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Cardiac Catheterization in the Early Post-Operative Period After Congenital Cardiac Surgery

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ABSTRACT

OBJECTIVES This study sought to demonstrate that early cardiac catheterization, whether used solely as a diagnostic modality or for the use of transcatheter interventional techniques, can be used effectively and with an acceptable risk in the post-operative period.

BACKGROUND Cardiac catheterization offers important treatment for patients with congenital heart disease. Early post-operative cardiac catheterization is often necessary to diagnose and treat residual anatomic defects. Experience with interventional catheterization to address post-operative concerns is limited.

METHODS This was a retrospective cohort study. The medical and catheterization data of pediatric patients who underwent a cardiac catheterization ≤30 days after congenital heart surgery between November 2004 and July 2013 were reviewed. Patients who underwent right heart catheterization and endomyocardial biopsy after heart transplantation were excluded.

RESULTS A total of 219 catheterizations (91 interventional procedures, 128 noninterventional catheterizations) were performed on 193 patients. Sixty-five interventions (71.43%) were dilations, either balloon angioplasty or stent implantation. There was no difference in survival to hospital discharge between those who underwent an interventional versus noninterventional catheterization ($p = 0.93$). One-year post-operative survival was comparable between those who underwent an intervention (66%) versus diagnostic (71%) catheterization ($p = 0.58$). There was no difference in the incidence of major or minor complications between the interventional and diagnostic catheterization cohorts ($p = 0.21$).

CONCLUSIONS Cardiac catheterization, including transcatheter interventions, can be performed safely in the immediate post-operative period after congenital heart surgery. (J Am Coll Cardiol Intv 2014;7:1437–43)
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Cardiac catheterization is often uniquely valuable in the evaluation and treatment of patients with congenital heart disease. Although the safety of catheterization in the non-acute setting has been described (1–4), early post-operative cardiac catheterization (EPOCC) is often regarded as high risk, particularly when patients are unstable or when interventions are anticipated. There is significant institutional variability with regard to access and timely referral for EPOCC. There is limited reported experience with cardiac catheterization in the early post-operative period (5–7).

At our institution, patients are often referred for cardiac catheterization in the early post-operative period to determine the significance of a residual cardiac lesion noted by noninvasive means (e.g.,

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ABBREVIATIONS AND ACRONYMS

ECMO = extracorporeal membrane oxygenation

EPOCC = early post-operative cardiac catheterization

IQR = interquartile range

echocardiography) or to assess physiology and/or anatomy in the struggling post-operative patient. We reviewed our institutional experience with perioperative cardiac catheterization in this patient group. The purpose of this study is to describe the safety and overall outcomes of cardiac catheterization procedures performed within 30 days after congenital heart surgery. We hypothesized that early cardiac catheterization, whether used solely as a diagnostic modality or as a percutaneous intervention, can be used effectively and with an acceptable risk in the post-operative period.

METHODS

STUDY PATIENTS. This is a single-center, retrospective cohort study. Medical and catheterization data of all pediatric patients who underwent a cardiac catheterization ≤30 days after congenital heart surgery at Children's Healthcare of Atlanta between November 2004 and July 2013 were reviewed. Patients were included if they underwent either a diagnostic or interventional cardiac catheterization ≤30 days after surgical repair/palliation for congenital heart disease. Patients who underwent right heart catheterization and endomyocardial biopsy as routine surveillance after orthotopic heart transplantation were excluded. This study was approved by the institutional review board.

TABLE 1 Patient Characteristics

	Total (N = 193)	Interventional (n = 65)	Diagnostic (n = 128)	p Value
Patient characteristics				
Age, yrs	0.32 (0.01–18.48)	0.31 (0.01–17.14)	0.35 (0.01–18.48)	0.49
Weight, kg	5.20 (3.40–8.50)	4.90 (2.30–51.31)	5.50 (2.20–98.50)	0.45
Time from surgery, days	6 (0–30)	8 (0–29)	5 (1–30)	0.01
Mechanical ventilator support	131	47	84	0.35
Inotropic support	129	39	90	0.16
ECMO	22	8	14	0.77
Genetic syndrome	45	11	34	0.14
Primary diagnosis				
Single ventricle	96 (50)	45 (69)	51 (40)	<0.01
Conotruncal anomalies (TOF, DORV, TA, PA-VSD, TGA)	55 (28)	15 (23)	40 (31)	0.24
AVSD	10 (5)	1 (2)	9 (7)	0.11
Other	31 (16)	3 (5)	28 (22)	<0.01

Values are median (range), n, or n (%).

AVSD = atrioventricular septal defect; DORV = double-outlet right ventricle; ECMO = extracorporeal membrane oxygenation; PA-VSD = pulmonary atresia–ventricular septal defect; TA = truncus arteriosus; TGA = transposition of the great arteries; TOF = tetralogy of Fallot.

CATHETERIZATION PROCEDURE. Demographic data collected included weight at catheterization (in kilograms), age at catheterization (years), and primary cardiac diagnosis. We also reported the initial surgical procedure performed, the interval from surgery to EPOCC (days), the indication(s) for EPOCC (cyanosis, low cardiac output, or other), the diagnosis of a genetic syndrome, the need for mechanical ventilation before EPOCC, the need for inotropic support, extracorporeal membrane oxygenation (ECMO) use at time of catheterization, in-hospital mortality, and 1-year survival post-surgery. Catheterization data collected included the procedure performed, the intervention involving a surgical anastomotic site, procedural mortality, the need for blood transfusion during the catheterization, and procedural complications (minor/major). Major complications included death, stroke, cardiopulmonary arrest, and the need for unplanned emergent surgery/procedure/ECMO support as a result of complication.

STATISTICAL ANALYSIS. Continuous variables were reported as median and interquartile range (IQR). The data were initially analyzed with a univariate followed by a multivariate regression analysis when applicable. The primary outcome measure was procedural complication. Covariates and factors were assessed using either a Wilcoxon rank sum test or a chi-square test, when applicable. Secondary endpoints included hospital discharge survival and 1-year survival. Kaplan-Meier log-rank univariate analysis was performed for time-dependent outcomes, and multivariable analysis was performed using Cox regression with SPSS Version 21.0 software (IBM, Armonk, New York).

RESULTS

During the study period, there were a total of 7,755 surgical cases at our institution. A total of 219 early post-operative catheterizations (91 interventional procedures, 128 noninterventional catheterizations) were performed on 193 of these patients. At the time of EPOCC, the median age was 0.32 years (IQR: 0.05 to 0.95 years), the median weight was 5.2 kg (IQR: 3.4 to 8.5 kg), and the median interval from surgery was 6 days (IQR: 3 to 12 days). A total of 132 patients were on mechanical ventilatory support, and 129 patients were receiving inotropic support. Twenty-two patients were on ECMO at the time of catheterization, whereas 45 patients were known to have a genetic disorder. Patient characteristics and indications for cardiac catheterization are summarized in Tables 1 and 2.

TABLE 2 Indications for Catheterization (N = 193)

	Interventional	Diagnostic	p Value
Cyanosis	28	26	<0.01
Low cardiac output	4	31	<0.01
Concern for residual defect	20	42	0.78
Effusion	2	6	0.64
Unable to wean ventilator support	5	9	0.85
Unable to wean CPB	3	9	0.54
Other	3	5	0.80

Values are n.
CPB = cardiopulmonary bypass.

A total of 65 patients underwent 91 interventional procedures, and 128 patients underwent diagnostic catheterization. In patients in whom an intervention was performed, catheterization occurred at a median of 8 days post-operatively compared with a median of 5 days post-operatively for patients who underwent a diagnostic evaluation ($p = 0.01$). Otherwise, the interventional and diagnostic EPOCC groups were similar (Table 1).

In total, 91 interventions were performed in 65 patients (Table 3). Sixty-five interventions (71.43%) were dilations, either balloon angioplasty or stent implantation. The interventional EPOCC group was more likely to have single-ventricle heart disease ($p < 0.01$) and to present for EPOCC due to cyanosis, whereas the indication of low cardiac output was associated with diagnostic catheterization ($p < 0.01$) (Table 2). There were 65 stent/angioplasty procedures and 14 occlusion procedures (Figures 1 to 3). Details of the range of interventions are presented in Table 3. A total of 45 (49.5%) of the interventional procedures were interventions at a fresh anastomotic site.

A total of 18 complications occurred among the entire EPOCC cohort; there were 7 major and 11 minor complications (Table 4). There was no difference in the incidence of major or minor complications between the interventional and diagnostic catheterization cohorts ($p = 0.21$).

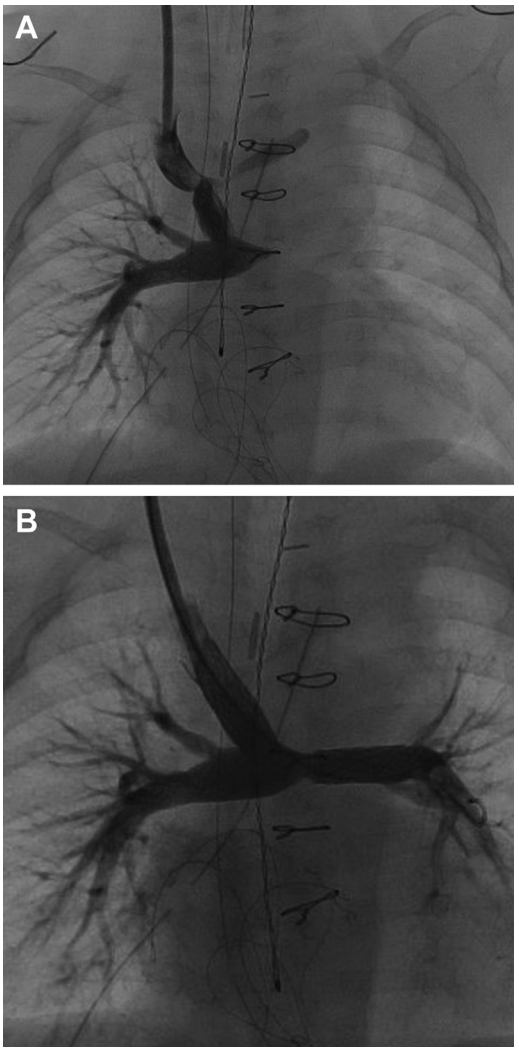

FIGURE 1 Left Pulmonary Artery Stenosis

(A) Hours after completion of a superior cavopulmonary connection, this patient was found to have complete left pulmonary artery occlusion and superior vena caval stenosis. **(B)** After recanalization and stenting of the left pulmonary artery and stenting of the superior vena cava, the patient improved rapidly.

TABLE 3 Interventional Procedure Types (N = 91)

	Location	n
Stent implantation, n = 28	Pulmonary artery	15
	Systemic vein	3
	BTS/RV-PA conduit	6
	Carotid/innominate artery	3
	Fontan circuit	1
Balloon angioplasty, n = 37	Pulmonary artery	13
	Aorta	6
	Systemic vein	15
	BTS	3
Occlusion, n = 14	AP collateral	7
	VV collateral	7
Other, n = 12	Thrombectomy	9
	Atrial septostomy	3

AP = aortopulmonary; BTS = Blalock-Taussig shunt; RV-PA = right ventricle pulmonary artery; VV = venovenous.

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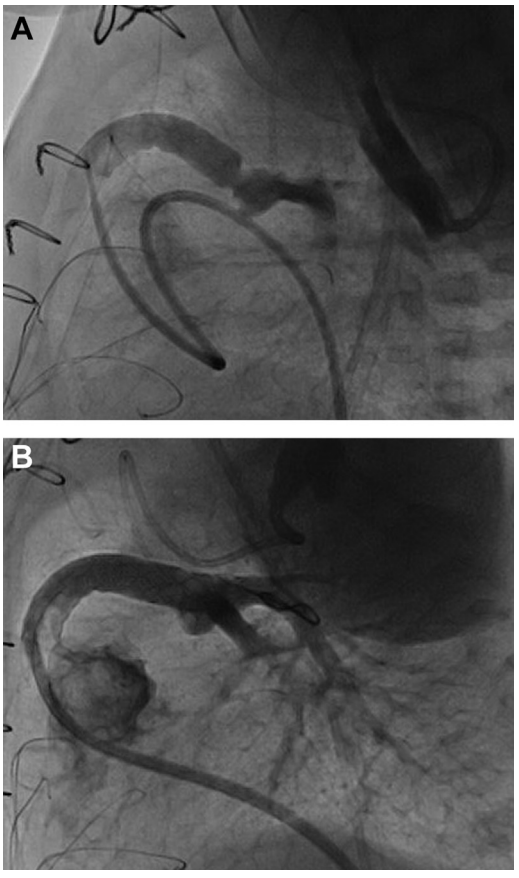

FIGURE 2 Distal Shunt Stenosis

Lateral projection demonstrating discrete distal right ventricle-to-pulmonary artery shunt stenosis before **(A)** and after **(B)** stent placement.

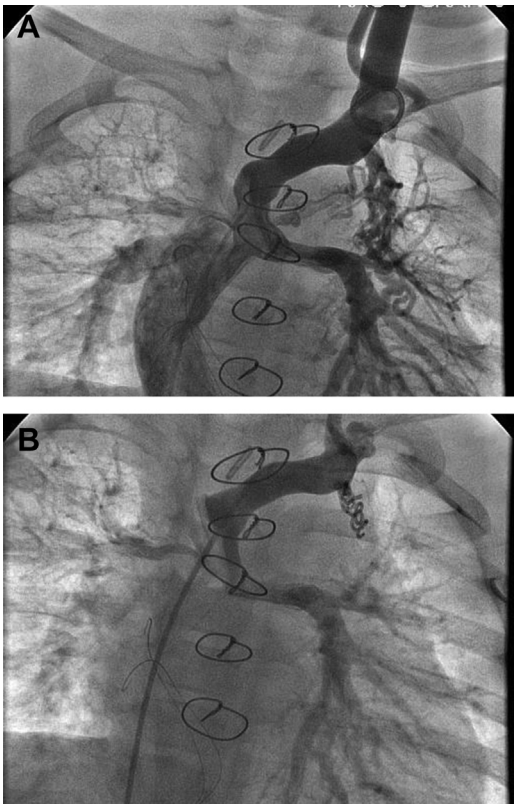

FIGURE 3 Venovenous Collateral

Anteroposterior projection demonstrating a venovenous collateral from the innominate vein to the left upper pulmonary vein before **(A)** and after **(B)** coil occlusion.

There were 7 major complications: 3 during interventional EPOCC and 4 in diagnostic EPOCC. One patient had pulmonary artery avulsion after angioplasty with a balloon-to-vessel diameter ratio of 6:1, and 1 patient had arterial dissection requiring ECMO rescue. Diagnostic EPOCC in 3 patients was associated with cardiac arrest; 1 of these patients then required ECMO. No single risk factor was associated with EPOCC-associated complications.

EPOCC was followed by return to the operating room to address important residual lesions in 43% of patients. In the interventional EPOCC group, 32 patients (49%) returned to the operating room within 10 days of the catheterization; in 17 patients, findings during catheterization prompted reoperation. In the diagnostic EPOCC group, 51 patients (40%) were brought back to the operating room within 10 days of catheterization. Of these, 33 reoperations can be attributed to findings during catheterization (Table 5).

Although procedural mortality was very low, survival to discharge and 1-year survival were disappointing in the entire EPOCC group. There was no difference in survival to hospital discharge between the interventional and diagnostic EPOCC groups ($p = 0.93$). In addition, 1-year post-operative survival was comparable in those who underwent an intervention (66%) versus diagnostic (71%) catheterization ($p = 0.58$) (Figure 4A). Not surprisingly, single-ventricle heart disease patients had a lower 1-year survival (Figure 4B).

For the entire cohort, multivariate regression analysis demonstrated that younger age at the time of surgery ($p = 0.05$), ECMO support at the time of EPOCC ($p = <0.01$), and single-ventricle heart disease ($p = 0.02$) were associated with a higher 1-year mortality rate.

DISCUSSION

After surgical repair of congenital heart disease, most patients follow a predictable post-operative course toward recovery. Many patients, unfortunately, do not follow the typical, expected course. Residual unaddressed cardiac lesions, post-surgical anatomic stenosis, and myocardial injury from prolonged cardiopulmonary bypass may account for the delay in recovery after cardiac surgery (8). In these situations, an early post-operative cardiac catheterization can delineate the physiology and the anatomy, prompting effective therapy that might otherwise have been delayed. Our findings justify this approach because a substantial number of patients underwent reoperation on the basis of findings during cardiac catheterization. Of course, the decision to take unstable patients to the catheterization laboratory involves weighing the potential risks and benefits of an invasive procedure. These infants and children pose challenges in transport to the catheterization laboratory, in ventilator and hemodynamic management during the procedure, as well as in performance of an often technically demanding procedure. As others have noted, dedicated anesthesia, surgical, and interventional teams are required to undertake such challenging procedures (7,9,10).

There are limited data on the safety and utility of cardiac catheterization in the immediate post-operative period after surgical repair of congenital heart disease (5–7,11). The most comprehensive review to date was published by Zahn et al. (7) in 2004. In that study, children catheterized within 6 weeks of cardiac surgery were reviewed. The authors noted that in the 26 patients (42% of the cohort) who underwent interventions across suture lines, no vascular disruptions were noted. Rosales et al. (6) reported their experience with angioplasty and stenting in the early post-operative period. The authors reported that angioplasty was inherently riskier than stenting; in particular, balloon diameter-to-stenosis ratios >2.5:1 were associated with vascular disruptions and major complications including death. Interestingly, the single death in our cohort was encountered after balloon angioplasty of a severely hypoplastic left pulmonary artery; the balloon-to-stenosis ratio in this patient was 6:1.

Our report is on the largest cohort of early post-operative catheterizations in children undergoing cardiac surgery. Our study involved patients who are younger and underwent catheterization closer to surgery than previously published data (5–7,11); this likely represents the trend over the past decade to undertake increasingly complex surgical repairs in increasingly smaller and more fragile patients. Our entire population underwent catheterization within 4 weeks after surgery, with two-thirds undergoing catheterization within 12 days of surgery, at a median age of 3.8 months.

Periprocedural complications are more commonly encountered in hemodynamically unstable patients (12). There is a commonly accepted notion that one should wait ~6 weeks after surgery before performing an intervention (10). Yet there are no published data indicating unusual suture fragility in the early post-operative period. Zahn et al. (7) astutely note an

TABLE 4 Catheterization Outcomes

	Rates of Events During Catheterization		
	Interventional Procedures (n = 91)	Diagnostic Procedures (n = 128)	p Value
Blood transfusion	22 (24)	22 (17)	0.01
Intervention involving surgical anastomotic site	45 (48)	–	–
In-hospital death	14/65 (22)	27/128 (21)	0.93
1-yr survival rate, %	66	71	0.58
Cath lab complications			
Procedural death	1	0	–
ECMO cannulation in the cath lab	1	1	0.67
Cardiopulmonary resuscitation	0	2	–
Cardiac rhythm disturbance*	1	8	0.16
Device/stent migration, retrieved percutaneously	2	0	–
Vascular tear†‡	2	0	–
Entrapment of venous catheter in ECMO cannula	0	1	–

Values are n (%), n, or n/N (%). *Spontaneous resolution or required direct current cardioversion or rapid atrial pacing to convert to normal sinus rhythm. †Umbilical artery, left pulmonary artery. ‡The vascular tear of the left pulmonary artery was the only procedural mortality.
ECMO = extracorporeal membrane oxygenation.

TABLE 5 Reoperation Characteristics

Reoperation	Total	Interventional	Diagnostic
Branch pulmonary arterioplasty	11	6	5
Systemic venoplasty	1	0	1
Open thrombectomy	3	2	1
Residual VSD closure	2	1	1
SCPC takedown, BTS placement	7	2	5
Fontan revision	2	1	1
Semilunar/atrioventricular valve repair/replacement	3	1	2
Systemic-to-PA shunt revision	9	3	6
Unifocalization of AP collaterals	3	1	2
Pulmonary vein repair	3	0	3
Coronary artery revision	4	0	4
Coarctation of the aorta repair	1	0	1
Atrial septectomy	1	0	1

Values are n.
AP = aortopulmonary; SCPC = superior cavopulmonary connection; VSD = ventricular septal defect; other abbreviations as in Tables 1 and 3.

inherent distinction between the placement of a single running suture line and a series of interrupted sutures. Indeed, at our center, vascular anastomoses are typically performed with running Prolene suture, which appears to accommodate larger balloon-to-vessel ratios. Our study provides further validation of the utility, feasibility, and safety of transcutaneous intervention and diagnostic evaluation in this high-risk patient population.

It is inherently challenging to demonstrate the benefit and utility of a hemodynamic/noninterventional cardiac catheterization in the early post-operative period. There is no reasonable control group with whom to compare the cohort who presented to the laboratory. However, we demonstrate acceptable safety in these cases. Given the cohort's intrinsic vulnerability, this safety is indeed notable.

Theoretically, performing an interventional procedure in the immediate post-operative period should be higher risk than performing a diagnostic catheterization in the same time period; however, we have shown similar survival rates among the 2 groups. In our patient cohort, overall prognosis was disappointing because 21% died in-hospital and 31% died within 1 year of surgery. There was no difference in survival whether the patient underwent a diagnostic or interventional catheterization. The high 1-year mortality rate likely reflects the generally poor prognosis that the patient faces who is so unwell as to need an early post-operative cardiac catheterization.

STUDY LIMITATIONS. This was a retrospective cohort study with the usual biases of such investigations. The timing of catheterization was not standardized; rather, it depended on the differing management strategies of both the cardiothoracic surgeon and cardiac intensivist. In addition, time to extubation and discontinuation of vasoactive infusions were not included in the analysis due to an inherent lack of control over differing management strategies.

CONCLUSIONS

Cardiac catheterization, including transcatheter intervention across newly created suture lines, can be performed with an acceptable risk and detects clinically significant residual defects in the immediate post-operative period after congenital heart surgery. Caution must be used whenever balloon dilation at suture lines is anticipated.

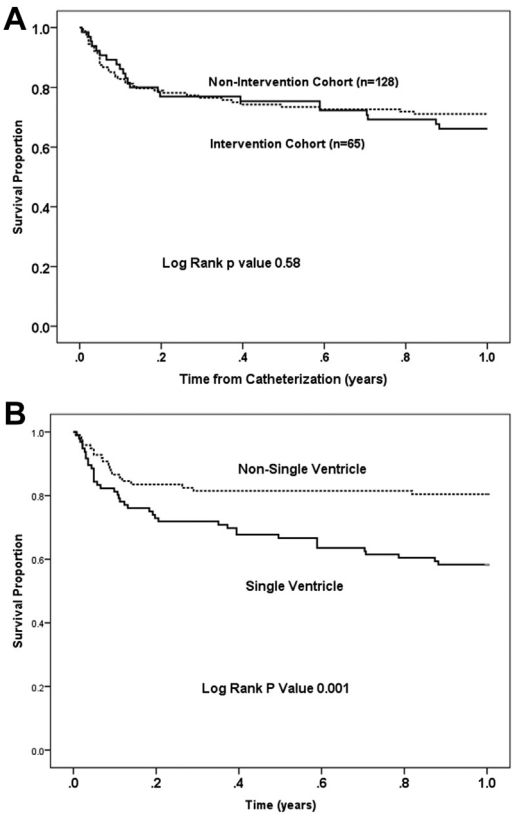

FIGURE 4 One-Year Survival

(A) Kaplan-Meier survival curves demonstrating no survival difference between those who underwent an intervention and those who underwent a diagnostic catheterization. **(B)** Patients with single-ventricle heart disease had a poor 1-year survival rate.

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KEY WORDS **cardiac catheterization, congenital cardiac surgery, congenital heart disease**