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Coronary artery bypass grafting in children

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Abstract

Background: We present our clinical experience with coronary artery bypass grafting (CABG) in children.

Methods: Ten children who underwent CABG between July 1995 and August 2017 were retrospectively analyzed. Data including congenital cardiac malformations, previous surgical procedures, age and sex, type of coronary complications, ischemic events preceding surgery, and ventricular function before and after CABG were recorded.

Results: The study population consisted of five males and five females with a median age of 2.5 years (range, 88 days to 15 years). Eight internal mammary arteries (IMAs) and two saphenous veins were used for grafting. Indications for bypass grafting were coronary artery (CA) complications related to the post-arterial switch operation in six, CA complications during the Ross procedure in two, and an iatrogenic CA injury during complete repair of tetralogy of Fallot with abnormal CA, crossing the right ventricular outflow tract in two patients. Six of the grafts were performed as rescue procedures. Three patients died during hospitalization. The mean follow-up time was 6.8 years (range, 3 months to 18 years). Anastomoses were evaluated by coronary angiography in four patients, and were all patent. Echocardiography revealed normal myocardial function in all patients.

Conclusion: Our study suggests that the IMA should be the graft of choice in children due to its growth potential and long-term patency.

KEYWORDS

coronary complications, coronary translocation, pediatric coronary artery bypass, rescue procedure

1 | INTRODUCTION

Coronary artery bypass grafting (CABG) is uncommon in children. CABG poses major surgical challenges due to small anatomical structures, difficulties in exposure, and limited graft options.

In 1966, Cooley and co-workers[1] first described coronary revascularization in children using an autologous saphenous vein graft (SVG) in an infant with an anomalous left coronary artery (CA) originating from the pulmonary artery (ALCAPA). In 1976, Kitamura et al[2] reported a successful double CABG in a 4-year-old child with Kawasaki disease. The need for pediatric CABG includes CA complications after Kawasaki disease, premature atherosclerosis, ALCAPA, congenital CA anomalies such as an abnormal aortic origin and course of CA, and iatrogenic CA

injuries and complications of the procedures requiring coronary manipulation such as the arterial switch operation (ASO) and the Ross procedure.[3–5] CABG has also been performed in adults with concomitant lesions such as tetralogy of Fallot.[6]

Currently, the internal mammary artery (IMA) is more commonly used than the SVG due to its excellent long-term patency rates and the ability to grow along with the developing child.[7] Recently, there have been reports using percutaneous myocardial revascularization in the pediatric population.[8,9] In this study, we present our clinical experience with CABG in children.

2 | METHODS

This study was approved by Acibadem University Ethics Committee and was conducted in accordance with the principles of the Declaration of Helsinki. A written informed consent was obtained from parents of each patient.

In this retrospective study, we included all patients who underwent pediatric CABG with either an arterial or vein graft between July 1995 and August 2017. Data including congenital cardiac malformations, previous surgical procedures, age and sex of the patient, and type of coronary anomaly were recorded. We also evaluated cardiac events including myocardial ischemia, death, patency of CABG by imaging studies, ventricular function, and need for subsequent CA interventions.

2.1 | Statistical analysis

Statistical analysis was performed using the NCSS (Number Cruncher Statistical System) 2007 Statistical Software (NCSS LLC, Kaysville, UT). Descriptive statistics were expressed as mean ± standard deviation (SD), median, frequency, and percentage.

3 | RESULTS

The demographic and clinical characteristics of the patients are shown in Table 1. A total of 10 patients who underwent pediatric CABG were included in this study. Five were males and five were females. The median age at the time of the coronary procedure was 2.5 years (range, 88 days to 18 years). The mean follow-up was 6.8 years (range, 3 months to 18 years). We used IMA grafts in eight patients and SVG in two patients; CABG was necessary due to stretching, buckling, and iatrogenic injury of coronary arteries during or following various congenital cardiac operations. In six patients, the procedure was performed as a rescue procedure. The in-hospital mortality rate was 30% (3/10).

Indications for CABG were early and late CA complications related to the ASO in six patients. Four of these patients had left main CA obstruction develop in the late postoperative period after the ASO. The left internal mammary artery (LIMA) was used in three patients and a SVG in one patient for the left anterior descending (LAD) CA revascularization, 2 months, 4 years, 16 months (Figure 1), and 11 years after the ASO. The patient who had a LIMA to LAD bypass 2 months after ASO died on day 138 after the operation due to sepsis and multi-organ failure (Figure 2). The remaining two patients requiring rescue revascularization at the time of ASO due to stretching of the right CA underwent LIMA to the RCA (Figure 3) and a RIMA to the RCA. The patient who had a RIMA to the RCA bypass grafting died on day 26 after the operation due to sepsis and multi-organ failure (Table 2).

In two patients, RCA revascularization was performed as a rescue procedure following the Ross operation. The RIMA to the RCA and SVG to the RCA bypass grafting were necessary due to endocarditis and destruction of the RCA and stretching of RCA. One of these patients who had a RIMA to the RCA has been followed and is in good condition. However, she is in need of a pulmonary valve

TABLE 1 Demographic and clinical characteristics of patients

Age (year)	
Min-Max (Median)	3-15 (2.5)
Mean ± SD	4.73 ± 5.18
Anatomic diagnosis; *n* (%)	
Congenital AS	1 (10)
Congenital AS, bicuspid aorta, and aortic valve endocarditis	1 (10)
TGA	3 (30)
TGA, VSD	2 (20)
TGA, VSD, PH	1 (10)
ToF	2 (20)
Main procedure; *n* (%)	
ASO	6 (60)
Ross procedure	2 (20)
ToF repair (Transannular patching)	2 (20)
Type of CA obstruction; *n* (%)	
Buckling of LMCA	1 (10)
Destruction of RCA	1 (10)
Iatrogenic injury of LMCA	2 (20)
Late LMCA stenosis	3 (30)
Stretching of RCA	6 (30)
Type of CABG; *n* (%)	
RCA	3 (30)
LAD	7 (70)
Follow-up (month)	
Min-Max (Median)	1-18 (3.75)
Mean ± SD	5.82 ± 6.68
Mortality	3 (30%)

AS, aortic stenosis; ASO, arterial switch operation; CA, coronary artery; LAD, left anterior descending coronary artery; LMCA, left main coronary artery; PH, pulmonary hypertension; RCA, right coronary artery; SD, standard deviation; TGA, transposition of the great arteries; ToF, tetralogy of Fallot; VSD, ventricular septal defect.

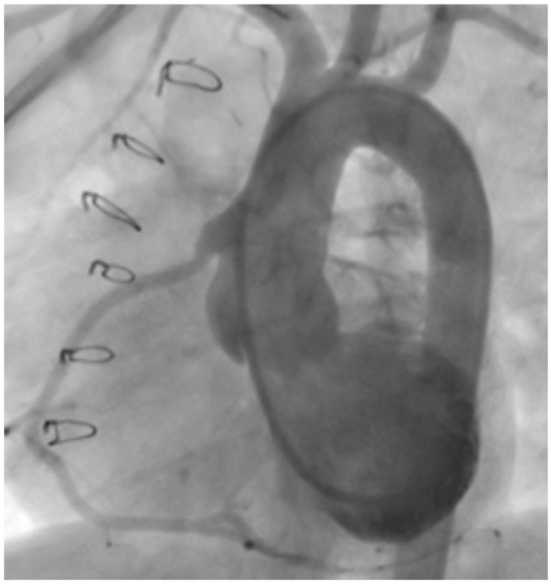

FIGURE 1 Coronary angiography showing left main ostial stenosis 17 months after arterial switch operation before coronary artery bypass grafting

replacement in the near future due to pulmonary valve insufficiency. The other patient who had a SVG to RCA bypass during the Ross procedure due to RCA stretching has had no ischemic symptoms and the ejection fraction (EF) was 65%, on echocardiography at the last follow-up visit.

Two patients with tetralogy of Fallot (ToF) had an unusual CA, crossing the right ventricular outflow tract (RVOT) and required LIMA to LAD bypass grafting as a rescue procedure following complete repair with transannular RVOT patching. In both patients, the left main coronary artery (LMCA) was crossing the RVOT, which was not diagnosed preoperatively, and was accidentally injured during the

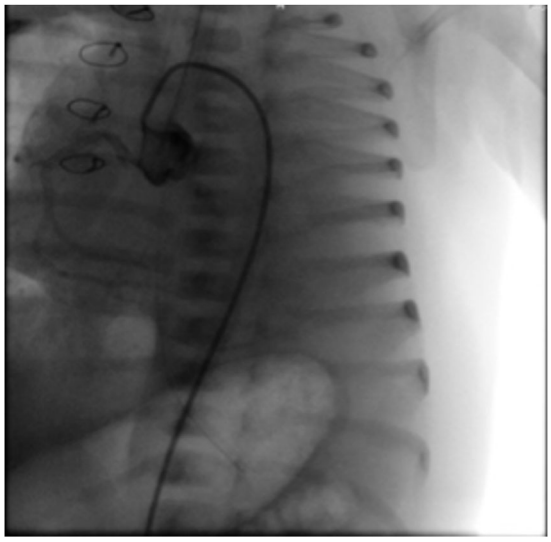

FIGURE 2 Coronary angiography showing left main ostial stenosis 51 days after arterial switch operation before coronary artery bypass grafting

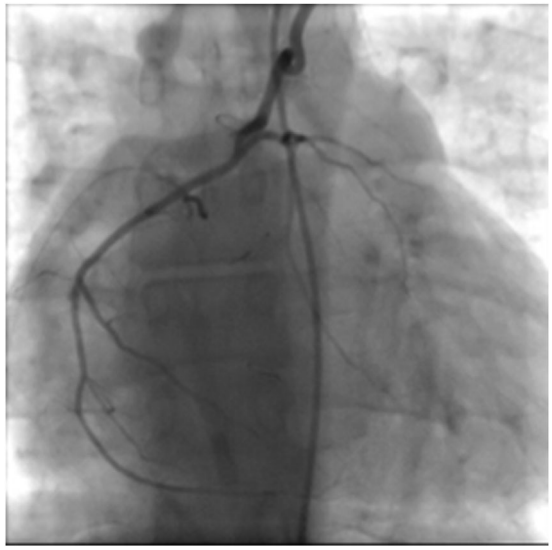

FIGURE 3 Arterial switch operation for transposition of the great arteries and ventricular septal defect closure requiring coronary artery bypass grafting as a rescue procedure due to stretching of the right coronary artery. Coronary angiography showing an excellent long-term patency of left internal mammary artery to right coronary artery anastomosis 18 years after coronary artery bypass grafting

RVOT transannular patching. The first patient underwent a LAD to LIMA anastomosis and early coronary angiography revealed a patent anastomosis (Figure 4). The second patient required extracorporeal membrane oxygenation (ECMO) support for 1 week and was then successfully weaned off ECMO. Coronary angiography revealed a patent LIMA to LAD anastomosis with good myocardial function (30% shortening fraction of left ventricle) (Figure 5). Unfortunately, the patient died 74 days after the operation due to sepsis and multi-organ failure, despite normal cardiac function.

All surviving patients had no angina or electrocardiographic changes. Postoperative coronary angiography studies were performed in four of 10 patients after CABG and demonstrated anastomotic patency in all patients without any evidence of stenosis, kinking, or delayed filling (Figures 3-6). Two of these coronary angiographies revealed excellent long-term patency (9.5 and 18 years) and showed growth potential of the IMA graft (Figures 3 and 6).

Two of 10 patients (Cases 4 and 7) listed in Table 2 did not have repeat coronary angiography. However, these patients were followed for 6.5 years and 18 years, respectively, and echocardiographic examinations revealed normal ejection fraction. None of them has any angina, new Q waves, or impaired EF. In addition, there were no late cardiac deaths or additional interventions related to coronary grafts or native vessels. All patients received lifelong aspirin after CABG.

4 | DISCUSSION

Indications for CABG are rare in children, compared to adults. Myocardial revascularization procedures are usually performed

TABLE 2 Operative procedures and long-term outcomes

	Age at CABG	Anatomic diagnosis	Main procedure	CA pattern	Type of CA obstruction	Type of CABG	Follow-up	Status
1	6 months	TGA, VSD	ASO	Single left CA origin	Stretching of RCA	LIMA to RCA-rescue	18 years	Alive, NHYA I (Figure 4)
2	12 years	TGA, VSD, PH	ASO	Usual coronary pattern	Late LMCA stenosis	LIMA to LAD-11 years after ASO	9.5 years	Alive, NHYA I (Figure 5)
3	3 months	TGA	ASO	Single left CA origin	Buckling of LMCA	LIMA to LAD-2 months after ASO	5 months	Died, 5 months after CABG procedure (Figure 1)
4	4 years	TGA	ASO	Usual coronary pattern	Late LMCA stenosis	SVG to LAD-4 years after ASO	6.5 years	Alive, NHYA I-II
5	13 months	TGA, VSD	ASO	Single left CA origin	Stretching of RCA	RIMA to RCA-rescue	1 months	Died
6	17 months	TGA	ASO	Intramural LCA	Late LMCA stenosis	LIMA to LAD-16 months after ASO	1 months	Alive (Figure 6)
7	8 years	Congenital AS, bicuspid aorta and aortic valve endocarditis	Ross procedure	Usual coronary pattern	Destruction of RCA	RIMA to RCA-rescue	16 years	Alive, NHYA I-II
8	15 years	Congenital AS	Ross procedure	Usual coronary pattern	Stretching of RCA	SVG to LAD-rescue	3 years	Could not be followed 3 years after CABG.
9	2 years	ToF	ToF repair (transannular patching)	Single ostium: RCA + LMCA	Iatrogenic injury of LMCA	LIMA to LAD-rescue	4.5 years	Alive, NHYA I-II (Figure 2)
10	3 years	ToF	ToF repair (transannular patching)	Single ostium: RCA + LMCA	Iatrogenic injury of LMCA	LIMA to LAD-rescue	74 days	Died 74 days after CABG due to MOF and sepsis (Figure 3)

AS, aortic stenosis; ASO, arterial switch operation; CA, coronary artery; CABG, coronary artery bypass grafting; LAD, left anterior descending coronary artery; LIMA, left internal mammary artery; LITA, left internal thoracic artery; LMCA, left main coronary artery; MOF, multi organ failure; NYHA, New York Heart Association; PH, pulmonary hypertension; RCA, right coronary artery; RIMA, left internal mammary artery; RITA, right internal thoracic artery; TGA, transposition of the great arteries; ToF, tetralogy of Fallot; VSD, ventricular septal defect.

during congenital cardiac procedures, such as ASO, Ross procedure, aortic root replacement, and ALCAPA repair.[10] Surgical manipulation on the coronary arteries in pediatric patients may be associated with potential serious complications, leading to myocardial ischemic dysfunction.[3,4]

Pediatric CABG was initially performed as a primary procedure in coronary complications of Kawasaki vasculitis and in premature atherosclerosis due to familial hypercholesterolemia.[3] Pediatric CABG is now most commonly performed for early and late CA complications of ASO and aortic root replacement operations for CA translocation, such as the Ross and Ross–Konno operations.[5,11–13] Six of 10 patients in our study underwent CABG due to coronary artery injuries during the repair of other congenital lesions.

As shown in Table 1, the majority of our patients are post-ASO procedures. Translocation of the CAs in ASO represents the most critical surgical step. ASO can result in buckling, stretching, or torsion of the CA during coronary transfer and can lead to acute coronary ischemia and, in most cases, may cause myocardial infarction or death. These types of problems are more likely to be seen in transposition of the great arteries with abnormal, inverted, or intramural CAs. Therefore, it is important to define the CA structure precisely in the preoperative period.

With the improvements in surgical techniques of ASO in recent years, the incidence of major coronary complications, even in neonates with unusual coronary patterns, has progressively decreased. However, late coronary obstruction may still develop.[14] Therefore, anatomic imaging following ASO is mandatory for all

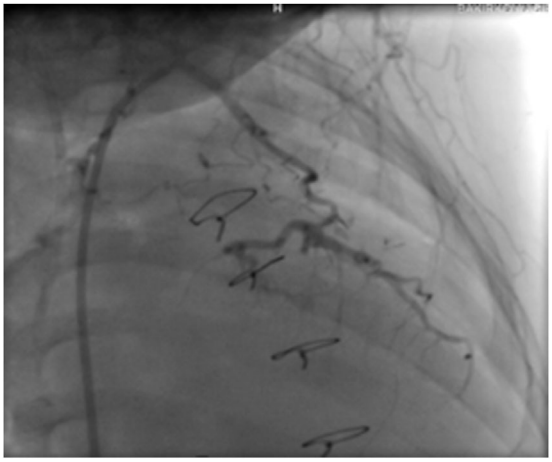

FIGURE 4 Tetralogy of Fallot repair with transannular patching requiring coronary artery bypass grafting as a rescue procedure. Coronary angiography showing left internal mammary artery to left anterior descending artery anastomosis 14 days after coronary artery bypass grafting

patients, particularly for those who have intramural coronary arteries, technical difficulties with button harvesting, and experience difficulty in weaning from bypass. Furthermore, mild or moderate lesions may progress in time.

Other congenital procedures which may result in late CA stenosis include the Ross procedure and an aortic root replacement due to endocarditis.[4,15]

Coronary artery anomalies in ToF are very rare; the most common anomaly is the abnormal origin of the left anterior descending CA from the right CA, crossing the RVOT.[16,17] Surgical CA injury can occur, with the transatrial approach, requiring emergency IMA to CA bypass, as in our two cases. It is, therefore, critical to define the CA course preoperatively to avoid CA injury.

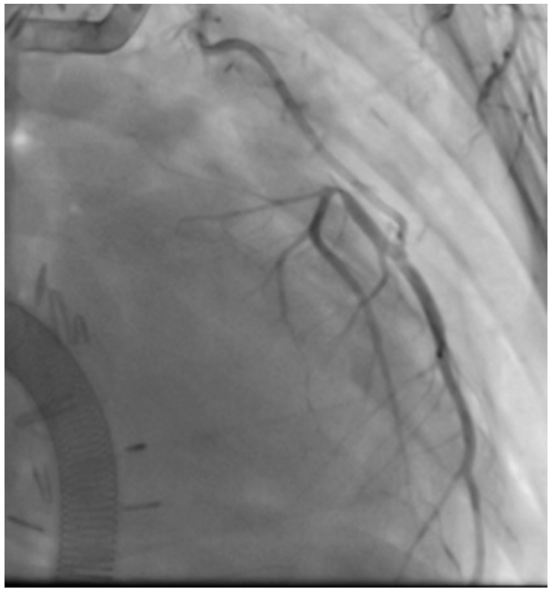

FIGURE 5 Tetralogy of Fallot repair with transannular patching requiring coronary artery bypass grafting as a rescue procedure. Coronary angiography showing left internal mammary artery to left anterior descending artery anastomosis one day after coronary artery bypass grafting CABG under extracorporeal membrane oxygenation support

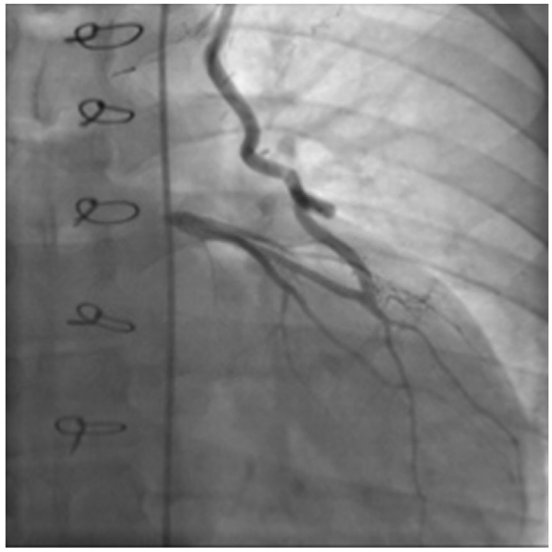

FIGURE 6 Arterial switch operation for transposition of the great arteries and ventricular septal defect requiring coronary artery bypass grafting 11 years after arterial switch operation due to late left main coronary artery stenosis. Coronary angiography showing an excellent long-term patency of left internal mammary artery to left anterior descending artery anastomosis 9.5 years after coronary artery bypass grafting

Some of the technical challenges of CABG in children include small target vessels, difficulties of exposure, and the availability of appropriate grafts. However, newborn and young infants have relatively large diameters of the internal thoracic and coronary arteries, which makes these arteries suitable for CABG, when indicated.[10,15,18] Another concern is the long-standing patency rate of the graft. The patency rate is significantly higher for arterial grafts than for venous grafts even in children younger than 3 years old.[19–22] The IMA also retains its natural curvature from the time of operation and is not stretched excessively by the patient's somatic growth.[23,24] More importantly, in the pediatric population, the arterial grafts have been demonstrated to grow with the rest of the body.[7] As seen in our two cases, the long-term function of the IMA grafts is excellent 9.5 and 18 years after CABG.

There are several limitations of the present study which includes its retrospective design with a limited number of patients. In addition, it is a single-center study and included a wide spectrum of patients undergoing pediatric cardiac surgery procedures.

5 | CONCLUSION

In conclusion, pediatric CABG procedures can be successfully performed in infants and children when necessary during complex

procedures with good long-term results. The IMA should be the graft of choice due to its growth potential and increased long-term patency rate, even in emergency intraoperative life-threatening conditions. Pediatric CABG patients will need life-long close follow-up with stress tests, myocardial scintigraphy, or catheterization when necessary.

CONFLICT OF INTEREST

The authors acknowledge no conflict of interest in the submission.

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