Right to left shunt through interatrial septal defects in patients with congenital heart disease: Results of interventional closure

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Key words: cardiac catheterisation, atrial septal defect, patent foramen ovale, cyanosis
Abstract

Objective: To study the effects of closure of interatrial communications associated with a right to left shunt, in congenital heart disease patients having had a biventricular repair.

Design: Retrospective study.

Setting: Tertiary referral centre.

Patients: 15 congenital heart disease patients with right to left shunt through an interatrial communication: 3 had repaired tetralogy of Fallot, 5 repaired pulmonary atresia with intact ventricular septum, 4 Ebstein disease, 3 other congenital heart diseases. Two patients had had a stroke before closure of the interatrial communication.

Interventions: Percutaneous atrial septal defect (ASD)(n=6) or patent foramen ovale (PFO)(n=9) closure. All patients underwent an exercise test before and after interatrial communication closure.

Results: Five patients were cyanotic at rest. At exercise, mean (SD) oxygen saturation diminished from 93.9 (3.8) to 84.3 (4.8) %, p<0.05. Interatrial communication closure led to immediate increase of oxygen saturation from 93.9 (3.8) to 98.6 (1.6) %, p<0.05. At a median follow-up of 3 years (range 0.5-5) all but one patient with a residual ASD have normal oxygen saturation at rest and at exercise. Maximal work load increased from 7.2 (1.9) to 9.0 (2.2) Mets, p<0.001.

Conclusions: Percutaneous closure of interatrial communications associated with a right to left shunt allows to restore a normal oxygen saturation at rest, to avoid desaturation at exercise and to improve exercise performance in congenital heart disease patients.
Introduction

Interatrial communications are usually closed, to prevent late right heart failure, arrhythmias and pulmonary hypertension, when they induce right ventricular overload by means of left to right shunt. [1]

Right to left shunt through a patent foramen ovale (PFO) or an atrial septal defect (ASD) has been reported in several conditions such as postoperative respiratory distress syndrome, [2] cardiac tamponade, [3] obstructive sleep apnoea, [4] platypnoea-orteodoxya syndrome [5] and right ventricular cardiomyopathy. [6] Closure of interatrial communications in these conditions usually improves or resolves symptoms. [5] Although several authors highlighted the importance of suppressing a surgically created right to left shunt in Fontan patients, no specific reports exist on closure of interatrial communications associated with right to left shunt in children with congenital heart disease (CHD) having had a biventricular repair.[7]

Right to left atrial shunt occurs when right atrial pressure is higher than left atrial pressure. This can be observed in patients with pulmonary hypertension, right ventricular dysfunction or diminished right ventricular compliance. [2] [3] [4] [5] [6] This latter condition can be unmasked at exercise. Right to left shunt through an interatrial communication is burdened by the risk of stroke. In addition, systemic desaturation at rest and/or at exercise can limit physical ability and impair life quality of patients with repaired CHD. [8]

The aim of our study was to present the results of interventional suppression of right to left shunt in 15 consecutive patients with congenital heart disease.

Population

From January 2000 to December 2004, 15 patients with congenital heart disease (median age 13 years, median weight 38 Kg) and a right to left shunt through an interatrial communication, underwent percutaneous ostium secundum type atrial septal defect (ASD)(n=6) or patent foramen ovale (PFO)(n=9) closure. Their clinical characteristics are illustrated in Table 1. Patient 14 had a surgically created ASD due to the presence of diminutive pulmonary arteries; it was included in the study even if, at time of ASD closure, he had a normal oxygen saturation at rest and a minimal decrease of oxygen saturation during exercise. Three patients had repaired tetralogy of Fallot, 5 repaired pulmonary atresia with intact ventricular septum, 4 unrepaired or palliated Ebstein disease, 3 other repaired CHD (Table 1). Three patients with unrepaired Ebstein disease had a minor form of the disease, without major incompetence or malformation of tricuspid valve. Surgical repair of tricuspid valve was not considered to be indicated in this subset of patients. Only one patient with Ebstein disease had had a partial cavopulmonary connection because plasty of tricuspid valve was not considered to be useful. Complete repair was preceded by a Blalock-Taussig shunt in patients 5, 10,13. Patients 5, 9 and 12 underwent percutaneous, and patient 7 surgical, Blalock-Taussig embolisation. Patient 9 had Blalock-Taussig embolisation during atrial septal defect closure. Patient 1 and 6 had had spontaneous closure of the Blalock Taussig shunt. Patient 8 underwent complete repair of tetralogy of Fallot at the age of 1 month, prosthetic substitution of the pulmonary valve (Hancock n° 12) at 6 months and substitution of the pulmonary outflow at the age of 5 years (homograft 16 mm). She had repeated percutaneous dilations of the pulmonary outflow and pulmonary arteries and finally she had 3 stent implantations in the pulmonary conduit and in both pulmonary arteries.
Patients 2 and 15 had had a stroke before ASD or PFO closure (table 1). Patient 2 had had repetitive visual troubles, migraine and vertigo since the age of 12 years; at the age of 15 years, she had a right cerebellar embolism, after which PFO closure was performed. She had a gradual complete resolution of symptoms.

Patient 15 had had several episodes of pulsatile migraine since the age of 13 years. At 16 years he had a right temporal embolism accompanied by left facial hemiparesis and cognitive troubles. He still has mild sequelae. Most patients complained of fatigue during mild exercise. Patient 4 had migraine, however neurological evaluation and imaging were normal. No patient had an hematocrit value higher than 48%.

Atrial communication closure was considered in the presence of mild or moderate desaturation at rest (≥ 85%) accompanied by low flow velocity through the interatrial communication at transthoracic echocardiography or when desaturation at exercise occurred. Patients with increased pulmonary arterial pressure and patients with desaturation at rest lower than 85% were excluded.

Methods

All but 2 patients underwent exercise test at a maximal interval of 3 months before and after percutaneous closure of the interatrial communication.

Patient 6 did not have an exercise test because of young age and patient 13 was unable to perform it because of severe scoliosis. Exercise test was performed on a stationary cycle following the Bruce protocol. [9] Maximal work load, maximal heart rate, maximal systolic arterial pressure and oxygen saturation at rest and at maximal exercise were measured. Maximal work load was expressed in Mets, utilising the following formula: \[ \frac{(\text{Watts} \times 10.3) + (\text{Kg} \times 3.5))}{(\text{Kg} \times 3.5)} \]. Cyanosis was defined as peripheral oxygen saturation < 95%.

Closure of interatrial communication was carried out under general anaesthesia, with fluoroscopic and transoesophageal echocardiographic monitoring. Antibiotic prophylaxis was administered.

Different devices were utilised, according with the anatomy of the interatrial communication. Briefly, through the right femoral vein, a multipurpose catheter and then a guide-wire, was advanced through the interatrial communication into the left superior pulmonary vein. The stretched diameter of the interatrial communication was measured inflating a non compliant balloon over the guide-wire through the atrial septum, until suppression of interatrial shunt occurred. [10] Balloon waist, measured at fluoroscopy and echocardiography, allowed to choose the appropriate device diameter. The technique did not differ from that used for closure of interatrial communications with left to right shunt; however, in patients with right to left shunt at rest, closure of interatrial communication was preceded by test occlusion, in order to exclude a possible significant increment of mean right atrial pressure. A long sheath was then advanced over the wire to the left atrium, the guide-wire was retrieved, the device was inserted into the sheath, advanced and deployed in accordance with the techniques recommended for each type of device. [11] [12] [13] In patients in whom an Amplatzer septal occluder was utilised, the device was not upsised as compared to patients with a left to right shunt. When echocardiography confirmed correct device positioning, the device was delivered and a final echocardiography was performed in order to evaluate any residual shunt, to highlight any possible impinging of parts of the device into cardiac structures and to rule
out the presence of pericardial effusion. A residual shunt was considered to be present if colour Doppler flow mapping showed a left to right or right to left shunt across the interatrial septum. It was defined as trivial (<1 mm color jet width), small (1 to 2 mm colour jet width), moderate (2 to 4 mm colour jet width) or large (>4 mm colour jet width). [1]

Age and weight were quoted as median and a range; continuous variables were presented as the mean (standard deviation). Comparison for individual parameters before and after interatrial communication closure was performed using the two-tailed paired t test. A two-sided p value of 0.05 or less was considered to indicate statistical significance.

Results

Five patients, 3 with Ebstein disease (patients 1, 4 and 5) and 2 with repaired pulmonary atresia with intact ventricular septum (patient 6 and 7) had desaturation at rest. In our series, hematocrit value did not correlate with oxygen saturation at rest, likely because desaturation at rest was often mild and present only in 5 patients. Maximal work load was 7.2 (1.9) Mets, maximal systemic arterial pressure 137 (15.2) mmHg and maximal heart rate 173 (16.8) beats/minute. Before ASD or PFO closure 8 patients performed a submaximal test. At maximal exercise mean oxygen saturation diminished from 93.9 (3.8) % to 84.3 (4.8) %, p<0.05.

Closure of interatrial communication was possible in all patients (table 2). It prompted an immediate increase of mean oxygen saturation from 93.9 (3.8) % to 98.6 (1.6)%, p<0.05. Mean right atrial pressure did not change significantly: from 8.3 (1.8) mmHg to 8.7 (2.1) mmHg, nor did end diastolic right ventricular pressure. Three patients had small and 1 had moderate residual shunt. No complications occurred.

Exercise test, performed 2.3±0.9 months after interatrial communication closure, showed that maximal work load increased from 7.17 (1.93) to 9,03 (2.2) Mets, p <0.001, whilst maximal systolic arterial pressure and maximal heart rate did not change significantly: 155 (31.8) mmHg and 183 (8.9) beats/min, respectively. Oxygen saturation at maximal exercise increased from 84.3 (4.8) % to 97.5 (2.8) %, p <0.001.

At a median follow-up of 3 years (range 0.5-5) all patients are asymptomatic. There was not recurrence of cerebral events. Migraine regressed in patient 2 and 15. Patient 11 had radiofrequency ablation of an accessory pathway (WPW syndrome), responsible of episodes of supraventricular tachycardia.

All patients with immediate postprocedural small residual shunt have no residual shunt at transthoracic echocardiography. Patient 4 has a residual ASD with trivial shunt at rest and mild right to left shunt at exercise (maximal oxygen saturation decreased from 96% to 82%). All the remaining patients have a normal oxygen saturation at rest and at exercise.

Discussion

Spontaneous or induced right to left shunt through an interatrial communication is associated with two main possible complications: systemic embolism and systemic desaturation. In adult
population, several conditions exist in which closure of an interatrial communication has been advocated to prevent or treat symptoms.

Percutaneous closure of patent foramen ovale is considered at least equivalent to medical treatment in patients with cryptogenic stroke and repeated cerebral embolism. [14] Patients affected by platypnoea-orthodeoxia syndrome generally completely recover after surgical or percutaneous suppression of the interatrial shunt. [5] [15] Other authors reported the results of percutaneous suppression of right to left shunt in patients with atrial right to left shunt and normal pulmonary arterial pressure. [16] Bassi et al reported the successful percutaneous suppression of a right to left interatrial shunt in the setting of a right ventricular infarction. [17]. Ebeid et al reported the feasibility of percutaneous atrial septal defects closure in 2 patients with pulmonary atresia and intact ventricular septum having a prominent eustachian valve. [18] However, at our knowledge, no reports exist concerning mid term results of percutaneous suppression of right to left shunt in patients with CHD having had a biventricular repair. In patients with repaired CHD, a right-to-left atrial shunt through an ASD or a PFO can occur at rest and/or at exercise, when one or more of the following conditions are present: diminished right ventricular compliance, right ventricular dysfunction or functional or anatomic tricuspid valve restriction such as in Ebstein anomaly.

Desaturation at rest is rare in repaired CHD. It can however be a prominent physical finding in patients with native or palliated Ebstein anomaly of tricuspid valve. The right to left shunt in this setting is the consequence of a number of factors, including interference of right ventricular filling by the redundant valve leaflets and insufficiency of the tricuspid valve into the atrialised portion of the right ventricle. [16] We included in our series 3 patients with a minor form of Ebstein disease, whose only symptom was systemic desaturation. None had a significant regurgitation of tricuspid valve that could have lead, after ASD closure, to further enlargement of the right atrium. Indeed, in these patients the risk of repeated stroke was considered important and the closure of the interatrial communication was not thought to prevent a possible future surgical option. In our series, apart 3 patients with Ebstein disease, two more patients with repaired pulmonary atresia an intact ventricular septum had desaturation at rest, likely because of a diminished right ventricular compliance and volume. Cyanosis at rest is typically associated with polycythemia, due to an erythropoietin mediated response to the hypoxic environment. Patients with cyanotic heart disease invariably have reduced exercise tolerance and are at risk of cerebral embolism, due to increase blood viscosity and clot formation. [19] Thus, cerebral events in polycythemic patients should be expected, mostly in the presence of a right to left shunt through the atrial septum. Increased cyanosis or appearance of cyanosis at exercise is due to diminished ventricular filling during more rapid heart rates. Patients who are still cyanotic in the absence of pulmonary vascular disease usually are able to exercise only at low intensity levels secondary to either increasing cyanosis with exercise or secondary to pulmonary limitations of exercise. [8]

In our series, right to left interatrial shunting was responsible of cyanosis either at rest or at exercise. In patients with normal oxygen saturation at rest, unmasked cyanosis at exercise revealed impaired right ventricular compliance when cardiac output and right ventricular end diastolic volume increased. This series included 1 patient with mild Ebstein disease and 9 patients with repaired obstructive disease of the right heart. Thus, desaturation at rest can persist in some patients with repaired obstructive disease of the right heart, although desaturation at exercise is more common in this group of patients.
Patients with evident cyanosis at rest and an increase in right atrial pressure higher than 5 mmHg were not considered to benefit from interatrial communication closure. Excessive increase of right atrial pressure could in fact be detrimental and prompt an increase in central venous pressure, with subsequent development of hepatomegaly and oedema. Unfortunately, at the time of the study, MRI, that would have helped us to evaluate right ventricular size and function, was not available for paediatric patients.

Cerebral events occurred in two 2 patients having either mild desaturation at rest or at exercise. In both, stroke was preceded by migraine and/or visual troubles. Thus, mild desaturation at exercise should not be underestimated in CHD patients and the risk of paradoxical embolism should be kept in mind.

Although we did not measure oxygen consumption, we showed that, in our series, work capacity improved early after interatrial communication closure. In addition, easy fatigability regressed in all but 1 patient with a residual shunt.

It is difficult to study right ventricular function in systole and diastole and therefore, to evaluate right ventricular compliance with standards echocardiographic methods.

However, standard exercise test is a widespread technique, capable to identify patients who could benefit from closure of an interatrial communication. Indeed, when desaturation occurs only at exercise, symptoms can be scanty. However, closure of the interatrial communication should be taken into consideration in these patients because of the risk of stroke. Standard exercise test should be recommended in patients with repaired obstructive disease of the right heart and in those with minor forms of Ebstein disease. However, in Ebstein patients suppression of right to left shunt could potentially lead to further enlargement of the right atrium and development of arrhythmias. Long term studies could probably clarify this issue.

In conclusion, our data show that percutaneous closure of interatrial communications associated with a right to left shunt allows to restore a normal oxygen saturation at rest, to avoid desaturation at exercise and to improve work capacity. Evaluation of oxygen consumption and more sophisticated studies of right ventricular compliance should be encouraged.

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References

Table 1. Characteristics of the patients at cardiac catheterisation

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<th>Weight Kg</th>
<th>ASD-PFO</th>
<th>Symptoms</th>
<th>Oxygen saturation at rest %</th>
<th>Oxygen saturation at maximal exercise %</th>
<th>Hematocrit %</th>
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Abbreviations: IS : intact septum, cTGA: corrected transposition of the great arteries, VSD: ventricular septal defect, PA: pulmonary atresia, * surgically created, BT: Blalock-Taussig, PCPC: partial cavopulmonary connection, RVOT: right ventricular outflow tract
Table 2. Haemodynamic data before and after interatrial communication closure

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Abbreviations. ASO: Amplatzer septal occluder, RAP: right atrial pressure, RVEDP: right ventricular end-diastolic pressure
Table 3. Ergometric data before and after interatrial communication closure, and outcome of patients

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<td>97</td>
<td>94</td>
<td>9.4</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Abbreviations: RF: radiofrequency ablation of accessory pathway