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Surgical procedures for coronary arteries in pediatric cardiac surgery: Risk factors and outcomes

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Abstract

Background: Limited data exist regarding the coronary revascularization procedures needed during the repair of several congenital and pediatric cardiac malformations. We aimed to determine risk factors for in-hospital mortality and long-term outcomes of various pediatric coronary revascularization procedures.

Methods: We retrospectively reviewed the records of 32 consecutive pediatric patients who underwent coronary revascularization procedures at our institution between May 1995 and June 2020. In-hospital mortality, risk factors, surgical indications, revascularization patency, and mid- and long-term follow-up data were investigated. Patients were categorized into the coronary artery bypass grafting ($n = 11$) and other coronary artery procedure ($n = 21$) groups.

Results: The median age and weight of patients at the time of surgery were 9 months and 4.8 kg, respectively. There were five in-hospital deaths (5/32, 15.6%). The mortality rates were 27.2% (3/11) in the coronary artery bypass grafting group and 9.5% (2/21) in the other coronary artery procedure group ($p = .206$; 95% confidence interval: 0.496–25.563). The mortality rates for planned and rescue procedures were 8.3% (2/24) and 37.5% (3/8) ($p = .06$), respectively. The median follow-up time was 12.5 years. Control imaging studies for coronary patency were performed in 70.3% (19/27) of surviving patients. The overall coronary patency rate was 94.7% (18/19).

Conclusions: Pediatric coronary revascularization procedures with elective-planned indications can be performed with good outcomes. Young age and rescue and emergency procedures may carry an increased risk of in-hospital mortality, although not found to be statistically significant. Surviving patients require lifelong follow-up regarding the patency of reperfused coronary arteries.

KEYWORDS

congenital coronary artery anomalies, coronary artery translocation, pediatric coronary revascularization, rescue procedures for coronary artery, unroofing of coronary artery

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1 | INTRODUCTION

The repair of several congenital and pediatric cardiac malformations, such as arterial switch operation (ASO), aortic root replacement, abnormal origin, and course of coronary arteries (CAs), and iatrogenic injuries of the CAs, includes various procedures related to CAs.[1–9] Pediatric coronary revascularization procedures (CRPs) comprise coronary artery bypass grafting (CABG) and other coronary artery procedures (OCAPs), which involve translocation of CAs with patch plasty, pericardial tube or composite tunnel interposition, CA unroofing, and other coronary reimplantation methods.[1–12]

Pediatric CRPs may carry high risk due to the small size of anatomical structures, difficulties in exposure, limitations in surgical options, and occurrence of life-threatening clinical situations and may cause abrupt acute myocardial dysfunction. Therefore, it becomes apparent that coronary revascularization is an exceptionally challenging surgical procedure, especially in children. Pediatric cardiac surgeons should have knowledge and expertise in the field of CA surgery. However, there is still a need to expand the sharing of knowledge and experiences on CA procedures in pediatric heart surgery.

The aim of this study was to investigate in-hospital mortality rate and risk factors according to data pertaining to patency and mid- and long-term outcomes in pediatric patients undergoing various CA procedures.

2 | MATERIALS AND METHODS

2.1 | Study population and data collection

Hospital records and follow-up data of pediatric patients who underwent cardiac surgery at our institution between May 1995 and June 2020 were retrieved from our institutional medical database and retrospectively reviewed. The study was approved by the Ethics Committee of Acıbadem University. The requirement for patient consent was waived due to the retrospective nature of the study. Among a total of 5593 pediatric patients (aged <18 years) that underwent cardiac surgical procedures during the study period, 32 needed CRPs. Patients who underwent noncomplicated ASOs were excluded from the study. The detailed demographic, diagnostic, and procedural data are summarized in Table 1 and Figure 1.

In-hospital mortality rate, risk factors, patency of revascularization, and mid- and long-term follow-up data were evaluated. The patients were categorized into the CABG (n = 11) and OCAPs (n = 21) groups. The procedures were also evaluated according to the indications and clinical status of the patients and divided into two groups: (1) planned procedures, which were part of the planned surgical strategy, and (2) rescue procedures, which were unexpectedly needed during the primary operation or performed as a life-saving procedure during an emergent situation.

2.2 | Statistical analysis

Statistical analysis was performed using Number Cruncher Statistical System 2007. Descriptive statistics (mean, *SD*, median, minimum, maximum, frequency, rate) were used to describe the study data. Logistic regression analysis was used to identify risk factors associated with in-hospital mortality. $p < .05$ was considered statistically significant.

3 | RESULTS

3.1 | Clinical data

Thirty-two patients (16 males and 16 females) that underwent CRPs during the study period were included in the study. The median patient age at the time of surgery was 9 months (range; 3 days to 180 months) and the median weight was 4.8 kg (range; 2.5–50.0 kg). Most of the patients (n = 18, 56.2%) were infants.

3.2 | Indications for revascularization

The types of CA lesions requiring revascularization included congenital CA anomalies (n = 12, 37.5%), aortic root surgery complicated by coronary perfusion problems (n = 18, 56.2%), and iatrogenic CA injuries during other cardiac procedures (n = 2, 3.1%). Planned procedures were performed in 24 (75%) patients (OCAP: n = 20, CABG: n = 4), whereas 8 (25%) patients (OCAP: n = 1, CABG: n = 7) required rescue procedures.

3.3 | Types of procedures

Eleven (34.3%) patients underwent CABG. The graft materials used, and targeted vessels are summarized in Table 1. CABG was performed in 7 (63.6%) cases of ASO: in three, owing to stretching kinking of translocated CAs, and in four, owing to CA obstruction (Figure 2A,B). The remaining four cases that underwent CABG were due to iatrogenic injury of abnormal CAs during tetralogy of Fallot (TOF) repair (n = 2) and damaged right coronary artery (RCA) during the Ross procedure (n = 2) (Figure 3A,B).

OCAPs (n = 21, 65.6%) were performed due to the following indications: handmade fresh autologous pericardial tube interposition for CA translocation (n = 4), pericardial patch plasty of the CA (n = 5), unroofing/unflooring of the main CA (n = 4), and anomalous left CA from the pulmonary artery (ALCAPA) repair (n = 10) (two patients underwent ALCAPA repair by pericardial tube interposition) with various technical modifications (Table 1; Figures 4A,B, 5A,B, and 6A,B).

3.4 | Early outcomes

Overall, there were five in-hospital deaths (5/32, 15.6%). The mortality rate of patients who underwent CABG and OCAPs was

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TABLE 1 Main diagnosis, primary operation, and type of procedures

Case	Age	Sex	Diagnosis/primary operation	Type of revascularization/affected coronary artery	Type of procedure	Postoperative imaging study	Coronary patency/ perfusion	Follow- up (months)	Outcome
1	9 days	F	TGA/ASO	Patch plasty/single LCA	Planned	CCTA	Patent	168.0	Alive
2	6 days	M	TGA/ASO	Patch plasty/single LCA	Planned	MPI	Normal	195.0	Alive
3	15 days	F	TGA/ASO	Patch plasty/single LCA	Planned			172.0	Alive
4	3 days	M	TGA/ASO	Patch plasty/single LCA	Planned	CCTA	Patent	191.0	Alive
5	9 days	F	TGA/ASO	Patch plasty/single RCA	Planned	MPI	Normal	177.0	Alive
6	3 days	F	TGA/ASO	Unroofing/intramural LMCA	Planned			1.0	In-hospital mortality
7	12 days	F	TGA/ASO	Pericardial tube interposition/ single LCA	Planned	Coronary angiography	Patent	120.0	Alive
8	48 months	M	TGA/ASO	Pericardial tube interposition/ single RCA	Planned			169.2	Alive
9	3 months	M	ALCAPA/repair	Pericardial tube interposition/LMCA	Planned	Coronary angiography	Patent	132.0	Alive
10	2 months	F	ALCAPA/repair	Pericardial tube interposition/LMCA	Planned			178.0	Alive
11	168 months	M	Anomalous origin of LMCA from right coronary sinus	Unroofing/LMCA	Planned	CCTA	Patent	160.0	Alive
12	24 months	M	Subaortic stenosis/High take-off RCA	Unroofing-reimplantation/RCA	Rescue			120.0	Alive
13	4 days	M	TGA/ASO	Unroofing of coronary artery/ intramural LMCA	Planned	MPI	Normal	110.5	Alive
14	18 months	M	ALCAPA/repair	Direct reimplantation/LMCA	Planned	Coronary angiography	Patent	190.1	Alive
15	9 months	F	ALCAPA/repair	Takeuchi procedure/LMCA	Planned			7.0	In-hospital mortality
16	60 months	F	ALCAPA/repair	Direct aortic implantation/LMCA	Planned			116.7	Alive
17	2.5 months	F	ALCAPA/repair	Takeuchi procedure/LMCA	Planned			105.9	Alive
18	64 months	M	ALCAPA/repair	Takeuchi procedure/LMCA	Planned			78.0	Alive
19	16 months	F	ALCAPA/repair	Extrapulmonary tunnel/LMCA	Planned	CCTA	Patent	85.0	Alive
20	3 months	M	ALCAPA/repair	Extrapulmonary tunnel repair/LMCA	Planned	Coronary angiography	Patent	19.1	Alive
21	2.5 months	F	ALCAPA/repair	Extrapulmonary tunnel repair/LMCA	Planned	Coronary angiography	Patent	283.4	Alive
22	9.5 months	M	TGA/ASO- late CA & Supravalvular AS stenosis	CABG (RIMA–RCA)—Patch aortoplasty 1 year after ASO	Planned			16.1	Alive

(Continues)

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TABLE 1 (Continued)

Case	Age	Sex	Diagnosis/primary operation	Type of revascularization/affected coronary artery	Type of procedure	Postoperative imaging study	Coronary patency/ perfusion	Follow- up (months)	Outcome
23	144 months	M	TGA+VSD/ASO- Late LMCA stenosis	CABG (LIMA–LAD) 11 years after ASO	Planned	Coronary angiography	Patent	144.2	Alive
24	3 months	F	TGA/ASO Late CA stenosis	CABG (LIMA–LAD) 2 months after ASO	Rescue			5.6	In-hospital mortality
25	17 months	M	TGA/ASO-Late CA stenosis	CABG (LIMA–LMCA)/Intramural LMCA (16 months after ASO)	Planned	CCTA	Patent	129.6	Alive
26	36 months	M	TOF/total repair- iatrogenic injury of abnormal CA (LAD from RCA)	CABG (LIMA–LAD)	Rescue	Coronary angiography	Patent	2.0	In-hospital mortality
27	48 months	F	TGA/ASO/Late LMCA stenosis	LMCA patch plasty + CABG (Ao–SVG–LAD) 4 years after ASO	Planned	Coronary angiography	(LMCA patch plasty patent, SVG occluded)	71.8	Alive
28	17 months	F	TOF Anomalous LMCA crossing RVOT/TOF repair	CABG (LIMA–LAD)	Rescue	Coronary angiography	Patent	75.0	Alive
29	12 months	F	TGA+VSD/ASO	CABG (RIMA–RCA)	Rescue			1.0	In-hospital mortality
30	6 months	M	TGA+VSD+ Single LCA/ASO	CABG (LIMA–RCA)	Rescue	Coronary angiography	Patent	216.0	Alive
31	96 months	F	Congenital AS, RCA destruction/ Ross procedure	CABG (RIMA–RCA)	Rescue	CCTA		192.0	Alive
32	180 months	M	Congenital AS/Ross procedure	CABG (Ao–SVG–RCA)	Rescue			36.0	Alive

Abbreviations: ALCAPA, anomalous left coronary artery from the pulmonary aorta; Ao, aorta; AS, aortic stenosis; ASO, arterial switch operation; CA, coronary artery; CABG, coronary artery bypass grafting; CCTA, coronary computed tomography angiography; F, female; LAD, left anterior descending artery; LCA, left coronary artery; LIMA, left internal mammary artery; LMCA, left main coronary artery; M, male; MPI, myocardial perfusion imaging; RCA, right coronary artery; RIMA, right internal mammary artery; RVOT, right ventricular outflow tract; SVG, saphenous vein graft; TGA, transposition of great arteries; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

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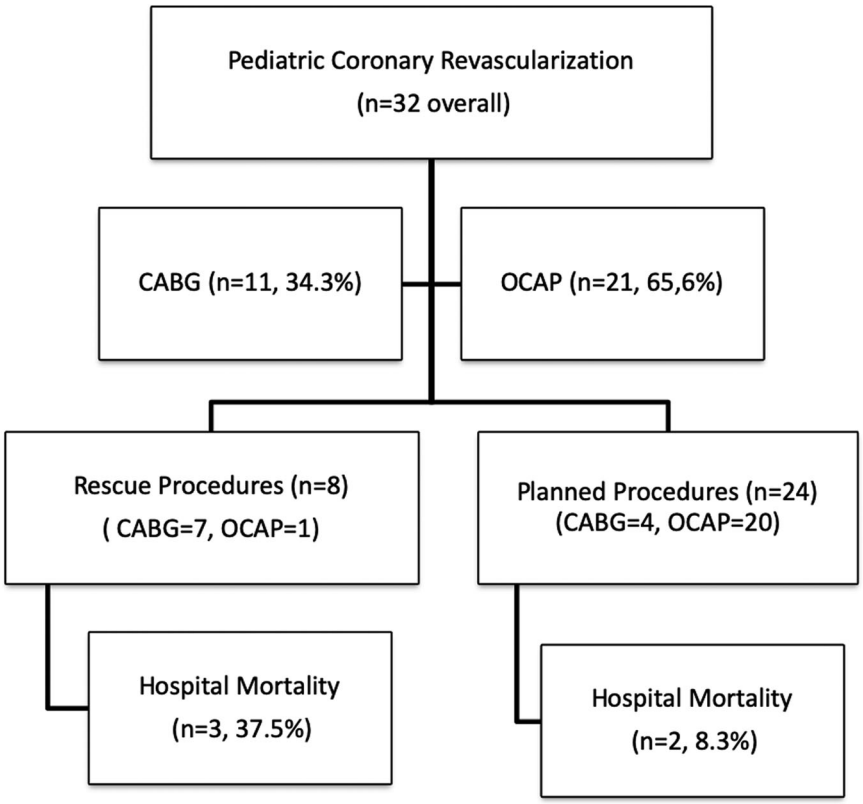

FIGURE 1 Diagram of the study population and outcomes. CABG, coronary artery bypass grafting, OCAP, other coronary artery procedure

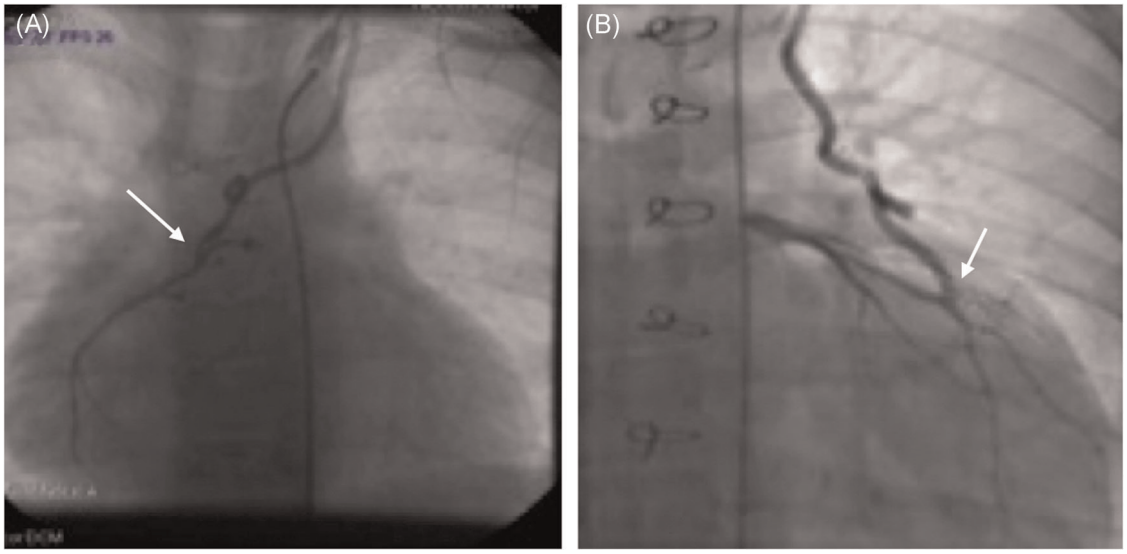

FIGURE 2 (A) Angiographic image of left internal mammary artery (LIMA) to right coronary artery (RCA) bypass (arrow) at 18 years postoperatively of a 6-month-old boy (Case 30) with transposition of great arteries, ventricular septal defect, and single left coronary pattern who underwent arterial switch operation (ASO) along with a rescue coronary artery bypass grafting due to stretching of the RCA. (B) Angiographic image of the LIMA to LAD bypass (arrow) at 9.5 years postoperatively in a 12-year-old patient (Case 23) with late LMCA obstruction after ASO

27.2% (3/11) and 9.5% (2/21), respectively. The mortality rate of patients who underwent planned and rescue procedures was 8.3% (2/24) and 37.5% (3/8) ($p = .069$), respectively. Detailed patient profiles are included in Table 1. Three deaths occurred in the CABG group among patients who underwent rescue procedures (Cases 24, 26, and 29). The remaining two deaths occurred in the OCAP group among patients who underwent planned procedures; one who underwent ALCAPA repair (Case 15) and another who underwent ASO due to unroofing of the left main coronary artery (LMCA) (Case 6). There was no in-hospital mortality among patients undergoing planned CABG procedures.

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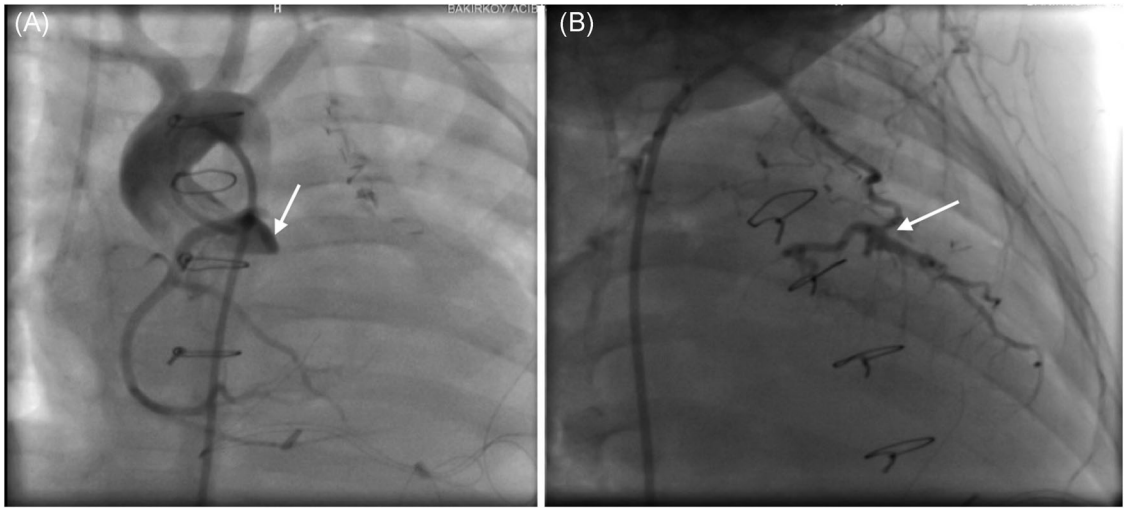

FIGURE 3 (A) Postoperative angiographic image of the right coronary artery (RCA) and interrupted left main coronary artery (arrow) and (B) a successful left internal mammary artery (arrow)-to-left anterior descending artery bypass in a 17-month-old girl (Case 28) with tetralogy of Fallot and single RCA origin with left coronary artery crossing the right ventricular outflow tract

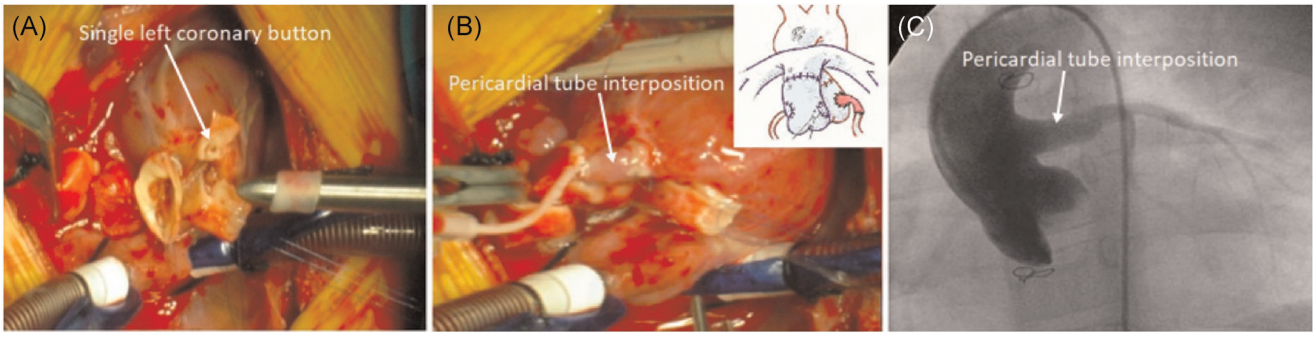

FIGURE 4 (A) Excision of a single left coronary artery button during arterial switch operation, and (B) translocation with a pericardial tube interposition. (C) Postoperative year 5 (Case 7) angiography image

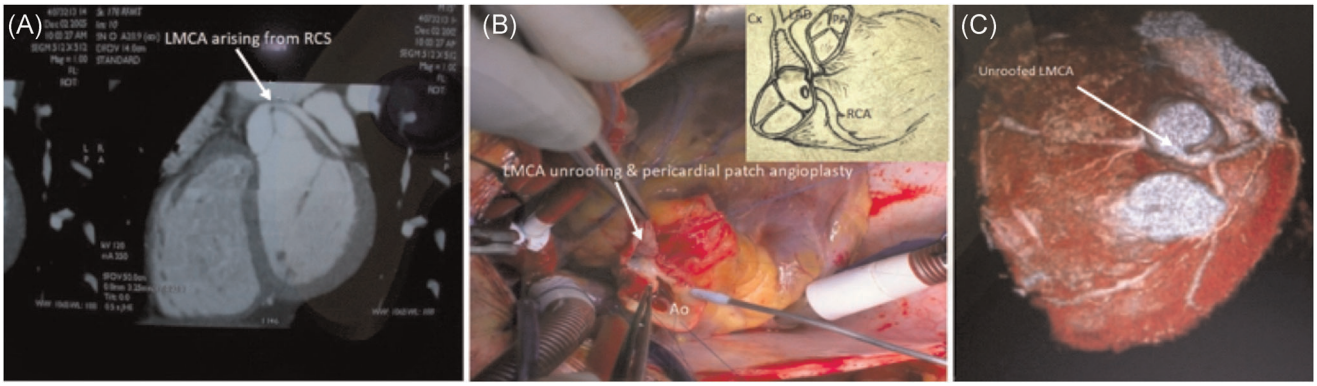

FIGURE 5 (A) Preoperative computed tomography (CT) angiography in a patient (Case 11) with a left main coronary artery (LMCA) arising from the right coronary sinus. (B) Unroofing of the LMCA and pericardial patch angioplasty. (C) Postoperative control CT angiography

Two patients required postoperative extracorporeal membrane oxygenation (ECMO) support due to left ventricular (LV) dysfunction. The first, a newborn baby undergoing ALCAPA repair, was weaned successfully from ECMO after 36 h; LV function returned to normal (fractional shortening [FS]: 37%), and the patient survived with good hemodynamic and functional capacity. The second patient underwent TOF repair with rescue CABG and was weaned from ECMO after 1 week. Although LV function was

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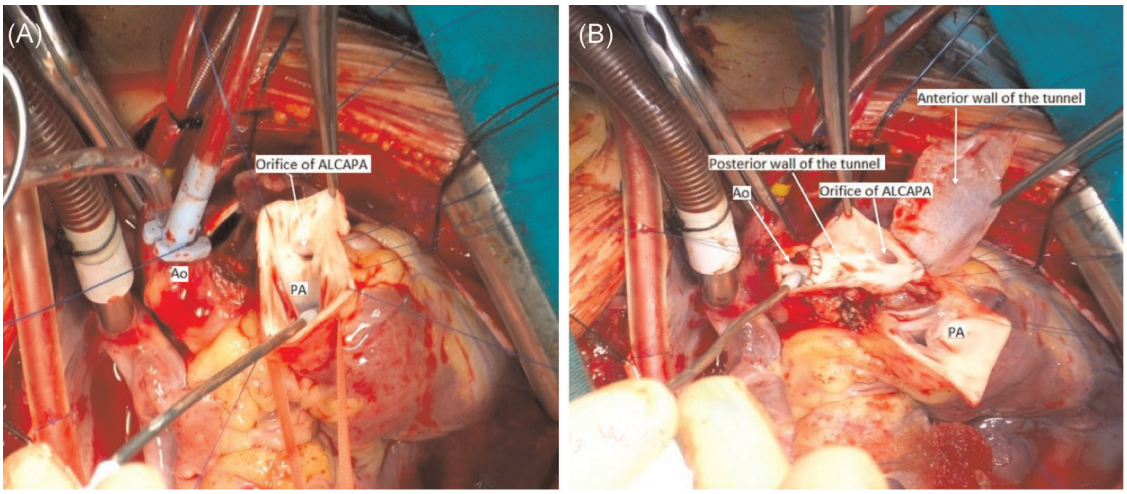

FIGURE 6 Extrapulmonary tunneling for anomalous left coronary artery from the pulmonary aorta (ALCAPA) repair. (A) Transected pulmonary artery and orifice of the ALCAPA. (B) The posterior wall was made from a piece of pulmonary artery, and the anterior wall was reconstructed using a pericardial patch (B) (Case 20)

restored (FS: 31%), the patient died 3 months later due to sepsis and multiorgan failure.

In another patient (a 3-month-old baby) who underwent ALCAPA repair with extrapulmonary tunneling, the tunnel was obstructed (likely with cloth) on postoperative Day 5. The obstruction was successfully treated by coronary stenting (3.5 × 8 mm, Xience Prime; Abbott Inc.) of the tunnel (Figure 7A,B), and LV function returned to normal (left ventricular ejection fraction [LVEF]: 65%) at discharge.

The results of the univariate and multivariate logistic regression analyses regarding the risk factors that affect mortality are provided in Table 2. There was no significant relationship between the planned and rescue procedures and mortality ($p = .069$); however, the mortality rate was higher in the rescue procedure group.

Age, sex, and rescue procedures, which were considered to affect mortality, were evaluated by multivariate logistic regression analysis; however, none of these factors were found to be significant (Table 2).

3.5 | Follow-up

The median follow-up of the 27 surviving patients was 12.5 years (range: 16 months to 25 years). Imaging studies to evaluate coronary

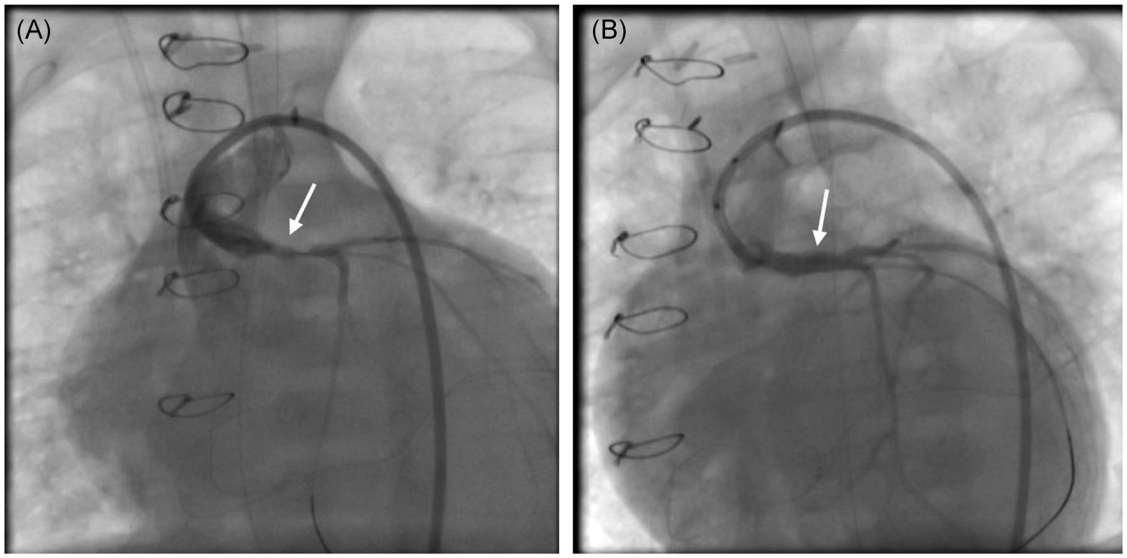

FIGURE 7 (A) Obstructed extrapulmonary tunnel (arrow) in a patient (Case 20) early after anomalous left coronary artery from the pulmonary aorta repair, which was successfully treated by (B) coronary stenting (arrow)

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TABLE 2 Univariate and multivariate logistic regression analyses of risk factors affecting mortality

	Alive (n = 27)	Mortality (n = 5)	p	OR	95% CI
Univariate logistic regression analysis					
Age (months)					
≤1 year	14 (77.8)	4 (22.2)	.267	3.714	0.366–37.708
>1 year (Ref)	13 (92.9)	1 (7.1)			
Min–Max (median)	0.1–180 (9.5)	0.1–36 (9)			
Mean ± *SD*	34.46 ± 52.88	12.02 ± 14.21			
Sex					
Female	12 (75.0)	4 (25.0)	.174	5.000	0.492–50.831
Male (ref)	15 (93.8)	1 (6.3)			
Weight (kg)					
Min–max (median)	2.5–50 (4.9)	3.7–15 (4.7)	.515	0.951	0.819–1.105
Mean ± *SD*	10.70 ± 13.12	6.56 ± 4.75			
Cardiopulmonary bypass time (min)					
Min–max (median)	70–314 (191.5)	77–308 (237)	.445	1.006	0.990–1.023
Mean ± *SD*	182.57 ± 69.22	214.75 ± 100.57			
Cross-clamp times (min)					
Min–max (median)	25–173 (94)	30–140 (131.5)	.537	1.009	0.981–1.038
Mean ± *SD*	93.86 ± 40.12	108.25 ± 52.40			
Type of revascularization					
OCAP (ref)	19 (90.5)	2 (9.5)			
CABG	8 (72.7)	3 (27.3)	.206	3.562	0.496–25.563
Type of procedure					
Planned (ref)	22 (91.7)	2 (8.3)			
Rescue	5 (62.5)	3 (37.5)	.069	6.600	0.862–50.541

	p	OR	95% CI	
			Lower	Upper
Multivariate logistic regression analysis				
Age (≤1 year)	.153	17.130	0.348	842.541
Sex (female)	.270	4.828	0.294	79.381
Type of procedure (rescue)	.175	10.006	0.359	278.770

Abbreviations: CABG, coronary artery bypass grafting, CI, confidence interval; OCAP, other coronary artery procedure; OR, odds ratio; ref, reference variable.

*p < .05.

patency were performed in 70.3% (19/27) of the surviving patients during a median follow-up of 10 years (range: 18 months to 22 years). Conventional coronary angiography (n = 10) and computed tomography angiography (n = 6) revealed patent coronary perfusion in all patients except for one (CABG; occluded saphenous vein graft to the left anterior descending artery [LAD]). This patient had normal LV function because patch reconstruction of the LMCA maintained normal antegrade CA flow despite the occluded aorta to the LAD vein graft. Myocardial perfusion imaging indicated no perfusion defects in the remaining three patients. Detailed information on imaging studies is summarized in Table 3.

The patient who underwent ALCAPA repair with extrapulmonary tunneling and postoperative coronary stent placement for obstructed extrapulmonary tunnel was asymptomatic, and echocardiographic LMCA flow and myocardial function were normal (LVEF: 68%) 2 years postoperatively (Figure 7A,B).

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TABLE 3 Outcomes according to type of revascularization and type of procedure

Type of revascularization	Total patients (n = 32)	In-hospital mortality	Late mortality	Cardiac function in surviving patients (n = 27)	Cardiac imaging studies in surviving patients (70.3%, 19/27)			Coronary patency/perfusion
					CAn	CCTA	MPI	
CABG	11	3 (27.2%)	-	No symptoms with normal EF	5	2	-	Patent: 6; obstructed: 1 (SVG to LAD bypass)
OCAP	21	2 (9.5%)	-	No symptoms with normal EF	5	4	3	Patent: 12
Type of procedure								
Planned	24	2 (4.1%)	-	No symptoms with normal EF	7	5	3	Patent: 14; obstructed: 1 (SVG to LAD bypass)
Rescue	8	3 (37.5%)	-	No symptoms with normal EF	3	1	-	Patent: 4

Abbreviations: CAn, coronary angiography; CCTA, coronary computed tomography angiography; EF, ejection fraction (normal: 0.55–0.68); MPI, myocardial perfusion imaging.

At the final follow-up, all 27 surviving patients were asymptomatic and had normal LV function (LVEF: 55%–68%) according to echocardiography and normal electrocardiography findings.

4 | DISCUSSION

In pediatric and congenital cardiac surgery, CABG and OCAPs, such as the translocation of CAs with patch plasty, pericardial tube or composite tunnel interposition, unroofing of the CA, and other coronary reimplantation methods have been performed as CA procedures. First of all, we think that there is a need to clarify the concept of CA revascularzation in children. We believe that not only CABG but also OCAPs (various surgical interventions and manipulations on CA) should be considered in the scope of CRPs. In fact, in the two largest multicenter studies,[1,3] OCAPs (coronary patch plasty, complicated coronary transfer/reimplantation, repair of anomalous origin of CA from pulmonary artery or aorta, unroofing etc.) have been included among the CRPs. We, therefore, believe that this point of view needs to be discussed in the field of pediatric cardiac surgery.

The most frequently performed coronary procedures in children are associated with ASOs.[1,3] During coronary translocation, several types of procedures, such as pericardial patch plasty, might be necessary to avoid kinking and stretching of anastomosis.[5,9,10,12–14] Regarding coronary button reimplantation and CA dissection, open excision technique is preferred, and the buttons are excised as large as possible. Extensive dissection of the proximal CA is avoided to minimize stretching and kinking of the CA during reimplantation. We believe that with the help of a pericardial tube interposition, almost every unusual coronary pattern can be successfully translocated to the neoaorta.[5,8–11,13–16] The patent autologous pericardial tube observed in four patients in our study 5 years postoperatively supports this notion.

In some cases, despite every effort, coronary malperfusion may occur. In such cases, CABG can be a life-saving rescue procedure. CABG was first applied by Cooley et al.[17] in 1966 as an aorta-saphenous bypass in an infant with ALCAPA. With improvements in surgical techniques, CABG has become a feasible CRP option even in neonates and young infants.[1,3,7–9,11–16,18]

Late coronary obstructive problems after ASOs occur in 2%–7% of cases.[11,12] If the obstruction is beyond the coronary orifice and proximal portion of the main CA, as in the three cases in our study (Cases 23, 25, and 27), CABG may be a rational solution.[6,7,9,14] If stenosis is isolated to the coronary orifice and proximal portion, aorto-coronary patch arterioplasty can also be considered as an alternative. In this study, we applied this method in one patient (Case 27) who also exhibited additional supra-annular aortic stenoses, which were enlarged with a simultaneous extended pericardial patch arterioplasty. This modification can be considered a preferable approach for combined ostial-proximal CA and supra-annular aortic stenosis.

The left CA arising from the right coronary sinus represents the most serious anomalous aortic origin of coronary artery (AAOCA),

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which can cause sudden death.[4,7,19] In our patient, a 14-year-old boy presenting with recurrent syncope, we performed unroofing of the LMCA and reconstruction of the main pulmonary artery, a surgical technique that has previously been reported (Figure 5A–C).[20] A high take-off aortic origin of the CA is an extremely rare anomaly.[15] One of our patients had a subaortic stenosis associated with a high take-off RCA, which was incidentally cut during aortotomy. We favored the unroofing repair procedure involving excision of the internal wall (unflooring) of the intramural part of the RCA to create a new enlarged ostium, which was reimplanted into the aorta by incorporating it into the closure line of aortotomy.

In patients with AAOCAs, CABG can be considered as an alternative option. However, we prefer to reserve CABG (particularly reserving internal mammary artery [IMA]) due to the possibility of exposure to atherosclerotic CA disease in adulthood. In addition, there are concerns regarding the competitive flow and long-term patency of the graft material in cases of unobstructed or minimally obstructed native coronary flow under non-stressed conditions.[4,7,9,19]

ALCAPA repair should be considered an important subgroup among pediatric CRPs. Direct reimplantation to the aorta may be an appropriate approach, particularly in young infants with ALCAPA arising from the medial pulmonary sinus.[7,21–24] In most of our current patients, LMCA arose from the lateral sinus of the pulmonary valve. In such cases, despite proper mobilization, direct translocation could cause stretching and compression of the LMCA. Therefore, we prefer to perform extrapulmonary tunneling, which is a safe and effective approach (Figure 6A,B).[21,23,24] Autologous pericardial tube interposition, as mentioned previously, is another option.[10]

CA stenting has rarely been performed in children. In one of our patients with ALCAPA, the stent, which was urgently placed for occluded extrapulmonary tunnel, was patent 2 years postoperatively. A similar case was reported by Paech et al.[25] who angiographically confirmed the long-term patency of the stent 16 years postoperatively. Intraoperative stent placement and LMCA stenting have been reported in previous studies.[1,3] Thus, it is suggested that in selected cases, coronary stent implantation may have an important role in pediatric CRPs.

There is no doubt that coronary revascularization is one of the most challenging cardiac surgical procedures in children. Thus, pediatric cardiac surgeons should be well equipped and acknowledgeable to perform CRPs successfully. Two multicenter studies from the United States and Europe have provided the largest source of information on pediatric CRPs to date.[1,3]

Thammineni et al.[3] reported that the overall in-hospital mortality rate was 14.6%; in the CABG group it was 18.1% and 10.8% in the non-CABG group. In their study, long-term patency follow-up data were available for 17.5% of patients. The graft/vessel patency was 58% for the CABG and 63% for the non-CABG group, and the 15-year transplant-free survival rate was 90.7% over a median follow-up period of 14.9 years. Similarly, Vida et al.[1] reported a 15% in-hospital mortality rate and 5.8% late mortality rate during a median follow-up period of 3 years. They also reported that 70% of survivors underwent control CA angiography; among them, 64% of pediatric patients who underwent CABG procedures and 75% of those who underwent OCAPs were patent. In our study, the overall in-hospital mortality rate was 15.6%, and no deaths occurred during the median follow-up period of 12.5 years. The higher mortality rate (27.2%) in the CABG group than in the OCAPs group (9.5%) was likely related to the number of rescue procedures required in the CABG group (7/11). There were no in-hospital deaths among patients who underwent planned CABGs. We performed imaging studies to evaluate coronary patency and myocardial ischemia in 19/27 (70.3%) surviving patients during the follow-up period. We found that the overall patency rate was 94.7% (18/19) in our study (Tables 1 and 3).

Similar to previous studies, we observed that newborns and young infants have relatively large CA and IMA diameters, which make these arteries suitable for CABG.[8,9,16,26,27] However, the long-term patency of pediatric CABGs remains debatable. Regardless, the patency rate of IMA grafts is markedly higher than that of venous grafts even in those aged <3 years. IMA retains its natural curvature and growth potential like the rest of the body.[1,7,16,18,20] The excellent long-term patency of IMA graft in two patients included in our study 9.5 and 18 years postoperatively is depicted in Figure 2A,B.

Due to emergent myocardial ischemic compromise and unexpected iatrogenic coronary injuries, rescue procedures are an important subset of pediatric CRPs. In our study, 8/32 (25%) patients underwent life-saving rescue procedures that have been described previously.[16,28] The risk of in-hospital mortality associated with rescue procedures has been shown to be significantly higher than that associated with planned coronary procedures. Vida et al.[1] and Thammineni et al.[3] reported that the in-hospital mortality rates of emergent-rescue procedures were 32.4% (11/34) and 29.8% (14/47), respectively. In our study, the mortality rate associated with rescue procedures (37.5%, 3/8) was also higher than that associated with planned procedures (8.3%, 2/24) ($p = .06$); these rates were comparable to those of previous reports.[1–3] The poor early outcomes of rescue procedures may be related to the clinical situation, young age, myocardial ischemic injury, and effect of prolonged cardiopulmonary bypass exposure.

It is apparent that we do not have sufficient data to draw definitive conclusions; however, with an acceptable in-hospital mortality rate and good long-term outcomes, we suggest that CRPs are a favorable surgical option for pediatric patients at a risk of impaired myocardial perfusion.

5 | LIMITATIONS

Our study has some limitations. First, the number of patients included was limited. Second, various revascularization procedures were performed, making it difficult to draw conclusions. Furthermore, although the median follow-up period was 12.5 years, direct and indirect information regarding the patency rate of reperfused CAs was limited.

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6 | CONCLUSIONS

Pediatric CRPs with elective-planned indications can be performed with good early and late outcomes. Young age, as well as rescue and emergency procedures, may carry an increased risk of in-hospital mortality. Surviving patients need lifelong follow-up regarding the patency of the reperfused CAs to prevent and treat any possible cause of further myocardial ischemia. As pediatric coronary revascularization requires exceptional expertise and knowledge, we thus propose that all pediatric heart surgeons should undergo CA surgery training.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

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