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Author for correspondence:
Amal Mahmoud El-Sisi, Cairo University, Pediatric Department, Egypt.
E-mail: amal.elsisi@kasralainy.edu.eg

Mid-term follow-up by speckle tracking and cardiac MRI of children post-transcatheter closure of large atrial septal defects

Amal Mahmoud El-Sisi[1], Ahmed Mohamed Abdallah[2], Noha Hossam El-dien Behairy[3], Dalia Saber Morgan[2], Ahmed Ramadan[3], Ranya Hegazy[1], Ahmed Gado[4] and Mahmoud Hodeib[2]

[1]Cairo University, Pediatric Department, Cairo, Egypt; [2]Beni-Suef University, Pediatric Department, Beni Suef, Egypt; [3]Cairo University, Radiology Department, Cairo, Egypt and [4]Cairo University, Anaesthesia Department, Cairo, Egypt

Abstract

This is a case–control study of our experience of mid-term follow-up of 40 children who had a transcatheter closure of very large atrial septal defects group (1). All cases had an atrial septal defect device size more than 1.5 times their weight, a ratio considered a contraindication for trans catheter closure (TCC) in some previous reports. The aim of this study is to report the outcomes and mid-term follow-up of transcatheter closure of large atrial septal defects using two-dimensional conventional echocardiography, tissue Doppler imaging, and four-dimensional speckle tracking imaging, and as such to compare results of same echocardiographic examination of age-matched control group of 40 healthy children group (2). Cardiac MRI was performed on cases group (1) only to detect right ventricle and left ventricle volumes and function and early signs of complications. There was no difference between cases and matched healthy controls in terms of the assessment of left ventricle and right ventricle by two-dimensional echocardiography, tissue Doppler imaging, and four-dimensional speckle tracking imaging. Similarly, there was no statistically significant difference between four-dimensional echocardiography and cardiac MRI in their respective assessment of both left ventricle and right ventricle volumes and function. We also detected no complications by echo or by cardiac MRI after a median follow-up period of 2 years and recorded a complete remodelling of right ventricle volumes in all children studied. This points to the safety and efficiency of transcatheter closure of large atrial septal defects in children on mid-term follow-up.

Atrial septal defect is a common form of congenital heart disease, accounting for nearly 5–10% of all congenital cardiac defects in children.[1] Transcatheter closure of secundum atrial septal defects is considered the best intervention whenever applicable; it is regarded as superior to surgical atrial septal defect closure, especially in terms of patient morbidity. It shows fewer complications, entails a shorter hospitalisation period, requires less blood products and, in most countries, incurs considerably lower treatment costs.[2,3] The Amplatzer septal occluder and similar self-centering devices are the most commonly used for transcatheter closure of large atrial septal defects.[4]

Whereas large atrial septal defects in adults are defined as an atrial septal defect larger than 20–25 mm,[5,6] there is no accepted definition for large atrial septal defect in children. There are also no conclusive results as to whether transcatheter closure is safe and feasible for large atrial septal defects in children.[7] For instance, Ohno et al. considered an atrial septal defect device/weight ratio larger than 1.5 to be a contraindication for transcatheter closure.[8] Conversely, Houeijeh et al. published a series of transcatheter closure of large atrial septal defects in young children with device/weight ratio more than 1.5. Cardiac erosion is a known complication after large atrial septal defect device closure.[9] The mortality associated with erosion is 19.6%; deficient aortic rim (present in 89% of the erosion cases) and a large device size to upstretched atrial septal defect ratio were identified as risk factors for erosion.[10,11]

Moreover, quantitative evaluation of right ventricular performance post-transcatheter closure remains challenging due to right ventricle complex anatomy and structure.[12] Two standard modalities for better assessment of right ventricle function and volume are four-dimensional echocardiography and cardiac MRI. Four-dimensional echocardiography can overcome two-dimensional limitations by neglecting geometric assumptions and by utilising multiple images to reconstruct the right ventricle chamber.[13] Myocardial strain and strain rate are more accurate than velocities as indices of ventricular contractility; by eliminating translational artefact, strain rate values are more dependent on pressure overload than volume overload.[14] Four-dimensional echocardiography is a potential useful tool in studying the atrial septal defect device and its points of contact or pressure especially in relation to the aorta, aortic-mitral plane, pulmonary, and systemic veins.[15]

Cardiac MRI is the gold standard for non-invasive measurements of right ventricle size and function.[16] It is also used to assess the size and location of atrial septal defects, to guide the real-time positioning of an atrial septal defect device, to depict the position of the atrial septal defect device with respect to adjacent structures (the right pulmonary veins, the superior and inferior venae cavae, the coronary sinus, the mitral valve, the aortic valve and root) and finally, to assess any early sign of erosion.[17,18]

Aim of the study

The main aim of this study is to evaluate outcome of transcatheter closure of very large atrial septal defects by using two-dimensional conventional echocardiography, tissue Doppler imaging, four-dimensional speckle tracking imaging and compare these results with age-matched control group of 40 healthy children group (2).

The secondary aim is to compare these results to cardiac MRI values of left ventricle and right ventricle volumes and function, to evaluate the capability of cardiac MRI to accurately depict the position of the large atrial septal defect devices with respect to adjacent structures, and to assess the safety and efficacy of transcatheter closure of very large atrial septal defects in young children at mid-term follow-up.

Patients and methods

This is a case–control study of 80 children divided into two groups:

Group 1 – Forty children post-transcatheter closure of atrial septal defect (device/weight ratio more than 1.5 and mid-term follow-up of at least 12 months) at paediatric cardiology clinics in two centres, Cairo University Children Hospital and Beni Suef University Hospital.

Group 2 – Control group of 40 healthy age-matched children who only have the echocardiographic studies.

The study was approved by both universities' Institutional Review Board, and all parents provided written informed consent.

Group (1) had the routine clinic follow-up. Echocardiography and Doppler examination were done in supine and left lateral positions using Philips EPIQ 7 C machine with probe X5-1, S8-3, or X7-2 MHz (multifrequency transducer) according to the age of the patient. Examinations consisted of:

(a) Conventional echo-Doppler: different Doppler velocity measurements of blood flow at the heart valves including M-mode measurements, two-dimensional, pulsed, continuous wave, and colour.
(b) Tissue Doppler: pulsed wave tissue Doppler imaging measures included systolic (S′) and diastolic (E′, A′, E′/A′ ratio), as well as the calculation of the global myocardial performance index (Tei index) of both right ventricle and left ventricle according to the guidelines of the American Society of Echocardiography.[19]
(c) Speckle tracking imaging: four-dimensional images were obtained. Offline speckle tracking analysis performed using 4D Tom-Tec software analysis programme.[20]

Group (1) had cardiac MRI using a Philips Achieva, the Netherlands (1.5 T) and Siemens Aera, Germany (1.5 T); patients were scanned in supine position using a phased array cardiac coil. Children below 6 years old were sedated using chloral hydrate under supervision of a senior anaesthetist. The examination was explained to patients more than 6 years old. First, a survey reference scan was taken. This was followed by steady-state free precession sequence with parallel imaging: balanced fast field echo was acquired in two-chamber, four-chamber, short axis, and axial zero angle scans in 30 cardiac phases covering the whole heart. Coronal oblique views were done to assess the pulmonary veins and venae cavae. The mitral valve was evaluated by a four-chamber view. Imaging of the left atrial roof was acquired with a sagittal oblique view in the intersection with the middle of the atrial septum. For the aortic annulus and root, the sequence was applied twice – first in the coronal oblique plane along the axis of the proximal ascending aorta, followed by an axial oblique plane parallel to the axis of the valve. The goal was to show the relationship of the device to all the venous openings to the atria, as well as to the aortic valve's annulus and root, the mitral valve, and the atrial roof. [17]

Cardiac MRI interpretation: Images were reviewed independently by two senior radiologists with no prior access to the echo results. Measuring the right ventricular volumes was done by manually tracing the endocardial and epicardial borders of the ventricle in axial zero angle views, while the left ventricular volumes were measured by tracing the short axis images with recheck on the right ventricle. Trans-aortic and transpulmonary flow assessment (Q-flow) and the assessment of associated congenital anomalies and complications were also done.[17] We also looked for any evidence of protrusion of the device disks into the opening of the systemic or the pulmonary veins in the atria during the cardiac cycle. Finally, we attempted to identify the presence of contact between the device and both, the mitral valve (anterior leaflet or annulus or both) and the left atrial roof.[18]

Statistical tests

Data were statistically described in terms of range, mean ± standard deviation, median, frequencies (number of cases), and percentages. To compare categorical data, Chi square test was performed. Student t test was used when comparing between two groups, while ANOVA test was used to compare between all groups. Finally, an exact test was used instead whenever the expected frequency was less than 5. p Values less than 0.05 were considered statistically significant.

Results

There was no statistical difference between the two groups as regard to sex, age, weight, height, body surface area, and heart rate (not significant p value) (Table 1).

Group (1) data at the time of the procedure are summarised in Table 2, which includes patient age, weight, interatrial septum length, device type and size, and device size/weight and device size/interatrial septum length and Qp/Qs ratios.

Group (1) follow-up at the time of investigations ranged from 1.4 to 10 years with a mean of 2.7 years and a median of 2.2 years.

Both groups were subject to two-dimensional conventional (echo-Doppler) as well as advanced echocardiography (tissue Doppler and speckle tracking imaging).

There was no statistical difference between the three methods as regards to both right ventricle and left ventricle parameters (Table 3).

Four-dimensional echocardiography assessment of right ventricle volumes, ejection fraction, and longitudinal strain using Tom-Tec software analysis programme in both groups showed

Table 1. Baseline characteristics of patients Gp1 and controls Gp2 at FU

Characteristics	Cases Gp1 (n = 40)	Controls Gp2 (n = 40)	p-value
Sex No (%)			
Males	16 (40)	18 (45)	0.651
Females	24 (60)	22 (55)	
Age (years)			
Mean ± SD	5.1 ± 2.9	6.05 ± 3.08	
Median (IQR)	4 (3-6)	5.5 (3-7)	0.095
Height (cm)			
Mean ± SD	105.1± 14.3	99.4 ± 11.1	
Median (IQR)	104.5 (81-148)	97 (82- 126)	0.085
Body weight (kg)			
Mean ± SD	18.3 ± 7.2	19.2 ± 7.7	
Median (IQR)	17 (11-14)	16.8 (11-19)	0.840
Body Surface Area (m^2)			0.98
Mean ± SD	0.48-1.46 (0.72	0.72	
Median (IQR)	0.69 (0.48–1.46)	0.66 (0.50–1.21)	
HR (per minute)			
Mean ± SD	106.4 ± 8.2	109.9 ± 10.2	
Median (IQR)	106 (90–120)	113 (92–124)	0.06

Gp: group, FU: follow up, No: number, cm: centimeters, kg: kilograms, HR: heart rate, IQR: interquartile range.

Table 2. Baseline characteristics of group (1)

Characteristics	Group 1 (cases)	Characteristics	Group 1 (cases)
Age at Procedure (Years)		**IASL (mm)**	
Mean ± SD	3.36 ± 2.5	Mean ± SD	36.4 ± 2.5
Median (IQR)	2.5 (2-8)	Median (IQR)	36 (34-38)
B.W at procedure (kg)		**ASD device size/B.Wt ratio**	
Mean ± SD	12.6 ± 2.3	Mean ± SD	1.76 ± 0.36
Median (IQR)	12 (9-16)	Median (IQR)	1.8 (1.5-2.4)
Size of ASD (mm)		**ASD/IASL ratio**	
Mean ± SD	19.2 ± 3.9	Mean ± SD	0.53 ± 0.09
Median (IQR)	19.5 (18-28)	Median (IQR)	0.55 (0.36-0.70)
Size of device (mm)		**Type of device No. (%)**	
Mean ± SD	21.8 ± 3.9	Memopart	13 (32.5)
Median (IQR)	22 (18-24)	Occulotech	17 (42.5
Qp/Qs		Amplatzer	8 (20)
Mean ± SD	2.3 ± 0.7	Hyperoin	2 (5)

ASD: Atrial Septal Defect, B.W: Body Weight, IASL: Interatrial Septal Length, No: number, mm: millimeters, HR: heart rate, Kg: kilograms, Qp: pulmonary flow, Qs, systemic flow, SD: standard deviation, IQR: interquartile range.

no significant difference between both groups. p Value is not significant for all studied parameters (Table 4).

Four-dimensional echocardiography assessment of left ventricle volumes, ejection fraction, mass, strain, twist, and torsion using Tom-Tec software analysis programme in both groups showed no significant difference between both groups. p Value is not significant for all studied parameters (Table 5).

Group (1) had cardiac MRI to detect left ventricle and right ventricle volume and function, early signs of complications, and relation of the large atrial septal defect devices to adjacent structures. Table 6 shows comparison between two-dimensional echocardiography, four-dimensional echocardiography, and cardiac MRI with regard to end diastolic and end systolic volumes, ejection fraction, and stroke volume of both left ventricle and right ventricle. There

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Table 3. Comparison of 2D echocardiography, TD and STI measurements of RV and LV between groups (1) and (2).

	Cases Gp1 Mean ± SD	Controls Gp2 Mean ± SD	*p* value	Cases Gp1 Mean ± SD	Controls Gp2 Mean ± SD	*p* value
2D Echocardiography		**Right Ventricle**			**Left Ventricle**	
EDD (cm)	1.94 ± 0.39	1.97 ± 0.38	0.234	3.55 ± 0.45	3.65 ± 0.38	0.381
ESD (cm)	–	–	–	2.37 ± 0.38	2.41 ± 0.29	0.801
FS (%)	–	–	–	31.23 ± 5.8	30.38 ± 4.5	0.736
TAPSE/MAPSE (cm)	2.31 ± 0.46	2 ± 0.48	0.321	1.81 ± 0.34	1.85 ± 0.33	0.350
Tissue Doppler		**Right Ventricle**			**Left Ventricle**	
E' (cm/s)	14.4 ± 2.8	14.02 ± 2.31	0.548	13.88 ± 2.2	13.65 ± 2.31	0.447
A' (cm/s)	9.4 ± 3.9	8.11 ± 1.93	0.075	7.05 ± 1.8	7.1 ± 1.43	0.557
S' (cm/s)	11.9 ± 2.58	12.18 ± 2.42	0.686	9.2 ± 2.8	8.1 ± 1.39	0.151
E/E'Ratio	5.52 ± 2	5.1 ± 1.2	0.252	5.97 ± 2.8	6.01 ± 1.47	0.722
MPI	0.54 ± 14	0.49 ± 14	0.233	0.56 ± 11	0.50 ± 14	0.211
STI Longitudinal Strain		**Right Ventricle**			**Left Ventricle**	
Basal Anterior (%)	−19.7 ± 8.6	−18.5 ± 4.7	0.140	−19.17 ± 8.6	−19.9 ± 3.06	0.961
Basal Antroseptal (%)	−16.1 ± 4	−16.05 ± 4.7	0.595	−16.8 ± 4.3	−17.35 ± 4.7	0.084
Basal Inferoseptal (%)	−15.3 ± 5.3	−14.9 ± 5.2	0.802	−19.6 ± 5.9	−20.4 ± 5.9	0.091
Basal Inferior (%)	−16.5 ± 7.7	−18.5 ± 4.7	0.535	−16.9 ± 7.7	−18.45 ± 4.5	0.536
Basal Infrolateral (%)	−18.0 ± 5.4	−18.6 ± 4.6	0.329	−18.12 ± 5.4	−18.7 ± 3.8	0.411
BasalAntrolatertal (%)	−17.6 ± 6.4	−16.4 ± 5.8	0.380	−19.3 ± 6.3	−21.3 ± 4.05	0.202
Mid Anterior (%)	−17.3 ± 8.07	−18.15 ± 4.7	0.999	−17.5 ± 8.08	−18.05 ± 5.4	0.931
Mid Anteroseptal (%)	−16.3 ± 5.9	− 16.9 ± 3.7	0.481	−17.07 ± 5.4	−15.4 ± 5.98	0.113
Mid Inferoseptal (%)	−16.7 ± 4.9	−17.7 ± 5.4	0.502	−17.3 ± 7.3	−17.7 ± 4.6	0.628
Mid Inferior (%)	−18.5 ± 7.1	−20.6 ± 4.9	0.220	−19.2 ± 7.6	−19.9 ± 5.2	0.735
Mid Inferolat (%)	−19.8 ± 5.01	−19.8 ± 4.5	0.915	−20.2 ± 5.1	−19.4 ± 5.5	0.754
Mid Anterolat (%)	−19.9 ± 7.4	−20.4 ± 4.6	0.681	−20.12 ± 6.7	−20.7 ± 5.2	0.915
Apical Anterior (%)	−20.8 ± 5.3	−21.0 ± 5.0	0.946	−20.2 ± 5.04	−21.6 ± 6.2	0.091
Apical Septal (%)	−20.1 ± 7.6	−17.5 ± 9.1	0.094	−24.5 ± 8.1	−22.8 ± 6.2	0.135
Apical Inferior (%)	−20.5 ± 9.3	− 17.5 ± 4.6	0.062	−21.57 ± 9.1	− 21.3 ± 5.5	0.428
Apical Lateral (%)	−17.6 ± 5.3	−18.5 ± 4.4	0.457	−19.3 ± 5.17	−19.64 ± 5.7	0.794
Global LS (%)	−18.4 ± 3.4	−17.1 ± 4.5	0.221	−13.7 ± 5.8	−14.3 ± 3.5	0.964

Gp: Group, 2D: two-dimensional, TD: tissue Doppler, LS: longitudinal strain, EDD: End diastolic diameter, ESD: End systolic diameter, TAPSE/MAPSE: Tricuspid/Mitral annular plane systolic excursion, MPI: Myocardial Performance Index, STI: Speckle tracking Imaging. *p*-value is considered significant <0.05.

was no significant difference between the three modalities' measurements. p Value is not significant (Table 6).

Cardiac MRI image analysis showed no encroachment on pulmonary or systemic veins. The devices touched the anterior mitral leaflet in five patients (Fig 1), but there was no effect on movement and no mitral regurgitation. There was extrinsic contact of the device with the aortic annulus in all examined patients (Fig 2). There was no device deformity nor pericardial effusion (as sign of early erosion) in any patient.

Discussion

Transcatheter closure of secundum atrial septal defects is now considered the first choice whenever applicable. It is superior to surgical atrial septal defect closure with regard to patient morbidity; it is characterised by fewer complications, shorter hospitalisation period, a reduced need of blood products, and in most countries considerably lower treatment costs.[2,3] With progressive experience in transcatheter closure of atrial septal defects, device size is gaining more close attention, as excessively large devices are prone to mushroom deformities, encroaching on cardiac structures and possible serious complications such as cardiac erosions.[4] However, Houeijeh et al. published a series of transcatheter closure of large atrial septal defects in young children with device/body weight ratio more than 1.5. This ratio of 1.5 was previously considered a contraindication for transcatheter closure of atrial septal defects in children.[8,9]

Our goal is to assess the safety and efficacy of transcatheter closure of large secundum atrial septal defects in children and to compare the patients on mid-term follow-up to matched healthy controls using multiple measurement modalities including two-dimensional, advanced four-dimensional, and cardiac MRI.

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Table 4. 4D Echocardiography of RV volumes, function, longitudinal strain, and dimensions comparison between the cases Gp1 and controls Gp2

Parameters	Cases (Gp1)	Controls (Gp2)	*p*-value
EDV (ml)			
Mean ± SD	42.4 ± 7.3	39.7 ± 5.5	0.138
Median (IQR)	40.4 (38.4-52.1)	39.1 (34.5-49.6)	
ESV (ml)			
Mean ± SD	14.14 ± 5	20.8 ± 3.4	0.069
Median (IQR)	22.3 (14.9-28.7)	21 (16.2-24.7)	
SV (ml)			
Mean ± SD	19.4 ± 3.9	19.4 ± 3	0.954
Median (IQR)	19.5 (12-29)	19.5 (15.9-35.8)	
EF (%)			
Mean ± SD	48.2 ± 7.2	49.1 ± 7.2	0.878
Median (IQR)	49.1 (34.4–55.4)	49.8 (33.4–50.9)	
	Mean ± SD	**Mean ± SD**	
LS Septal (%)	−14.2 ± 4.5	−14.8 ± 8.4	0.067
LS Free Wall (%)	−19.6 ± 5.9	−18.9 ± 5.4	0.538
Base Diameter D1 (mm)	21.2 ± 2.5	21.8 ± 2.4	0.154
Mid Diameter D2 (mm)	24.3 ± 4.9	25.2 ± 4.8	0.392
Longitudinal Diameter D3 (mm)	56.9 ± 8.1	55.8 ± 12.6	0.862
FAC (%)	36.9 ± 14.9	36.1 ± 9.5	0.350

Gp: group, RV: right ventricle, EDV: end diastolic volume, ESV: end systolic volume, SV: stroke volume, EF: ejection fraction, LS: longitudinal strain, FAC: fractional area change, IQR: interquartile range.

Table 5. 4D Echocardiography of LV volumes, function, mass strain, twist and torsion comparison between the groups 1 and 2

Parameters	Cases (Gp 1)	Controls (Gp 2)	*p*-value
EDV (ml)			
Mean ± SD	47.5 ± 9.5	39.7 ± 5.5	0.780
Median (IQR)	46.7 (41.5–51.2)	46.8 (42.3–50.6)	
ESV (ml)			
Mean ± SD	25.7 ± 7.1	25.8 ± 3.5	0.069
Median (IQR)	24.7 (22.2–28.1)	24.6 (2.3–27.6)	
SV (ml)			
Mean ± SD	23.2 ± 6.7	23.6 ± 4.6	0.630
Median (IQR)	24 (18.3–26.1)	23.2 (20.4–27.1)	
EF (%)			
Mean ± SD	48.3 ± 6.5	49.3 ± 6.4	0.507
Median (IQR)	49.6 (44.4–51.3)	49.6 (45.6–54)	
	Mean ± SD	**Mean ± SD**	
Mass (gm)	80.5 ± 20.5	74.6 ± 7.5	0.180
Global LS (%)	−17.2 ± 3.3	−16.1 ± 3.6	0.197
Global CS (%)	−18.8 ± 4	−19.3 ± 3.8	0.721
LVSDI (%)	8.7 ± 3.5	9 ± 5	0.840
LV Twist (°)	8 ± 5.9	11.6 ± 8.2	0.070
LV Torsion (°)	1.7 ± 0.8	1.9 ± 0.9	0.060

Gp: group, SD: standard deviation, IQR: interquartile range, EDV: end diastolic volume, ESV: end systolic volume, SV: stroke volume, EF: ejection fraction, LS: longitudinal strain, CS: circumferential strain, SDI: strain delay index.

Table 6. Comparison of 2DE, 4DE, CMRI measurements between RV and LV.

Modality		Right ventricle				Left ventricle			
		EDV	ESV	EF	SV	EDV	ESV	EF	SV
2D Echo (mean ± SD)		69 ± 27.5	27.7 ± 12	50.2 ± 16.7	–	60.6 ± 14.1	24.5 ± 6.9	57.9 ± 6.9	–
4D Echo (mean ± SD)		71 ± 27.4	28.1 ± 12.5	53.3 ± 12.2	39.4 ± 13.9	61.5 ± 9.5	25.7 ± 7.1	58.4 ± 6.5	36.2 ± 6.7
CMRI (mean ± SD)		73.8 ± 27.8	30.7 ± 13.3	55.7 ± 14.1	42 ± 12.5	63.5 ± 18.9	25.1 ± 7.1	60.9 ± 4	38.5 ± 10.7
p value	Overall	0.644	0.976	0.439	0.654	0.768	0.876	0.543	0.343
P1	2D≠4D	0.975	0.543	0.435	–	0.898	0.546	0.170	–
P2	2D≠CMR	0.976	0.856	0.876	–	0.565	0.856	0.232	–
P3	4D≠CMR	0.954	0.996	0.975	0.865	0.787	0.999	0.453	0.854

E=echocardiography; RV=right ventricle; LV=left ventricle; EDV=end diastolic volume; ESV=end systolic volume; SV=stroke volume; EF=ejection fraction; CMRI=cardiac MRI.

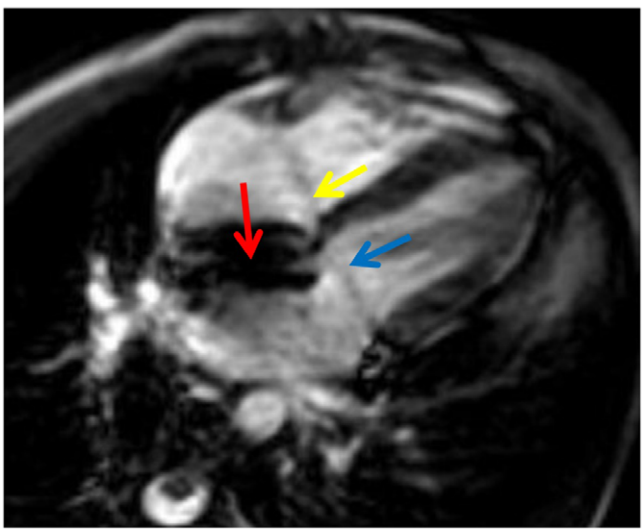

Figure 1. Steady state free precision (SSFP) Four chamber view showing large ASD device in place (red arrow). The ASD device is seen touching the anterior mitral leaflet (blue arrow), the yellow arrow refers to the tricuspid valve.

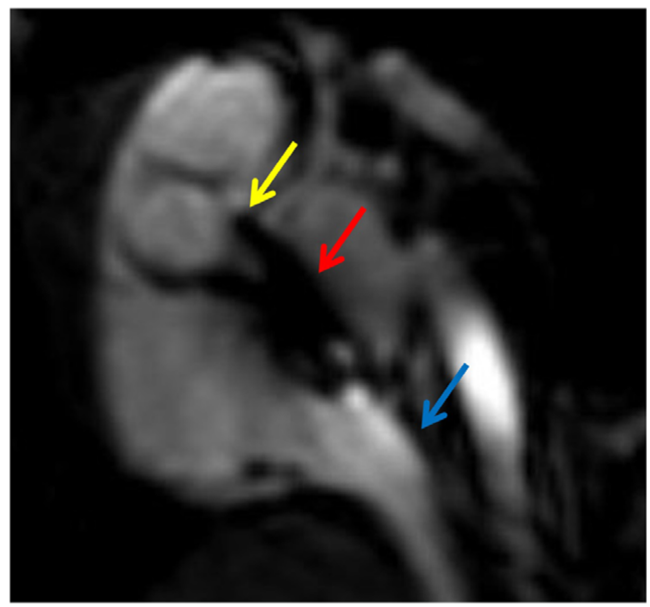

Figure 2. Steady state free precision (SSFP) oblique short axis view: showing the ASD device in place with no deformity (red arrow), the yellow arrow shows extrinsic contact of the large ASD device with the aortic annulus. The blue arrow points to the inferior venae cavae (IVC) opening into the the right atrium.

There are different definitions of large atrial septal defects in children,[4,7,9] and few reports of transcatheter closure of large atrial septal defects in infants and children.[21] The device/body weight ratio in previous series of transcatheter closure of secundum atrial septal defects in small children was less than 1.5.[22,23] In our study, analogous to Houeijeh et al., the atrial septal defect size mean was 19.2 (±3.9) and ranged from 12 to 30 mm, and the device/body weight ratio mean was 1.76 (±0.36) with a range of 1.5–2.5 .[9] Our study was at mean follow-up period of 2.7 years, a range of 1.4–10, and a median 2.2 years. This is the first report to our knowledge of mid-term follow-up of transcatheter closure of such large atrial septal defects by different modalities.

There were different device types in our study: Memopart (32.5%), Occlutech (42.5%), Amplatzer (20%), and Hyperion (5%) (Table 2), these devices are all self-centering Amplatzer like. The choice of the device was dependent on the availability at the time of the procedure. There was no difference between any of the devices used on FU, in accordance with Faccini and Butera study which showed no difference between different device in transcatheter closure of atrial septal defects.[24]

Two-dimensional, tissue Doppler, and speckle tracking imaging echocardiography of right ventricle and left ventricle showed no difference between patients at mid-term follow-up and healthy matched controls as shown in Tables 3 and 4. There was no significant difference as regard two-dimensional echocardiography measurements, fraction shortening, tricuspid annular plane systolic excursion, mitral annular plane systolic excursion, E, A, S (waves), E/E' ratio, myocardial performance index, longitudinal strain (septal, mid, basal), and global strain. This proves return of right ventricle and left ventricle to normal relatively early despite large atrial septal defects in young children. This is in accordance with Ozturk et al who noted significant decrease in right ventricle diameter and significant increase in right ventricle myocardial performance index and right ventricle longitudinal strain and no significant change in left ventricle size 1 month following transcatheter closure of atrial septal defects.[25]

In our study, four-dimensional echocardiography assessment of left ventricle volumes, ejection fraction, mass, strain, twist, and torsion using Tom-Tec software analysis programme in both patients and healthy control groups showed no significant difference (p value not significant) for all studied parameters as shown in

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Table 5, despite large Qp/Qs and volume overload prior to intervention. This is in accordance with Teo et al. who showed a significant reduction in right ventricle volumes at 6 months post-atrial septal defect closure ($p < 0.0001$) and right ventricle ejection fraction was significantly increased ($p = 0.025$).[26] There was a significant increase in the left ventricular volumes ($p = 0.003$ and $p = 0.016$), that is, return of both right ventricle and left ventricle volumes and function to normal.[26] In contrast to our study, in Veldtman et al.'s study of 40 patients aged 20–71 years (median 38), only a third of the patients demonstrated persistent right ventricle enlargement at 1 year follow-up.[27] This emphasises that late device closure in adult patients leads to incomplete remodelling and confirms the need for early closure of atrial septal defects in childhood.

Cardiac MRI is a valuable imaging modality for precise morphologic and functional information before and after transcatheter closure of atrial septal defects. It detects contact of the device with adjacent structures, early pericardial effusion plus the volume and function of right ventricle and left ventricle.[28,29] There are many reports that oversizing of the atrial septal defect device is the culprit, leading to erosion and perforation of the atrial wall.[10,30] Large atrial septal defect devices in young children lead to significant protrusion and contact with the adjacent structures, especially the left atrial roof and the aortic root which were observed in 76 and 100% of patients, respectively, in Lapierre et al study.[28] Most of the complications from erosion occur within 1 year of device closure, but more than 10% of the cases of erosion occurred more than 1 year after device closure.[31] Our study median follow-up is 2.2 years which ensured that there are no signs of late erosion.

In our study, there was no significant difference between cardiac MRI assessment of right ventricle and left ventricle volumes and function and assessment by two-dimensional- and four-dimensional echocardiography, in accordance with Sarwar et al.[32] This is different than Van der Zwaan et al. who proved that correlations between right ventricle volumes obtained by three-dimensionall echo and cardiac MRI ($r = 0.71–0.97$) were significantly better than the two-dimensional echo-derived correlations ($p < 0.001$).[33] In our study, cardiac MRI showed no encroachment on pulmonary or systemic veins, the devices touched the anterior mitral leaflet in five patients (Fig 1), but there was no effect on movement and no mitral regurgitation. This is in accordance with Lapierre et al. who found contact of atrial septal defect devices with mitral valve in three patients, 9 years post-atrial septal defect device closure.[28] Our study also echoed a similar result that there was no encroachment on pulmonary or systemic veins as Lapierre et al.[28]

In large atrial septal defects, there is typically deficient or absent retro-aortic rim.[30] The original design of the self-centering Amplatzer-like devices required that the disks of the device circumferentially straddle the rims of the septal defect. The use of the device in large atrial septal defects, where the rims of the defect are typically deficient in the retro-aortic region, required the straddling of the disks.[28] This explains the extrinsic contact of the device with the aortic annulus by cardiac MRI in all patients group 1 (Fig 2). Cardiac MRI also showed no device deformity and no pericardial effusion (as sign of early erosion) in any patient. Erosion is rare in children and this is explained by growth of the atria which gradually reduces the contact of the edges of the device with the free atrial walls and the aortic root providing better protection against erosion compared with adults.[29] In contrast, a recent study has shown that the absence of the aortic rim, poor posterior rim consistency, septal malalignment, and dynamic morphology of the atrial septal defect in echocardiographic findings can significantly increase the risk of erosion.[31] This study further emphasise the importance of long-term follow-up as erosion risk is higher in cases of large atrial septal defects device closure like our series.

Limitations

The definition of a "large atrial septal defect" remains controversial. In fact, the larger diameter of the atrial septal defect is probably not accurate as the shape of the defect is often not round but rather oval or crescentic. However, this diameter criterion is widely used in most of the published studies.[24,] The other limitation is the non-availability of pre-catheter advanced echo data.

Conclusion

Mid-term follow-up of children with very large atrial septal defect devices showed that right ventricle and left ventricle volumes and function returned to normal values. This was confirmed by comparing results with control group of healthy children with matched ages. There were no complications detected by echo or by cardiac MRI post-large atrial septal defect device closure, which proves safety of large devices in young children. There was also no significant difference (by p value) between four-dimensional and cardiac MRI in assessment of both right ventricle and left ventricle volumes and function. This favours the usage of 4-dimensional Echo in the assessment of right ventricle and left ventricle volumes and functions as it proves to be a less invasive, less time consuming, and more affordable method of reaching an accurate assessment of cardiac functions.

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Ethical standards. The authors assert that all procedures contributing to this work complied with the Helsinki declaration of 1975, as revised in 2008. The Study was approved by Ethics Review Board in both of Cairo University and Beni Suef university.

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