

What is the Clinical Utility of Routine Cardiac Catheterization Before a Fontan Operation?

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Abstract Patients with single-ventricle circulation presenting for Fontan completion routinely undergo cardiac catheterization despite ongoing debate concerning its additive value. Increasing interest in noninvasive preoperative evaluation alone led the authors to analyze the utility of routine pre-Fontan catheterization and to determine whether a subset of patients could avoid this invasive procedure. Patients younger than 5 years referred for pre-Fontan evaluation were retrospectively reviewed. Medical records and catheter angiograms were examined, and catheterizations were categorized as “additive” based on predetermined criteria. Associations between precatheterization variables, catheterization findings, and short-term postoperative outcomes were evaluated. Cardiac catheterization was clinically nonadditive for 89 of 175 patients undergoing pre-Fontan evaluation (51%). There were no robust precatheterization predictors of a nonadditive catheterization. Echocardiography did not fully demonstrate the relevant anatomy of 115 patients (66%), most frequently due to inadequate visualization of the pulmonary arteries, and 22 patients had additive catheterizations due to new diagnostic findings alone. Interventions at catheterization were frequent and deemed “important” for 64 patients (37%). Catheterization hemodynamic data were not associated with early postoperative outcomes. Minor catheterization complications occurred for 51 patients (29%) and major

complications for 4 patients (2%). Although at least 50% of the patients presenting for Fontan completion may be able to avoid routine catheterization safely, an echocardiography-based imaging strategy alone is insufficient to allow proper identification of those who could be evaluated noninvasively. A more comprehensive imaging strategy not based solely on echocardiography should be considered.

Keywords Cardiac catheterization · CHD · Echocardiography · Fontan · Imaging · Univentricular heart

Patients with a functionally univentricular heart typically undergo a series of palliative operations that culminate in a modified Fontan procedure. Before Fontan, echocardiography and cardiac catheterization are routinely performed to assess anatomic and hemodynamic suitability for Fontan completion. This is standard practice at many centers [8]. However, catheterization may be associated with morbidity for high-risk patients [2, 4, 5, 28, 30], and there is mounting evidence that ionizing radiation exposure in childhood is associated with an increased risk of cancer [19].

Published information is limited regarding the utility of pre-Fontan catheterization compared with noninvasive imaging for high-risk patients, and in the current era, few patients are excluded from Fontan completion based on catheterization data [8, 23]. As a result, there has been recent interest in reexamining the role of routine pre-Fontan catheterization in an attempt to identify a group that could safely avoid this procedure [24, 25].

We conducted a retrospective review of patients undergoing pre-Fontan evaluation at our institution to analyze the role of routine preoperative catheterization, including the utility of hemodynamic data as well as the frequency and nature of new diagnostic findings and

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catheter-based interventions. We also sought to identify precatheterization predictors of a nonadditive catheterization that could be used to identify patients for whom catheterization would provide no additional benefit beyond clinical evaluation and noninvasive imaging alone.

Methods

Subjects

After obtaining approval from the Department of Cardiology Scientific Review Committee and the Children's Hospital Committee on Clinical Investigations, we reviewed the medical records of patients younger than 5 years undergoing catheterization at our institution from January 2001 through December 2005. Patients listed as undergoing pre-Fontan evaluation and those who may have been Fontan candidates based on anatomy and prior procedures were included in the review.

To minimize bias related to institutional practice variability, only patients undergoing both pre-Fontan echocardiography and catheterization at our institution were included. Patients whose echocardiogram preceded catheterization by more than 6 months were excluded. Demographic, anatomic, and prior surgical data were obtained from the medical record.

Echocardiography

Data from the pre-Fontan echocardiogram were abstracted from the final report. For patients with multiple echocardiograms, the study in closest temporal proximity to the pre-Fontan catheterization was selected. Echocardiograms were considered complete if they visualized all the following: superior vena cava in patients with a Glenn circulation, pulmonary veins, atrial septum, atrioventricular valves, pulmonary outflow in patients with antegrade pulmonary blood flow, mediastinal pulmonary arteries, systemic outflow, ascending aorta and aortic isthmus in patients at risk for arch obstruction (e.g., prior Norwood procedure or left-sided obstructive lesions), and ventricular function.

Catheterization

Hemodynamic and interventional data from the pre-Fontan catheterization were recorded. Due to practice variability in the catheterization laboratory and the discretionary nature of many transcatheter interventions, we convened a panel of experts not initially involved in the study (a senior interventional catheterizer, a cardiac surgeon, and a noninvasive cardiologist within our department) to develop

definitions of a clinically "important" intervention during pre-Fontan catheterization (Table 1).

Using these criteria, all available angiograms and hemodynamic data were reviewed by a single cardiologist, and each intervention was categorized as "important" or "discretionary." Any catheterization that showed new diagnostic information affecting perioperative management or during which an "important" intervention was performed was considered clinically additive. For example, a catheterization that showed pulmonary artery stenosis not seen by echocardiography in a patient who subsequently went on to have pulmonary artery plasty at surgery was considered clinically additive. Similarly, catheterizations that included a pulmonary artery balloon angioplasty meeting the definition of an "important" intervention (Table 1) were considered additive.

Statistical Analysis

Continuous data are presented as mean \pm standard deviation or as median and range. Patient characteristics and echocardiographic information were compared for additive versus nonadditive catheterizations, new diagnostic findings, and "important" transcatheter interventions using the Wilcoxon rank sum test for continuous variables and Fisher's exact test for categorical variables. Variables significant at the 0.20 level in univariate analysis were considered for inclusion in multivariable logistic regression models. Variables significant at the 0.05 level were retained in the final models. Odds ratios (OR) and 95% confidence intervals (CI) were calculated. The Spearman rank correlation coefficient was used to examine relationships between short-term post-Fontan outcomes and catheterization hemodynamic variables.

Results

Subjects

Of the 175 patients who met the inclusion criteria, 105 (60%) were male. Six patients were excluded from the review: five because the interval between echocardiography and catheterization exceeded 6 months and one due to missing hemodynamic records. The median age at catheterization was 30 months (range, 4–49 months). The mean weight was 12 ± 2.3 kg, and the mean height were 87 ± 8 cm. The mean hemoglobin level was 16.3 ± 1.5 gm/dl, and the mean systemic oxygen saturation was $84 \pm 5\%$. The most common diagnosis was hypoplastic left heart syndrome ($n = 69$, 39%). Other common diagnoses included tricuspid atresia ($n = 28$), double-outlet right ventricle ($n = 18$), and unbalanced atrioventricular

Table 1 Criteria used to categorize interventions as important by expert panel consensus

Intervention type	Criteria for nondiscretionary interventions ^a
Hemodynamic ^b testing	Necessary
Electrophysiology studies	Necessary
Pulmonary vein angioplasty	Necessary
Aortic arch angioplasty	Significant obstruction (peak gradient ≥ 15 mmHg or $\geq 50\%$ luminal narrowing), even with normal hemodynamics and function Or Mild obstruction (peak gradient = 10–14 mmHg or 30–50% luminal narrowing) and evidence of hemodynamic compromise (\geq moderate systemic ventricular dysfunction, filling pressures ≥ 14 mmHg, or calculated cardiac index ≤ 2.5 l/min/m ²)
Pulmonary artery balloon angioplasty	Significant pulmonary artery obstruction ($\geq 50\%$ angiographic obstruction or gradient ≥ 2 mmHg) in an arterial segment not normally accessible to surgical plasty at Fontan (e.g., peripheral pulmonary vessels)
Venovenous collateral coiling	A systemic-to-systemic venous collateral measuring >2 mm in patients not going on to either Fontan or biventricular repair surgery Or A systemic-to-pulmonary venous collateral (or other effective right-to-left shunting collateral) measuring >2 mm
Systemic-to-pulmonary collateral coiling	Systemic-to-pulmonary arterial collaterals to a lobar lung segment supplied by a patent pulmonary artery that does not receive antegrade flow on pulmonary arterial angiography Or Systemic-to-pulmonary arterial collaterals in the setting of ventricular end-diastolic pressure >14 mmHg with no other anatomic or functional cause for elevated end-diastolic pressure
Other interventions	Evidence of significant hemodynamic effect of the lesion, coupled with poor accessibility to the surgeon and no likelihood of improved accessibility after the Fontan operation

^a Interventions not meeting these thresholds were considered discretionary

^b Includes vasodilator testing (oxygen, inhaled nitric oxide) and test occlusion of atrial septal defects

canal defect ($n = 17$). Heterotaxy syndrome was present in 24 patients (14%).

Most patients had undergone a prior bidirectional Glenn operation ($n = 159$, 91%), 22 (13%) of which were bilateral. Three patients (2%) had undergone a Kawashima operation, and 6 (3%) had a pulmonary artery band alone.

Echocardiography

The echocardiographic findings are summarized in Table 2. Two-thirds of echocardiograms were performed with the patient under sedation, but only 34% were considered complete. The most common reason for an incomplete echocardiogram was inadequate visualization of the Glenn pathway and pulmonary arteries (57%). The median time from echocardiogram to catheterization was 1 day (range, 0–157 days).

Catheterization

The catheterization results are summarized in Table 3. The results showed that 12 patients (7%) had pulmonary arterial pathway obstruction, 5 patients (3%) had arch obstruction that required intervention, and 4 patients (2%) had pulmonary vein stenosis. The mean fluoroscopy time was

Table 2 Echocardiographic findings ($n = 175$)

	<i>n</i> (%)
Complete echocardiogram	60 (34)
Incomplete visualization of the branch pulmonary arteries	100 (57)
Echocardiograms with patient under sedation	118 (67)
Branch pulmonary artery or Glenn obstruction	27 (15)
\geq Moderate systemic atrioventricular valve regurgitation	27 (15)
\geq Moderate systemic ventricular dysfunction	12 (7)
\geq Moderate aortic arch obstruction	5 (3)
Restrictive or absent atrial septal defect	4 (2)
Pulmonary vein stenosis	4 (2)

61 \pm 38 min. New diagnostic findings resulted from 48 procedures (27%). Interventions were performed for 112 patients (64%) and determined to be “important” for 64 patients (37%) (Table 4). Thus, 86 patients in the entire cohort (49%) had clinically additive catheterizations: 38 based on important interventions alone, 22 based on new findings alone, and 26 based on both.

Complications of Cardiac Catheterization

As summarized in Table 5, 4 patients (2%) had major catheterization complications, and 51 patients (29%) had

Table 3 Results of catheterization ($n = 175$)

Hemodynamic data	
Superior vena cava saturation	$63 \pm 7\%$
Cardiac index	3.5 ± 1.0 l/min/m ²
Common atrial pressure	9 ± 3 mmHg
Systemic ventricular end-diastolic pressure	10 ± 3 mmHg
Mean pulmonary artery pressure	13 ± 4 mmHg
Pulmonary resistance	1.9 ± 0.8 WU
New diagnostic findings affecting management ^a : n (%)	
Total	48 (27)
Glenn pathway or pulmonary artery stenosis	30 (17)
Persistent left superior vena cava	10 (6)
Pulmonary venous anomaly	4 (2)
Aortic arch obstruction	2 (1)
Hemodynamic abnormalities ^b	2 (1)
Other ^c	4 (2)
Interventions performed: n (%)	
Any intervention	112 (64)
At least one “important” intervention	64 (37)

^a Some patients had more than one new finding at catheterization

^b Unexplained elevated end-diastolic pressure of 17 mmHg ($n = 1$), elevated pulmonary artery pressure of 20 mmHg in a patient with significant bilateral systemic-to-pulmonary collaterals ($n = 1$)

^c Relationship between ventricular septal defect and pulmonary artery ($n = 1$), subaortic stenosis ($n = 1$), large leak in hemi-Fontan patch ($n = 1$), right ventricular aneurysm ($n = 1$)

minor complications. One cardiac arrest occurred for a patient with hypoplastic left heart syndrome undergoing catheterization for progressive tricuspid regurgitation and new-onset complete heart block. Early in the procedure, before any interventions, the patient experienced worsening hypoxemia, bradycardia, and subsequent cardiac arrest, which was treated with cardiopulmonary resuscitation and mechanical circulatory support. On day 2 after

catheterization, the patient underwent tricuspid valvuloplasty and pacemaker placement but remained in critical condition and died on postoperative day 13.

Exclusion from Fontan Completion or Its Delay

All but 13 patients (7%) underwent Fontan completion as planned. Of these 13, two were excluded from Fontan because of newly diagnosed pulmonary vein stenosis. One patient had Fontan surgery postponed because of an unexplained elevated ventricular end-diastolic pressure (17 mmHg). One patient had prominent systemic-to-pulmonary arterial collateral flow with elevated pulmonary artery pressure (20 mmHg) and therefore underwent coil embolization of multiple collateral arteries with a plan to reassess with catheterization in the future. Two patients underwent tricuspid valvuloplasty without Fontan completion. One of these patients was found at catheterization to have left pulmonary artery occlusion and underwent placement of an aorta-to-left pulmonary artery shunt only. Four patients underwent conversion to a biventricular circulation and therefore did not complete a Fontan procedure. The remaining two patients were favorable Fontan candidates, but the first patient was lost to follow-up evaluation, and the second patient with good hemodynamics and lack of symptoms had Fontan surgery postponed.

Predictors of Nonadditive Catheterization

Preoperative demographics and clinical characteristics were not predictive of an additive or nonadditive catheterization. In both uni- and multivariate analysis, the only precatheterization predictor of a nonadditive catheterization was the presence of a restrictive atrial septal defect on

Table 4 Interventions at catheterization

Intervention type	Discretionary n (%)	Important n (%)	Total n (% of patients)
Hemodynamic testing	–	–	–
Electrophysiology studies	–	9	9 (5)
Pulmonary vein angioplasty	–	2	2 (1)
Aortic arch angioplasty	2	6	8 (5)
Pulmonary artery angioplasty	9	3	12 (7)
Venovenous collateral coiling	10	18	28 (16)
Systemic-to-pulmonary collateral coiling	51	34	85 (49)
Other interventions	6	1 ^a	7 (4)
Any interventions: n (% of patients)	49 (28%) ^b	64 (37%) ^c	112 (64)

^a Creation of a ventricular septal defect in a patient with a severely hypertensive left ventricle not amenable to surgical treatment

^b Catheterizations where all interventions were deemed discretionary

^c Catheterizations where at least one intervention was deemed important. Some catheterizations had more than one important intervention

Table 5 Complications of catheterization

	<i>n</i> (%)
Minor complications ^a	51 (29)
Acidosis (pH <7.25)	20 (11)
Transient access-site complications ^b	19 (11)
Blood product transfusion	11 (6)
Intensive care unit admission	8 (5)
Arrhythmia >30 s or requiring therapy	6 (3)
Unplanned intubation	5 (3)
Initiation of vasopressor medications	2 (1)
Laryngospasm	2 (1)
Stridor	2 (1)
Pneumonia	2 (1)
Major complications	4 (2)
Pneumothorax/hemothorax requiring chest tube	3 (2)
Cardiac arrest ^c	1 (1)

^a Some patients had more than one minor complication

^b Self-resolved access-site hematomas and transient loss of distal pulse

^c See text for details

echocardiography (OR, 2.6; 95% CI, 1.2–5.9; *p* = 0.02). Furthermore, the only significant predictor of new findings at catheterization was incomplete echocardiographic visualization of the pulmonary pathway (OR, 2.2; 95% CI, 1.0–5.0; *p* = 0.03), and the most common new finding at catheterization was pulmonary artery stenosis (30 patients). Univariate analysis did not identify any independent predictors of important interventions at cardiac catheterization.

Short-Term Postoperative Outcomes

Table 6 summarizes the short-term postoperative outcomes. Of the 162 patients who underwent Fontan completion, the majority (92%) had an intracardiac lateral tunnel Fontan, and nearly all (98%) were fenestrated. There was no short-term (<30 days) postoperative mortality and no Fontan failures requiring a takedown of the Fontan circulation or heart transplant. Three patients (2%) required postoperative mechanical support, and 18 patients (11%) underwent reintervention, defined as repeat operative procedure such as pacemaker implantation or interventional catheterization, within 30 days of surgery.

Of the 18 patients requiring reintervention, 14 underwent postoperative catheterization: 7 patients for dilation or stenting of their Fontan fenestration, 4 patients for other interventions such as coiling of collaterals, and 3 patients for hemodynamic assessments alone. Four patients required placement of a permanent pacemaker, and two patients underwent chest exploration or mediastinal cleanout for

Table 6 Fontan surgical outcomes (*n* = 162)

	<i>n</i> (%)
Type of Fontan procedure	
Intracardiac	149 (92)
Extracardiac	13 (8)
Fenestrated Fontan procedures	158 (98)
Additional procedures at time of Fontan ^a	73 (45)
Pulmonary artery plasty	24 (15)
Atrioventricular valve plasty	19 (12)
Main pulmonary artery division	14 (9)
Atrial septal defect enlargement	10 (6)
Other ^b	21 (13)
Short-term (<30 days) postoperative outcomes	
Mortality	0
Fontan failure ^c	0
Need for mechanical circulatory support	3 (2)
Need for reintervention	18 (11)
Catheterization	14 (9)
Pacemaker implantation	5 (3)
Mediastinal exploration	2 (1)

^a Some patients had more than one additional procedure

^b Including electrophysiology procedures such as pacemaker implantation (*n* = 7), right ventricular plication (*n* = 3), pulmonary vein surgery (*n* = 3), aortic arch plasty (*n* = 2), and other miscellaneous procedures (*n* = 8)

^c Defined as the need for Fontan takedown or transplantation

bleeding and infection. Some patients had more than one postoperative intervention.

The median of intensive care unit (ICU) stay was 4 days (range, 2–106 days), and the median hospital stay was 10 days (range, 6–180 days). The median duration of mechanical ventilation was 2 days (range, 1–68 days), and the median duration of chest tube drainage was 7 days (range, 3–132 days). Catheterization hemodynamic data were not significantly associated with any of the short-term post-Fontan outcomes assessed, including duration of chest tube drainage, mechanical ventilation, and ICU or hospital stay (data not presented). Clinically additive catheterizations were weakly associated with exclusion from Fontan (10% vs. 3%; *p* = 0.08) but not with length of postoperative hospital stay or reintervention within 30 days.

Discussion

Recently, there has been interest in reexamining the role of routine catheterization before single-ventricle palliative procedures. A retrospective study from our institution suggested that in a subset of patients, routine cardiac catheterization before Glenn operation rarely results in new

findings or interventions [4]. A subsequent prospective trial demonstrated that cardiac magnetic resonance imaging (MRI) can be used effectively instead of routine catheterization for pre-Glenn evaluation, with fewer complications, lower cost, and similar perioperative and short-term outcomes [5].

Two retrospective studies have also evaluated the role of routine catheterization before Fontan completion. The first study, by Ro et al. [25], indicated that cardiac catheterization might be avoided for a subset of patients undergoing pre-Fontan evaluation. However, a large number of Fontan candidates were excluded from their study, and relatively few pre-Fontan transcatheter interventions were performed at their institution (6% of patients). Thus, the generalizability of their findings regarding the frequency of clinically additive catheterizations to other centers is unclear.

The second study, by Prakash et al. [24], evaluated whether history, echocardiographic data, or angiography alone would provide sufficient preoperative information to predict both candidacy for Fontan completion and postoperative adverse events. They found that their algorithm correctly identified all patients subsequently deemed inoperable, and although the sensitivity and specificity of the algorithm at predicting postoperative outcome was only 51% and 78%, these were not improved by addition of hemodynamic markers from catheterization. However, catheter interventions in their cohort were common (48% of patients), but these were not incorporated into their analyses. Consequently, the actual utility of catheterizations in their study group may be uncertain.

In the large, unselected group of patients presenting to our institution, in which transcatheter interventions are common, we still found that preoperative catheterization was clinically nonadditive for approximately half of the patients. Although transcatheter interventions were common among our patients, a large number of these interventions were considered discretionary by our predetermined criteria. Furthermore, hemodynamic information obtained at catheterization did not predict short-term postoperative outcomes.

Catheterization complications, mostly minor, were also common in this patient population. Appropriate stratification of patients into those who are and those who are not likely to benefit from catheterization could therefore allow a large number of patients to avoid the risks of catheterization, including exposure to ionizing radiation and procedural complications.

For many years, one of the primary indications for pre-Fontan catheterization has been the ascertainment of hemodynamic data [1]. Measurements of ventricular end-diastolic pressure [6], pulmonary artery pressure [18], and pulmonary vascular resistance [15] have been used to

identify and exclude patients at risk for a poor post-Fontan outcome. A prior study from our institution found that for patients undergoing a Fontan operation from 1987 through 1991, preoperative pulmonary vascular resistance was associated with early Fontan failure [26]. However, with more contemporary cohorts both in our study and that by Prakash et al. [24], no significant correlation between preoperative hemodynamic data and the short-term post-Fontan outcome variables evaluated was found. Furthermore, only two patients in our current cohort had Fontan surgery postponed on the basis of hemodynamic findings alone: one patient with an elevated end-diastolic pressure of unknown etiology that improved with a few weeks of medical therapy and another patient with an elevated end-diastolic pressure and multiple systemic-to-pulmonary collateral vessels who underwent coil occlusion of these vessels then returned for repeat catheterization followed by Fontan completion at a later date. These differences likely reflect evolution in practice and surgical technique over time. Patients in the previous cohort from our institution were older at the time of Fontan (mean age, 3.9 vs. 2.7 years), had fewer prior bidirectional Glenn procedures (13% vs. 93%), and had fewer fenestrated Fontan procedures (63% vs. 98%). Our data suggest that catheterization for the purpose of hemodynamic assessment alone may be avoided for a majority of patients presenting for Fontan completion in the current era.

Another commonly cited indication for pre-Fontan catheterization is the optimization of preoperative hemodynamics and anatomy via transcatheter interventions. In fact, interventions such as arch angioplasty and coil embolization of collateral vessels were common in our cohort (64% of patients), with more than one-third of our patients having “important” interventions according to our predefined criteria. This rate of interventions is considerably higher than in the study by Ro et al. [25] but similar to that reported by Prakash et al. [24]. Our data reflect an institutional bias toward aggressive transcatheter treatment of collateral vessels, pulmonary artery stenosis, and aortic arch obstruction.

For some interventions such as relief of aortic arch obstruction, the clinical benefit is widely accepted [7, 9]. For others, such as coil embolization of systemic-to-pulmonary collaterals, however, data are contradictory or lacking, and no consensus exists in the literature [3, 16, 17, 20, 21]. Until prospective data evaluating the clinical benefit of such interventions are available, however, identifying patients who may benefit from such procedures preoperatively will continue to be an integral part of the pre-Fontan assessment.

Identifying this subgroup of patients, however, continues to be a challenge. In contrast to previous reports, we did not attempt to predefine a low-risk group but rather

examined all patients presenting for Fontan to identify predictors of a nonadditive catheterization and were unable to find any such robust predictors. This may have been due, in part, to the fact that we did not exclude patients who could be categorized as requiring catheterization based on history and electrocardiography alone. This included, for example, patients with a history of tachyarrhythmias who required electrophysiologic testing and possible intervention before Fontan. Similarly, patients being considered for higher-risk surgeries, such as a two-ventricle repair, would not be regarded as “routine” candidates for single-ventricle palliation, and for such patients, catheterization may help in stratification to a bi- or univentricular circulation.

Furthermore, our difficulty in finding predictors of a nonadditive catheterization may have been further impaired by the frequent inability of echocardiography to demonstrate the relevant anatomy of this patient population. Adequate noninvasive imaging should help in discriminating between those who should and those who should not undergo catheterization. Patients with significant aortic arch obstruction on noninvasive imaging, for example, could be identified as potentially requiring transcatheter balloon angioplasty. Similarly, those with significant tricuspid regurgitation or ventricular dysfunction may be in the subset of “high-risk” patients for whom hemodynamic assessment at catheterization may allow better perioperative planning and management. With echocardiography frequently failing to provide sufficient anatomic information, however, many patients had clinically additive catheterizations on the basis of new anatomic findings not visualized by echocardiography. Indeed, nearly all the new diagnostic findings at catheterization were anatomic, most frequently pulmonary artery stenosis, which echocardiography often was unable to assess. Even among patients with “complete” echocardiograms, catheterization often identified pulmonary artery stenosis not seen by ultrasound so that echocardiographic data were a poor predictor of additive catheterizations.

More comprehensive preoperative imaging may allow better stratification than can be achieved using echocardiography alone by providing better anatomic assessment, thus helping to recognize patients at “high risk” and identifying those who may benefit from transcatheter interventions. Although not evaluated in this study, other studies have shown that cardiac MRI accurately and adequately visualizes anatomic details including mediastinal vessels such as the aortic arch, branch pulmonary arteries, and large systemic-to-pulmonary collateral vessels in patients with congenital heart disease [10–13, 22, 27, 29]. Its preoperative use could, therefore, show additional anatomic abnormalities missed by echocardiography and significantly reduce the need for anatomic assessment by catheterization. It also may identify the patients who may

benefit from preoperative transcatheter interventions such as those with significant proximal pulmonary arterial obstruction or large collateral vessels. However, the use of cardiac MRI is not yet a part of the standard preoperative assessment at our institution, and the published data comparing cardiac MRI to cardiac catheterization in this patient population are limited.

One report by Harris et al. [14] retrospectively evaluated whether cardiac MRI assessment of pulmonary arteries could predict postoperative outcomes and found that branch pulmonary artery size on pre-Fontan cardiac MRI was inversely correlated with post-Fontan length of hospital stay. However, half of their patients also underwent cardiac catheterization, but very little data regarding the catheterizations were provided. Moreover, comparisons between those who did and those who did not undergo catheterization were not done. Furthermore, their sample size precluded multivariable analyses accounting for potential confounders that may also be associated with length of hospital stay.

Despite the limited data, however, some centers have already begun to use a preoperative strategy that replaces routine cardiac catheterization with thorough noninvasive assessment using echocardiography and cardiac MRI. The clinical utility and cost effectiveness of this strategy should be evaluated by a prospective clinical trial, especially because robust predictors of nonadditive catheterization are lacking.

Study Limitations

This study was prone to all the limitations inherent in retrospective investigations. However, as a large retrospective review, it provides the background data and highlights the need for a prospective trial.

An additional limitation was the exclusion of patients who did not have both echocardiogram and catheterization at our institution. In so doing, we may have excluded patients who had a reassuring outside echocardiogram that was not repeated here before catheterization, thereby omitting a number of “low-risk” patients and falsely elevating the relative frequency of additive catheterizations. However, we also eliminated any potential between-center variability in echocardiographic and catheterization techniques.

A further limitation was the use of an expert panel rather than published data to define “important” transcatheter interventions. Until data regarding the importance of these interventions are available, however, expert opinion is the only available standard. By convening a panel that crossed disciplines within our program, we created a set of criteria that would be acceptable to many cardiologists and surgeons.

Finally, as a single-center report from our institution that relies heavily on transcatheter treatment of anatomic abnormalities as well as routine fenestration of the Fontan pathway, our results may not be strictly applicable to other centers who prefer alternative management strategies.

Conclusions

In this large retrospective study from a single institution, the pre-Fontan catheterization was not clinically additive for approximately half of the patients. Hemodynamic data were not associated with short-term postoperative outcomes. However, echocardiography often provided incomplete anatomic information, and transcatheter interventions were common and frequently not predicted by the echocardiographic findings. Thus, although at least 50% of patients presenting for Fontan completion may be able to avoid routine catheterization safely, an echocardiography-based imaging strategy alone is insufficient to allow proper identification of those who could be evaluated noninvasively. A prospective study is needed to assess whether careful patient selection and a more comprehensive imaging strategy will allow targeted referral of more appropriate patients for pre-Fontan catheterization and help in evaluating the efficacy of preoperative transcatheter interventions.

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