Transcatheter closure of ruptured sinus of Valsalva aneurysm using the Amplatzer duct occluder: immediate results and mid-term follow-up

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Received 9 April 2010; revised 20 June 2010; accepted 30 July 2010; online publish-ahead-of-print 9 September 2010

Aims
To assess the immediate and mid-term outcome of transcatheter closure (TCC) using the first-generation Amplatzer duct occluder (ADO) in patients with ruptured sinus of Valsalva aneurysm (SOVA). Ruptured SOVA is a rare cardiac shunt lesion, with scant data about its TCC.

Methods and results
Twenty patients (8 females and 12 males) aged 17–52 years (median 27 years) with ruptured SOVA were selected for TCC. Most (13/20) were in symptomatic NYHA class III or IV. Three had previous cardiac surgeries. Associated defects were bicuspid aortic valve in one, trivial pre-existing aortic regurgitation (AR) in five, coarctation of the aorta in one, and secundum atrial septal defect in one. Patients with co-existing ventricular septal defect or significant AR requiring surgery were excluded. Echocardiography revealed ruptured SOVA from right coronary sinus to right atrium (RA) in 4 and right ventricular (RV) outflow in 5, whereas non-coronary sinus ruptured into RA in 10 and RV inflow in 1. At cardiac catheterization, the defect was 4–11 mm (median 9 mm) at its aortic end as measured by online transoesophageal echocardiography or angiography. The $Q_p/Q_s$ ratio ranged from 1.5 to 3.2 (mean 2.32 ± 0.53). In all patients, the defect was closed from the venous side, using ADOs 2–4 mm larger than the aortic end of the defect. The ADO sizes ranged from 8/6 to 16/14 mm (median 13/11 mm). The procedure was successful in 18 out of 20 patients (90%). Of these 18, 13 had a complete closure at discharge. Five had a residual shunt (four small and one moderate with self-abating haemolysis). Trivial AR occurred in four. On a median follow-up of 24 months (range 1–60 months), 15 patients were in NYHA class I and 3 in class II. The residual shunt disappeared in three and was small in two; procedure-related AR vanished in two of four. There was no AR progression, recurrence, infective endocarditis, or device embolization.

Conclusion
In appropriately selected patients with ruptured SOVA, TCC is an attractive alternative to surgery with encouraging short- and mid-term outcomes.

Keywords
Intervention • Non-surgical • Congenital heart disease • Transoesophageal echocardiography

Introduction
Ruptured sinus of Valsalva aneurysm (SOVA) is a rare but well-described clinical entity. Sinus of Valsalva aneurysm is relatively more common in Asians in whom it presents typically in adolescence and young adulthood.1 It is usually congenital in origin with a tendency to rupture into the right-sided chambers of the heart, resulting in a left-to-right shunt. The unrepaired SOVA is usually asymptomatic; however, when it ruptures into one of the cardiac chambers, the haemodynamic effects are profound and nearly 80% of the patients are symptomatic.2 Open surgical repair with cardiopulmonary bypass has been conventionally the
mainstay of therapy for ruptured SOVA. However, successful transcatheter closure (TCC) is being increasingly reported in recent times, mainly as anecdotal single case reports or as small series. This report describes the largest hitherto published experience including mid-term follow-up of TCC of ruptured SOVA with special emphasis on patient selection and technique.

**Methods**

**Patient characteristics**

Between July 2004 and December 2009, 20 patients were chosen for TCC of ruptured SOVA with the first-generation Amplatz duct occluder (ADO, AGA Medical Corporation, Plymouth, MN, USA). During this period, we encountered 13 other patients with ruptured SOVA. Four out of these 13 were considered eligible for TCC; 7 others were referred for surgical correction due to associated ventricular septal defect (VSD) in 5, moderate aortic regurgitation (AR) in 2, subaortic membrane in 1, large defect in 1, and SOVA burrowing into interventricular septum before rupture in 1; and the remaining 2 succumbed to infective endocarditis and heart failure. The 20 study patients were 17–52 years old (median 27 years). There were 12 men and 8 women. Three patients were in NYHA class IV, 10 in class III, and the others in class II. All patients underwent clinical examination, chest X-ray, electrocardiogram, transthoracic echocardiography (TTE) with colour Doppler interrogation, and intraprocedural transoesophageal echocardiography (TOE). The diameter of the ruptured SOVA was measured at the aortic end as well as at the site of rupture. Only those patients without associated defects requiring surgical correction (like VSD or significant AR) were selected. Also patients with large ruptured SOVA (aortic origin more than 12 mm) and those with any suspicion or evidence of infective endocarditis were excluded. An informed consent was taken for all patients.

**Procedure**

The procedure was performed under general anaesthesia with TOE guidance (Figure 1A–D) as described before. The femoral vein and artery were accessed. Intravenous heparin (100 IU/kg) and cefazolin were given. Right and left heart pressures and saturations were obtained, and aortic root angiography was performed. The left anterior oblique with cranial tilt projection (Figure 2A and B) was preferred for SOVA draining into right atrium (RA) and right ventricular (RV) inflow and the right anterior oblique view (Figure 2C and D) for SOVA rupturing into RV outflow tract (RVOT). Additional orthogonal views were taken if necessary. The ruptured SOVA was measured at its aortic end as well as at the rupture site both on TOE and angiography. The larger of the two measurements was considered for device selection. The size of the ADO selected was such that its aortic segment was 2–4 mm larger than this diameter. The defect was crossed from the aortic side using a 4F Judkins right coronary catheter and a 0.035 in. angled tip glide wire (Terumo Inc., Japan). This was exchanged for a 300 cm long noodle wire (AGA Medical) that was snared with an Amplatz gooseneck snare (Microvena, White Bear Lake, MN, USA).

![Figure 1](image-url) Intraprocedural transoesophageal echocardiography in aortic short-axis view showing (A) typical windsock-like aneurysm from right coronary sinus draining into the right atrium with turbulent colour flow across. (B) Following Amplatz duct occluder placement, there is a complete closure with no colour flow. (C) The Amplatz delivery sheath can be seen crossing the defect from the right atrium into the ascending aorta. (D) The aortic disk with its attached delivery cable being pulled to block the aortic end of the defect.
from the vena cavae or the pulmonary artery and exteriorized out of the femoral vein. A stable arteriovenous wire loop was thus established, over which the Amplatzer delivery sheath (AGA Medical) was introduced from the femoral vein and placed into the ascending aorta across the defect (Figure 1C). An appropriately sized ADO with its attached delivery cable was then inserted through the delivery sheath, and its aortic disk was deployed in the ascending aorta. The whole assembly was pulled back till the aortic disk blocked the aortic end of the SOVA as seen on online TOE (Figure 1D). After confirming the precise placement, the rest of the ADO was deployed on the right side across the defect. During this manoeuvre, a gentle traction was exerted on the delivery cable, but special care was taken to ensure seating of the aortic disk on the aortic side without slippage into the aneurysm. The ADO was then released from the delivery cable only after making certain that there was no significant AR, tricuspid regurgitation (TR), or any encroachment on coronary arteries as seen on TOE or control angiography. All patients except Case 12 were discharged 48–72 h after the procedure. They were studied clinically and by TTE at discharge, 1, 3, 6 months, and annually thereafter. Eight unselected patients had an angiographic follow-up between 3 and 12 months. All patients received aspirin 150 mg once daily for 6 months. In addition, except for the first five patients, all others received clopidogrel 75 mg/day for 6 weeks. Procedure-related AR was defined as the occurrence of any grade of new AR or worsening by more than one grade of pre-existing AR.

**Results**

The patient characteristics are summarized in Table 1. Echocardiography with colour Doppler revealed ruptured SOVA from right coronary sinus to RA in 4 and RV outflow in 5, whereas non-coronary SOVA ruptured into RA in 10 and RV inflow in 1. One patient (Case 4) had two defects, one 4/4 mm and other tiny 2/2 mm that was left alone. The mean diameter of the defect at the aortic end was 8.70 ± 2.15 mm (median 9 mm) and the mean diameter at the rupture site measured 6.31 ± 1.52 mm (median 6 mm). The pulmonary to systemic flow ($Q_p/Q_s$) ratio ranged from 1.5 to 3.2 (mean 2.32 ± 0.53). The device size was
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<th>Associated lesions</th>
<th>Defect location</th>
<th>Defect size (aortic origin/rupture site) (mm)</th>
<th>ADO size (mm)</th>
<th>Qp/Qs</th>
<th>PA pressure: systolic/diastolic (mmHg)</th>
<th>Residual shunt/ procedure-related AR at discharge</th>
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ADO, Amplatzer duct occluder; PA, pulmonary artery; AR, aortic regurgitation; CABG, coronary artery bypass grafting; CAD, coronary artery disease; NCC, non-coronary cusp; RA, right atrium; RCC, right coronary cusp; RV, right ventricle; RVOT, right ventricular outflow tract; CoA, coarctation of aorta; IVC, inferior vena cava; ASD, atrial septal defect.
16/14 mm in six patients, 14/12 mm in four patients, 12/10 mm in four patients, 10/8 mm in two patients, and 8/6 mm in four patients (median 13/11 mm). The mean procedure time was 87 ± 30 min, and the fluoroscopy time was 23.2 ± 9.4 min.

Deployment success and failure
The ADO was successfully deployed in 18 out of 20 patients (90% success). In Case 9, the largest available ADO (16/14 mm) kept slipping through a ruptured non-coronary SOVA to RA (11 mm at the aortic end). This patient underwent uneventful surgical closure. In Case 14, despite downsizing and using two ADOs (10/8 and 8/6 mm), there was occurrence of moderate AR on TOE before release. In three patients, more than one attempt was made at device placement. In Case 2, a 12/10 mm ADO slipped through an 8/6 mm defect. It was retrieved before release from the delivery cable and a larger 14/12 mm ADO was deployed successfully. Out of the 18 successful patients, 13 had a complete closure at 48 h.

Complications
Residual shunts at discharge were present in five patients, excluding the patient (Case 4) who continued to have a small continuous flow through the unaddressed 2 mm defect. Four out of five had small residual shunts, whereas one had moderate. The patient (Case 12) with a moderate residual shunt developed haemolysis and haemoglobinuria, which abated on conservative therapy on Day 3 without the need for blood transfusion. Four patients developed trace procedure-related AR. No patient had an increase in TR, RVOT obstruction, or device embolization.

Follow-up
All patients were followed for a median period of 24 months (range 1–60 months). At the time of last follow-up, 15 patients were in NYHA class I and three were in class II. Echocardiography showed that residual shunts disappeared in three and were small in two. Interestingly, the patient with a moderate residual shunt at discharge had a complete closure at 1-year angiographic follow-up (Figure 3). Trivial procedure-related AR disappeared in two out of four and did not progress in the other two. The patients with pre-existing AR had no progression or regression in AR. No patient had infective endocarditis or device embolization during the follow-up.

Discussion
Sinus of Valsalva aneurysm, usually a congenital anomaly, almost always ruptures into the right side of the heart causing a left-to-right shunt with profound haemodynamic effects, especially when the rupture is sudden. With the recent advances in non-surgical closure of other left-to-right shunts, it is expected that this rare anomaly is also amenable to TCC. To the best of our knowledge, the present series is the largest study of patients with this rare defect undergoing TCC.

Case and device selection
Our first patient was a critically ill patient with a previous coronary artery bypass grafting surgery. Encouraged by the excellent outcome of this patient, we offered TCC to all patients of isolated ruptured SOVA as well as to those with associated defects amenable to transcatheter therapy. One of the patients (Case 8) underwent coarctation stenting at the same session, whereas another patient (Case 15) had TCC of an associated secundum atrial septal defect (ASD) at a second sitting, mainly to decrease the complexity of the procedure in a haemodynamically compromised (NYHA class IV) patient and to allow for a decrease in the heart size and therefore the ASD device size as reported previously.

We chose to exclude patients of ruptured SOVA with aortic end diameter > 12 mm after failing in Case 9 wherein the ADO kept slipping, despite avoiding excessive traction on the delivery cable. The margins of ruptured SOVA are thin and flimsy, especially at the rupture site, and hence, there may be a need to upsize the device at times. In Case 9, TCC could have been achieved by using a larger Amplatzer VSD device or an atrial septal occluder. But we did not wish to further prolong the procedure, having already made two attempts at placing the largest available 16/14 mm ADO from the mandatory venous route, which necessitates creation of the cumbersome arteriovenous loop. Conceptually, retrograde arterial delivery of the devices with the

Figure 3 (A) Aortic root angiography in Case 12 showing a large ruptured non-coronary sinus to right atrial aneurysm. (B) Following device placement, there is a moderate residual shunt. (C) One-year later, follow-up angiogram shows a complete closure.
recently available long sheaths could make the procedure easier. However, most devices for left-to-right shunts are designed to be delivered from the venous side. Since ruptured SOVAs are commonly ‘windsock’-like with a broader aortic end, we believe that the first-generation ADO is best suited for this defect, although others have used other Amplatzer devices as well as coils. We chose an ADO that measured 2–4 mm larger than the aortic end of the defect in an attempt to close the defect at the stouter aortic end. The recently available ADO II (AGA Medical Corporation) can be delivered from the arterial side with ease. However, since it is available only in waist sizes 3–6 mm, it could be potentially utilizable only for ruptured small SOVAs with aortic end <4 mm.

We excluded patients of ruptured SOVA with multiple rupture sites, although one case report describes the closing two rupture sites with ADOs. In Case 4, a patient with a previous surgery had two defects, but the second defect was tiny. Hence, we addressed only the larger 4/4 mm defect. Post-procedure continuous flow through the tiny unaddressed defect was evident on colour Doppler, but clinically the patient had only a systolic murmur. Case 16 underwent surgical closure in view of the two large defects. Unfortunately, post-operatively, he had a significant residual shunt through the missed defect, which was closed by TCC successfully. It is important to rule out infective endocarditis as a possible aetiology for the acute presentation of the patient with ruptured SOVA accordingly we excluded any patient of ruptured SOVA even with a suspicion of infective endocarditis. Using the above discussed inclusion and exclusion criteria, about 70% of the patients of ruptured SOVA are potentially eligible for TCC in a referral centre like ours.

Technical considerations

The technique was very similar to TCC of perimembranous VSD, since the defect is located just above the aortic valve instead of below. Online TOE and colour Doppler interrogation were of utmost importance for (i) sizing the aortic end of the defect and hence to choose the device size (2–4 mm larger than the aortic end), (ii) understanding the SOVA anatomy as regards its neighbouring structures namely the aortic valve, tricuspid valve, and RVOT, (iii) guiding the ADO deployment, particularly ensuring seating of the aortic disk on the aortic side without slipping into the body of the aneurysm, (iv) most importantly, monitoring AR occurrence and residual shunting on colour Doppler, and (v) limiting contrast use by obviating the need for control angiography in some of these critically ill patients. Although Arora et al. have used TTE guidance, we believe that TOE guidance is crucial. Unlike Arora et al., we did not utilize balloon sizing of the defect since we were able to size the defect well on TEE. Moreover, akin to TCC of patent ductus arteriosus (PDA), there is little argument to balloon-size a funnel-shaped, ‘windsock’-like defect.

We attempted to close the ruptured SOVA at the aortic end similar to a ‘surgeon’s repair’ since closure at the rupture site (exit point) would leave behind an aneurismal sac exposed to arterial pressure with a potential to rupture at another site in the long term. Moreover, SOVAs could have more than one rupture sites. Fedson et al. have used two ADOs to close two rupture sites in an effort to stay away from the aortic valve cusps. With our approach, it would be imperative to rule out any interference with aortic valve cusp movements with online TOE as exemplified by failed Case 14. However, despite our best attempts to close the aortic end of the ruptured SOVA, in three patients, the aortic disk tilted slightly into the aneurysm. These patients have had no recurrence on mid-term follow-up.

Complications

Failure to deploy

Although we did not encounter technical difficulties in advancing the delivery sheath or the ADO in any of our patients, Chang et al. were compelled to use a Gianturco coil instead of the ADO to overcome tortuosity of the ruptured SOVA tract. Our failures were related to (i) large size of the defect in Case 9 as explained earlier and (ii) the occurrence of significant procedure-related AR before release in Case 14 due to encroachment of the aortic disk of the ADO on the aortic leaflet. On retrospective review, this may have been due to a short margin of the defect from the hinge point of the aortic leaflet and lack of an aneurismal pouch.

Residual shunting

Residual shunting at discharge seen in 5 of 18 successful procedures tended to be invariably mild and disappeared as the follow-up period increased. Interestingly, even the patient with a moderate residual shunt (despite receiving largest available ADO 16/14 mm) had a complete closure at 1-year follow-up (Figure 3). This patient had developed significant haemolysis and haemoglobinuria (with a haemoglobin drop of 2 g/dL), which abated spontaneously on the third post-operative day. A similar outcome has been described following TCC of a large PDA too. Residual shunting and severe haemolysis requiring repeat intervention and eventual surgery were also reported in one out of eight patients undergoing TCC of ruptured SOVA, emphasizing the need to achieve complete occlusion as far as possible.

Procedure-related aortic regurgitation

The occurrence of trivial procedure-related AR detected only by the sensitive colour Doppler modality in 4 out of 18 successful patients might seem worrisome, especially since perioperative AR has been reported as the single most important determinant of long-term outcomes following surgical repair of ruptured SOVA. Aortic regurgitation occurrence could be due to (i) the slight deformity of the cusps related to the device or (ii) a sudden increase in afterload caused by disconnection of the low resistance pulmonary circuit as described following TCC of PDA. Interestingly, in two of these four, the trivial AR had disappeared on follow-up, presumably related to chronic adaptation to the increased afterload or due to remodelling of the sinuses following endothelialization resulting in a lesser traction on the cusps by the ADO. In the other two patients, there has been no progression in the grade of AR. It is imperative to assess the presence of AR before, during, and immediately after the procedure by colour Doppler to draw any meaningful conclusions about TCC of ruptured SOVA. Although the surgical incidence of post-procedural AR is 6%, no procedure-related AR has been...
reported so far in the anecdotal case reports and small series,\textsuperscript{9–11} involving TCC of ruptured SOVA. Most surgical incidences are based on aortography and not on the sensitive colour Doppler modality. Our higher incidence in the immediate post-procedure period may be related to our penchant to prevent recurrence. Also we have carefully looked for such trivial procedure-related AR occurrence, which may have been missed by others. We think that the magnitude of this procedure-related AR is only trivial (less than Grade I) and not a cause for concern. Progression of such AR, if at all, is likely to be very gradual and stable over next 10–20 years.\textsuperscript{15} It only emphasizes the need for vigilant online TOE monitoring and the need for a longer follow-up of these patients.

**Potential for coronary encroachment**

Although encroachment of the ADO on the coronary arteries is carefully looked for both on TOE and control aortography, we do not perform selective coronary angiography unlike others.\textsuperscript{9,10} The coronary ostia are located quite high in relation to the SOVA, and device impingement of the coronaries is only a theoretical possibility that has never been reported.

**Conclusions**

Preliminary results of TCC of ruptured SOVA indicate that it is a promising alternative to surgery in appropriately selected cases in the immediate and mid-term period. However, this procedure should be directly compared with surgery to evaluate its safety and efficacy.

**Acknowledgements**

The authors wish to acknowledge Ms Durgesha Khobrekar for maintaining echocardiography records and Mr Karan Chavan for collecting catheterization and angiography data.

**Conflict of interest**: none declared.

**References**