Late coronary artery lesions after neonatal arterial switch operation: results of surgical coronary revascularization

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Abstract

Objective: To evaluate the results of surgical revascularization in children with coronary artery lesions following neonatal arterial switch operation (ASO).

Methods: Among 755 neonates who underwent ASO, there were 713 late survivors (94%). Coronary lesions were detected in 34 patients (5%). Coronary revascularization was carried out in 19 children (mean age: 5.6 ± 3.2 years) in whom myocardial ischemia was demonstrated by myocardial perfusion imaging studies. Coronary lesions involved the left main coronary artery in 14 cases, the left anterior descending artery in 3, and the right coronary artery in 2. Sixteen patients had coronary angioplasty (left main coronary artery in 11, left anterior descending artery in 3, right coronary artery in 2). Two patients underwent a mammary bypass and one had a saphenous vein proximal bypass.

Results: There was no mortality or coronary event. Mean follow-up was 6.3 ± 2.8 years. Patency of coronary repair was demonstrated in all patients; however, in one child with angioplasty of the left main coronary artery, there was a residual stenosis of the left anterior descending artery, and reoperation with a mammary bypass was required. Myocardial perfusion imaging was performed in 18 patients; myocardial perfusion was normal in 16 and 2 had minimal residual perfusion defects. Treadmill exercise testing was performed in 11 patients and was normal in all.

Conclusions: (1) Following ASO, coronary lesions are not uncommon and they are progressive. Routine and sequential coronary evaluation is necessary. (2) Coronary revascularization can be achieved using coronary angioplasty in most cases. Mammary bypass may be used in selected circumstances. Normal myocardial perfusion is restored in most patients.

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1. Introduction

The arterial switch operation (ASO) has become the treatment of choice for neonates with transposition of the great arteries (TGA). Current operative mortality is low but remains related predominantly to coronary ischemia. Late results are outstanding, although complications may occur, namely supravalvar pulmonary stenosis, neoaortic valve regurgitation, and coronary artery obstruction.

The incidence, pathophysiology, and treatment of coronary lesions remain matters of debate [1—4]. Therapeutic options include medical management, percutaneous transluminal dilation [5,6], and surgical revascularization [7,8].

To date, it has been our policy to perform surgical coronary revascularization in patients with coronary obstruction and evidence of myocardial ischemia. The present study was undertaken to evaluate the results of this approach.

2. Materials and methods

2.1. Arterial switch population

Between January 1987 and September 2006, 755 neonates have undergone arterial switch operation at our institution. There were 32 (4.2%) in-hospital deaths and 11 (1.5%) late deaths after hospital discharge (all occurring within the first year after surgery). This left 713 late survivors.

The coronary anatomy distribution in the survivors was the following: usual coronary anatomy in 453 (63%), coronary patterns with anterior and/or posterior loops in 224 (31%), and coronary arteries coursing between the great arteries (with or without intramural course) in 36 (6%).

Among the 713 late survivors, 290 patients (41%) underwent at least one selective coronary angiography. Coronary angiography was performed for one of the following reasons:
(1) electrocardiographic and/or echocardiographic findings suggestive of myocardial infarction or myocardial ischemia, 
(2) unusual coronary pattern potentially associated with a higher risk of coronary complications (coronary arteries coursing between the great arteries, with or without intramural course), (3) intraoperative difficulties in coronary transfer (particularly when coronary anastomosis revision was necessary), (4) systematic evaluation of patients who underwent coronary reimplantation using a single orifice technique [9], and (5) routine postoperative evaluation of coronary patency in ASO patients.

Coronary lesions were detected in 34 patients (12% of all patients undergoing coronary angiography, 5% of all late survivors). Surgical revascularization was not indicated in 15 patients, either because this was deemed technically impossible (2 patients) or because there was no evidence of myocardial ischemia at myocardial perfusion imaging (13 patients).

The remaining 19 patients who underwent surgery for coronary revascularization constitute the study group. This study was approved by the local ethics committee.

2.2. Study population (19 patients)

2.2.1. Arterial switch procedure

There were 14 boys and 5 girls. Mean age at operation was 9 ± 5 days (range 3—23 days). Twelve neonates had TGA with an intact ventricular septum (one of them had associated aortic coarctation) and seven had TGA with ventricular septal defect (VSD) (three with associated aortic coarctation). Eleven patients had usual coronary anatomy; four had coronary patterns with anterior and/or posterior loops, and four had coronary arteries coursing between the great arteries with an intramural coronary branch (left main in one and left anterior descending in three).

Coronary transfer was performed using standard techniques in 14 cases and using a single orifice technique in 5 cases [9]. The side-by-side reimplantation technique was associated with an unacceptably high incidence of coronary lesions and its use must be strongly discouraged [10]. In addition to ASO, seven patients underwent VSD closure and five had aortic coarctation repair.

All patients had an unremarkable early postoperative course and were discharged from hospital with normal electrocardiographic and echocardiographic evaluation.

2.2.2. Diagnosis of coronary lesions

Coronary lesions were detected after a mean interval of 33 ± 38 months (range 1 month—10 years) following ASO. One patient sustained a myocardial infarction with severe left ventricular dysfunction 1 month post-ASO. In seven patients, echocardiographic findings suggestive of myocardial ischemia developed several weeks after ASO (hyperechogenicity of a papillary muscle of the mitral valve with or without mitral insufficiency); all had normal global left ventricular function. In the last 11 patients, coronary lesions were detected at the time of routine coronary angiography, with normal electrocardiographic and echocardiographic findings.

Coronary lesions involved the left main coronary artery in 14 cases (9 stenoses and 5 occlusions), the left anterior descending artery in 3 cases (3 occlusions), and the right coronary artery in 2 cases (1 stenosis and 1 occlusion). Details regarding coronary lesions according to coronary anatomy are given in Table 1.

Thallium myocardial perfusion imaging was performed in all patients and showed myocardial ischemia during exercise or after injection of dipyridamole in all. In addition, one patient (with myocardial infarction and left ventricular dysfunction) had positron emission tomographic (PET) imaging study with fluorodeoxyglucose to demonstrate myocardial viability.

2.2.3. Surgical revascularization

Surgery was undertaken after a mean interval of 32 ± 34 months (range 15 days—8.4 years) following the diagnosis of coronary obstruction. Surgery was delayed in many patients as long as there was no clear evidence of myocardial ischemia. At the time of operation, mean age was 5.6 ± 3.2 years (range 3 months—10.5 years).

Most patients (16/19) underwent coronary angioplasty. Our technique has been reported elsewhere [7]. After median resternotomy and institution of cardiopulmonary bypass, the aorta was cross-clamped and cardioplectic solution was administered. The neopulmonary trunk was transected and both pulmonary stumps were freed from surrounding structures, thus exposing the aortic root and the coronary neo-ostia. The aorta was opened anteriorly and the incision was extended toward the involved coronary ostium. In stenotic lesions, the incision was extended across the stenotic area until a normal coronary arterial wall was reached; in atretic lesions, the coronary trunk beyond the obstruction was opened and both aortic and coronary incisions were joined together across the occluded area. An onlay patch was used to enlarge not only the coronary stem but also the aortic incision in order to give the new coronary ostium a funnel shape. A saphenous vein patch was used in 15 patients and an innominate vein patch in the last patient.

In two patients, the right coronary artery (arising from the left-sided ostium in one) was enlarged. In these patients, the left anterior descending coronary artery was repaired. In the remaining 11 patients, the coronary angioplasty involved the left main coronary artery (arising from the right-sided ostium.

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Table 1: Coronary lesions according to coronary anatomy

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<tr>
<th>Coronary anatomy</th>
<th>Lesions</th>
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<td>Site</td>
<td>Type</td>
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<td>------------------------------------------</td>
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<tr>
<td>Usual coronary anatomy (11 patients)</td>
<td>LMCA (10) Stenosis (6)</td>
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<tr>
<td></td>
<td>RCA (1) Occlusion (4)</td>
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<tr>
<td>Anterior and/or posterior loops (4 patients)</td>
<td>LMCA (1) Stenosis (1)</td>
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<td>LAD (1) Stenosis (1)</td>
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<td></td>
<td>RCA (1) Stenosis (1)</td>
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<tr>
<td>Intramural coronary arteries (4 patients)</td>
<td>LMCA (1) Stenosis (1)</td>
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<td>LAD (1) Stenosis (1)</td>
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<td></td>
<td>LMCA: left main coronary artery; RCA: right coronary artery; Cx: circumflex coronary artery; LAD: left anterior descending coronary artery.</td>
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in 2 cases); in 4 of these patients, the incision was extended across the left main stem onto the origin of the left anterior descending artery.

One patient with a long atretic segment of the left main stem underwent implantation of a short saphenous vein bypass between the ascending aorta and the distal left main coronary artery, the distal anastomosis involving the origin of the left anterior descending artery.

Two patients had a mammary bypass using the left mammary artery; in one with occlusion of the left main stem, the bypass was implanted in a standard fashion on the left anterior descending artery; in the other patient with occlusion of an isolated left anterior descending artery, the artery was transected and anastomosed end-to-end to the mammary artery.

In addition to coronary revascularization, one patient underwent aortic arch repair for aortic recoarctation.

3. Results

3.1. Hospital events

All patients had an uneventful postoperative course. No myocardial infarction or acute ischemic event occurred during the hospital stay.

3.2. Late results

3.2.1. Follow-up

Mean follow-up was $6.3 \pm 2.8$ years (range 1–11 years). No patient was lost to follow-up. Evaluation was performed on a yearly basis.

3.2.2. Evaluation of coronary patency

The adequacy of coronary repair was evaluated in all patients. Most patients (17/19) underwent conventional coronary angiography; a total of 24 angiographic studies was performed after a mean follow-up of $2.5 \pm 3.0$ years.

In addition to coronaryography, nine of these patients had coronary evaluation using multislice computed tomographic (MSCT) angiography. In the last two patients, coronary repair was evaluated using MSCT angiography alone.

All patients, except one, had a satisfactory angiographic result (provided by conventional and/or MSCT angiography). The two mammary bypasses (Fig. 1) and the saphenous vein bypass (Fig. 2) were patent. Fifteen of the 16 coronary angioplasties provided a satisfactory angiographic result (Fig. 3).

In one patient who had had a coronary angioplasty of the left main stem extending onto the left anterior descending artery, a stenosis of the LAD was detected 2 years after surgery. Myocardial perfusion imaging showed a persistent perfusion defect. The patient underwent a mammary bypass to the LAD with an excellent angiographic result at 6 months and 9 years (Fig. 4).

3.2.3. Myocardial perfusion imaging

All patients except one (the last patient in this series) underwent postoperative myocardial perfusion imaging study after a mean follow-up of $2.7 \pm 2.5$ years.

In one patient (with myocardial infarction), there was a persistent perfusion defect in the infarcted area but the lateral perfusion defect had disappeared. In another patient (who underwent a mammary bypass) there was a limited apical perfusion defect 8 years postoperatively, whereas there was a large anterior defect before revascularization.
Progressive intimal proliferation may finally lead to severe coronary obstruction or even complete occlusion [11]. It must be pointed out that late coronary lesions may occur in all patients, even after the most straightforward initial operation and postoperative course.

The exact incidence of coronary lesions following ASO is difficult to evaluate because most patients with coronary obstruction are symptom-free and do not show any electrocardiographic or echocardiographic evidence of myocardial ischemia. Only systematic coronary angiography can detect such lesions. It has recently been shown that multislice computed tomographic angiography may replace conventional coronary angiography [12].

Our current policy is to perform coronary exploration (by coronary angiography and/or MSCT angiography): (1) early in the presence of any echocardiographic finding, even minimal, suggestive of myocardial ischemia, (2) during the first postoperative year in patients with unusual coronary patterns or intraoperative difficulties in coronary transfer, and (3) routinely before 5 years of age. Because the lesions are most probably progressive, coronary evaluation should be repeated at regular intervals during the late follow-up of ASO patients.

The optimal management of post-ASO coronary lesions remains to be determined. There are only a few reports dealing with this difficult problem. Recently, percutaneous transluminal coronary angioplasty has been shown to provide satisfactory mid-term results [6]. Potential surgical approaches include internal mammary artery grafting and coronary angioplasty. Internal thoracic artery—coronary artery bypass is technically feasible in most children and provides satisfactory patency rates for various indications in infancy and childhood [13]. However, the blood flow through a mammary bypass may be inadequate, particularly when a large myocardial area must be revascularized. Surgical coronary angioplasty has been used for atherosclerotic [14] as well as non-atherosclerotic lesions [7,15].

Surgical angioplasty restores a normal physiologic coronary perfusion and is likely to better preserve the future of the patients. Various materials can be used to achieve adequate revascularization: autologous pericardium, native aorta or pulmonary artery, internal thoracic artery, and saphenous vein. The optimal material for the long term remains to be determined.

The results of the present study show that coronary angioplasty can be performed in most children with post-ASO coronary lesions. The coronary obstruction (even when it is complete) is usually proximal and short and the coronary artery distal to the lesion is normal. It is, therefore, possible to achieve adequate enlargement from the aorta, across the stenotic or occlusive lesion, down to a normal coronary artery. The use of mammary grafting should be reserved to long and complete occlusion or to residual distal obstruction after primary coronary angioplasty (as it was the case in one of our patients).

Our data shows that (1) coronary angioplasty can be performed with a very low operative risk and a high patency rate and (2) successful revascularization restores normal myocardial perfusion in most cases, as assessed by myocardial perfusion imaging. The long-term fate of this procedure...
remains to be evaluated. The potential risks of progressive narrowing distal to the patch or modification of the patch material (aneurysmal dilation and/or progressive intimal thickening) should not be underestimated. To date, revascularization has been carried out only in patients in whom myocardial ischemia at rest or under stress (or dipyridamole infusion) could be demonstrated. In many patients, surgery was even delayed for several months or years after the diagnosis of coronary obstruction, until frank ischemia could be shown. Owing to satisfactory results, our current policy is to propose surgery as soon as the diagnosis of coronary lesion with myocardial ischemia is performed. Revascularization should probably also be considered in the absence of obvious ischemia in order to restore normal coronary anatomy and perfusion, particularly in patients with coronary lesions and poor intercoronary collateral circulation.

5. Conclusions

1. Long-term coronary patency may well be the main determinant of long-term success following neonatal ASO. Proximal coronary intimal thickening is common. Obstructive coronary lesions are not rare. Sequential coronary evaluation using coronary angiography and/or MSCT angiography is clearlymandatory.

2. Coronary revascularization using surgical coronary angioplasty (or mammary grafting in selected cases) provides satisfactory mid-term results and restores normal myocardial perfusion in most cases. The long-term results, however, remain to be evaluated, particularly regarding the late fate of venous material in coronary position.

Acknowledgement

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References