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Hemodynamic Consequence of Interventional Cardiac Catheterization in the Early Postoperative Period after Congenital Heart Surgery

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Abstract: While still considered a high-risk procedure, cardiac catheterization during the early postoperative period is being performed more frequently in the current era. Limited data are currently available concerning the acute hemodynamic consequences of these procedures. Therefore, the purpose of this study was to evaluate the safety/efficacy of cardiac catheterization performed within thirty days of congenital heart surgery. We completed a retrospective review of all catheterizations within 30 days of congenital heart surgery. Procedures were performed due to failure to progress or hemodynamic deterioration. There were 1873 congenital heart surgeries during the study period. One hundred and three (6.2%) patients with a median age of 124 days underwent catheterization. Sixty-three cases received interventions, and forty patients underwent diagnostic catheterization. Early cardiac catheterization did not show a significant immediate change in the hemodynamics or inotrope score. Survival for patients undergoing diagnostic Cath (81%) did not differ significantly from the intervention group (89%). Although cardiac catheterization was performed on patients at the highest risk for death in the postoperative period, catheter intervention did not increase the risk of death. Those patients undergoing catheter intervention did not seem to experience major adverse events but achieved mild improvement in tissue perfusion.

Keywords: congenital heart disease; congenital heart surgery; cardiac catheterization; cardiac intensive care unit

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1. Introduction

The evolution in the management of complex congenital heart disease has proven the usefulness of diagnostic and interventional catheterization [1–3]. In efforts to optimize the results, patient selection for catheterizations has previously been limited to non-acutely sick children no longer in the postoperative period. While still considered to be a high-risk procedure, cardiac catheterization in an acutely ill patient still within the early postoperative period has grown in popularity and applications over the past decades as a means to manage a complicated postoperative course [4,5]. The hemodynamic impact of these procedures on the immediate cardiac intensive care unit (CICU) course has yet to be defined in the literature.

For the past decade, it has been our practice to take critically ill patients to the Cath lab for evaluation and intervention if residual lesions are suspected, regardless of the time from surgery. Our working hypothesis has been that patients with lesions amenable to intervention will have significant improvements in the hemodynamic parameters, as well as inotrope requirements, shortly upon return to the CICU. With this in mind, we sought to quantify the changes in clinical hemodynamic variables such as heart rate, pulse oximetry, blood pressure, and inotrope requirement following the procedure to define the catheterization's immediate effects on the CICU course. Furthermore, in an effort to better define this subpopulation, the patient characteristics (diagnosis, surgical staging, clinical syndromes, indications for procedure, catheterization findings and interventions, time to catheterization, and reoperation rates) were reviewed and correlated with the days to discharge, mortality, and intervention versus non-interventional groupings.

2. Materials and Methods

2.1. Patient Selection

The inclusion criteria for this retrospective chart review incorporated all patients under twenty-one years of age who underwent catheterization within thirty days of congenital heart surgery at Nicklaus Children's Hospital (formerly known as Miami Children's Hospital) between January 2002 and February 2009. Patients whose clinical conditions did not warrant ICU admission or were electively scheduled for catheterization were excluded. A waiver for consent was granted by institutional review, given the retrospective approach of the study.

2.2. Catheterization Procedure

All catheterizations were performed by a pediatric interventional cardiologist in a bi-planar digital laboratory. General anesthesia was administered under the supervision of a pediatric cardiac anesthesiologist with the presence or immediate availability of a cardiac intensivist, a congenital heart surgeon, and supporting operating room staff for all cases. Standard techniques were followed for all balloon angioplasties, stents, valvuplasties, and for vascular occlusion with devices or particles. Previously published criteria were applied to determine the success or failure of interventional procedures [6–9].

2.3. Data Collection

Heart rate, systolic/diastolic blood pressure, and pulse oximetry were dependent variables considered valuable in defining the hemodynamic response to catheterization. Utilizing CICU charting records maintained in the EMTEK electronic nursing program, vital documentation was reviewed specifically for measurements taken immediately prior to leaving the unit, immediately upon arrival to the unit following the procedure, and twenty-four hours following the procedure. To define the effect of catheterization on the inotrope requirements, weight-based dosing rates for dopamine, epinephrine, and milrinone were recorded immediately prior to the procedure, upon return to the CICU, and again at twenty-four hours. An inotrope score was then calculated for each patient using a previously described scoring system [10]. Finally, in an effort to define the changes in renal function and tissue perfusion, the serum creatinine and lactate levels were reviewed and recorded if the specimen collection time corresponded to the pre-procedure, immediate post-procedure, and twenty-four-hour post-procedure times.

2.4. Statistical Analysis

The pre- and post-procedure variables were compared using paired t-tests or Wilcoxon rank-sum analysis as appropriate for normality utilizing Sigma Stat, version 3.1. Significance was considered at a p-value < 0.05.

3. Results

3.1. Pre-Cath Patient Characteristics

During the study period, a total of 1873 congenital heart surgeries were performed, of which 1673 surgeries required cardiopulmonary bypass. Of the total surgical cases, 103 patients (6.2%) at a median age of 124 days (5 days–16.7 years; neonates n = 43, infants n = 37) and a mean weight of 8.1 kg underwent 116 catheterizations on the mean postoperative day 11.1. The diagnostic group underwent investigation at age 33 days compared to the interventional at 172 days (p = 0.005). Interventional patients were 1.4 times larger in weight than diagnostic patients (p = 0.001). Diagnostic patients were twice as likely to have had an open chest at any time during their admission (RR = 2.09, p = 0.009), and single ventricle physiology was more prevalent in the interventional group, though without statistical significance (73.9% versus 55.8%, p = 0.071) (Table 1). Hypoplastic left heart syndrome, Tetralogy of Fallot/pulmonary atresia with VSD, and double outlet right ventricle anomalies accounted for 59% of the primary diagnoses (Table 2). Fontan was the predominant surgical stage at the time of catheterization (Table 3). Failure to wean inotropic and ventilatory support was the most common indication for catheterization (Table 4).

Table 1. Patient characteristics.

Patients Information	Combined	Interventional	Diagnostic	*p*-Value
PRE-CATH				
Patients	103	63 (61%)	40 (39%)	
Catheterizations	116	73	43	
Median Age (days)	124	172	33	0.005
Median Weight (kg)	4.8	5.3	3.6	0.001
Syndromes	18	12	6	
Single Ventricle Physiology at Cath	67.2%	73.9%	55.8%	0.071
Median Days After Surgery	10	9	11	0.447
Open Chest at Any Time During Admission	32.7%	23.3%	48.8%	0.009
Open Chest at Time of Cath	17%	12%	26%	0.116
POST-CATH				
Contrast administration (median mL/kg)	7.8	8.6	6.6	
Median Inotrope Requirement (Days after Cath)	6	5	7	0.193
Reoperation Rate within Thirty Days of Cath	18 (17.4%)	9 (12.7%)	12 (25%)	0.18
Median Days to Discharge following Surgery	28	26	33	0.24
Median Days to Discharge following Cath	14.5	14	15	0.350
Mortalities within Thirty Days of Surgery	12 (11.7%)	5 (7.9%)	7 (17.5%)	0.25
Late Mortalities	18 (17.5%)	9 (14.3%)	9 (22.5%)	0.42
Median Days to Mortality	39	58	37	0.97

Table 2. Diagnoses.

Type of Diagnosis	Combined	Interventional	Diagnostic
HLHS	29.3%	32.9%	23.3%
TOF/PAVSD	18.1%	17.8%	18.6%
DORV	14.7%	19.2%	7.0%
Aortic Arch Obstruction	6.9%	8.2%	4.7%
PAIVS	5.2%	2.7%	9.3%
HRHS	4.3%	4.1%	7.0%
TAPVR	4.3%	2.7%	7.0%
TGA	2.6%	2.7%	2.3%
AVSD	3.4%	0.0%	7.0%
Aortic Stenosis	3.4%	2.7%	2.3%
Single ventricle variant	2.6%	4.1%	0.0%
DILV	1.7%	2.7%	0.0%
Truncus Arteriosus	1.7%	0.0%	4.7%
Subaortic Stenosis	0.9%	0.0%	0.0%
Valvular Insufficiency	0.9%	0.0%	2.3%

Table 3. Surgical stage at catheterization.

Surgical Stage	Combined	Interventional	Diagnostic
Fontan	21.6%	28.8%	9.3%
BDGlenn	17.2%	23.3%	7.0%
Norwood	14.7%	11.0%	20.9%
BT Shunt	13.8%	11.0%	18.6%
TOF/PAVSD Repair	14.7%	15.1%	14.0%
Arch Reconstruction	4.3%	4.1%	4.7%
TAPVR	2.6%	1.4%	4.7%
TGA Repair	1.7%	1.4%	2.3%
AVSD	1.7%	0.0%	4.7%
PDA Closure	1.7%	1.4%	2.3%
Truncus Repair	1.7%	0.0%	4.7%
Pulm Band	1.7%	0.0%	4.7%
Sub Aortic Resection	0.9%	0.0%	2.3%
PAIVS Repair	0.9%	0.0%	2.3%
AV Valvuloplasty	0.9%	0.0%	2.3%

Table 4. Indications for catheterization.

Indications for Catheterization	Interventional	Diagnostic
Inability to wean from inotropic/ventilatory support	30.1%	39.5%
Persistent/severe cyanosis	23.3%	14.0%
Persistent/severe effusions (pleural/ascites)	23.3%	11.6%
Echocardiographic diagnosis of residual defects	6.8%	11.6%
Inability to wean from cardiopulmonary support	9.6%	11.6%
Low cardiac output state	6.8%	9.3%
ECG changes	0.0%	2.3%

3.2. Catheterization Procedure

Sixty-three patients underwent 73 interventional catheterizations, during which 97 interventions were performed. Forty-eight percent of all procedures revealed new findings, with pulmonary artery stenosis (21.6%) and collateralization (12.9%) being the most common (Table 5). Stenting of the pulmonary arteries, particle/device occlusion of aortopulmonary collaterals, and balloon angioplasty of pulmonary arteries accounted for 50.5%, 23.7%, and 16.5% of all interventions, respectively (Table 6). The success rate for all interventions was 97%.

Table 5. Findings during catheterization.

Findings during Catheterization	Combined	Interventional	Diagnostic
No new findings/confirmed prior echo	51.7%	39.7%	72.1%
Pulmonary Artery Stenosis	21.6%	28.8%	9.3%
Collaterals	12.9%	19.2%	2.3%
Conduit Stenosis	5.2%	5.5%	4.7%
Pulm HTN, Glenn, Fontan	2.6%	1.4%	4.7%
Vascular occlusion	1.7%	1.4%	2.3%
Septal defect/PDA	0.9%	0.0%	2.3%
Intimal tear/aneurysm	0.9%	0.0%	2.3%
Valvular Insufficiency	0.9%	1.4%	0.0%
aortic valve/arch Stenosis	0.9%	1.4%	0.0%
Fontan Fen. Occlusion	0.9%	1.4%	0.0%

Table 6. Interventions and locations.

Interventions				Frequency	
Stenting				49	50.50%
	Pulm arteries		38		
	IVC/SVC/Fontan baffle		4		
	Aorta		3		
	BT shunt		2		
	Fontan Fenestration		2		
Vascular occlusion with device/particles				23	23.70%
	Aorto-pulmonary Collateral		16		
	Venous collateral		6		
	BT shunt		1		
Angioplasty				16	16.50%
	Pulm arteries		11		
	Aorta		2		
	BT shunt		2		
	Fontan Fenestration		1		
Stenting, angioplasty by hybrid				3	3%
	Pulmonary artery		2		
	Aorta		1		
Septostomy				3	3%
	ASD	(1 FAILURE)	3		
Vascular/septal closure				2	2%
	Ventricular	(1 FAILURE)	1		
	Fontan Fenestration		1		
Valvuloplasty				1	1%
	Aortic		1		
			SUM	97	

3.3. Complications

Among the entire cohort, twelve patients encountered a total of fourteen complications, with all but three occurring in the interventional group. Of the eleven complications within the interventional group, there were seven arrhythmias, two pulmonary artery intimal tears without hemorrhage, and one atrial septal stent device that migrated and required surgical retrieval. In the diagnostic complication group, there was one arrhythmia and two vascular site complications (Table 7).

Table 7. Complications during catheterization.

Complications	Combined	Interventional	Diagnostic
Total Complications (*n* patients)	14 (12)	11 (10)	3 (2)
Arrhythmia	8	7	1
Intimal Tear (w/o heme)	2	2	0
Vascular Occlusion at access site	1	0	1
Device Failure/migration	1	1	0
Cardiac Arrest	1	1	0
Coagulopathy/bleeding	1	0	1
Death During Cath	0	0	0

3.4. Hemodynamic and Post-Procedure Characteristics

Prior to catheterization, there were no significant differences in heart rate, systolic, diastolic, pulse oximetry, serum lactate, inotrope score, and cardiopulmonary support use (CPS) between interventional and diagnostic patients; however, the diagnostic group was 19% more likely to be intubated than the interventional group (p = 0.057). At one hour post-catheterization, no significant changes were seen in any of the hemodynamic parameters, and at 24 h post-procedure, the only statistically significant change was in the serum lactate, albeit clinically insignificant (−0.3 mg/dL, $p = 0.01$) (Table 8).

Table 8. Hemodynamic changes: interventional versus.

Diagnostic Catheterizations	Type of Cath	Pre-Cath	Variables	1 h Post-Cath	Variables	24 h Post-Cath
		(p *)		Δ (p **)		Δ (p ***)
Heart Rate (BPM)	Diagnostic Interventional	139 133 (0.30)	142 142	+3 (0.66) +9 (0.35)	141.5 133	+2.5 (0.67) 0 (0.94)
Systolic (mmHg)	Diagnostic Interventional	85 90 (0.18)	84 90	−1 (0.83) 0 (0.143)	86.5 88	+1.5 (0.37) −2 (0.66)
Diastolic (mmHg)	Diagnostic Interventional	47 50.5 (0.20)	48 50	+1 (0.47) −0.5 (0.206)	47 50	0.0 (0.87) −0.5 (0.54)
Pulse Oximetry (SpO2)	Diagnostic Interventional	88 86 (0.29)	91 90	+3 (0.62) +4 (0.25)	88.5 88	+0.5 (0.79) +2 (0.85)
Serum Lactate (mmol/L)	Diagnostic Interventional	1.5 1.3 (0.78)	1.7 1.4	+0.2 (0.37) +0.1 (0.31)	1.3 1	−0.2 (0.55) −0.3 (0.010)
Serum Creatinine (mg/dL)	Diagnostic Interventional	0.5 0.4 (0.034)	0.7 0.6	+0.2 (0.44) +0.2 (0.059)	0.5 0.5	0.0 (0.57) +0.1 (0.18)
Inotrope Score	Diagnostic Interventional	15 15 (0.54)	12 15	−3 (0.63) 0 (0.585)	19 15	+4 (0.87) 0 (0.78)
Intubation Status	Diagnostic Interventional	74.4% 54.8%, (0.057)		-- --	76.7% 56.3%	+2.3%, 1.00 +1.5%, 0.985
Cardiopulmonary support	Diagnostic Interventional	18.6% 12.3%, (0.52)		-- --	9.5% 7%	−9.1%, 0.37 −5.3%, 0.43

* p-value comparing diagnostic versus interventional values pre-Cath; ** delta and p-value comparing values at 1 h post-Cath versus pre-Cath; *** delta and p-value comparing values at 24 h post-Cath versus pre-Cath.

3.5. Comparison by Mortality

During the study period, there were a total of 1770 surgeries not requiring emergent Cath with a mortality prevalence of 5.8% and early and late mortality rates of 1.5% and 4.2%, respectively. The reoperation rates, median days to discharge following both Cath and surgery, and mortalities and time to mortality lacked significance between the two groups (Table 1). For the entire cohort, the thirty-day and late mortalities were 11.7% and 17.5%, respectively, for a total mortality prevalence of 30%. The interventional and diagnostic groups lacked statistical differences in the early mortality rates (7.9% and 17.5%, respectively), as well as late mortality (14.3% and 22.5%, respectively).

To further delineate the risk factors, the entire cohort was separated into early mortalities (<31 days after surgery), late deaths, and survivors. Early mortalities were more likely to be younger, smaller in weight, and to have received a Norwood procedure prior to the Cath. An open chest during Cath or any time during admission, as well as cardiopulmonary support before and after the Cath, was more prevalent among early deaths. One hundred percent of the early mortalities were intubated pre- and 24 h post-cath. There were no statistical differences in the fluoroscopy times and contrast administration during the Cath (Table 9).

In comparing late mortalities against the survivors, prior to the Cath, the late mortality group was more likely to also have recently undergone a Norwood procedure, be smaller in weight, intubated, hypoxic, and have a higher heart rate than the survival group. Interestingly, the survivor group was more likely to undergo Cath sooner, nine days post-surgery, than the mortality group at 16.5 days ($p = 0.01$). Following the Cath, the median 24-h inotrope scores were 50% lower in the survivors ($p = 0.039$). Cardiopulmonary support, pre- and post-lactates, fluoroscopy time, contrast dosing, and reoperation rates were not statistically different (Table 10).

Table 9. Early mortalities versus late deaths + survivors.

Patients Information	Mortalities < 31 Days	Survivors and >30 Days	*p*
N	12	91	
Age days (median)	18	130	0.026
Weight Kg (median)	2.7	5.0	0.014
Single ventricular physiology	67%	66%	0.812
Previous Surgery (Norwood)	46%	11%	0.003
Days Post-Surgery (median)	3	11.5	0.012
Open Chest at Cath	62%	12%	<0.001
Open Chest at Anytime During Admission	85%	26%	<0.001
Pre-Cath Heart Rate (median)	153	135	0.069
Pre-Cath Systolic Pressure mmHg (median)	65	89	<0.001
Pre-Cath Diastolic Pressure mmHg (median)	41	50.5	0.007
Pre-Cath Pulse Oximetry (median)	83	87	0.21
Pre-Cath Inotrope Score (median)	23	13	0.007
1-h Post-Cath Inotrope Score (median)	13	10.8	0.11
24-h Post-Cath Inotrope Score (median)	21	15	0.22
Inotrope Requirement Post-Cath Days	6	6	0.63
Pre-Cath Intubation	100%	57%	0.007
Intubation at 24 h Post-Cath	100%	60%	0.022
Cardiopulmonary Support Pre-Cath	62%	8.7%	<0.001
Cardiopulmonary support 24 h Post-Cath	60%	2.9%	<0.001
Lactate Pre-Cath mg/dL(median)	3	1.25	<0.001
Lacate 1 h Post-Cath mg/dL(median)	4.7	1.4	<0.001
Lactate 24 h Post-Cath mg/dL(median)	3.7	1	<0.001
Fluoroscopy Time (median)	20.7 min	20.8 min	0.37
Contrast (median)	8.8 mL/kg	7.7 mL/kg	0.48
Reoperation Rate	25%	16.5%	0.75

Table 10. Late mortalities versus survivors.

Patients Information	Mortalities > 30 Days	Survivors	*p*
N	18	73	
Age days (median)	44	158	0.10
Weight Kg (median)	3.75	5.3	0.047
Single/ biventricular physiology	85%	64%	0.12
Previous Surgery (Norwood)	30%	6%	0.007
Previous Surgery (Fontan)	15%	25%	0.49
Days Post Surgery (median)	16.5	9	0.01
Open Chest at Cath	10%	12%	0.9
Open Chest at Anytime During Admission	45%	22%	0.065
Pre-Cath Heart Rate BPM(median)	143	131	0.033
Pre-Cath Systolic Pressure mmHg (median)	80	90	0.137
Pre-Cath Diastolic Pressure mmHg (median)	48	52	0.17
Pre-Cath Pulse Oximetry SpO2% (median)	83	91	0.027
Pre-Cath Inotrope Score (median)	18	10	0.25
1-h Post-Cath Inotrope Score (median)	20	10	0.19
24-h Post-Cath Inotrope Score (median)	20	10	0.039
Inotrope Requirement Post-Cath Days	8	5	0.055
Pre-Cath Intubation	85%	51%	0.011
Intubation at 24 h Post-Cath	90%	53%	0.005
Cardiopulmonary Support Pre-Cath	10%	8%	0.83
Cardiopulmonary support 24 h Post-Cath	10%	1%	0.17
Lactate Pre-Cath mmol/L (median)	1.25	1.25	0.32
Lactate 1 h Post-Cath mmol/L (median)	1.3	1.4	0.69
Lactate 24 h Post-Cath mmol/L (median)	1.25	1	0.15
Flouro time (median)	22.7 min	20.7 min	0.73
Contrast (median)	7.1 mL/kg	7.7 mL/kg	0.63
Reoperation Rate	15%	14%	0.77

4. Discussion

Originally, it was hypothesized that, by palliating residual lesions, interventional patients would see an immediate improvement in the hemodynamic status upon returning from the Cath lab compared to diagnostic patients. Our data failed to demonstrate improvement in the hemodynamic parameters such as heart rate, blood pressure, lactate, and oxygenation within 24 h of the procedure. The explanation for this lack of improvement may include no true benefit from the intervention or delay in the resolution of hemodynamic instability past the 24-h window that we investigated. Significant differences in the time to discharge and ultimate mortality outcomes are lacking, which raises the question as to whether these interventions are truly necessary. Due to ethical considerations, we are limited in our ability to characterize the benefits of interventions in the early postoperative period against true controls (patients with lesions but withheld from the intervention). A hypothesis that would prove difficult to test could be made that a true control group would have poorer cardiac output, exaggerated hemodynamic instability, longer hospitalizations, and higher mortality rates than our interventional group, all of which would justify exposing a critically ill patient to the risk of catheterization to palliate residual lesions.

Concern for the increased mortality risk of an invasive procedure in critically ill patients cannot be dismissed. While Asoh et al. encountered a six-month mortality rate approaching 50%, our series again demonstrated a low mortality rate at 6 months of 29% for all Caths and 22% for interventional catheterizations [11]. Furthermore, characteristics such as an open chest at Cath (17% and 22%), the interval from surgery to catheterization (10 and 7–10 days), and presenting congenital lesions are similar between the two study groups. Similar procedural success rates (95% versus 98%) suggest that the technical aspects of interventions can be reliably reproduced. However, variations in the reoperation rates, 37% in the Asoh series and 17% in ours, suggest that complete appreciation of the original and coexisting lesions, as well as an alternative surgical technique, can have a favorable impact on postoperative survival. Appreciation of concomitant lesions has improved with the application of three-dimensional imaging modalities such as angiographic computed tomography and traditional computed tomography, which can provide a definitive anatomical diagnosis of undiscovered lesions [12]. Recent studies have demonstrated growing trends in using three-dimensional rotational angiographies, which has been associated with superior outcomes in diagnostic and interventional procedures [13,14]. Hybrid procedures, initially intended for initial palliation of the hypoplastic left heart and complex single ventricle, have now been expanded to address septal defects and stenotic pulmonary arteries. Further employment of the hybrid operating room can alleviate the burden of postoperative lesions, thus reducing the length of ICU stays [15].

Taking a critically ill postoperative patient to the Cath lab requires considering the risks and benefits of the procedure, which may not be clear when the patient's ICU course has been tenuous; however, delaying a catheter examination also carries its own risk/benefit ratio. Asoh et al. described in their series of sixty-two postoperative procedures that a delayed catheter procedure was associated with higher in-house mortality, particularly when two to three weeks out from the index surgery [11]. We found a similar association with survivors in our series who were taken to the Cath lab on average a week sooner than the late mortality group. This pattern of an earlier invasive examination would suggest that earlier intervention and/or understanding of the hemodynamics can have a significant impact on ICU management and the subsequent outcomes.

Nicholson et al. described their experience in performing cardiac Cath in the early postoperative period and reported a low mortality rate and acceptable feasibility [16]. These results mirrored the current series, in which 97% of interventions were successful, with a thirty-day survival of 92%. Furthermore, a recent article showed that cardiac catheterizations within six weeks of cardiac surgery had a low rate of complications [17]. Our series encountered the associated weaknesses of a retrospective review within a single institution. With the aid of electronic charting, accurate charting of vitals and lab draws can be improved, but the variations cannot be completely eliminated.

5. Conclusions

Catheter investigation in the early postoperative period continues to play a reliable role in both clarifying labile hemodynamics, as well as addressing residual lesions with a variety of interventions. With careful patient selection, these interventions can be safely employed and spare the patient from return visits to the operating room. An earlier catheterization interrogation may lead to the earlier detection of unfavorable hemodynamics or lesions, which can improve the clinical course and morbidity.

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References

1. Pihkala, J.; Nykanen, D.; Freedom, R.M.; Benson, L.N. Interventional cardiac catheterization. *Pediatr. Clin. N. Am.* **1999**, *46*, 441–464. [CrossRef]
2. Andrews, R.E.; Tulloh, R.M.R. Interventional cardiac catheterisation in congenital heart disease. *Arch. Dis. Child.* **2004**, *89*, 1168–1173. [CrossRef]
3. Nykanen, D.G.; Zahn, E.M. Transcatheter techniques in the management of perioperative vascular obstruction. *Catheter. Cardiovasc. Interv. Off. J. Soc. Card. Angiogr. Interv.* **2005**, *66*, 573–579. [CrossRef]
4. Mendelsohn, A.M.; Banerjee, A.; Meyer, R.A.; Schwartz, D.C. Predictors of successful pulmonary balloon valvuloplasty: 10-year experience. *Catheter. Cardiovasc. Diagn.* **1996**, *39*, 236–243. [CrossRef]
5. Zahn, E.M.; Dobrolet, N.C.; Nykanen, D.G.; Ojito, J.; Hannan, R.L.; Burke, R.P. Interventional catheterization performed in the early postoperative period after congenital heart surgery in children. *J. Am. Coll. Cardiol.* **2004**, *43*, 1264–1269. [CrossRef] [PubMed]
6. Nugent, E.W.; Freedom, R.M.; Nora, J.J.; Ellison, R.C.; Rowe, R.D.; Nadas, A.S. Clinical course in pulmonary stenosis. *Circulation* **1977**, *56*, I38–I47. [PubMed]
7. O'Laughlin, M.P.; Perry, S.B.; Lock, J.E.; Mullins, C.E. Use of endovascular stents in congenital heart disease. *Circulation* **1991**, *83*, 1923–1939. [CrossRef] [PubMed]
8. Sim, J.Y.; Alejos, J.C.; Moore, J.W. Techniques and applications of transcatheter embolization procedures in pediatric cardiology. *J. Interv. Cardiol.* **2003**, *16*, 425–448. [CrossRef] [PubMed]
9. Rhodes, J.F.; Blaufox, A.D.; Seiden, H.S.; Asnes, J.D.; Gross, R.P.; Griepp, R.B.; Rossi, A.F. Cardiac arrest in infants after congenital heart surgery. *Circulation* **1999**, *100*, II194–II199. [CrossRef] [PubMed]
10. Wernovsky, G.; Wypij, D.; Jonas, R.A.; Mayer, J.J.E.; Hanley, F.L.; Hickey, P.R.; Walsh, A.Z.; Chang, A.C.; Castañeda, A.R.; Newburger, J.W.; et al. Postoperative course and hemodynamic profile after the arterial switch operation in neonates and infants. A comparison of low-flow cardiopulmonary bypass and circulatory arrest. *Circulation* **1995**, *92*, 2226–2235. [CrossRef] [PubMed]
11. Asoh, K.; Hickey, E.; Dorostkar, P.C.; Chaturvedi, R.; van Arsdell, G.; Humpl, T.; Benson, L.N. Outcomes of emergent cardiac catheterization following pediatric cardiac surgery. *Catheter. Cardiovasc. Interv. Off. J. Soc. Card. Angiogr. Interv.* **2009**, *73*, 933–940. [CrossRef] [PubMed]
12. Glatz, A.C.; Zhu, X.; Gillespie, M.J.; Hanna, B.D.; Rome, J.J. Use of angiographic CT imaging in the cardiac catheterization laboratory for congenital heart disease. *JACC Cardiovasc. Imaging* **2010**, *3*, 1149–1157. [CrossRef] [PubMed]

13. Söder, S.; Wällisch, W.; Dittrich, S.; Cesnjevar, R.; Pfammatter, J.-P.; Glöckler, M. Three-Dimensional Rotational Angiography during Catheterization of Congenital Heart Disease—A ten Years' experience at a single center. *Sci. Rep.* **2020**, *10*, 6973. [CrossRef] [PubMed]
14. van der Stelt, F.; Siegerink, S.N.; Krings, G.J.; Molenschot, M.M.C.; Breur, J.M.P.J. Three-Dimensional Rotational Angiography in Pediatric Patients with Congenital Heart Disease: A Literature Review. *Pediatr. Cardiol.* **2019**, *40*, 257–264. [CrossRef] [PubMed]
15. Feltes, T.F.; Bacha, E.; Beekman, R.H., 3rd; Cheatham, J.P.; Feinstein, J.A.; Gomes, A.S.; Hijazi, Z.M.; Ing, F.F.; de Moor, M.; Morrow, W.R.; et al. Indications for cardiac catheterization and intervention in pediatric cardiac disease: A scientific statement from the American Heart Association. *Circulation* **2011**, *123*, 2607–2652. [CrossRef] [PubMed]
16. Nicholson, G.T.; Kim, D.W.; Vincent, R.N.; Kogon, B.E.; Miller, B.E.; Petit, C.J. Cardiac catheterization in the early post-operative period after congenital cardiac surgery. *JACC Cardiovasc. Interv.* **2014**, *7*, 1437–1443. [CrossRef] [PubMed]
17. Yeh, M.J.; Gauvreau, K.; Armstrong, A.K.; Batlivala, S.P.; Callahan, R.; Gudausky, T.M.; Hainstock, M.R.; Hasan, B.; Nicholson, G.T.; O'byrne, M.L.; et al. Early Post-Operative Congenital Cardiac Catheterization Outcomes: A Multicenter Study. *Ann Thorac Surg.* **2022**, *116*, 86–93. [CrossRef] [PubMed]