Cardiology in the Young

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Safety, timing, and outcomes of early post-operative cardiac catheterisation following congenital heart surgery

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Abstract

Objective: The safety of early post-operative cardiac catheterisation has been described following congenital heart surgery. Optimal timing of early post-operative cardiac catheterisation remains uncertain. The aim of this study was to describe the safety of early post-operative cardiac catheterisation and its impact on cardiac ICU and hospital length of stay, duration of mechanical ventilation, and extracorporeal support. *Methods:* This single-centre retrospective cohort study compared clinical and outcome variables between "early" early post-operative cardiac catheterisation (less than 72 hours after surgery) and "late" early post-operative cardiac catheterisation (greater than 72 hours after surgery) groups using Chi-squared, Student's t, and log-rank test (or appropriate nonparametric test). *Results:* In total, 132 patients were included, 22 (16.7%) "early" early post-operative cardiac catheterisation, and 110 (83.3%) "late" early post-operative cardiac catheterisation. Interventions were performed in 63 patients (51.5%), 7 (11.1%) early and 56 (88.9%) late. Complications of catheterisation occurred in seven (5.3%) patients, two early and five late. There were no major complications. Patients in the late group trended towards a longer stay in the cardiac ICU (19 days [7, 62] versus 11.5 days [7.2, 31.5], $p = 0.6$) and in the hospital (26 days [9.2, 68] versus 19 days [13.2, 41.8], $p = 0.8$) compared to the earlier group. *Conclusion:* "Early" early post-operative cardiac catheterisation was associated with an overall low rate of complications. Earlier catheterisations trended towards shorter cardiac ICU and hospital length of stays. Earlier catheterisations may lead to earlier recovery for patients not following an expected post-operative course.

Despite significant improvements in outcomes following congenital heart surgery, there is still considerable post-operative morbidity and mortality.[1] The presence of residual post-operative lesions can contribute to this morbidity and mortality and is associated with longer duration of mechanical ventilation and cardiac ICU stay, especially for surgeries of greater complexity, i.e. The Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery Score five category procedures.[2] Residual lesions can be a reason why post-operative patients require extracorporeal membrane oxygenation support and should be suspected as a cause of failure to wean from extracorporeal membrane oxygenation within 72 hours.[3–5] Therefore, diagnosing and addressing post-operative lesions earlier in a patient's course is beneficial. The safety and use of cardiac catheterisation to identify and potentially intervene on residual post-operative lesions in patients struggling in the early post-operative period have been described; however, there remains great variability in timing and indications for early post-operative cardiac catheterisation. [6–12]

Historically, early (<6 weeks) post-operative cardiac catheterisations were considered high risk and often delayed, especially in patients on extracorporeal membrane oxygenation. Several studies have shown that cardiac catheterisations can be safely performed within the first four to six weeks following surgery.[6–12] The safety of performing cardiac catheterisation in pediatric patients on extracorporeal support has also been demonstrated.[5,13] These studies demonstrate that patients who undergo earlier cardiac catheterisations while on extracorporeal membrane oxygenation have improved survival and shorter durations on extracorporeal membrane oxygenation due to earlier intervention on residual lesions.[4,5,13–16] Despite these studies, there is still significant institutional variability in timing and willingness to perform early post-operative catheterisation and limited data on the impact of early post-operative cardiac catheterisation on hospital outcomes.[11,17]

The primary aim of this study was to describe the safety of early post-operative cardiac catheterisation at our institution. The secondary aim was to describe the association of early post-operative cardiac catheterisation with cardiac ICU and hospital length of stay, duration of mechanical ventilation, and duration of extracorporeal membrane oxygenation support.

Materials and methods

Patient population and study design

This is a single centre, retrospective cohort study of patients who underwent congenital heart surgery at our centre between January 1, 2010 and December 31, 2019 and had a cardiac catheterisation within 30 days following surgery. We excluded patients who underwent cardiac catheterisation for left atrial decompression on extracorporeal membrane oxygenation, routine endomyocardial biopsy after heart transplantation, scheduled balloon atrial septostomy post hybrid procedure, as well as patients who underwent two cardiac catheterisations in the defined time period, due to concerns that including these patients would lead to inconsistencies in outcomes for length of stay as well as duration of mechanical ventilation and extracorporeal membrane oxygenation support.

We collected patient demographic and clinical variables; timing of cardiac catheterisation, indication for cardiac catheterisation, complications of cardiac catheterisation, duration of mechanical ventilation and extracorporeal membrane oxygenation support, as well as cardiac ICU and hospital length of stay.

The study protocol was reviewed and approved by the Children's Mercy Hospital Institutional Review Board.

Analyses

An "early" early post-operative cardiac catheterisation was defined as a catheterisation less than or equal to 72 hours after index cardiac surgery and a "late" early post-operative cardiac catheterisation as a catheterisation greater than 72 hours to 30 days after surgery. The 72-hour cut-off was selected based on prior work suggesting residual lesions being a cause of failure to wean from extracorporeal membrane oxygenation within 72 hours.[5] We compared clinical variables between patients in the "early" early post-operative cardiac catheterisation group and the "late" early post-operative cardiac catheterisation group by Chi-squared, Student's t, or Wilcoxon rank-sum test, and log-rank test for categorical, continuous, and time-to-event (duration) variables, respectively. The age- and sex-adjusted weight z-scores were calculated using the LMS method.[18]

Complications of the cardiac catheterisation procedures were obtained from the cardiac catheterisation reports. The severity of complication was defined using the International Pediatric and Congenital Cardiac Code.[19]

Due to skewed distributions in cardiac ICU and hospital length of stay outcomes, their log scales were used as the dependent variable in linear regression to control for covariates. For cardiac ICU and hospital length of stay outcomes, we considered the following potential covariates associated with the "early" vs. "late" early post-operative cardiac catheterisation in multiple linear regression: Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery Score category, age- and sex-adjusted weight z-score, and clinical characteristics (mechanical ventilation, extracorporeal membrane oxygenation, vasoactive infusions, and arrythmia) prior to catheterisation. A best subset of covariates was then determined by Bayesian Information Criterion via the exhaustive search. The adjusted effect of "early" vs. "late" early post-operative cardiac catheterisation and the corresponding 95% confidence interval were then exponentiated back to the original scale.

Kaplan-Meier estimator was used to estimate the median and 95% confidence interval of duration of mechanical ventilation and extracorporeal membrane oxygenation after the catheterisation. For the outcome of mechanical ventilation post catheterisation, we considered Cox proportional hazard model with all the predictors except prior mechanical ventilation because patients with post-catheterisation mechanical ventilation all had prior mechanical ventilation. Moreover, the baseline hazard was stratified on extracorporeal membrane oxygenation prior to catheterisation to satisfy the proportional hazard assumption. For the outcome of duration of extracorporeal membrane oxygenation post catheterisation, we excluded extracorporeal membrane oxygenation prior to catheterisation as a predictor because all patients with extracorporeal membrane oxygenation post catheterisation had it prior to catheterisation. We identified the best subset of covariates in Cox models using the golden section primal-dual active set algorithm for both duration outcomes. For either outcome, surgical complexity using Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery Score categories was not selected to be in the best subset of covariates.

The analyses were conducted using R programme language[20] on the RStudio platform,[21] and the bestglm and the BeSS packages to identify the best subset in linear and Cox regression models, respectively.[22,23]

Results

There were a total of 2542 surgeries performed during the study period. One hundred and sixty-five of those patients underwent a cardiac catheterisation within the defined 30 days from the index surgery. Twenty-six patients met exclusion criteria: 10 for post-transplant biopsies, six for standard post hybrid procedure balloon atrial septostomies, five had "staged" hybrid procedures with PDA stent placement planned a few days after pulmonary artery banding, three patients had a cardiac catheterisation upon readmission to the hospital after initial discharge within 30 days of their index surgery, one patient had a cardiac catheterisation only to retrieve an embolised mitral valve clip, and one patient only had angiography through existing lines. Additionally, seven patient records were excluded due to undergoing two catheterisations within the 30-day time frame, leaving 132 patients for analysis.

Patient characteristics

A summary of the descriptive statistics can be seen in Table 1. Twenty-two (16.7%) patients had an "early" early post-operative cardiac catheterisation while the remainder (110 patients, 83.3%) had a "late" early post-operative cardiac catheterisation. The median time from surgery to catheterisation was 11 days with a range of 1 day to 30 days for the whole cohort. Of the 132 patients, 83 (62.9%) were mechanically ventilated prior to their catheterisation and 28 (21.2%) were on extracorporeal membrane oxygenation. The patients in the "early" early post-operative cardiac catheterisation group were more likely to be on extracorporeal membrane oxygenation (45.5% vs. 16.4%, $p = 0.006$) prior to their catheterisation compared to the patients

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Table 1. Descriptive characteristics

	Early EPOCC (≤72 hours) n = 22 (16.7%)	Late EPOCC (>72 hours) n = 110 (83.3%)	p value
Age, months, median [IQR]	3.0 [0.7, 12.5]	2.0 [0.7, 6.0]	0.67
Weight, kg, median [IQR]	5.4 [3.3, 7.1]	3.9 [3.2, 5.8]	0.17
Weight z-score, median [IQR]	−1.4 [−1.9, −0.6]	−1.8 [−2.8, −0.9]	0.06
Mechanical Ventilation prior to EPOCC, n (%)	18 (81.8)	65 (59.1)	0.05
Arrhythmia prior to EPOCC, n (%)	5 (22.7)	26 (23.6)	1.0
Vasoactive Infusion at time of EPOCC, n (%)	16 (72.7)	73 (66.4)	0.74
VIS, Median [IQR]	7.2 [5.0,10.5]	7.5 [5.0, 12.0]	0.72
ECMO Prior to EPOCC, n (%)	10 (45.5)	18 (16.4)	0.006*
Mortality, n (%)	7 (31.8)	32 (29.1)	1.0
CICU Days post EPOCC, Median [IQR]	11.5 [7.2, 31.5]	19.0 [7.0, 62.0]	0.60
Hospital Days post EPOCC, Median [IQR]	19.0 [13.2, 41.8]	26 [9.2, 68.0]	0.80

EPOCC = early postoperative cardiac catheterisation, IQR = inter-quartile range, VIS = vasoactive infusion score, ECMO = extracorporeal membrane oxygenation, CICU = cardiac intensive care unit, *denotes statistically significant value.

Table 2. STAT score for each EPOCC group

STAT score	Early EPOCC n = 22 (16.7%)	Late EPOCC n = 110 (83.3%)
1, N	0	6
2, N	9	28
3, N	4	21
4, N	7	29
5, N	2	24
N/A, N	0	2

P value between the two groups was not significant at 0.43.
STAT = The Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery, EPOCC = early post-operative cardiac catheterisation, N/A = not available, IQR = inter-quartile range.

in the "late" early post-operative cardiac catheterisation group. There was no significant difference in vasoactive infusion score, arrhythmias, or mortality between the two groups (Table 1). There was a wide range of surgical complexity in both groups and there was no statistically significant difference in Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery Score category (p = 0.43) between the early and late groups (Table 2).

Catheter-based interventions

In the cohort, 63 patients had catheterisation- based interventions at the time of early post-operative cardiac catheterisation. This included seven patients in the "early" early post-operative cardiac catheterisation group (11.1% of the total cohort, 31.8% of the early group) and 56 (88.9% of the total cohort, 51% of the late group) in the "late" early post-operative cardiac catheterisation group. The most common interventions were aortopulmonary or venovenous collateral vessel occlusion (n = 9). Other common interventions included balloon atrial septostomy or atrial septal stent placement (n = 8), interventions on the branch pulmonary arteries (n = 7), and balloon or stent angioplasty of the aortic arch (n = 6). There was a total of 13 combination procedures. Less common interventions included valvuloplasty (either on the aortic or pulmonary valve) (n = 3), interventions on the modified Blalock-Thomas-Taussig (mBTT) shunt (n = 4), or PDA (n = 5). Nine patients underwent other miscellaneous interventions, which included stenting/angioplasty of other systemic arteries and or veins (n = 5), TPA administration into an aortic root thrombus (n = 1), right ventricular outflow tract stent placement (n = 1), ventricular septal defect device closure (n = 1), and stenting of a Fontan fenestration (n = 1).

The interventions in the early group included: stenting a residual coarctation of the aorta, balloon atrial septostomy, transeptal puncture and placement of a stent in the atrial septum, balloon dilation and stent placement in unfocalized collaterals, balloon angioplasty of a mBTT shunt, mechanical and Angiojet thrombectomy of an innominate vein, and stent angioplasty in a Fontan conduit.

Complications

In our cohort, seven (5.3%) patients had complications related to cardiac catheterisation as reported in the cardiac catheterisation reports. Complications only occurred in the interventional catheterisations. There were two patients in the "early" early post-operative cardiac catheterisation group that had complications (28.6%), while five patients in the "late" early post-operative cardiac catheterisation group had a complication (8.9%) (Fig. 1).

The most common complications were related to arrhythmias or ST segment changes, which required only medical treatment to resolve and are considered Level 3, or moderate, complications based on the International Pediatric and Congenital Cardiac Code.[19] Two patients, both in the "late" early post-operative cardiac catheterisation group, experienced brief cardiac arrest requiring chest compressions or epinephrine administration without any significant sequelae related to the arrest and are considered level 4, or major complications. The aetiology of the arrests included: catheter-induced complete heart block and difficulty with ventilation leading to desaturation and bradycardia.

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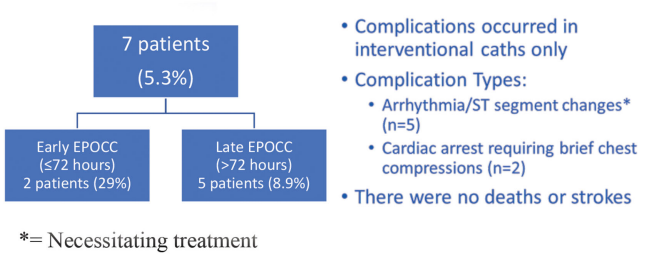

Figure 1. Figure displaying the breakdown of complications between Early and Late EPOCC groups. EPOCC = Early post operative cardiac catherization.

There were no deaths, strokes, or need for new extracorporeal membrane oxygenation support associated with the catheterisation procedures.

Outcomes

Length of stay

The median cardiac ICU length of stay after early post-operative cardiac catheterisation in the "early" early post-operative cardiac catheterisation group was 11.5 days [inter-quartile range 7.2, 31.5] compared to a median of 19.0 days [inter-quartile range 7, 62] for the late group ($p = 0.60$) (Table 1). Seventeen patients were excluded from this analysis because they were on the general cardiology service at the time of their catheterisation. After controlling for mechanical ventilation prior to catheterisation, which was determined to be the best subset model, patients with "late" early post-operative cardiac catheterisation on average stayed at 1.38 (95% confidence interval 0.72–2.64, $p = 0.32$) times longer in the cardiac ICU compared to patients in the "early" early post-operative cardiac catheterisation group, though the difference was not statistically significant.

The median hospital length of stay after early post-operative cardiac catheterisation in the "early" early post-operative cardiac catheterisation group was 19 days [inter-quartile range 13.2,41.8] compared to 26 days [inter-quartile range 9.2, 68] for the late group ($p = 0.80$) (Table 1). After adjusting for vasoactive infusions prior to early post-operative cardiac catheterisation, which was determined to be the best subset model, patients with "late" early post-operative cardiac catheterisation on average trended towards a 1.08 (95% confidence interval 0.60–1.94, $p = 0.79$) times longer stay in the hospital compared to patients with "early" early post-operative cardiac catheterisation.

Duration of post early post-operative cardiac catheterisation mechanical ventilation

There were 83 patients (62.9%) who required mechanical ventilation prior to their catheterisation. One patient was excluded from the analysis as he was transferred to another centre for further management, therefore his mechanical ventilation duration is unknown. Thirty patients (36.1%) were censored for the following reasons: death on mechanical ventilation ($n = 23$, 27.7%), tracheostomy placement and continued mechanical ventilation ($n = 2$, 2.4%), and reintubation within 0–3 days ($n = 5$, 6%).

The median duration of mechanical ventilation after catheterisation for the "early" early post-operative cardiac catheterisation group was 9 days (95% confidence interval 5, N/A due to small sample size) and 10 days (95% confidence interval 6, 23) for the "late" early post-operative cardiac catheterisation group ($p = 0.57$) (Fig. 2a). Adjusting for extracorporeal membrane oxygenation use prior to early post-operative cardiac catheterisation did not change the results: patients with "late" early post-operative cardiac catheterisation had a longer duration (HR 0.56, 95% confidence interval 0.28–1.10, $p = 0.09$) of mechanical ventilation post catheterisation, but this difference was not statistically significant.

Duration of post early post-operative cardiac catheterisation extracorporeal membrane oxygenation

There were a total of 28 patients (21.2 %) requiring extracorporeal membrane oxygenation prior to catheterisation. The same patient excluded for the duration outcome of mechanical ventilation was also excluded here. Six patients (21.4%) were censored due to death on extracorporeal membrane oxygenation, two from the "early" early post-operative cardiac catheterisation group and four from the "late" early post-operative cardiac catheterisation group.

The median duration of extracorporeal membrane oxygenation after catheterisation for the early group was 5 days (95% confidence interval 5, N/A due to small sample size) and 6 days (95% confidence interval 3, N/A due to small sample size) for the "late" early post-operative cardiac catheterisation group ($p = 0.76$) (Fig. 2b).

Discussion

The presence of residual post-operative lesions is a known cause of morbidity and mortality after congenital cardiac surgery.[2] While the safety of early post-operative cardiac catheterisation has been demonstrated, there remains variability in timing of post-operative catheterisations and limited data on effects of early catheterisations on hospital outcomes.[6–12] Our study aimed to describe the safety of early post-operative catheterisations in our institution and secondarily describe its associations with outcomes on cardiac ICU and hospital length of stay as well as duration of mechanical ventilation and extracorporeal membrane oxygenation.

To our knowledge, this is the first study to evaluate the safety of catheterisations within 72 hours of cardiac surgery and compare this to catheterisations that occurred between 72 hours and 30 days. As in a recently published multi-center study on early post-operative catheterisations, complications were more common in patients who underwent an intervention.[24] However, of the 132 patients who underwent catheterisations in our study, only seven had complications. Complications occurred in the "early" early post-operative cardiac catheterisation group in 9.1% of patients and in 4.5% of patients in the late group. The complications experienced were relatively minor including arrythmias and ST segment changes that resolved after medical treatment. Two patients did experience cardiac arrest that required cardiopulmonary resuscitation, however, had no sequelae related to the event. There were no serious complications such as death, stroke, or need for new extracorporeal membrane oxygenation support secondary to the catheterisation. Based on our data, it appears that catheterisation within the first 72 hours following surgery may represent some increased risk but this risk assessment should be tailored to an individual patient and balanced with the potential for shorter duration of mechanical ventilation, cardiac ICU, and total hospital length of stay.

This was also the first study that we know of comparing outcomes between catheterisations that took place early vs. late in the post-operative course. While not statistically significant, the patients with "early" early post-operative cardiac catheterisation trended towards shorter stays in the cardiac ICU as well as total hospital stay. These findings could have implications for increased

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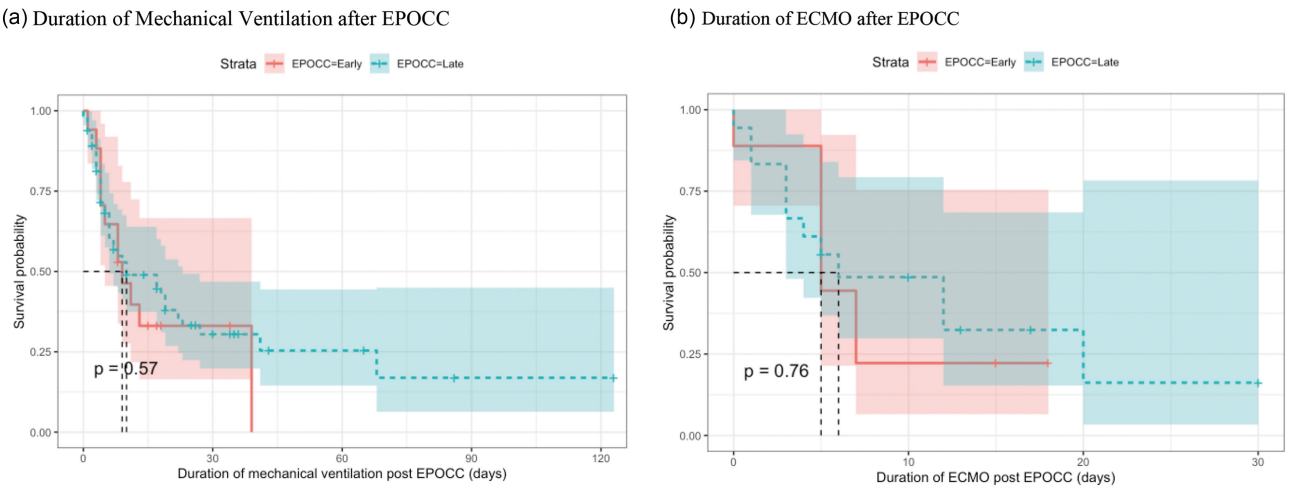

Figure 2. Duration of mechanical support after early post-operative cardiac catheterisation. (***a***) Duration of mechanical ventilation after early post-operative cardiac catheterisation. (***b***) Duration of extracorporeal membrane oxygenation after early post-operative cardiac catheterisation.

hospital costs as well as the known complications associated with prolonged ICU and hospital stays.

There was no significant difference in duration of mechanical ventilation or extracorporeal membrane oxygenation days between the groups. However, prolonged mechanical ventilation and extracorporeal membrane oxygenation are associated with known complications such as ventilator-associated pneumonia and strokes, and a thorough investigation into the aetiology of a patient's inability to wean from mechanical ventilation or extracorporeal membrane oxygenation is imperative to their care.

We did have to exclude five patients (a total of seven patient records related to some duplicates) from our outcomes analysis because they underwent multiple catheterisations within a few days. Three of these patients had an early catheterisation that led to a repeat catheter-based intervention within a few weeks (Supplemental Table S1). We felt that including these patients in our outcomes analysis would lead to inconsistencies in data regarding length of stay as well as duration of mechanical ventilation and extracorporeal membrane oxygenation support, however, left them in the discussion as their clinical findings were of some interest and are discussed below.

Seventeen patients in the cohort (7 "early" early post-operative cardiac catheterisation, 10 "late" early post-operative cardiac catheterisation) underwent a separate intervention within 2 weeks of their cardiac catheterisation. Fifteen of these interventions included a surgical intervention based on the catheterisation findings. The "early" early post-operative cardiac catheterisation group had five patients who proceeded to surgical intervention after their catheterisation and two patients who proceeded to a repeat interventional catheterisation (one within 7 days of their index surgery and another one within 10 days of their index surgery). Patients who did not undergo a follow up intervention either had changes in their medical management or continued their current course of management depending on the cardiac catheterisation findings. Further details regarding timing and type of interventions after the initial cardiac catheterisation can be seen in Supplemental Table S1.

The patients who did undergo repeat catheterisations had them in a "staged" manner to allow the care team to have further discussions regarding the next best steps in management. This highlights that early catheterisations can be beneficial in diagnosing residual lesions, and pending patient stability it does allow the gathered information to be brought back to the care team for decision-making in regard to the next step in addressing the residual lesion.

This data suggests that consideration for earlier catheterisations for patients not following an expected post-operative course could have beneficial outcomes. Earlier catheterisations can diagnose and potentially address residual lesions, known to be associated with worse outcomes, sooner. This can be done either via repeat catheterisation when the team feels suture lines would be more stable vs. surgical intervention. Patients who do not have intervenable lesions but undergo a diagnostic catheterisation can lead to potential changes in medical management i.e initiating treatment for elevated pulmonary vascular resistance or increasing diuretics for an increased pulmonary to systemic blood flow ratio. These interventions, whether procedural or medical, can lead to better post-operative haemodynamics and therefore quicker recovery.

While there is understandable hesitancy to performing certain types of interventions in the immediate post-operative period, the data at our institution show that some balloon and or stent angioplasty was performed without serious complications even within 72 hours of surgery. This will always require a risk and benefit discussion with the care team. If there is thought to be too much risk of an interventional catheterisation, diagnostic catheterisations can also help determine the haemodynamic impact of residual lesions and assist in decision-making surrounding need for reintervention (either operative or catheter based) vs. optimising medical management.

Limitations

The limitations of this study include its retrospective nature and the small sample sizes for the duration (especially the extracorporeal membrane oxygenation) outcomes. The study population is also quite heterogeneous as it includes diverse surgical procedures with varying expected outcomes. We did attempt to account for this by controlling for surgical complexity using Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery Score category and found that it had no significant effect on outcomes. Nor did it change the early post-operative cardiac

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catheterisation effect. Future studies with larger sample sizes may be needed to confirm the effects. One of the major limitations of the study is a selection bias that cannot be accounted for. As with many studies of this type, it is difficult to say that the catheterisation is truly the reason why the patient improved, unless there was a clear intervention addressing a haemodynamically significant residual lesion. Children in the "early" early post-operative cardiac catheterisation group may have gotten better on their own without intervention, especially if they only had a diagnostic catheterisation and this is a bias that is difficult to account for.

Conclusions

We acknowledge the many limitations of this study and due to these limitations, we cannot make a solid conclusion regarding the benefits of early post-operative cardiac catheterisation. We did find that early post-operative cardiac catheterisations are associated with an overall low rate of complications, and to our knowledge, this is the first paper looking at safety of cardiac catheterisations within 72 hours of cardiac surgery. Earlier catheterisations trended towards shorter cardiac ICU and hospital length of stays. Consideration for earlier catheterisations may lead to earlier recovery for patients not following an expected post-operative course. Further studies, with larger sample sizes, are needed to solidify the benefits of early post-operative cardiac catheterisations.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1047951124000568.

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Competing interests. None.

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