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Transcatheter closure of perimembranous ventricular septal defects (VSDs) using the Amplatzer duct occluder I device

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1. Introduction

Isolated ventricular septal defects (VSDs) are the commonest congenital cardiac malformation. Approximately 80% of clinically relevant defects are perimembranous (pm VSD) [1]. Device closure of muscular and perimembranous VSD appears to offer a real alternative to the standard surgical approach [2]. However, the initial enthusiasm for transcatheter closure of clinically relevant pmVSDs was hampered with the anatomical challenges and the reported high rate of early and late heart block. Muscular defects are more amenable to closure, being distant from important structure. Perimembranous defects, on the other hand, lie in close proximity to the aortic valve and the conduction tissue crosses through the posterior margin of the defect [3]. Furthermore, defects are not infrequently complicated by the presence of aneurysmal fibrous tissue from the septal leaflet of the tricuspid valve, making the use of the devices technically challenging and increasing the potential risk of inducing increased tricuspid insufficiency [4]. Factors that govern the risk of development of heart block, remains poorly defined. The authors of most case series are in agreement that device size in relation to the defect size is likely to be a critical factor. Additional factors are defect position, the age and weight of the patients as well as the type of the device used [5].

Amplatzer duct occluder I (ADO I) devices appear to be an attractive option in perimembranous defects. The design of the device with absent bulk on the right ventricle (RV) side appears to be suitable for pmVSDs having tricuspid tissue at the edge. In developing countries, the lack of availability of early and affordable surgery, and the relatively high cost of currently available devices specifically designed for VSD closure create additional problems in relation to access of patients to appropriate therapy. We therefore report on the immediate and midterm follow up results of using ADO I devices to close pmVSDs in a consecutive series of young patients.

2. Patients & Methods

The study is a retrospective case note review of all children referred to transcatheter closure of pm VSD using the ADO I device. Case details were available for review on all patients who underwent the procedure. The cases were presented and approved for transcatheter closure in a meeting within the pediatric cardiology department including at least three experienced pediatric cardiology members with special experience in interventional catheterization. Clinical inclusion criteria: at least 3 of the following had to be present: 1- Overt heart failure, not improving with appropriate medications, 2- Failure to thrive, predominantly due to hemodynamic effects of the VSD, 3- Recurrent respiratory infections (defined as ≥6 events in the preceding 12 months), 4- Cardiothoracic ratio on chest X-ray of ≥0.55, 5- Left atrial to aortic diameter ratio on long-axis echocardiogram > 1.5, 6- Left ventricular (LV) end-diastolic *z*-score on echocardiogram, indexed to body surface area of ≥2.0, 7- Estimated pulmonary to systemic blood flow ratio > 1.5 at cardiac catheterization, 8- History of infective endocarditis related to the VSD. Morphologic inclusion criterion: Isolated pm VSD, up to 10 mm in minimum diameter, as assessed by transthoracic echocardiography (Fig. 1). Morphologic exclusion criterion: pm VSD with bidirectional or predominantly right to left shunt on color Doppler echocardiography (calculated RV pressure of ≥70% of systemic pressure). Transesophageal echocardiography was performed prior to the procedure, confirming the anatomical position of the VSD, the distance to important structures such as the aortic valve, the diameter of the defect at the LV and RV sides, the shape of the defect and the presence of tricuspid tissue from the septal leaflet trying to estimate the needed device size. Adverse events were recorded, including procedural complications as regards vascular access, pulses, limb perfusion and management as well as procedural complications including hemodynamic instability, arrhythmias especially heart block, device deployment in an unsatisfactory position,

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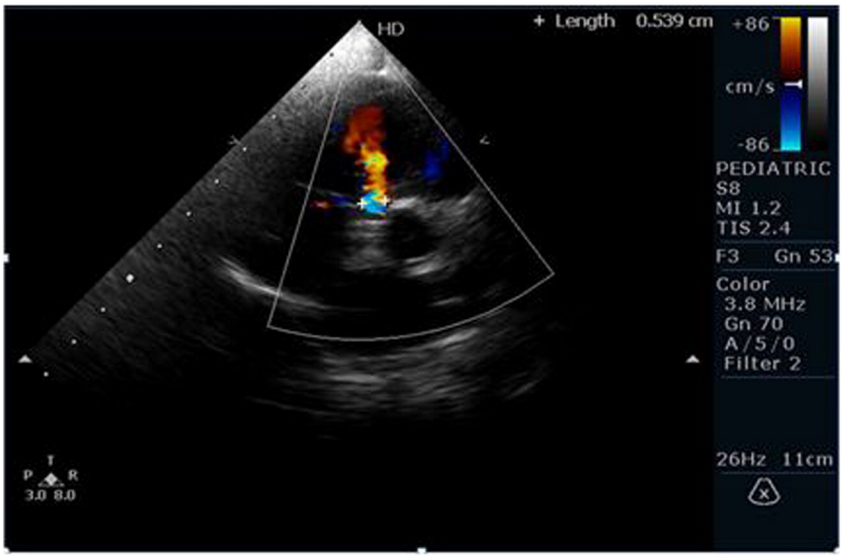

Fig. 1. Transthoracic echocardiography with color Doppler showing the PM VSD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

residual shunts or device embolization post-deployment, hemolysis, stroke or death.

3. The ADO I Device

The ADO I is a conical device with a cylindrical body and a retention skirt on the aortic side, for positioning in the ampulla of the duct. The retention skirt is 1 to 2 mm larger in diameter than the diameter of the device at the pulmonary side.

4. Technique

Cardiac catheterization was performed under general anesthesia in all patients, after obtaining informed consent. Initial access was obtained with a 6 Fr short pediatric sheath in the right or left femoral vein and a 5 Fr short pediatric sheath in the right or left femoral artery. Intravenous heparin (100 U/kg) was given after femoral artery access was obtained. Right and left heart catheterization was performed including hemodynamic assessment. Left ventricular angiography with long axial angulation to assess the defect size and location was performed. Procedures were monitored by transesophageal echocardiography (TEE) including the delivery of the disc on the LV side and the delivery of the rest of the device, assessment of the position of the device in relation to the aortic valve and the tricuspid valve and the presence of residual shunts. An attempt was done initially to assess the VSD from the RV to the LV to avoid the need for establishing an arteriovenous loop. If this was not possible, a retrograde approach was attempted. The device was chosen so that the diameter at the pulmonary end was 1 mm greater than the smallest VSD diameter after performing left ventricular angiogram (Fig. 2).

In 12 patients, the VSD was crossed retrograde from the left ventricular side, using a 4F Judkins right coronary catheter (Cordis Corporation, Miami, Florida) and a 0.035″ Terumo wire (Terumo Europe, Leuven, Belgium). The catheter was then advanced either to the pulmonary trunk or to the superior vena cava. The Terumo wire was replaced with a 260 cm long noodle wire which was then snared using a 10 or 15 mm PFM snare (pfm Medical, Inc., Germany) and exteriorised, to create an arteriovenous guidewire loop. In the remaining 16 patients, the VSD was crossed directly from the right to the left ventricle, using a 4F Judkins right coronary catheter and 0.035″ Terumo guidewire, which were advanced through the defect and into the ascending aorta. The Terumo wire was then replaced with an extra stiff guidewire (Boston Scientific Inc., USA). In this subset of patients, the arterial access was used only for check angiography during deployment and following release of the device. According to the device size selected, an appropriate 5, 6 or 7F delivery sheath was advanced through the VSD from the femoral vein and into the ascending aorta. The dilator and guidewire were removed, and the chosen ADO I device was loaded and advanced to the ascending aorta. Under TEE guidance the device was partially protruded through sheath tip while in the ascending aorta, and then pulled back through the valve into the left ventricle. The retention skirt was opened beneath the valve and pulled against the septum, and the rest of the device deployed by fixing the delivery cable and pulling back the delivery sheath. The position of the device is checked at first by TEE checking the position of the device, the presence of aortic or tricuspid incompetence as well as the presence of residual shunts. This is followed by left ventricle angiography (to assess device position) and ascending aorta (to exclude aortic valve insufficiency) (Fig. 3) and transthoracic echocardiography (Fig. 4), the device was released.

After achieving femoral hemostasis, heparin infusion was started at10–20 units/kg/h for 24 h and the patient was monitored in the intensive care unit. A 12 lead ECG and transthoracic echocardiography were performed prior to discharge from hospital. For children in whom a

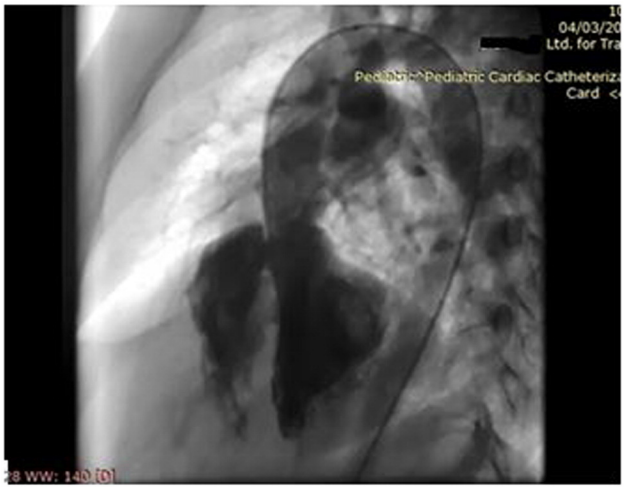

Fig. 2. Left ventricular angiogram demonstrating a perimembranous subaortic VSD.

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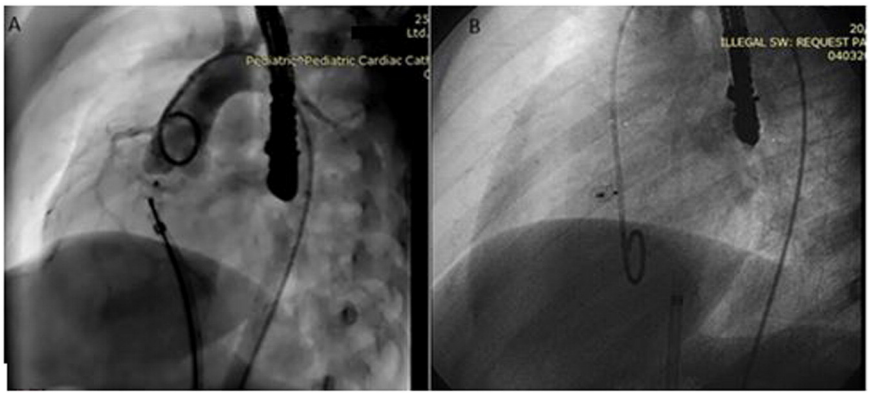

Fig. 3. a) ADO I device in situ before release, aortogram showing no AI. B): ADO I device in situ after release.

device was placed, aspirin in a dose of 5 mg/kg/day was prescribed for 6 months and antifailure medications were discontinued in the majority of patients prior to discharge. Follow up outpatient clinic visits were planned at 1, 3, 6, and 12 months after the procedure.

Successful procedure was defined as placement of the device in a stable position completely closing the VSD and not causing any significant aortic or tricuspid regurge and without arrhythmia was placed securely over the defect. Mild residual flow was defined if the flow is <2 mm and mild to moderate flow if >2 mm in diameter.

5. Results

The median age of the 28 included patients (16 females and 12 males) was 4 years ranging from 13 months to 12 years and the median weight was 15 kg ranging from 6.5 kg to 51 kg Table 2. The median *z* score of the left ventricular end diastolic (LVEDD) was 1.42 ranged from −0.97 to +4.34. Eight patients were failing to thrive (28.6%). One patient was Down syndrome and another two patients were neurologically delayed. Pulmonary hypertension was encountered in ten patients (35.7%); four of them with severe pulmonary hypertension and the other six patients with mild to moderate degree. Associated cardiac defects were in the form of minor defects as small ASD, tiny PDA, mild AR or mitral valve prolapse. Ten patients had history of recurrent chest infection and only one patient had history of infective endocarditis.

The median VSD diameter as measured by transthoracic echocardiography was 5.75 mm (range 4 to 8 mm), and by angiography was 5.2 mm (3.75 to 9 mm). The ADO I devices sizes were 10/8 in 23 patients (46.4%) followed by 8/6 in 8 patients (28.5%), then 6/4 in 5 patients (17.9%) and 12/10 in 2 patients (7%) (Table 1). Placement of the device was successful in 85.7% of the patients ($n = 24/28$). Three procedures were aborted after initial crossing of the VSD due to the chosen device pulling through the defect with subsequent failure to re-cross the VSD, so the procedures were postponed to another sessions. In a fourth procedure, the device embolized after release to the RV and was snared and retrieved; the procedure was aborted at this stage.

Two devices were tried in 5 patients; the initially chosen device being too small with proper positioning of the next selected device which was successfully deployed. In four patients the trial was aborted, as described above. The median fluoroscopic time was 55 min ranging from 34.5 to 99 min, and was significantly shorter in patients in whom the anterograde approach was used to cross the VSD; being 44.3 min versus 58 min for the retrograde approach respectively. None of the patients had permanent loss of arterial pulsations. Only one patient had temporary heart block during the procedure, received dexamethasone, sinus rhythm was regained with successful completion of the procedure and no recurrence of the heart block. None of the patients developed AV block during a follow-up period ranged from 2 to 17 months. None of the patients had thromboembolic manifestations. Among the 24 cases with successful deployment of the device, complete closure was achieved in 22/24 cases (91.7%), as documented by LV angiography and transthoracic echocardiography, this rate increased to 95% (23/24) at the 3 months follow-up. One patient had trivial aortic valve insufficiency (AI) prior to VSD closure that did not change after closure. None of the patients developed new onset AI after the procedure. Tricuspid valve insufficiency did not increase in any of the patients. There was no mortality, early or late. Those patients who achieved successful VSD closure showed improved symptoms during the follow up period with withdrawal of the antifailure treatment and drop of the pulmonary artery pressure estimated by echocardiography.

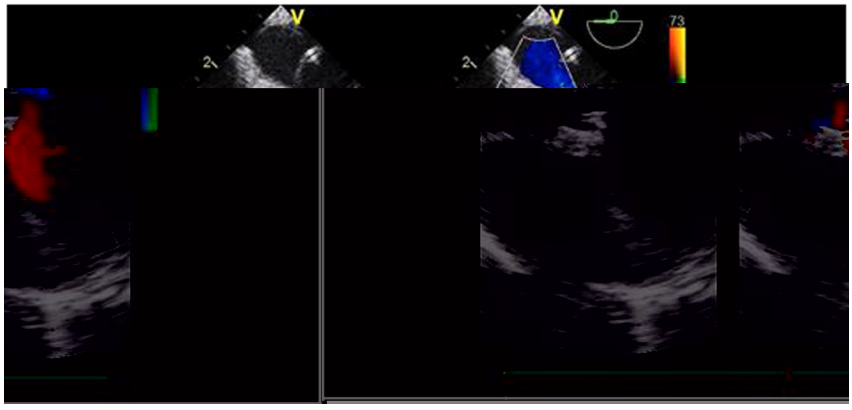

Fig. 4. Transesophageal echocardiography with & without color Doppler showing the device closing the VSD with no residual flow. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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Table 1
Characteristic of the 28 studied patients who underwent VSD closure.

Variables	Median (range)
Age (years)	4 (13 months–12 years)
Weight (kg)	15 (6.5–51)
BSA (m^2)	0.64 (0.4–1.39)
Angiographic minimum VSD diameter (mm)	5.2 (3.75–9)
Procedural details	
Fluoro time (min)	55 (34.5–99)
Device diameter/length	Number of patients (%)
6 × 4	5 (17.9%)
8 × 6	8 (28.6%)
10 × 8	13 (46.4%)

6. Discussion

In our series, the transcatheter closure of pm VSD with Amplatzer ductal occluder I was successful in 95% without any residual flow or heart block. In developing countries, many children with clinically relevant pmVSDs are denied appropriate therapy, due to reasons of lack of access to surgery, or prohibitive costs of surgical or device therapy. In 1988, Lock and his coworkers reported the first human experience of transcatheter closure of muscular defects using the Rashkind double umbrella device [6]. Since then, various devices have been used, initially to close muscular VSDs and subsequently for pmVSDs. The Amplatzer membranous occluder allowed closure of defects with small subaortic rim. The major complication of transcatheter closure of pmVSDs has been early or late onset heart block. In a multi-center retrospective study, Carminati et al. reported a 5% incidence of transient or permanent complete AV block, occurring either during or within 1 week of the procedure. The majority of patients were considerably older than in our series. On multivariate analysis, young age (median < 5 years) or low body weight (≤20 kg) were risk factors for this complication [7]. In a single institution, the mean age for transcatheter closure of pmVSDs was 14 years, the complete heart block was observed in patients <6 years of age and the permanent pacemaker implantation was required in 5.7% of patients [8]. Complete heart block occurred in 4 out of 20 infants and children in whom pm VSD closure was performed using the Amplatzer membranous occluder up to 3 years following device closure. The majority of those patients had hemodynamically significant defects, and met criteria for surgical closure. No specific risk factor for the occurrence of heart block either age, weight, or defect size could be identified [9]. Due to high incidence rate of heart block, there has been a marked reluctance to undertake device closure of pmVSDs in young patients, or those with low body weight. However, this subset of patients is specifically those who require early intervention, particularly in the setting of the developing world. In contrast, no incidence of AV block by using the ADO II device in Koneti et al. series including 57 patients with hemodynamically relevant pmVSDs. The largest pm VSD that could be closed using this device was ≤6.5 mm, due to unavailability of larger device sizes [10]. The previous two studies [9,10] included patients comparable to our series concerning their age and their weight. El Said and her colleagues reported a success rate of 90% using the ADO I for closure of pm VSD with no AV block in up to mid-term follow up encountered [11].

Table 2
Clinical findings of the included patients.

Variable	Number (%)
Presence of failure to thrive	8 (28.6%)
Pulmonary hypertension	10 (35.7%)
Associated cardiac defects	7 (25%)
Patients on antifailure treatment	20 (71%)
History of infective endocarditis	1 (3.5%)
Recurrent respiratory infections	10 (35.7%)
Other systemic illnesses	3 (10%)

Also, Ghaderian and co-workers who included a comparable group of children in their study, reported an immediate success rate of 65.7% at completion of the procedure, rising up to 79.5% at discharge and 96.4% during follow-up with no AV block development [12]. Recently, Mahimarangaiah and his colleagues published their experience on 81 patients using different types of ductal occluders for pm VSDs closure, but the age of their cohorts had wider range extending from 1 to 41 years with a median of 8 years. Amplatzer Duct Occluder-II device was used for 45 patients. Only two cases developed complete heart block; one was temporary and the other developed on follow up and needed pacemaker implantation [13]. The ADO I occlude may be advantageous when compared to other devices for several reasons. First, it is not a double umbrella device, and therefore entrapment of the aortic valve cusp or the septal leaflet of the tricuspid valve within the device during the deployment is less common. This allows the device to be used even in the virtual absence of a rim to the septal leaflet of the tricuspid valve. To avoid the creation of aortic insufficiency, a minimum distance from the aortic cusp of 2 mm is mandatory as the retention skirt is 2 mm larger in diameter than the pulmonary end of the device. Using very large devices in very small children also has the potential for creation of left ventricular outflow obstruction caused by the device, although this has not been observed in our series. To avoid this potential complication, we have restricted ourselves to attempting device closure for pm VSDs of up to 10 mm in minimum diameter. The high incidence of complete atrioventricular block (CAVB) after device closure of a pm VSD has been a serious and worrisome complication [9,10,14–17]. The most likely mechanism of AV block caused by the double umbrella device is the compression of the conduction tissue between the two disks of the device. This potential complication is also avoided with the ADO I device as the reported incidence in most published series with ADO I is much less than other devices [11–13,18]. The presence of a membranous septal aneurysm is also not critical for placement of the ADO I occluder. The device is mechanically wedged into the pm VSD, and does not rely on the presence of an aneurysmal pouch to hold it in place. Indeed, the presence of a pronounced septal aneurysm may favor the use of other devices.

7. Potential Limitations

The ADO I device can only be used in the setting where there is a clear difference in pressure between the left and right ventricles; so it is not recommended in patients with pulmonary hypertension due to the potential for device embolization into the left ventricle. As discussed, we limited ourselves to attempting device closure for pm VSDs of up to 10 mm in minimum diameter. Limited numbers of the studied population and short period of follow-up are the study limitations

8. Conclusions

Amplatzer ductal occluder I is safe and effective for transcatheter closure of pmVSDs in symptomatic infants and children. The device is affordable and widely available. The antegrade venous approach is feasible in the majority of our cohort, and reduces significantly the fluoroscopic time of the procedure.

Author Contributions

Hala Hamza, Aya M. Fattouh and Rodina Sobhy were involved with study concept and design. Amal El-Sisi, Hala Agha, Hala Hamza and Sonia A El-Saiedi are the main operators for VSD closure. Aya M. Fattouh, Rodina Sobhy, Wael Attia and Doaa M Abdelaziz were involved in patient examination, collection of data and follow up. Rodina Sobhy and Aya M. Fattouh were involved in data tabulation and analysis. Rodina Sobhy wrote the manuscript. Aya Fattouh revised the manuscript. All authors reviewed the manuscript

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Conflict of Interest

No conflict of interest.

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