Hybrid approaches to complex congenital cardiac surgery

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Abstract

Objectives: A hybrid operation is a joint procedure involving the interventional cardiologist and the cardiac surgeon concomitantly to optimise surgical management. The aim of our study was to demonstrate the conceptual development and the feasibility of a hybrid approach to complex congenital cardiac surgery. Methods: Descriptive study of two different indications for concomitant intervention by the cardiologist and the cardiac surgeon. Seven patients with complex congenital heart defects requiring high risk operative interventions were included in the study. The indications were: (1) intraoperative stenting of a pulmonary artery stenosis with concomitant additional surgical procedures (n = 4). (2) Balloon occlusion of Blalock-Taussig shunts or major aorto-pulmonary collateral artery to control pulmonary blood flow during surgical repair (n = 3). Results: All patients had successful hybrid procedures. There were no important complications related to the temporal proximity of the interventional procedure and cardiac surgery, the latter being significantly facilitated by the former. Conclusions: Intraoperative stenting of pulmonary artery stenosis with additional surgical repair and balloon occlusion on cardiopulmonary bypass can be performed safely and may be complementary in patients with complex lesions by providing a better result in combination than either alone can offer. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Complex congenital heart defects; Hybrid; Catheterisation; Surgery

1. Introduction

Surgery remains the treatment of choice for the majority of children with complex heart disease. Over the last two decades, however, it has become possible to treat an increasing number of anatomically simpler conditions by interventional cardiology [1].

With increasing experience of both approaches it is becoming apparent that surgery and interventional techniques may be complementary, with pre- and postoperative intervention used to augment the results of surgery. Occasionally, the operative procedure itself cannot be accomplished by sequential surgery and catheter-based intervention. A simultaneous approach may optimally be required to minimise risk, reduce complexity of the procedure, or improve the outcome.

In adult cardiac surgery, the term ‘hybrid’ has been used to describe the combined surgical and interventional myocardial revascularisation in sequential fashion. In complex congenital cardiac diseases, the hybrid procedure is undertaken in the same setting as opposed to the staged procedures in adults [2].

The first description of a combined surgical and interventional approach was reported by Bhati and colleagues in 1972 [3]. They used a balloon catheter to temporarily occlude a persistent ductus arteriosus which was not easily accessible intraoperatively. With the balloon positioned in the duct from an incision in the pulmonary artery it was possible to suture the duct from inside. Subsequently, intraoperative stenting has been reported and we have already described the current status of intraoperative closure of ventricular septal defect (VSD) [4]. We report here two additional indications and the successful use of the hybrid approach in complex congenital heart disease. The aims of using the hybrid approach were to reduce the number of interventions, reduce the operative complexity, and to avoid prolonged cardiopulmonary bypass.

2. Patients and interventions

Seven interventions in seven surgical patients are described, and the indications for a hybrid approach are categorised into two groups.
1. Intraoperative stenting of pulmonary artery stenosis with additional surgical procedures (n = 4).

2. Balloon occlusion of systemic-to-pulmonary arteries connection to control pulmonary blood flow during cardiopulmonary bypass (n = 3).

2.1. Intraoperative stenting of pulmonary artery stenosis with additional surgical procedures (Table 1)

2.1.1. Case 1

A 9-year-old girl with double inlet/double outlet right ventricle, a previous pulmonary artery banding, a previous modified left Blalock-Taussig shunt and a bidirectional cavopulmonary anastomosis, experienced decreasing effort tolerance and increasing cyanosis (haematocrit 77%, resting oxygen saturation 60%). Cardiac catheterisation demonstrated reverse flow from the pulmonary artery to the superior vena cava and a left pulmonary artery stenosis at the site of the previous shunt. With the patient on cardiopulmonary bypass, the superior vena cava was reconnected to the right atrium with a 22 mm Gore-tex tube and a 8 mm central shunt was inserted. Due to dense adhesions and a rather posterior and distal position, the stenotic left pulmonary artery was difficult to access and it was decided to balloon dilate intraoperatively. The stenosis was dilated using a size 8 and a size 10 balloon, which was inserted under direct vision. The balloon angioplasty was reinforced with a size 10 mm Palmaz stent. Postoperative chest X-ray showed a good position and size (Fig. 1). The patient was extubated the following day and discharged after 9 days.

2.1.2. Case 2

A 3-year-old boy post correction of tetralogy of Fallot had a dislodged pulmonary artery stent in the right ventricular outflow tract during attempted balloon angioplasty and stenting of the bifurcating pulmonary artery stenoses. The child underwent surgery using cardiopulmonary bypass. The right ventricular outflow tract was opened and the dislodged stent was retrieved. Due to severe right ventricular hypertrophy and dilatation and dense adhesions, the pulmonary artery stenoses were difficult to access surgically, and intraoperative angioplasty and stenting of both pulmonary arteries were performed by 6 mm stents. A size 19 mm pulmonary homograft was used to reconstruct the right ventricular outflow tract. After discontinuation of bypass the right ventricular pressure was less than 50% of systemic arterial pressure.

At cardiac catheterisation 2 years later there was mild intimal growth at both stents. The right pulmonary artery stent was balloon dilated to 8 mm and the left was balloon dilated to 9 mm.

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Table 1

<table>
<thead>
<tr>
<th>Age</th>
<th>Diagnosis</th>
<th>Intervention</th>
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<tbody>
<tr>
<td>Case 1 (9 years)</td>
<td>DIRV/DORV. s/p LMBTS. s/p bidirectional Glenn with reverse flow from PA to SVC</td>
<td>Reconnection of SVC to RA with Gore-tex tube. Central shunt. Balloon dilatation and stenting of LPA stenosis</td>
</tr>
<tr>
<td>Case 2 (3 years)</td>
<td>s/p Fallot repair. RPA and LPA stenosis. Dislodged PA stent in RVOT during attempted balloon angioplasty and stenting</td>
<td>Removal of displaced stent in RVOT. Intraoperative stenting of LPA and RPA. Homograft from RV-PA</td>
</tr>
<tr>
<td>Case 3 (9 years)</td>
<td>Absent right atrio-ventricular connection, ventriculo-arterial discordance, restrictive VSD. s/p CoA + PA banding + Damus-Kaye-Stansel + TCPC. SVC to RPA stenosis. Compression of IVC to PA tunnel with proximal SVC stenosis. Compression of LPA behind aorta</td>
<td>Gore-tex repair of SVC + IVC tunnel. Stent in upper part of IVC tunnel. Stent in LPA</td>
</tr>
<tr>
<td>Case 4 (18 years)</td>
<td>Pulmonary atresia, VSD. s/p RMBTS (not patent). s/p central shunt (not patent). s/p LMBTS (stenosed)</td>
<td>Surgical enlargement of LPA and shunt. Stenting of LPA. LMBTS temporarily closed during CPB</td>
</tr>
</tbody>
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*a CoA, coarctation of aorta; CPB, cardiopulmonary bypass; DI/DORV, double inlet/double outlet right ventricle; IVC, inferior vena cava; LMBTS, left modified Blalock-Taussig shunt; LPA, left pulmonary artery; MPA, main pulmonary artery; PA, pulmonary artery; RA, right atrium; RMBBS, right modified Blalock-Taussig shunt; RPA, right pulmonary artery; RV, right ventricle; RVOT, right ventricular outflow tract; SVC, superior vena cava; TCPC, total cavopulmonary connection; and VSD, ventricular septal defect.

Fig. 1. Chest X-ray showing the positioning of the stent in the left pulmonary artery in a 9-year-old girl with functional univentricular heart.
2.1.3. Case 3
A 9-year-old boy with absent right atrioventricular connection, ventriculo-arterial discordance and a restrictive VSD, had a previous coarctation repair and a pulmonary artery banding followed by a Damus-Kaye-Stansel procedure and a total cavo-pulmonary connection (lateral tunnel type). He was admitted because of increasing cyanosis and deteriorating exercise tolerance. Cardiac catheterisation showed stenosis of the superior vena cava to right pulmonary artery anastomosis, a long segment (1.5 cm) compression of the left pulmonary artery posterior to the aorta and compression of the inferior vena cava pathway to the pulmonary artery with a severe stenosis at the cardiac end of the proximal superior vena cava. He underwent redo total cavopulmonary connection. The channel was opened from the inferior vena cava towards the superior vena cava but not right across to avoid the area of the sino-atrial node. As this area was still narrow, a stent (18 mm long) was positioned and inflated by a 15 mm balloon.

In addition, due to the deep position of the compressed left pulmonary artery behind the aorta, surgical reconstruction would carry a higher risk than placement of a stent. Therefore, a 3 cm stent was placed and inflated by a 15 mm balloon. Postoperative echocardiogram showed good ventricular function. The patient was in sinus rhythm. An injection angiogram through the internal jugular vein catheter showed that the superior vena cava and the inferior vena cava pathways were widely patent, as was the left pulmonary artery.

2.1.4. Case 4
An 18-year-old girl born with pulmonary atresia, a VSD and with the aorta from the right ventricle, was diagnosed to have an occluded right modified Blalock-Taussig shunt and an occluded central shunt. A left modified Blalock-Taussig shunt was patent with preferential flow to the left lung. There was a severe stenosis (4 mm in diameter and 1 cm in length) of the left pulmonary artery medial to the shunt insertion.

The pulmonary artery and the shunt were opened across the stenosed area. As the shunt was very close to the left upper lobe artery and to a posterior branch to the left lower lobe, further opening of the stenosed area was not possible. Gore-tex (0.4 mm) was patched into the opening of the pulmonary artery and the shunt. Due to concerns about residual stenosis at the pulmonary artery end of this reconstruction, balloon dilatation and stenting (9 mm) was performed. Cardiac catheterisation was performed 2 days following repair. Left pulmonary artery pressure was 29/25 mmHg and there was a good flow across the reconstructed shunt. Oxygen saturation was 81%.

2.2. Balloon occlusion of systemic-to-pulmonary artery connections to control pulmonary blood flow during cardiopulmonary bypass (Table 2)

2.2.1. Case 5
An 8-year-old girl who had concordant atrio-ventricular connection with straddling tricuspid valve and hypoplastic left ventricle, double outlet right ventricle with subpulmonary VSD, severe pulmonary stenosis, Blalock-Hanlon atrial septectomy and bilateral Blalock-Taussig shunts, underwent a cardiac catheterisation because of increasing cyanosis and breathlessness.

Angiography showed severe stenosis of the right pulmonary veins at the veno-atrial junction and a restrictive atrial septal defect (ASD). Prior to surgery for direct relief of pulmonary venous stenosis and enlargement of the ASD, the child was taken to the catheter laboratory and a balloon catheter was positioned un-inflated in each of the Blalock-Taussig shunts. The child was then transferred to the operating theatre. The cardiopulmonary bypass was established and the two shunts were balloon occluded (Fig. 2). The perfusion pressure increased from 32 to 60 mmHg and there was little pulmonary venous return interfering with the operative field. The atrial septectomy was enlarged and the pulmonary venous stenosis was then surgically relieved using a sutureless pericardial patch technique. The two balloons were deflated intraoperatively and removed in the intensive care unit.

Table 2
Balloon occlusion of systemic-to-pulmonary artery connections

<table>
<thead>
<tr>
<th>Age</th>
<th>Diagnosis</th>
<th>Intervention</th>
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<tr>
<td>Case 5 (8 years)</td>
<td>DORV. Subpulmonary VSD. Hypoplastic LV. Straddling TV. Severe PA stenosis. Bilateral BTS. Severe stenosis of right pulmonary veins</td>
<td>Temporary balloon occlusion of RMBT and LMBT shunts. Repair of pulmonary venous stenosis.</td>
</tr>
<tr>
<td>Case 6 (21 years)</td>
<td>Tricuspid atresia. Pulmonary atresia. TGA. Disconnected pulmonary arteries. MAPCA from descending aorta supplying the left lung. Stenosed 6 mm Gore-tex shunt from subclavian artery to RPA. Restrictive VSD</td>
<td>Temporary occlusion of MAPCA while connecting the pulmonary arteries. Insertion of an 8 mm Gore-tex shunt. VSD enlargement</td>
</tr>
<tr>
<td>Case 7 (7 years)</td>
<td>Left atrial isomerism, absent left atrioventricular connection, bilateral SVC, aygys continuation of IVC, s/p PA banding, s/p Damus-Kaye-Stansel procedure. s/p RMBTS (not patent). s/p LMBTS. Severe RAVVR</td>
<td>Balloon occlusion of LMBTS while on bypass. Annuloplasty and bilateral cavo-pulmonary anastomoses. Take-down of LMBTS</td>
</tr>
</tbody>
</table>

a BTS, Blalock-Taussig shunt; DORV, double outlet right ventricle; IVC, inferior vena cava; LMBTS, left modified Blalock-Taussig shunt; LPA, left pulmonary artery; LV, left ventricle; MAPCA, major aorto-pulmonary collateral artery; PA, pulmonary artery; RAVVR, right atrioventricular valve regurgitation; RMBTS, right modified Blalock-Taussig shunt; RPA, right pulmonary artery; SVC, superior vena cava; TCPC, total cavopulmonary connection; TGA, transposition of the great arteries; TV, tricuspid valve; and VSD, ventricular septal defect.
Postoperative echocardiogram showed laminar flow at the right pulmonary vein anastomosis. Both shunts were patent. The child was discharged a week later with normal neurological status.

2.2.2. Case 6

A 21-year-old man with tricuspid atresia, pulmonary atresia, transposed great vessels, disconnected pulmonary arteries, and a major aortopulmonary collateral artery from the descending aorta supplying the left lung (Fig. 3), had previously undergone surgery to place a 6 mm Gore-tex shunt from the right subclavian artery to the right pulmonary artery when he was 6 years of age. He presented with increasing cyanosis and decreasing exercise tolerance with a drop in oxygen saturation to 60% on exercise. Stress echocardiography disclosed a restrictive VSD (gradient 50 mmHg) and angiography demonstrated a stenosed right Blalock-Taussig shunt, the right pulmonary artery connecting to the left pulmonary artery via a pinhole opening. Right pulmonary artery pressure was a mean 11 mmHg and the left pulmonary artery pressure was a mean 15 mmHg. Prior to surgery, a balloon catheter was inserted un-inflated in the major aortopulmonary collateral artery to assist the cardiopulmonary bypass and minimise the risk of systemic hypoperfusion. The patient was taken to the operating theatre where the atretic area of the main pulmonary artery was patched and an 8 mm Gore-tex systemic to pulmonary artery shunt was inserted. Cardiopulmonary bypass was then established and the balloon was inflated in the major aortopulmonary collateral artery. The bypass perfusion pressure was entirely satisfactory at around 60 mmHg with the balloon occlusion, and the heart was arrested and the VSD enlarged via the aortic valve. Once bypass was discontinued, the balloon in the major aorto-pulmonary collateral artery was deflated and the patient had stable haemodynamics, normal renal function and normal neurological status.

2.2.3. Case 7

A 7-year-old boy with left atrial isomerism, absent left atrioventricular connection, bilateral superior vena cavae, and azygos continuation of the inferior vena cava to the right superior vena cava, had previously undergone banding of the pulmonary artery and later a Damus-Kaye-Stansel procedure and a right modified Blalock-Taussig shunt. Because of blockage of the shunt he later had a left modified Blalock-Taussig shunt. At the age of 7 years he developed severe right atrioventricular valve regurgitation and needed a valvuloplasty procedure. At the same time it was decided to take down the shunt and create bilateral bidirectional anastomoses. The left modified Blalock-Taussig shunt was not accessible from the front without being on cardiopulmonary bypass. It was therefore decided to position a balloon catheter in the shunt prior to operation in order to balloon occlude the shunt during cardiopulmonary bypass to minimise systemic hypoperfusion and flooding of the surgical field. The perfusion pressure was kept above 30 mmHg throughout the cardiopulmonary bypass. The valve anuloplasty was performed and bilateral cavopulmonary anastomoses were created and the left shunt was accessed. The balloon was deflated, the catheter was withdrawn, the shunt was closed and the child was successfully weaned from cardiopulmonary bypass.

Fig. 2. Positioning of inflated balloons in left and right modified Blalock-Taussig shunts in an 8-year-old girl with functional univentricular heart.

Fig. 3. Angiogram demonstrating a major aortopulmonary collateral artery coming off the descending aorta supplying the left lung.
3. Discussion

In complex pulmonary atresia there is a long tradition for the interventional cardiologist and the surgeon to work closely together to repair a difficult defect. The sequential approach, where major aortopulmonary arteries are occluded in the catheter laboratory before or after unifocalisation or final repair, has proved very successful. This paper describes a new approach in which the interventional cardiologist and the cardiac surgeon work together simultaneously: the hybrid approach. In our small series of hybrid procedures there were no important complications related to the temporal proximity of the interventional procedure and cardiac surgery, the latter being significantly facilitated by the former. The simultaneous collaboration between cardiologists and surgeons has not only added new possibilities for treatment but has also decreased the risks related to the surgical treatment in complex congenital disease. Even within our small series, three important indications for the hybrid approach have been established.

3.1. Surgical access

We have previously described the benefits of the simultaneous approach in VSD closure [4]. An apical VSD can be difficult to localise from the right side due to the richly developed network of crossing trabeculas, and difficult to access without jeopardising ventricular function by right or left sided ventriculotomies. Intraoperative positioning of a catheter device may be easier and may reduce surgical scarring. At present the indication is limited to the small infant with an apical VSD in whom the transcatheter closure is impossible and the need for a ventriculotomy more likely, and where a staged approach with pulmonary artery banding and later repair is considered a less optimal treatment. The intraoperative device closure may also be a better option than a ventriculotomy in larger patients [4].

Another example of problems with surgical accessibility is the Blalock-Taussig shunt in complex reoperation or a major aortopulmonary collateral artery arising from the descending aorta. Occlusion of major aorto-pulmonary collateral arteries can cause significant cyanosis because of the reduction in pulmonary blood flow. The combined approach where the surgical repair and the coil occlusion are done in the same procedure reduces the risk of cyanosis.

3.2. Interventional access

Interventional access is another important indication for hybrid procedures. When intravascular access to the pulmonary circulation is difficult or impossible, a surgical approach to placement of pulmonary artery stents at complex stenoses may be an option. In this series we have used the intraoperative stenting when a concomitant operative procedure for an additional surgical problem had offered a possibility. We have also used the approach when a sufficient pulmonary circulation with low resistance was necessary for the operative result, such as in a Fontan circulation. Other possible indications are when it has not been possible to perform the balloon dilatation and stenting before surgery due to intravascular inaccessibility and the stenoses were too peripherally located to be accessible to surgery.

The simultaneous approach enabled us to undertake complex surgical cases with reduced risk. In children, long term durability of stenting is an issue [5] and this procedure may be especially attractive in the grown-up congenital heart patient population, where growth is not a concern. Stenting of superior vena cava stenoses has also been described as a safe procedure with good results [6].

3.3. Intervention for control during surgical procedures (radical redo palliation)

During cardiopulmonary bypass it is necessary to occlude shunts and the major aortopulmonary collateral artery to avoid run off to the pulmonary circulation with possibilities for both hypotensive cerebral damage and flooding of the operative field by the pulmonary venous return. The latter renders surgery much more difficult or impossible. Furthermore, the Gore-tex material of which most shunts are made may fracture when clamped from outside, and both shunts and the major aorto-pulmonary collateral artery may be very difficult to access during surgery, especially during complex redo surgery.

In this series, systemic perfusion was maintained at an adequate level while intracardiac surgery was performed, and high risk surgical dissection in anatomical areas difficult to access was avoided. There is a growing population of patients surviving their palliative surgical procedures who experience a need for subsequent operations. The largest single risk factor for mortality and morbidity is probably related to difficult reoperation and often this is related to the dissection of shunts and collaterals. By temporary intravascular balloon occlusion, the surgeon can limit the dissection to the area of interest for the repair and thus reduce the risk of bleeding and nerve damage. In addition, the duration of the surgical procedure may be reduced.

4. Conclusions

In the management of cardiac diseases, the collaboration between cardiologists and surgeons is essential and the hybrid approach is an example of how this collaboration makes it possible to perform complex procedures that could not be done by surgeons or cardiologists alone. The cases described represent a small group of patients having multiple previous operations needing an additional high-risk operation. The hybrid approach may result in reduced risk, less invasive procedures, and improved outcome.
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