Closure of Atrial Septal Defects With the Amplatzer Occlusion Device: Preliminary Results

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Objectives. This study reports our clinical experience with transcatheter closure of secundum atrial septal defects (ASDs) in children, using the Amplatzer, a new occlusion device.

Background. None of the devices previously used for transcatheter closure of interatrial communications has gained wide acceptance.

Methods. We examined the efficacy and safety of the Amplatzer, a new self-centering septal occluder that consists of two round disks made of Nitinol wire mesh and linked together by a short connecting waist. Sixteen patients with secundum ASD met established two- and three-dimensional echocardiographic and cardiac catheterization criteria for transcatheter closure. The Amplatzer’s size was chosen to be equal to or 1 mm less than the stretched diameter. The device was advanced transvenously into a 7F long guiding sheath and deployed under fluoroscopic and ultrasound guidance. Once its position was optimal, it was released.

Results. The mean ASD diameter by transesophageal echocardiography was 14.1 ± 2.3 mm and was significantly smaller (p < 0.001) than the stretched diameter of the ASD (16.8 ± 2.4 mm). The mean device diameter was 16.6 ± 2.3 mm. No complications were observed. After deployment of the prosthesis, there was no residual shunt in 13 (81.3%) of 16 patients. In three patients there was trivial residual shunt immediately after the procedure that had disappeared in two of them at the 3-month follow-up.

Conclusions. The Amplatzer is an efficient prosthesis that can be safely applied in children with secundum ASD. However, a study including a large number of patients and a longer follow-up period are required before this technique can be widely used.

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Although surgical repair of interatrial communications is a safe, widely accepted procedure with negligible mortality, it is associated with morbidity, discomfort and a thoracotomy scar (1). As an alternative to surgery, a variety of devices for transcatheter closure of atrial septal defects (ASDs) have been developed over the past 20 years, but none has gained wide acceptance. Large delivery sheaths, cumbersome implantation techniques, inability to recapture, structural failure, dislodgement and embolization of the device are some of the limitations of previously prescribed techniques (2–12). This study describes our experience with transcatheter closure of ASDs in children using a new self-expanding, self-centering and repositionable device, the Amplatzer. This device was tested at the University of Minnesota and has been evaluated in animal in vivo experimental studies (13) with promising results that support initiation of clinical trials.

Methods

Device and delivery system. The Amplatzer and delivery system have been described in detail in previous reports (13). In brief, this device consists of two self-expandable round disks made of 0.004- to 0.005-in. Nitinol wire mesh that are linked together by a short (4 mm) connecting waist, corresponding to the thickness of the atrial septum (Fig. 1). The left atrial disk extends 7 mm radially around the connecting waist and the right disk 5 mm. The left disk is slightly larger than the right because of the higher left atrial pressure. Both disks are angled slightly toward each other to ensure firm contact with the atrial septum. The prosthesis is filled with Dacron fabric to facilitate thrombosis. Prostheses are currently available in sizes ranging from 4 to 20 mm at increments of 1 mm. The device is attached by a microscrew mechanism onto a 0.038-in. delivery cable made of stainless steel (Fig. 2A). It is loaded into a long 6F or 7F (occluders >10 mm) introducer sheath. For introduction into the delivery sheath the device is pulled into a loader (Fig. 2B).

Patients. Twenty-two patients from 4 to 14 years of age (median 9.2) with a secundum ASD awaiting surgical closure were evaluated at our institution with two-dimensional and color Doppler echocardiography. Eighteen of these patients met echocardiographic criteria for transcatheter closure with the Amplatzer device (AGA Medical Corporation, Golden
Valley, MN) and subsequently underwent device implantation. One of the patients had a significant residual defect after surgical ASD closure and another had severe valvar pulmonary stenosis associated with a secundum ASD.

All devices were implanted under research protocol approved by the Ethical Committee on Clinical Investigation of “Aghia Sophia” Children’s Hospital, Athens. The Amplatzer prosthesis was approved by the Office of Compliance, Center for Devices and Radiological Health of the U.S. Food and Drug Administration for export and investigational use. Informed parental consent was obtained for each patient.

**Study protocol.** Patients were screened by transthoracic two-dimensional Doppler echocardiography with multiple subxyphoid and precordial windows. Five patients with poor transthoracic echocardiographic windows were further evaluated with biplane transesophageal echocardiography. In the last 10 patients transthoracic three-dimensional echocardiography was also performed in order to define the spatial anatomy of the ASDs. Patient inclusion criteria were 1) the presence of an ostium secundum ASD, 2) left to right shunting across the ASD, 3) maximal ASD diameter of <20 mm, 4) a distance of >5 mm from the margins of the defect to the mitral and tricuspid valves, superior vena cava, right upper pulmonary vein and coronary sinus, and 5) dilation of the right ventricle with evidence of right ventricular volume overload. Patients who met these criteria were further evaluated with transesophageal echocardiography under general anesthesia before cardiac catheterization. All patients underwent balloon sizing to establish the stretched diameter of the ASD, which was then used to select the appropriate size of the occluding device. In patients with a balloon-stretched ASD diameter of >21 mm closure was not undertaken. The device size was selected to be equal or 1 mm less than the measured stretched diameter.

**Procedure.** The patients were intubated and placed under general anesthesia. After percutaneous puncture of the femoral vein, a complete hemodynamic evaluation was performed with pressure and saturation measurements taken in all cardiac chambers. A pulmonary arteriogram was performed in a 35° left axial oblique projection with 35° cranial angulation (four chamber view) with an 8F Berman angiographic balloon catheter (Arrow International Inc., Reading, PA) to rule out anomalous pulmonary venous connections. Subsequently, contrast medium was injected at the junction of the left atrium with the right upper pulmonary vein to delineate the anatomy of the ASD. A 7F balloon-tipped end-hole catheter (Arrow

**Figure 1.** Amplatzer septal occluder made of 0.005-in. Nitinol wire tightly woven into two round disks with a 4-mm connecting waist (arrowheads). Arrow indicates the negative microscrew adaptor mounted on the right atrial disk.

**Figure 2.** A, Delivery cable of the Amplatzer prosthesis (arrowheads). Vertical arrow indicates the plastic vice that facilitates release (unscrewing) of the device. B, Adaptor tube (arrowheads) used for introduction of the device into the delivery sheath.
International Inc., Reading, PA) was manipulated through the ASD into the left upper or lower pulmonary vein. Using an exchange 260 cm, J-tipped guidewire, a 27-mm, 100-cm occlusion balloon catheter (Meditech, Watertown, MA) was introduced into the left atrium. The balloon catheter was inflated with various increments of contrast medium and pulled across the ASD under fluoroscopic and transesophageal echocardiographic observation. A slight deformity of the sizing balloon was used to determine the stretched diameter. The sizing balloon was then removed, reinflated with the same amount of contrast medium and passed through calibrated openings in a sizing plate to determine the stretched diameter. The occluding device was selected to be the same size or 1 mm smaller than the stretched diameter. The device size refers to the diameter of the connecting waist.

The device was screwed to the tip of the delivery cable, immersed in normal saline and drawn into the loader. A Y connector was applied to the proximal end of the loader to allow flushing with saline. A 7F, long guiding sheath and dilator were advanced over the guidewire through the communication into the left atrium. The correct position of the delivery sheath was verified by a test injection of contrast medium. The loader with the collapsed device was then advanced into the guiding catheter by pushing the delivery cable (Fig. 3A). Under fluoroscopic (Fig. 3B) and ultrasonic guidance, the left atrial disk was deployed and pulled gently against the atrial septum, which was both felt and observed by transesophageal echocardiography. Using gentle tension on the delivery cable, the sheath was pulled back and the right atrial disk was deployed (Fig. 3C). To and fro motion of the delivery cable ensured a secure position across the ASD. This was also observed by two-dimensional Doppler echocardiography and fluoroscopy. Biplane transesophageal color Doppler echocardiography was performed after device deployment to check for the presence of residual shunt, possible obstruction to systemic or pulmonary venous return and impairment of the atrioventricular valves. Once its position was optimal, the device was released by counterclockwise rotation of the delivery cable. After release of the Amplatzer both color Doppler echocardiography and pulmonary angiography were performed to detect any residual shunt (Fig. 3D and 4). In 10 patients accurate device position was confirmed by en-face three-dimensional echocardiographic views from the right and left atrium. Intravenous antibiotics (ampicillin 200 mg/kg body weight and gentamycin 5 to 6 mg/kg) were delivered immediately after placement of the prosthesis and repeated at 8 and 16 h, for a total of three doses. All patients were discharged on the day after the procedure with instructions to take aspirin 3 to 5 mg/kg daily for 3 months.

Follow-up studies. A chest radiograph and a transthoracic color Doppler echocardiographic study were performed on all patients at 24 h after the procedure and at 1 and 3 months.
later. A transesophageal echocardiographic study was scheduled for the 6-month follow-up.

Persistent atrial shunts were angiographically (immediately after the procedure) and echocardiographically defined as “foaming” (minor diffuse leak through the Dacron fabric), trivial (faint right atrial opacification and jet ≤1 mm in diameter), small (minor right atrial opacification and jet 1 to 2 mm in diameter), moderate (obvious right atrial opacification and jet 3 to 4 mm in diameter) and large (intense right atrial opacification and jet >4 mm in diameter).

**Statistical analysis.** Results are expressed as mean value ± SD, with confidence intervals given where applicable. The Student paired $t$ test was used to compare transesophageal echocardiographic and balloon-stretched ASD diameter. A $p$ value <0.05 was considered statistically significant.

**Results**

Two patients had a balloon-stretched ASD diameter >21 mm and were excluded from transcatheter closure. Transcatheter closure of secundum ASDs was carried out in the remaining 16 patients. Descriptive statistics and outcome for all patients are shown in Table 1. Delivery of the device was successful in all patients. The mean ASD diameter determined by transesophageal echocardiography was 14.1 ± 2.3 mm (range 10 to 19) and was significantly smaller (p < 0.001) than the stretched diameter of the ASD measured by balloon sizing (16.8 ± 2.4 mm; range 12 to 21). The mean device diameter was 16.6 ± 2.3 mm (range 12 to 20). There was left to right shunt across the ASD in all patients, both by color Doppler echocardiography and oximetry at the time of catheterization. The pulmonary/systemic flow ratio ($Q_p/Q_s$) varied between 1.5 and 2.9 (mean 2.01 ± 0.46).

Misplacement of the device occurred in one patient and was successfully managed by withdrawing both discs into the delivery sheath and redeploying the device. No complications were observed as a result of the procedure. After release of the prosthesis, pulmonary artery cineangiography and color Doppler echocardiography revealed no residual shunt in 13 (81.3%, 95% confidence interval [CI] 54.35% to 95.95%) of 16 patients. “Foaming,” documented by both angiography and transesophageal echocardiography, was present in five patients (31.3%) but disappeared within 15 to 20 min. In three patients there was a trivial residual shunt immediately after the procedure. The device waist diameter used in these patients was 1 mm less than the stretched ASD diameter. In the patient with coexisting valvar pulmonary stenosis, a successful balloon pulmonary valvuloplasty was performed before transcatheter closure of the ASD.

Fluoroscopy time was 20.3 ± 3.5 min (range 14 to 26) and total procedure time was 67.5 ± 8.1 min (range 55 to 82). Immediate transesophageal echocardiographic examination revealed no obstruction to the superior and inferior venae cavae, the coronary sinus or the right upper pulmonary vein. Neither retention disk was in contact with the mitral or the tricuspid valve and valve regurgitation was not observed.

A good quality image for three-dimensional echocardiographic reconstruction was obtained in 9 of 10 patients who

### Table 1. Pertinent Patient Data* and Outcome After Transcatheter Atrial Septal Defect Closure With the Amplatzer Prosthesis

<table>
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<tr>
<th>Pt No./Age (yr)</th>
<th>Wt (kg)</th>
<th>ASD Diameter</th>
<th>Device Size</th>
<th>Outcome</th>
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<td>Stretched (mm)</td>
<td>Immediate (A + TED)</td>
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*Statistical analysis was performed comparing the TEE diameter and the stretched diameter of the ASDs. †Mean value ± SD. A = angiogram; ASD = atrial septal defect; C = complete closure; Pt = patient; TED = transesophageal color Doppler; TEE = transesophageal echocardiography; TS = trivial residual shunt; TTD = transthoracic color Doppler; Wt = weight.
were evaluated with transthoracic three-dimensional echocardiography. In these patients we were able to see both atrial disks from the right and left atrial views and exclude obstruction of the superior vena cava, right upper pulmonary vein or coronary sinus. In addition, the proximity of both disks to the atrioventricular valves was evaluated. In all these patients the device was in the appropriate position and no interference with the surrounding cardiac structures was observed (Fig. 5).

Follow-up echocardiographic data were available in all 16 patients at 1 and 3 months after the procedure. There was no evidence of residual shunt in 15 (93.75%, 95% CI 69.77% to 99.84%) of the 16 patients. In one of the three patients with a trivial residual shunt immediately after the procedure the shunt was still present at the 3-month follow-up. No complications were observed during short-term follow-up.

Discussion

Although several reports of successful transcatheter closure of secundum ASDs have appeared in the literature, the procedure has not yet achieved widespread clinical use and it is still under investigation. This is most likely because of difficulties related to the implantation technique and drawbacks in the design of the occlusion devices (2–12).

In the present study a new ASD occluder, the Amplatzer, was employed for transcatheter closure of ASDs (ranging from 12 to 21 mm) in 16 patients. Complete occlusion was achieved in 15 (94%) of 16 patients, with no complications during the procedure or at short-term follow-up. It appears that the efficacy and safety of the technique are predominantly owing to the simplicity of the deployment and the novel design of the Amplatzer septal occluder.

Comparison with other devices. The Amplatzer was designed to overcome many of the drawbacks of previously used devices. Previous devices include the clamshell septal occluder (3,4), the Sideris prosthesis (buttoned device) (5,7), the atrial septal defect occlusion system (8,9), the Das Angel Wing (10,11) and the Pavcnik monodisk (12). Besides the Sideris prosthesis, which is delivered through an 8F sheath for devices up to 40 mm, all other occluders require a large 9F to 13F sheath, which makes their application difficult or impossible in small children. The Amplatzer is delivered through a 6F to 7F sheath, which facilitates its use even in infancy. Moreover, the other devices are limited in that they require a large device/ASD diameter ratio (2- to 2.5-fold the stretched ASD diameter) to ensure complete closure if they are not perfectly centered. The Amplatzer is a self-centering prosthesis and the round retention disks extend radially beyond the defect, resulting in a much smaller overall size than all other devices. The Das Angel Wing and the Pavcnik monodisk are the only currently used devices with a self-centering mechanism (10,12). Of these two devices, the Pavcnik monodisk has the advantage of requiring a rather small device/ASD diameter ratio but it offers a questionable centering mechanism and there is very limited clinical experience. The Das Angel Wing prosthesis has a more reliable centering mechanism, but not during deployment, and consequently, the retention skirts have to remain oversized.

In contrast to the atrial septal occluders that accomplish closure of the ASD by the retention flanges (patches), the Amplatzer uses a short (4 mm) communicating waist to stent the defect, forcing blood flow through a network of highly thrombogenic polyester material. Indeed, we observed “foaming” with transesophageal echocardiography and angiography immediately after deployment, which completely disappeared within 15 to 20 min. Moreover, the inward inclination of both retention disks allows firm contact with the atrial septum, which enhances endothelialization and reduces the risk of residual shunting. The previously reported incidence of residual shunting (20% to 39%) is much higher than in the present study (6%) (4,7,9,11).

Selection of the appropriate device size is of paramount importance for effective and safe ASD closure regardless of
device type. Balloon sizing to establish the stretched ASD diameter has remained the gold standard in spite of the more convenient echocardiographic measurement. This technique is less reliable because many communications are not perfectly round (4,14). Three patients in our study had a trivial residual shunt that disappeared in two patients within 1 month and 3 months, respectively, after the procedure. It should be noted that in all three patients the size of the device was 1 mm less than the measured balloon-stretched ASD diameter. Therefore, we believe that it is essential to choose a device identical to the measured balloon-stretched diameter of the defect in order to maximize the efficacy of this particular design.

A very important property of the Amplatzer is retrievability while the device is still attached to the delivery cable, which allows repositioning in case of misplacement, thus obviating surgical removal. Most of the other devices, with the exception of the clamshell septal occluder (4), are not retrievable or once deployed it is very laborious to reposition or to remove them (7–9,11,12). The Amplatzer prosthesis can be fully recaptured into the sheath with the delivery cable. Because of its superelastic properties, the nitinol frame of the device retains its initial shape even if it is deployed several times. Indeed misplacement of both discs across the defect was encountered in one of our patients and was easily corrected by withdrawing and redeploying the device. An additional advantage of this prosthesis are the two round disks. Devices with corners or spokes may cause accidental injury of atrophicventricular valves or perforations of an intracardiac structure during disk deployment. Also, delayed perforations can occur. Furthermore, complications previously reported, such as metal fatigue fractures (15), structural failure or embolizations of the device (15), structural failure or embolizations of the device (4–7,16), atrial perforation (7,16) and atrioventricular valve damage (7), were not observed in the present study, although the follow-up is short.

As compared with other devices, the Amplatzer’s loading, technical deployment and recapturing is simple, without complicated mechanisms. This significantly reduces the procedural and fluoroscopy time and shortens the learning curve of each operator. Indeed the procedural (67.5 ± 8.1 min) and fluoroscopy (20.3 ± 3.5 min) times in this study were very short for this type of intervention. In the atrial septal defect occlusion system experience in children, procedural times ranged from 132 to 194 min and fluoroscopy times from 17 to 39 min (9).

Biplane transesophageal color Doppler echocardiography was used in this study for guidance of transcatheter closure of the ASDs. Echocardiographic imaging is superior to fluoroscopy as it provides unique information regarding the anatomy of the defect, the position of the device across the atrial septum and its relation to adjacent cardiac structures (17,18). An important benefit of the Amplatzer is its optimal echogenicity, owing to its Nitinol mesh structure, which makes it easily visible in the short-axis and longitudinal views of the device and residual shunting can be precisely delineated.

Recently, three-dimensional transesophageal or trans-thoracic echocardiography was used for patient selection and guidance of transcatheter closure of ASDs (19,20). Three-dimensional echocardiography displays the defect as a dynamic structure whose size and morphology change with the cardiac cycle, and its maximal diameter can be better appreciated when the periphery of the defect is seen in an en-face view. Additionally, one can visualize both atrial discs of the occlusion device and their dynamic anatomic relation to the adjacent cardiac structures. In this study the use of three-dimensional transthoracic echocardiography proved useful in the preselection of patients and provided guidance of ASD closure with the Amplatzer prosthesis.

Conclusions. Our results indicate that the Amplatzer is an efficient prosthesis that can be safely used in children with secundum ASDs. It is simple in construction, easy to deploy and can be withdrawn and repositioned many times. Further studies are required to establish its value in a larger number of patients, for closure of larger ASDs and patent foramen ovale. Furthermore, long-term follow-up is needed to exclude possible adverse side effects.

References


