial performance is limited [3]. The closure of ASD can initiate or exaggerate atrial tachyarrhythmia [4].

The aim of this study was to assess atrial function using different echocardiographic modalities, atrial rhythm using Holter monitoring after percutaneous closure of atrial septal defect.

PATIENTS AND METHODS

This study included 40 patients with secundum ASD who were candidates for ASD device closure. The patients were referred to The Cardiology Departments at Al-Zahraa University Hospital and Bab El-She'riya University Hospital (Al-Azhar University Hospitals) between March 2021 and June 2023.

Inclusion criteria: Patients referred for elective transcatheter closure of secundum ASD, in accordance with the 2020 European Society of Cardiology (ESC) Guidelines for the management of adult congenital heart disease [5]**. Exclusion criteria:** Patients not suitable for ASD device closure per the ESC guidelines, patients with a permanent pacemaker, those with serious rhythm disturbances, patients with secundum ASD associated with other congenital heart diseases, patients with significant mitral regurgitation (greater than mild), and those with inadequate echocardiographic assessments**.**

Methodology: All participants underwent the following assessments:

- Comprehensive medical history and clinical evaluation
- Transthoracic echo-Doppler assessment of right and left atrial mechanical function including conventional linear diameters using M-mode and 2D imaging. Atrial volumes (maximal, minimal, and precontractile) and functions derived from volumetric equations were measured. Advanced echo-Doppler modalities (TDI and 2D STE) were used to assess reservoir, conduit, and contractile functions before and early after ASD device closure, as well as the shunt.
- 12-lead ECG and 24-hour Holter monitoring to detect average, maximum, and minimum heart rates, supraventricular and ventricular ectopic arrhythmias, and HRV parameters before and after ASD device closure.
- Transcatheter closure of the ASD was performed under fluoroscopic and transesophageal echocardiographic (TEE) guidance.

The study adhered to the recommendations of the American Society of Echocardiography (ASE) and the consensus of the EACVI/ASE task force on standardized deformation imaging [6, 7].

Ethical considerations: The study was done after being accepted by The Research Ethics

Received: 03/04/2024
Accepted: 03/06/2024

Committee, Faculty of Medicine for Girls (FMG), Al-Azhar University. All parents provided written informed consents prior to enrolment of their children. The consent form explicitly outlined their agreement to participate in the study and for the publication of data, ensuring protection of their confidentiality and privacy. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Statistical analysis: Data management and statistical analysis were performed using SPSS version 26 (IBM, Armonk, New York, United States). Quantitative data were assessed for normality using the Kolmogorov–Smirnov test, Shapiro-Wilk test, and visual inspection methods. Depending on the normality of the data, quantitative variables were summarized as means with standard deviations for normally distributed data, or as medians with ranges for non-normally distributed data. Categorical data were summarized as frequencies and percentages. For comparison of quantitative data between the groups, the paired t-test was used for normally distributed variables, and the Wilcoxon signed-rank test for non-normally distributed variables. Categorical variables were compared using the Chi-square or Fisher's exact test. All statistical tests were two-sided, and a P value ≤ 0.05 was considered statistically significant.

RESULTS

The study population was assessed both mechanical (different echo modalities) and electrical (ECG and Holter) before and early after ASD closure: ***Group A1* (before-closure),** which included the forty patients before trans-catheter ASD device closure, ***group A2* (early after closure)** that included the forty patients early after trans-catheter device closure (1-4 days). Among our studied patient 75% of them were female (30 patients).

Conventional echocardiographic data of all studied patients: The conventional echocardiographic data of our patients, showed that the mean RA diameter was 40 mm (ranging from 21-55 mm) and mean RA volume was 14 ml (3.9-27.6 ml). The mean LA diameter was 30 mm (range between 18-37 mm) and the mean LA volume was 15 ml (4.5-34 ml), the mean ASD defect size was 19.33 mm, ranged between 8-33 mm and the mean size of the device used in the study was 25 mm (13-36 mm) (Table1).

Table (1): Conventional echocardiographic data of all studied patients

Variable	Total number (n)=40
RA diameter (mm)	40 (21-55)
RA volume (ml)	14.9 (3.9-27.6)
LA diameter (mm)	30 (19-37)
LA volume (ml)	15 (4.5-34)
ASD defect size (mm)	19.33 (8-33)
ASD device size (mm)	25 (13-36)

RA: Right Atrium, LA: Left Atrium, ASD: Atrial Septal Defect, mm: Millimeters, ml: Milliliters.

Right atrium function:

Comparison between group A1 and group A2 regarding conventional Right atrial echocardiographic function showed that group A2 had statistically significant lower right atrial diameters and volumes than group A. Group A2 had statistically significant reduced functions derived from volumetric equations than group A1. Group A2 had significantly lower reservoir, conduit and contractile function measured by tissue Doppler imaging velocities or 2D STE than group A1 (Table 2).

Table (1): Comparison between group A1 and A2 regarding conventional right atrial echocardiographic data

Variable	Group A1 (Before) (means ±SD)	Group A2 (Early after) (means ±SD)	*P* value	Sig.
RA SI diam.(mm)	41.23 ± 7.26	35.3 ± 7.34	**<0.001**	S
RA ML diam.(mm)	34.43 ± 6.92	29.23 ± 6.39	**<0.001**	S
RA MAX VOL(ml)	14.54 ± 5.43	10.36 ± 4	**<0.001**	S
RA PRE VOL(ml)	10.9 ± 4.81	7.43 ± 2.94	**<0.001**	S
RA MIN VOL(ml)	7.38 ± 3.2	5.14 ± 1.89	**<0.001**	S
RA R func.(ml/m2)	7.16 ± 3.11	5.22 ± 3.02	**<0.001**	S
RA CD func.(ml/m2)	3.64 ± 1.98	2.93 ± 2.16	**0.022**	S
RA CT func.(ml/m2)	3.52 ± 2.89	2.29 ± 1.9	**0.010**	S
RA TDI S(cm/s)	6.86 ± 1.55	6.25 ± 1.4	**<0.001**	S
RA TDI E(cm/s)	5.67 ± 1.54	5.18 ± 1.54	**<0.001**	S
RA TDI A(cm/s)	5.06 ± 1.46	4.61 ± 1.67	**<0.001**	S
RA R func. %	34.58 ± 11.69	28.73 ± 11.52	**<0.001**	S
RA CD func. %	23.6 ± 8.06	20.5 ± 7.89	**<0.001**	S
RA CT func. %	11.2 ± 5.92	8.23 ± 5.27	**<0.001**	S

RA SI diam= right atrium superior inferior diamete, RA ML diam.= right atrium medio-latral diameter, RA MAX VOL =right atrium maximum volume, RA PRE VOL =right atrium precontractile volume, RA MIN VOL =right atrium minimum volume, RA R func =right atrium reservoir function, RA CD func. =right atrium conduit function, RA CT func. =right atrium contractile function RA TDI S= right atrium Tissue Doppler imaging peak systolic velocity, RA TDI E= Right atrium tissue Doppler imaging early diastolic velocity, RA TDI A= Right atrium tissue Doppler imaging late diastolic velocity, RA R func.= Right atrium reservoir function, RA CD func.= Right atrium conduit function, RA CT func.= Right atrium contractile function.

Left atrium function:

Comparison between group A1 and A2 regarding conventional Left atrial echocardiographic function showed that group A2 had statistically significantly lower LA diameters and volumes than group A1. Group A2 had statistically significantly reduced reservoir and conduit functions using volumetric assumption than group A1. While, no significant difference in the LA contractile function between both groups. Group A2 showed statistically significant reduced TDI peak systolic velocity. No significant changes between groups A1 and A2 regarding TDI diastolic parameters (early and late peak diastolic velocities). Group A2 showed statistically significant lower reservoir, conduit and contractile functions using 2D speckle tracking than group A1 (Table 3).

Table (3): Comparison between group A1 and A2 regarding conventional Left atrial echocardiographic data

Variable	Group A1 (Before) (means ±SD)	Group A2 (Early after) (means ±SD)	*P* value	Sig.
LA AP diam. (mm)	29.9±7.3	28.8±6.6	**0.03**	S
LA ML diam.(mm)	39.88 ± 7.84	37.43 ± 7.2	**<0.001**	S
LA SI diam.(mm)	34.03 ± 6.71	30.68 ± 6.76	**<0.001**	S
LA MAX VOL(ml)	16.14 ± 7.52	11.56 ± 4.84	**<0.001**	S
LA PRE VOL(ml)	12 ± 5.44	8.6 ± 3.35	**<0.001**	S
LA MIN VOL(ml)	7.85 ± 3.99	4.91 ± 2.34	**<0.001**	S
LA R func.(ml/m2)	8.29 ± 4.99	6.65 ± 3.83	**0.003**	S
LA CD func.(ml/m2)	4.14 ± 2.79	2.96 ± 2.37	**0.002**	S
LA CT func.(ml/m2)	4.15 ± 3.4	3.69 ± 2.68	0.241	NS
LA TDI S(cm/s)	**4.85 ± 1.8**	**4.46 ± 1.57**	**<0.001**	**S**
LA TDI E(cm/s)	**4.3 ± 1.73**	**4.07 ± 1.57**	**0.053**	**NS**
LA TDI A(cm/s)	**3.45 ± 1.71**	**3.37 ± 1.59**	**0.580**	**NS**
LA R func. %	**31.4 ± 7.28**	**27.08 ± 6.93**	**<0.001**	**S**
LA CD func. %	**21.73 ± 6.41**	**19.83 ± 5.8**	**<0.001**	**S**
LA CT func. %	**9.7 ± 3.57**	**7.53 ± 2.94**	**<0.001**	**S**

LA AP diam. = Left atrium anteroposterior diameter. LA ML diam.= left atrium mediolateral diameter, LA SI diam.=left atrium superior inferior diameter, LA MAX VOL= left atrium maximum volume, LA PRE VOL =left atrium precontractile volume, LA MIN VOL = left atrium minimum volume, LA R func. =left atrium reservoir function, LA CD func. = left atrium conduit, LA CT func. = left atrium contractile function LA TDI S= left atrium tissue Doppler imaging peak systolic velocity, LA TDI E= left atrium Tissue Doppler tissue Doppler imaging early diastolic velocity, LA TDI A= left atrium Tissue Doppler imaging late diastolic velocity, LA R func.= left atrium reservoir function, LA CD func.= left atrium conduit function, LA CT func.= left atrium contractile function**.**

Comparison between A1 and A2 in respect to Holter monitoring data showed that there were statistically significant lower of average, max and minimum HR in group A2 than in group A1. Regarding arrhythmia group A1 had statistically significant higher SVES than group A2 however the increase in VECS did not reach a statistically significant value. Group A2 had statistically significant improvement in HRV parameters in the form of significant increase in SDDN SDANN and significant reduction in PNN 50% (Table 4).

Table (4): Comparison between group A1 and A2 regarding Holter data

Variable	Group A1 (Before) (means ± SD)	Group A2 (Early after) (means ± SD)	P value	Sig.
HR AVG (1/min)	98.08 ± 13.51	92.05 ± 13.23	<0.001	S
HR MAX (1/min)	137 ± 17.88	129.2 ± 16.33	<0.001	S
HR MIN (1/min)	71.9 ± 13.09	63.88 ± 10.79	<0.001	S
VEC NU	5.7 ± 9.75	9.73 ± 24.03	0.170	NS
VEC %	0.01 ± 0.03	0.04 ± 0.12	0.153	NS
SVEC NU	34.18 ± 54.02	206.38 ± 232.8	<0.001	S
SVEC %	0.08 ± 0.19	0.41 ± 0.46	<0.001	S
SDANN (m)	74.88 ± 7.96	81.75 ± 7.51	<0.001	S
SDNN (ms)	89.65 ± 8	96.28 ± 10.08	<0.001	S
PNN50%	8.5 ± 2.45	6.48 ± 2.6	<0.001	S
LF/HF	2.41 ± 0.59	2.22 ± 2.29	0.603	NS

HR AVG: Heart Rate Average, HR MAX: Heart Rate Maximum, HR MIN: Heart Rate Minimum, VEC NU: Ventricular Ectopic Numbers, VEC %: Ventricular Ectopic Percentage, SVEC NU: Supraventricular Ectopic Numbers, SVEC %: Supraventricular Ectopic Percentage, SDANN: Standard Deviation of Sequential 5-minute NN Interval Means, SDNN: Standard Deviation of the NN Interval, PNN50%: Proportion of NN Intervals Differing by More than 50 ms, LF/HF: Low Frequency/High Frequency, NS: Not Significant, S: Significant.

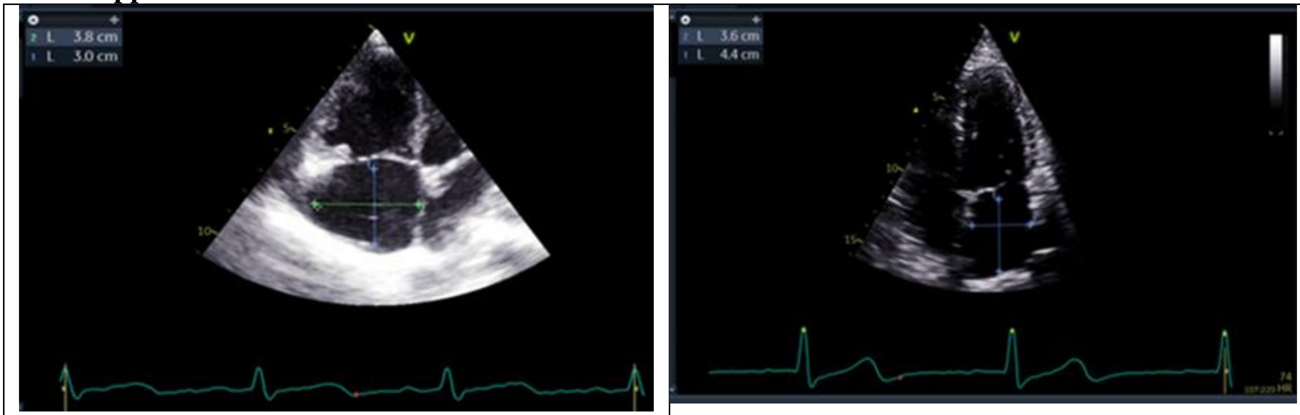
Correlation between LA Reservoir function and different parameters showed that LA reservoir function using 2D STE had strongly positive correlation with TDI systolic flow velocity of both LA and RA either before closure or early after closure (Table 5).

Table (5): Correlation between LA reservoir function before closure and different parameters

TDI LA and RA Before closure	LA Reservoir function before	
	r	***P***
LA TDI Lateral S before	**0.761**	**<0.001**
TDI RA Lateral S before	**0.748**	**<0.001**
LA TDI Lateral S early after	**0.738**	**<0.001**
TDI RA Lateral S early after	**0.731**	**<0.001**

Cases: Patient No (1)

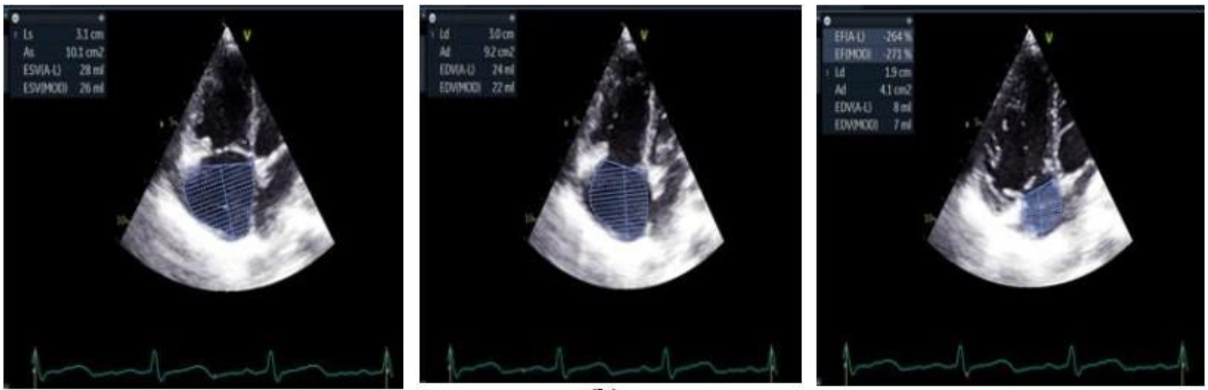
I. Echo-Doppler measures for the RA and LA assessment Liner diameters before closure:



(a) **(b)**

(a) 2D 4Ch view measurement of RA diameters (superior-inferior and medio-lateral) and (b) 2D 4Ch view measurement of LA diameters (superior-inferior and medio-lateral) of our studied cases before closure (Case 1).

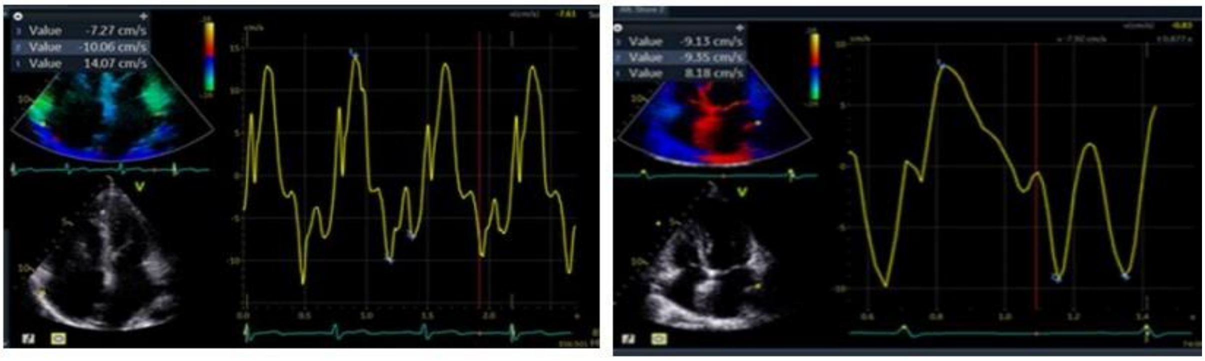
II. Two-dimensional RA volumes:



(a) **(b)** **(c)**

2D apical 4Ch view (a) RA Maximal volume (b) pre-contractile volume and (c) minimum volume guided by ECG of our studied cases before closure (Case 1).

III. Tissue Doppler velocities of the RA and LA



Off-Line tissue Doppler assessment of RA and LA function at mid segment of lateral free wall apical 4ch view measuring Sm, Em and Am of our studied cases before closure (Case 1).

(a) **(b)**

I. Speckle tracking longitudinal strain of the RA

Left atrial specific software off line 2D-STE of the apical 4 chamber view showing (a) RA reservoir(S-R), conduit (R-CD) and contractile (R-CT) function of our studied cases before closure (b) early after closure.

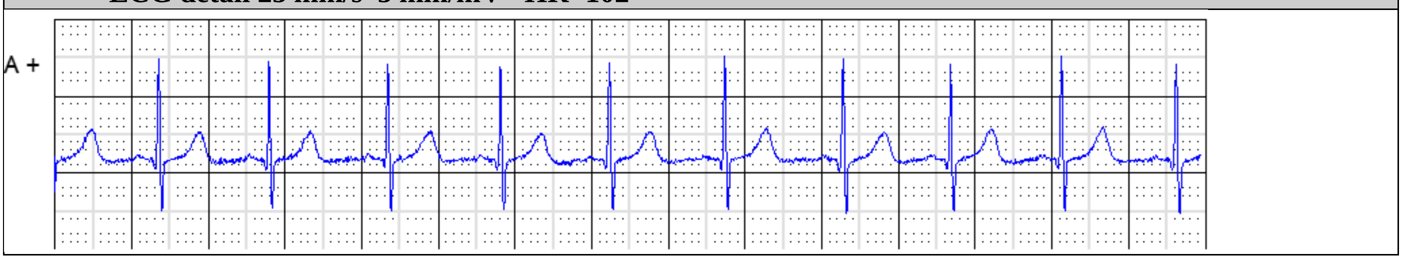
II. Left atrial specific software off line 2D-STE of the apical 4 chamber view showing (a) LA reservoir(S-R), conduit (R-CD) and contractile (R-CT) function of our studied cases before closure, (b) early after closure.

Holter ECG monitoring data showing samples of the supraventricular and the ventricular arrhythmias detected early after ASD device closure.

Patient No (1).

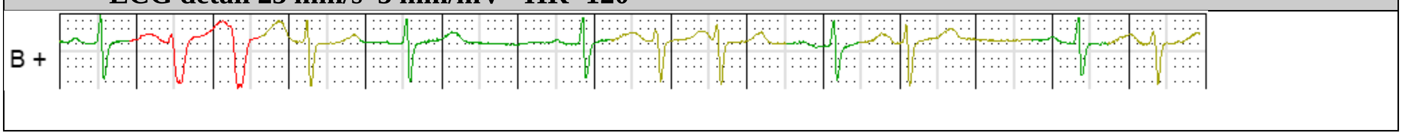
Before closure Patient No (1).

ECG detail 25 mm/s 5 mm/mV ~HR=102



Early after closure Patient No (1).

ECG detail 25 mm/s 5 mm/mV ~HR=120



DISCUSSION

A secundum ASD is one of the most common congenital heart diseases. Trans-catheter device closure of secundum type ASD has now become the treatment of choice in those with suitable rims [4]. The current study aimed to assess atrial function using different echocardiographic modalities and atrial rhythm (electrical function) using Holter monitoring early after percutaneous closure.

Our study population included two main groups: Group A1 (before-closure): This included the forty patients before ASD trans-catheter device closure. Group A2 (early after closure): The same forty patients early after trans-catheter device closure (1-4) days. In our study females to male ratio 3 to 1 (75 % Vs 25%), which is in agreement with **Bosshardt *et al.*** [8]. Also, is concordant with **Hafez *et al.*** [9] about 75 % female predominance. Group A2 had statistically significant decrease in RA diameters and volumes than group A1. This is in agreement with **Saedi *et al.*** [2] and **Hafez *et al.*** [9] who found that RA diameters and volumes started to decrease early after closure (24 hr) in their studied patients. And these results could be explained by increased myocardial stress resulting from right side volume overload in ASD patients leading to increased diameters and volumes of right sided heart chamber before closure and their reduction early after closure of the ASD due to the elimination of this volume overload and this is concordant to **Samiei *et al.*** [3]**, Suzuki *et al.*** [10] and **Badano *et al.*** [7]. We found that the RA functions derived from volumetric equations showed a statistically significant reduction in group (A2) compared to group (A1). These results are in agreement with the results of **Hajizeinali *et al.*** [11].

In our study the TDI peak systolic velocity of the lateral wall of the RA (RA reservoir), the early peak diastolic velocity (conduit function) and the late peak diastolic velocity (contractile function) were significantly lower in A2, which is similar to the results of **Saedi *et al.*** [2]**.** Early after closure of ASD, the RA will accommodate a lower volume, which leads to pumping a sufficient stroke volume at a decreased functional state as TDI is load dependent [12]. This; explanation is in the same line with our results. Other explanation was that presence of a device anchoring on an atrial wall without deformation of any magnitude leads to decreased deformation in the other walls [11]. Our finding was discordant with **Abd El Rahman *et al.*** [13] we explained this discordance by small sample size of his study. Our study demonstrated that there was a statistically significant decrease in the RA reservoir, conduit and contractile function in Group A2 compared to group A1. Our study is in agreement with **Hajizeinali *et al.*** [11] and **Samiei *et al.*** [3] who reported a reduction in RA reservoir value and explained his result by the reduction in RA preload, which occurs early after ASD closure and our results are in the same line.

Our results disagree with **Ozturk *et al.*** [14] they found that peak RA longitudinal strain increased after device closure, this alteration in results were due to their intermediate after closure follow up (one month).

Group A2 had a significantly reduced LA diameters and LA volumes than A1 group, which is similar to **Saedi *et al.*** [2]. Also, **Hajizeinali *et al.*** [11] where their results are similar to our results and they concluded that LA diameters and volumes were reduced early after ASD closure.

We found that reservoir and conduit functions using volumetric equations were significantly reduced in A2 than in A1, while contractile function did not reach a statistically significant reduction. This is in agreement with **Elhefnawy and El-Sherbeny** [15]**.**

In our study all LA function parameters measured by TDI were reduced in group A2. The peak systolic velocity of the lateral wall of the LA (LA reservoir) was significantly lower in group A2 than in A1. However, the early and late peak diastolic velocities (conduit and contractile functions) decreased but did not reach a statistically significant reduction. Our results were partially concordant with **Abd El Rahman *et al.*** [13]. This could be explained by his small sample size.

Group A2 demonstrated statistically significant reduction in the LA reservoir, conduit and contractile function using 2D STE longitudinal strain than in group A1. Our results are partially concordant to **Elhefnawy and El-Sherbeny** [15] **and Suzuki *et al.*** [10] who concluded that there is a resistance in LA conduction of blood and interaction of the device with atrial bundle integrity causing LA dysfunction early after the procedure

ECG is potentially a valuable tool in examination in ASD assessment. In our study RBBB manifested in 42% of our studied patients

In our study group A2 had statistically significant lower average, maximum and minimum HR early after closure (1-4 days) than in group A1, the average HR of group A1 and group A2. In the present study there were no statistically significant difference between groups A1and A2 regarding the remaining ECG parameters? This result is concordant with **Kamphuis *et al.*** [16], who hypothesized that decease in HR is due to deactivation of the Bainbridge reflex after ASD closure.

Group A2 had significantly increased numbers of SVES than group A1. Arrhythmia numbers in group A1 and A2 were (34.18 ± 54.02 vs 206.38 ± 232.8) respectively and percentage was (0.08 ± 0.19 % Vs 0.41 ± 0.46%) respectively. During the procedure in our studied cases, three patients (7.5%) developed AF and one patient developed transient complete heart block intra procedure. Atrial arrhythmias (AAs) that occur early after closure are thought to result from transient tissue edema, inflammation around the device and acute increases in left atrial pressure during the closure (pro-arrhythmic state). This result is matching with the results enrolled with **Roberts *et al.*** [17] and **Park *et al.*** [18] who revealed that conduction disturbances was due to volume overload on RT side. HRV is used to evaluate the parasympathetic and sympathetic systems on the sinus node, cardiovascular events, and mortality risk in patients. Our study revealed significantly increase in SDANN and SDNN early after ASD device closure in group A2, while the pNN50% significantly decreased after closure (A2). These findings can be explained by increase of vagal activity and the decrease of sympathetic activity after the procedure and reduction of HR. This result is concordant with **Alstrup *et al.*** [19] and **Cansel *et al.*** [20] who explained that by the procedure there may be reduced sympathetic hyperactivation and increased vagal tonus. Following transcatheter ASD closure, ventricular baroreceptor dysfunction was absent because the HRV values improved early after the decrease in the right ventricular size, atrial diameter, and blood volume. The sympathetic and parasympathetic balance appeared to be restored by the sixth month.

Limitations of this study include a relatively small sample size, which may limit the generalizability of the results. The follow-up period was short, focusing only on early outcomes (1-4 days post-closure), so long-term atrial function and rhythm changes could not be evaluated. Additionally, the study did not account for potential confounding factors such as pre-existing arrhythmias or other underlying cardiac conditions that might influence atrial performance after device closure. Furthermore, the reliance on echocardiographic modalities, while effective, may not fully capture subtle electrical changes that could be better evaluated with more advanced electrophysiological studies.

CONCLUSION

We concluded that the right and left atrial dimeters and volumes were reduced early after device closure in addition to reduction in the atrial functions (reservoir, conduit and contractile). 2D STE can detect subtle changes of atrial functions rather than other echo-Doppler modalities. However, it had a positive correlation with Tissue Doppler modality. As regards the atrial electrical function, the current research workers found that there were an increase in the percentage and numbers of supraventricular and ventricular arrhythmias during and early after device closure and there was improvement in the average heart rate and HRV parameters early after closure. There was positive correlation between the size of the defect and occurrence of arrhythmias before ASD device closure.

Financial support and sponsorship: Nil.
Conflict of Interest: Nil.

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