SURGICAL ANGIOPLASTY OF THE MAIN CORONARY ARTERIES IN CHILDREN

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Objective: To determine the safety and efficacy of surgical angioplasty of the coronary arteries in children. **Methods:** We performed 9 surgical reconstructions of the left main coronary artery and 1 of the right coronary artery ostium in 10 children (mean age 5.7 years; range 2 months–15 years). The basic diseases included the following: congenital atresia of the left coronary artery (n = 2) and atresia of the right coronary artery in a patient with an aortoventricular tunnel (n = 1); stenosis of the left main coronary artery (1) in a patient with Williams syndrome (n = 1), (2) in a patient with familial hypercholesterolemia (n = 1), (3) after the arterial switch operation for transposition of the great arteries (n = 3), (4) after reimplantation of an anomalous left main coronary artery from the pulmonary artery (n = 1), and (5) by compression after a *réparation à l'étage ventriculaire* procedure (n = 1). Myocardial viability was assessed by single photon emission computed tomography (thallium 201; 7/10). The coronary artery stem was enlarged with a saphenous (n = 5), a pericardial (n = 4), or a polytetrafluoroethylene patch (n = 1). **Results:** There was 1 hospital death and 9 patients are alive (mean follow-up 46 ± 30 months; range 12 months to 10.5 years). Eight of 9 survivors had a selective coronary artery angiogram and had normal coronary artery ostia. Two patients had stenosis of the left anterior descending coronary artery, 1 of whom underwent successful internal thoracic artery grafting. **Conclusions:** Surgical angioplasty of the coronary stems restores physiologic coronary perfusion and conserves bypass material. It can be performed safely in children and provides encouraging midterm results. (J Thorac Cardiovasc Surg 1999;117:352-7)

Coronary artery diseases in the pediatric population include mainly the sequelae of Kawasaki disease and congenital malformations of the coronary arteries.¹⁻³ However, the improvement of the methods of detection of myocardial ischemia and the subsequent expansion of the indications for selective coronary artery angiograms in children have led to the emergence of new coronary artery anomalies in this population, mainly postoperative coronary artery obstructions.⁴⁻⁸ Consequently, the indications for myocardial revascularization have expanded. Although severe stenosis of

the main left coronary artery is potentially life-threatening, 2 obstacles to surgical revascularization exist: First, it is difficult to prove that the myocardium is ischemic, because myocardial perfusion studies frequently yield ambiguous results concerning coronary artery patency, particularly in children who previously underwent cardiopulmonary bypass (CPB).⁹ Second, the surgical technique to be applied for proximal lesions of the coronary arteries is also a matter of controversy.¹⁰

The internal thoracic artery (ITA) has been applied successfully as a bypass graft in children and infants with various indications for bypass.¹¹⁻¹⁴ However, in the presence of isolated stenosis of the origin of one of the coronary arteries, conventional coronary artery bypass consumes bypass material and may restore only retrograde perfusion to an extensive myocardial area.¹⁵ In addition, surgical angioplasty does not preclude additional procedures later in life.

Herein we report on a series of 10 infants and children who underwent myocardial reperfusion during surgical reconstruction of either the left main coronary artery or

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Table I. Preoperative and postoperative myocardial perfusion and angiographic studies

Patients	Indication	Preoperative findings		Postoperative follow-up	
		Myocardial perfusion	Angiographic findings	Myocardial perfusion	Angiographic findings
1	After ALCAPA reimplantation	Perfusion defect	MLCA stenosis	Normal	Normal
2	Congenital atresia of the MLCA	—	MLCA atresia	Normal	?
3	Congenital atresia of the MLCA	—	MLCA atresia	Operative death	
4	Homozygous hypercholesterolemia	Perfusion defect	MLCA stenosis	Normal	Normal MLCA (stenosis of the Cx artery)
5	After arterial switch operation	Perfusion defect	MLCA stenosis	Apical defect	Normal MLCA (stenosis of the LAD)
6	After arterial switch operation	Perfusion defect	MLCA stenosis	Normal	Normal
7	After arterial switch operation	Perfusion defect	MLCA stenosis	Normal	Normal
8	After endoventricular repair for TGA, VSD, and pulmonary stenosis	Perfusion defect	MLCA stenosis	Normal	Normal
9	Aortoventricular tunnel	—	RCA atresia (perioperative)	Normal	Normal
10	Williams syndrome	Perfusion defect	MLCA and LAD stenosis	Anterior defect	Normal MLCA (severe stenosis of the LAD)

ALCAPA, Anomalous left coronary artery from the pulmonary artery; Cx, circumflex artery; LAD, left anterior descending coronary artery; MLCA, main left coronary artery; RCA, right coronary artery; TGA, transposition of the great arteries; VSD, ventricular septal defect.

the right coronary artery for severe stenosis or occlusion of these vessels.

Patients and methods

Population. From 1988, 10 children (mean age 5.7 years; range 2 months–15 years) with congenital or acquired severe stenosis or occlusion of one coronary artery stem underwent surgical angioplasty of the affected coronary artery. All patients were operated on in a single institution by a single surgeon. Indications for coronary revascularization are shown in Table I. The coronary distribution in the 3 patients who underwent an arterial switch operation were of the normal type. The presenting symptoms of the coronary artery disease were left ventricular dysfunction with associated electrocardiographic anomalies in 7 patients and syncope with myocardial ischemia during exercise in 2 patients. In the last patient (patient 9), the lesion was discovered during the operation.

Investigations. Documentation of myocardial ischemia relied on echocardiographic or myocardial perfusion imaging studies, or both. Preoperative thallium 201 myocardial perfusion imaging studies demonstrated myocardial ischemia during exercise or after injection of dipyridamole in 7 of 10 patients. In addition, positron emission tomographic (PET) imaging studies with fluorodeoxyglucose demonstrated myocardial viability in 3 patients in whom redistribution was incomplete at rest within the area of the perfusion defect. In 3 patients, perfusion imaging studies were not performed: the 2 patients with congenital atresia of the left main coronary artery had congestive heart failure and were receiving mechanical ventilation; in the patient with an aortoventricular

tunnel, the atresia of the right coronary artery was a perioperative discovery. Catheterization was undertaken with local anesthesia by the femoral arterial approach. Selective coronary artery angiography was performed with left and right coronary catheters (Cordis Corp, Miami, Fla; Cook, Bjæverfkov, Denmark) measuring between 4F and 5F and with various curvatures (Judkins 1.5, 2, 2.5, 3.5, and 4). The 2 smaller sizes were made available on specific order (Cordis, Viry-Chatillon, France). All patients (except patient 9, who was not catheterized before the operation) had imaging of both ITAs before surgery.

Surgical technique. The operation was performed with standard CPB. Myocardial preservation was achieved through hot-induction blood cardioplegia, repeated cold blood cardioplegia, and warm reperfusion. In all patients with left coronary lesions, the main pulmonary trunk was transected to allow adequate exposure of the aortic root, left coronary ostium, and left main stem; this was done in patients with normally related great arteries, as well as in patients with previous translocation of the great arteries by the Lecomte maneuver.

After aortic crossclamping, the incision was started on the anterior aspect of the aortic root and was extended laterally 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 2 cases, the incision was extended onto the left anterior descending artery (patients 5 and 10). In atretic or occluded lesions, the left main stem beyond the obstruction was opened and both aortic and coronary incisions were joined together across the

Fig 1. **A**, Scheme of the angioplasty of the main left coronary artery after an arterial switch operation. The main pulmonary trunk was transected to allow adequate exposure of the aortic root, left coronary ostium, and left main stem. **B**, The left main stem beyond the obstruction is opened and both aortic and coronary incisions are joined together across the occluded area. An onlay patch is used to enlarge not only the main coronary stem, but also the adjacent aortic incision, so as to give the new coronary ostium a funnel shape.

occluded area. An onlay patch was used to enlarge not only the main coronary stem, but also the adjacent 1 to 2 cm of the aortic incision, so as to give the new coronary ostium a funnel shape. A saphenous vein patch was used in 5 patients, a fresh autologous pericardial patch in 4 patients, and a polytetrafluoroethylene onlay patch in the last patient. The rest of the aortic incision was closed directly (Fig 1).

Additional procedures were performed in 2 patients: repair of an aortoventricular tunnel in patient 9 and replacement of a Hancock tube in patient 8.

Results

Hospital events. One patient (patient 3) with congenital atresia of the left coronary ostium could not be weaned from CPB because of severe left ventricular dysfunction before the operation and died in the operating theater. In the other 9 patients, postoperative recovery was uneventful. No myocardial infarction or acute ischemic events were documented during the hospital stay.

Follow-up. All survivors are still alive after a mean follow-up of 46 ± 30 months (range 12 months–10.5 years). None had an acute ischemic event during follow-up. Eight patients are fully symptom-free and receive no cardiac medication but aspirin. The remaining patient (patient 10) still has a severe ischemic cardiomyopathy and receives angiotensin-converting enzyme inhibitors and diuretics. Left ventricular function was normal in 7 patients; 1 patient had moderate hypokinesia of the anterior wall (patient 6) although this segment was dyskinetic before the operation, and

the severe ischemic cardiomyopathy of patient 10 did not improve after the operation.

Myocardial perfusion imaging studies and angiographic restudy were obtained at an average of 29 months (6–52 months). Results are shown in Table I. Seven patients (66%) had normal myocardial perfusion during exercise or after injection of dipyridamole. Patient 5 had a limited apical perfusion defect without redistribution despite exhibiting a large anterior perfusion defect during exercise before the operation. Finally, patient 10 still had a large anterior perfusion defect both at rest and after dipyridamole injection. PET imaging could not be performed in this 3-year-old child for technical reasons.

Angiographic restudy revealed a perfect patency of the left main stem in 8 patients (Fig 2). Catheterization was refused by the parents of patient 2, who had normal myocardial perfusion. In the patient with familial homozygous hypercholesterolemia, atherosclerosis progressed and a stenosis of the circumflex artery developed distal to the surgical angioplasty of the left main coronary artery. Patient 5, in whom the incision was extended to the left anterior descending coronary artery, had a stenosis of this artery. The first myocardial scintiscan performed 6 months after angioplasty of the left main coronary artery showed normal findings, although the stenosis of the left anterior descending coronary artery was already present. One year later, the patient underwent another myocardial perfusion imaging, which revealed an apical perfusion defect, and successfully underwent an ITA bypass. Finally, patient 10 (Williams syndrome) still had a critical tubular stenosis of the left anterior descending coronary artery with left ventricular dysfunction and myocardial ischemia. Coronary artery bypass is the recommended treatment.

Discussion

Herein we report on an alternative technique for revascularization of the coronary arteries in children. Different authors recently reported on ITA–coronary artery bypass grafting in infants and children with congenital or acquired coronary artery disease.¹⁶ The largest experience of coronary artery revascularization using bypasses comes from the series of patients with Kawasaki disease.¹¹ Although the sequelae of Kawasaki disease are of major concern in the pediatric population, indications for revascularization are particularly rare in our experience. In addition, the coronary artery anomalies are usually distal and do not affect the coronary artery ostia. Other indications for myocardial reperfusion are very unusual in children except for those with anomalous origin of the left coronary artery

Fig 2. **A**, Aortic root angiograms showing a severe stenosis of the main left coronary artery in a patient who underwent an arterial switch for transposition of the great arteries. **B**, Postoperative angiogram in the same patient who underwent a reconstruction of the left main coronary artery with a saphenous patch.

from the pulmonary artery.¹⁷ Most reported cases of ITA–coronary artery grafts in children concerned patients with transposition of the great arteries, in whom the course of the coronary arteries prohibited a conventional transfer, or patients with tetralogy of Fallot, in whom there was an injury to the left anterior descending coronary artery coursing over the ventricular outflow tract.^{13,14} Indeed, during the period of our study, 1 newborn infant with transposition of the great arteries and intramural course of the left anterior coronary artery successfully underwent an ITA bypass during the arterial switch operation.

The increasing frequency of reconstructive surgery with transfer of the coronary arteries, that is, the arterial switch operation and the anatomic correction of double discordances, has focused attention on postoperative myocardial perfusion.⁹ We have previously shown the need for documentation or reliable exclusion of coronary artery lesions in these patients.^{7,8} However, although detailed anatomy of the obstructed coronary artery and collateral vessels can be obtained by selective angiograms, expertise had to be gained for the documentation of myocardial ischemia in young patients. In the present report, we relied on myocardial scintigraphy with thallium 201 to assess myocardial ischemia. In addition, PET imaging studies were performed in 3 patients to confirm viability in the myocardial area perfused by the obstructed coronary artery. In view of the important limitations of the different treatments in young children with severe coronary artery lesions, an accurate demonstration of reversible myocardial ischemia had to be made before surgical revascularization was attempted. In our patients with coronary artery obstructions after the arterial switch operation, we rec-

ommended surgical revascularization of the affected coronary artery, not only on the basis of severe coronary artery lesions but also on the basis of myocardial ischemia at rest or during exercise. In our series of 30 patients with coronary artery obstruction after the arterial switch operation,⁸ 10 had myocardial ischemia and severe coronary lesions amenable to revascularization. Five of these patients with a normal distribution of the coronary artery underwent surgery: 3 had surgical angioplasties (in this manuscript) and 2 had an ITA bypass. Two additional coronary artery bypasses were performed in 2 patients with stenosis of the left anterior or descending artery arising alone from the left ostium. Finally, 3 patients are being medically treated with β -blockers because their parents refused surgery. No patient with a lesion of the circumflex artery was advised to have surgical revascularization, and the remaining patients had either minor lesions or normal myocardial perfusion. All of them are given aspirin and have annual myocardial scintigraphy. No cardiac event was noticed during follow-up. Our experience with revascularization for coronary artery lesions after the arterial switch operation remains limited, and further follow-up is necessary to give accurate advice for patients with this condition.

The conventional surgical treatment of isolated stenosis of the left main coronary artery consists in bypass grafting of either 1 or 2 left coronary artery branches.¹⁸ This attitude, albeit effective, has some inconveniences: occlusion of the left main coronary artery, competitive flow and even steal phenomenon in the presence of 2 bypass grafts, and retrograde perfusion of a wide myocardial area when only 1 bypass graft is constructed. Surgical angioplasty of the left

main coronary artery has been used in adults, and the results have been similar to those achieved by conventional grafting.¹⁹ In the pediatric population, surgical angioplasty has the major advantage to economize bypass material and is likely to better preserve the future of these young patients starting their lives with severe coronary artery disease. More recently, the availability of stents and their success in reducing acute complications and restenosis prompted attempts to stent unprotected left main coronary artery stenoses in adults.²⁰ Preliminary results seem promising inasmuch as immediate procedural success was obtained in selected patients. Percutaneous transluminal coronary angioplasty is technically limited in children. Indeed, the size of the coronary arteries makes such procedures hazardous and adapted material is not available. Furthermore, the late outcome of stenting of the left main coronary artery is unknown, and stenting may be deleterious to the growth of the coronary arteries.

The results are encouraging in our series. Operative mortality occurred in only 1 patient with end-stage heart failure. This patient was in very poor hemodynamic condition at operation, and death probably resulted from left ventricular incompetence. It is of note that a similar observation was reported by Mavroudis and associates,¹⁶ who reported that an emergency ITA-left anterior descending coronary artery bypass was necessary to successfully wean a patient from CPB. It might be of interest to consider the role of adjuvant coronary artery bypass in such situations. Follow-up coronary angiograms were satisfactory in the 8 patients in whom results of surgery were good. In our hypercholesterolemic patient, the surgical angioplasty allows subsequent percutaneous angioplasty if the atherosclerotic process progresses. Stenosis of the anterior descending coronary artery was observed in 2 patients. In the first patient, the incision of the left main coronary artery was extended to the anterior descending coronary artery, and the injury of this coronary artery led to constrictive vascular remodeling, as observed after balloon angioplasty.^{21,22} In the second patient, who has Williams syndrome, the anterior descending coronary artery stenosis is due to the progressive luminal narrowing that complicates the arteriopathy of the syndrome as the luminal narrowing of the artery extends beyond the surgical incision.²³ As in the previous patient, the injury to the coronary artery may have accelerated a remodeling process of the arterial wall in this connective tissue disorder. Provided that the distal bifurcation of the left main coronary artery was not involved in the stenotic process, the surgical angioplasty of the left main coronary artery and of the right

coronary artery gave excellent functional and anatomic results in our series.

Conclusions

Expanding indications for coronary revascularization in childhood require that safe and reliable techniques commonly used in the adult population be adapted for pediatric patients. However, one has to keep in mind the limited availability of bypass material in infants and the need to allow normal coronary artery growth, together with adequate myocardial perfusion. Inasmuch as our results appear to be encouraging, we believe that, when technically feasible, surgical angioplasty should be the first surgical procedure in these children. We are aware that long-term patency and reoperation rates have yet to be determined.

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