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Transcatheter closure as an alternative and equivalent method to the surgical treatment of atrial septal defect in adults: Comparison of early and late results

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Summary

Background: The clinical efficacy of transcatheter atrial septal defect (ASD) closure with the Amplatzer Septal Occluder (ASO) can only be judged against the results of contemporaneous surgery. The present study compared early and late results of ASD closure using ASO versus open-heart surgery.

Material/Methods: Forty-eight adult patients were found eligible for transcatheter closure in transesophageal echocardiography. The surgical group consisted of 52 patients with isolated ostium secundum ASD. All patients underwent standard ECG, 24-hour ECG recording, and transthoracic echocardiography pre-procedure at 1-month and at 1-year follow-up. Physical fitness was assessed by cardiopulmonary exercise testing (CPX) prior to ASD closure and at 1-year follow-up.

Results: ASD closure was successful in all surgical patients and in 94% of the ASO group (0% mortality). The total complication rate for surgical vs. device closure was not significantly different (19.2% vs. 26.7%; p=0.383), despite more serious complications in the surgical group. Hospital stay was significantly shorter in the ASO group (5.4±2.2 vs. 9.1±1.2 days; p<0.001). Although echocardiographic parameters did not differ significantly between the respective groups at 1-year follow-up, CPX revealed a higher decrease in the VE/VCO_2 slope in the ASO group (–3.7±3.4 vs.–1.2±4.8; p=0.003).

Conclusions: As surgical and device closure appear similarly effective in adults with ASD, avoidance of thoracotomy and cardiopulmonary bypass, in conjunction with a shorter hospital stay, argues in favour of device closure in selected patients.

key words: **atrial septal defect • surgical closure • transcatheter closure**

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Background

Atrial septal defect (ASD) accounts for 10% of congenital heart abnormalities recognized at birth, and for up to 40% of congenital heart lesions detected in adults 40 years of age or older [1,2]. While this defect often remains asymptomatic in childhood, in adults a significant shunt is likely to cause symptoms over time, whereas symptomatic patients become progressively more impaired functionally as they age. It is generally accepted that elective closure of ASD is the treatment of choice if pulmonary-to-systemic blood flow ratio is >1.5. Surgical treatment of ASD has been practiced for over 50 years and appears to be a safe and effective procedure. Transcatheter closure of ASD with the Amplatzer Septal Occluder (ASO) has become a feasible alternative to conventional surgical closure in selected patients [3–5]. Transcatheter closure has the advantage of avoiding the need for sternotomy, cardiopulmonary bypass and intensive care stay, facilitates rapid patient recovery, and confers tangible social benefits and financial returns. On the other hand, this promising new technique must be effectively proven to facilitate comparable outcomes to justify its continued use. The clinical efficacy of ASD closure with ASO can only be judged against the results of contemporaneous surgery. Excellent early results of device closure do not guarantee a favourable late outcome; therefore long-term follow-up is necessary for final justification.

There are only a few studies comparing the results of surgical and device ASD closure, focusing predominantly on early outcomes and peri-procedural complications [6-10]. The present study aimed to compare the results of transcatheter ASD closure versus open-heart surgery in 1 institution at 1-year follow-up.

Material and Methods

A total of 100 adult patients with haemodynamically significant ostium secundum ASD underwent closure, either surgical or transcatheter using the Amplatzer Septal Occluder (ASO) in our cardiology center. The device group (ASO group) consisted of 48 prospectively enrolled patients who met transesophageal echocardiographic criteria for transcatheter closure between January 2003 and December 2005. In the surgical group, data for 52 consecutive patients operated on for isolated ASD between January 2001 and December 2003 were analysed retrospectively.

Table 1 summarizes baseline demographic and clinical data in the surgical and ASO groups. The groups did not differ significantly in age, gender distribution, incidence of systemic hypertension, stroke, diabetes and coronary artery disease, or the number of smokers. Neither was there any significant difference between groups in baseline echocardiographic and CPX data prior to ASD closure (Table 2).

Surgical closure

Surgery was performed through a median sternotomy with standard cardiopulmonary bypass, aortic cross-clamping, moderate systemic hypothermia (28–30°C) with flow rates of 2–2.2 l/min/m^2 and mean arterial pressure of 50–60 mmHg. Myocardial protection was achieved by the infusion of cold crystaloid cardioplegia into the aortic root (St Thomas' Hospital formula) and with topical hypothermia. A right atrial incision was made with care to avoid the area of the sino-atrial node around the insertion of the superior vena cava. The method used to close the defect (direct suture or pericardial patch) depended on its size and anatomical type. The same team of experienced surgeons performed all procedures.

Transcatheter closure with ASO

All patients with ASD deemed potentially eligible for transcatheter closure in transthoracic echocardiography were investigated in detail by transesophageal echocardiography (TEE). Cases of ASD with a transesophageal echocardiographic diameter of 29 mm or less with a septal rim of at least 5 mm from the right pulmonary veins, coronary sinus, superior caval vein, inferior caval vein and mitral valve, were considered suitable.

The protocol for device closure has been reported previously in detail [11]. Overall, the procedures were performed under local anesthesia, echocardiographic guidance and intermittent fluoroscopy. Following standard right heart catheterization and haemodynamic measurements, an exchange guide wire was placed in a left pulmonary vein. A sizing balloon was passed into the left atrium and the stretched diameter of the ASD was determined. Inclusion criteria included the ASD diameter as measured by sizing balloon – a stretched diameter of 38 mm or less. The sizing balloon was then exchanged for an appropriately sized device delivery sheath, and, following de-airing in the inferior caval vein, the appropriately sized ASO device was deployed and released across the defect. The correct sizing of the device and any residual shunting were assessed by transesophageal echocardiography of the atrial septum.

All patients underwent physical examination, standard resting ECG, 24-hour ECG recording and transthoracic echocardiography pre-procedure at 1-month and at 1-year follow-ups. Physical fitness was assessed by cardiopulmonary exercise testing (CPX) prior to ASD closure and at 1-year follow-up.

Transthoracic echocardiography (TTE)

In a 2D parasternal long axis view the right ventricular diastolic dimension (RV_d), left ventricular end-diastolic (LV_d) and left ventricular end-systolic (LV_s) dimensions were measured. The left ventricular ejection fraction (EF), using the Simpson method, and the right atrial area (RA_{area}) were evaluated in the 4-chamber view. In every patient the pulmonary-to-systemic flow ratio (Qp/Qs) was calculated, and right ventricular systolic pressure (RVSP) was measured in patients with tricuspid valve incompetence using the simplified Bernoulli formula. After ASD closure we performed TEE to exclude the residual shunt if TTE was not sufficient.

Cardiopulmonary exercise test (CPX)

A symptom-limited, incremental cardiopulmonary exercise test (modified Bruce protocol) was performed on a Marquette Treadmill 2000 Case 16 before ASD closure and a year after the procedure. The patients were encouraged to exercise to exhaustion. The testing procedure has been described in detail in a separate publication [12].

Table 1. Baseline demographic and clinical data for patients in the surgical and ASO groups.

	Surgical group n=52	ASO group n=45	*p*
Age (years)	38.9±14.7 17–68	42.4±13.0 18–62	0.218
Women	33 (63%)	28 (62%)	0.919
NYHA class	2.2±0.5 (1–3)	2.2±0.7 (1–3)	0.791
Systemic hypertension	4 (7.7%)	5 (11.1%)	0.820
Stroke/TIA	0	1(2.2%)	0.942
Diabetes	2 (3.8%)	1 (2.2%)	0.645
Coronary artery disease	0	1 (2.2%)	0.942
Smoking	3 (5.8%)	4 (8.9%)	0.843

Data are expressed as the means ±SD and range or number of patients, with percentages given in parentheses.

Submaximal exercise capacity was assessed by measuring oxygen consumption at anaerobic threshold, expressed as the percentage of the predicted maximal oxygen consumption – AT ($\%VO_{2max}$). The anaerobic threshold was determined from the plot of carbon dioxide output (VCO_2) against oxygen uptake (VO_2), where the slope of this linear relation increased owing to a rise in VCO_2 (V-slope method).

Maximal exercise capacity was assessed by peak oxygen consumption expressed both in ml/kg/min (VO_{2peak}) and as the percentage of the predicted value ($VO_2\%$). Pulse-O_2 was calculated as VO_2 ml/min divided by heart rate.

Ventilatory response to exercise, expressed as ventilation (VE) per unit of carbon dioxide production (VCO_2) – VE/VCO_2, was obtained by linear regression analysis of the data acquired throughout the entire period of exercise.

Table 2 summarizes baseline echocardiographic and CPX data in the surgical and ASO groups. There was no significant between-group difference in echocardiographic and CPX data prior to ASD closure.

Statistical analysis

Data for measurable variables were expressed as the mean ±SD and range. The non-parametric Mann-Witney U test was used to compare the baseline and follow-up echocardiographic and CPX data between the surgical and ASO groups that were not normally distributed. Comparisons of baseline and follow-up data from the study groups were assessed using the Wilcoxon test. The extent of improvement of CPX and echocardiographic data was assessed by calculating the difference between the follow-up and baseline variables in the surgical and the ASO groups. Categorical variables were compared using the chi-square test with the Yates correction if needed. A p-value <0.05 was considered significant.

Table 2. Baseline echocardiographic and CPX data for patients in the surgical and ASO groups.

	Surgical group n=52	ASO group n=48	*p*
Qp/Qs	2.6±0.7 1.5–4.3	2.4±0.7 1.5–5.1	0.104
RVSP (mmHg)	36.8±11.3 24–85	33.3±10.7 19–90	0.127
RV_d (mm)	38.0±6.1 29–50	36.1±4.8 28–44	0.086
RA_{area} (cm^2)	27.2±4.6 20–35	27.5±3.4 21–35	0.71
LV_d (mm)	43.9±5.3 35–58	45.8±6.2 32–56	0.092
LV_s (mm)	26.8±5.2 19–48	28.2±5.3 18–42	0.16
LVEF (%)	65.9±5.1 53–75	67.6±8.6 39–85	0.244
VO_{2peak} (ml/kg/min)	23.4±8.9 9.3–45.6	23.5±3.1 16.8–28.5	0.932
$VO_2\%$	64.3±18.0 31–100	70.4±12.0 60–112	0.053
AT ($\%VO_{2max}$)	39.8±7.8 26–59	40.4±4.3 28–47	0.624
Pulse-O_2	12.5±3.9 5.8–24.4	11.8±2.1 8.4–16.7	0.244
VE/VCO_2 slope	28.7±5.6 18–42	29.9±2.5 25.1–36.2	0.178

Data are expressed as the means ±SD and range.

Results

Early results

All patients from the surgical group underwent successful ASD closure by either a pericardial patch: 12 (23%) patients, or direct suture: 40 (77%) patients. Postoperative echocardiographic examination revealed total occlusion in all cases.

Successful deployment of ASO was achieved in 45 (94%) out of 48 patients. In 3 cases the device was not deployed, as the stretched diameter of the defect exceeded 38 mm and proved too large for the available device. These patients were referred for surgery.

TTE performed at 1-month follow-up revealed total occlusion in all patients.

Complications

No surgical or device-related death was recorded in either group. The complications encountered in each group within the early post-procedural period are listed in Table 3.

The total complication rate for surgical vs. device closure was not significantly different (19.2% vs. 26.7%; p=0.383),

Table 3. Peri-procedural complications in the surgical and ASO groups.

	Surgical group n=52	ASO group n=45	p
Surgical re-intervention (due to excessive bleeding)	1 (1.9%)	0	1.000
Bleeding requiring blood transfusion	3 (5.8%)	0	0.294
Episodes of hypotension requiring inotropic support	3 (5.8%)	0	0.294
Pneumothorax	1 (1.9%)	0	1.000
Total number of rhythm and conduction disturbances	1 (1.9%)	10 (22.2%)	0.005
Supraventricular tachycardia	1 (1.9%)	8 (17.8%)	0.008
Atrial fibrillation '*de novo*'	0	1 (2.2%)	0.942
Bradycardia	0	1 (2.2%)	0.942
Haematoma	0	2 (4.4%)	0.412
Post-pericardiotomy syndrome	1 (1.9%)	0	1.000
Total number of complications	10 (19.2%)	12 (26.7%)	0.383

Data refer to the number of patients, with percentages given in parentheses.

Table 4. Echocardiographic and CPX data for patients in the surgical and ASO groups at 1-year follow-up.

	Surgical group n=52	ASO group n=48	p
RVSP (mmHg)	26.5±6.2*** 17–42	25.0±7.6*** 19–70	0.282
RV_d (mm)	27.9±4.8*** 20–42	26.0±5.7*** 19–39	0.084
RA_{area} (cm^2)	18.4±2.7 12–25	18.7±2.4 13.5–24	0.48
LV_d (mm)	48.7±4.5*** 41–59	51.0±7.7*** 32–65	0.071
LV_s (mm)	31.0±6.8*** 22–53	30.9±5.1*** 18–40	0.918
LVEF%	67.3±6.6 50–78	68.6±8.5 39–85	0.374
VO_{2peak} (ml/kg/min)	29.7±10.2*** 12.4–54.8	31.7±8.3*** 19–50	0.286
VO_2 %	83.1±20.3*** 49–128	86.6±13.5*** 60–112	0.314
AT (%VO_{2max})	48.5±10.4*** 30–72	47.8±5.8*** 40–59	0.645
Pulse-O_2	14.4±0.9*** 12.7–16.2	14.0±1.6*** 8.6–17	0.154
VE/VCO_2 slope	27.1±4.2* 20.3–40.5	26.3±3.0*** 21-33	0.258

p<0.05, ***p<0.001 as compared with pre-procedure parameter. Data are expressed as the means ±SD and range.

although complications in the surgical group were more serious and resulted mainly from the surgical approach.

There was 1 surgical re-intervention due to excessive bleeding and another 3 patients required blood transfusions. Hemodynamic instability treated with inotropic support occurred in 3 patients. One patient had pneumothorax requiring pleural drainage and another suffered from supraventricular tachycardia.

The most serious complications in the device group were rhythm disturbances. Supraventricular tachycardia occurred in 2 patients: 1 patient suffered from atrial fibrillation following device closure and another had transient bradycardia (up to 30 beats per minute). The total number of rhythm and conduction disturbances in the device group was significantly higher as compared with the surgical group (1.9% vs. 22.2%; p=0.005).

There was a significant difference in length of hospital stay between patients from the surgical and ASO groups: 9.1±1.2 (range: 7–13) vs. 5.4±2.2 (range: 2–8) days; p<0.001.

Late results

There was no residual shunt observed on TTE or other late complications in either group at 1-year follow-up.

The mean NYHA class decreased significantly after ASD closure both in the surgical (2.2±0.5 vs. 1.2±0.4; p<0.001) and the ASO group (2.2±0.7 vs. 1.1±0.4; p<0.001), however, there was no significant between-group difference.

Table 4 summarizes echocardiographic and CPX data a year after ASD closure in the surgical and device groups. No significant differences in echocardiographic parameters a year after ASD closure were found between the study groups. The RV_d, RA_{area} and RVSP decreased significantly after the procedure, whereas LV_d and LV_s increased significantly in both groups. There was no significant difference in left ventricular ejection fraction in either group a year after ASD closure.

After surgical and ASO closure a significant increase in oxygen uptake was noted both at anaerobic threshold (AT) and peak exercise (VO_{2peak}), as well as a significant decrease in VE/VCO_2. Exercise capacity improved significantly, irrespective of the actual method of closure, and no significant differences between the groups were observed.

Table 5 compares the changes in echocardiographic and CPX parameters in the surgical and ASO groups at 1-year follow-up. There were no significant differences in echocardiographic data between the surgical and ASO groups, nor

Table 5. Comparison of changes in echocardiographic and CPX parameters in the surgical and ASO closure groups at 1-year follow-up.

	Surgical group n=52	ASO group n=48	p
RVSP (mmHg)	−9.5±8.7	−8.4±5.5	0.462
RV_d (mm)	−10.2±5.2	−10.1±4.5	0.893
RA_{area} (cm^2)	−8.9±3.3	8.8±2.4	0.92
LV_d (mm)	4.9±3.4	5.2±6.7	0.744
LV_s (mm)	4.3±7.3	2.6±3.8	0.177
LVEF (%)	1.3±6.9	1.0±4.7	0.811
VO_2 (ml/kg/min)	6.3±7.0	8.2±6.5	0.155
VO_2 peak%	18.7±18.5	16.1±9.5	0.376
AT (%VO_{2max})	8.8±9.5	7.4±4.9	0.359
Pulse-O_2	2.0±2.4	2.2±2.4	0.639
VE/VCO_2 slope	−1.2±4.8	−3.7±3.4	0.003

Data are expressed as the means ±SD.

did we find any significant differences in peak oxygen uptake, anaerobic threshold or pulse-O_2. However, there was a significant difference in VE/CO_2 decrease between the surgical and ASO groups (–1.2±4.8 vs. –3.7±3.4; p=0.003).

Discussion

Several reports have demonstrated that transcatheter ASD closure with the ASO is a safe and effective procedure [3–5]. However, there are only a few studies comparing the results of surgical and device closure which focused predominantly on early outcomes and peri-procedural complications [6–10]. Moreover, in these studies the groups of patients undergoing device or surgical closure varied in age (both children and adults were enrolled), Qp/Qs and RVSP, and therefore any attempt at comparing the results of ASD closure using these methods may well be biased.

To preclude significant baseline differences between the respective study groups (since 2003 transcatheter ASD closure has widely been performed in our center, and therefore only a select group of patients is referred for surgery) we compared outcomes in the group of consecutive adult patients after device closure (between 2003 and 2005) and consecutive surgical patients with isolated ostium secundum defect (between 2001 and 2003). In this way we collected data from groups of patients with no significant differences in demographic, clinical and haemodynamic variables.

Zero mortality was recorded in both groups of patients, which is consistent with the results of previous studies [3,13]. Total occlusion was achieved in all surgical patients and in 94% of patients in the device group. We believe that a higher closure rate in the device group may have been achieved through gaining more experience with accurate selection of patients on the basis of TEE.

Peri-procedural complications occurred irrespective of the method of closure, although they proved more serious in the surgical group (1 patient required surgical re-intervention due to excessive bleeding). Other serious complications included bleeding and subsequent need for blood transfusion, as well as episodes of hypotension and pneumothorax. Although all patients with a complicated peri-procedural course effectively recovered, their hospital stay and recuperation period were longer than in the ASO group.

The most common complications in the device group were cardiac arrhythmias in the wake of the procedure itself, which eventually disappeared during the follow-up, a problem also addressed by other investigators [14,15]. No other serious complications, e.g. device embolization or thrombus formation in the left atrial disc, were encountered, although other authors have recorded such occurrences. This might be attributable to the relatively small number of patients in the device group.

To the best of our knowledge the present study is the only one to date comparing late results of surgical and device ASD closure in CPX and echocardiography. Thus far only the acute effects of right ventricular hemodynamics of surgical versus transcatheter closure of ASD have been investigated [16].

The hospital stay in the ASO group was significantly shorter in comparison to the surgical group: 5.4±2.2 (range: 2–8) vs. 9.1±1.2 (range: 7–13) days; p<0.001. In fact, the hospitalization for the ASO group could have been shorter still, as ambulatory diagnosed ASD can be closed in one day's hospitalization. The long hospitalization of patients in the ASO group was due to methodological reasons: time was required to perform diagnostic TEE, TEE, 24-hour ECG tracing and CPX.

At 1-year follow-up patients improved their NYHA class and cardiopulmonary capacity, irrespective of the actual method of closure. Interestingly, after ASD closure, VE/CO_2 slope decreased more in the ASO than in the surgical group. The mechanism by which the method of closure might affect ventilation is not well understood, however. Recently, the increased VE/VCO_2 slope has been proven to be a strong predictor of mortality in adults with congenital heart diseases, including patients with ASD [17]. If the greater decrease in VE/VCO_2 slope in the ASO group is corroborated by other studies, it might facilitate outcomes superior to the surgical approach.

Limitations of the study

The study was not a randomised trial for a number of logistic and ethical reasons. Another limitation was a relatively short follow-up period.

Conclusions

Surgical and device closure appear to offer similar efficacy in adults with ASD. Since thoracotomy and cardiopulmonary bypass, given their potential for serious complications, may be effectively avoided and length of hospital stay reduced, device closure seems a feasible alternative for selected patients. On the other hand, the extent to which transcatheter technique may prove useful must ultimately be verified in long-term follow-up studies.

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