Selective use of cardiac computed tomography angiography: An alternative diagnostic modality before second-stage single ventricle palliation

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Objectives: To assess the accuracy and risk of substituting cardiac computed tomography for cardiac catheterization in select patients for evaluation of anatomy before second-stage single ventricle palliation.

Methods: This is a retrospective review of consecutive diagnostic cardiac catheterization (n = 16) and computed tomography studies (n = 16) performed before second-stage single ventricle palliation from March 2010 to July 2012 at a single institution. Risk (anesthesia, vascular access, contrast, and radiation exposure), accuracy, and postoperative course were compared. Nonparametric analysis was used to compare differences in group medians.

Results: General anesthesia was used for 16 of 16 cardiac catheterization studies and 1 of 16 computed tomography studies. Vascular access was central venous and/or arterial for all cardiac catheterization studies and a peripheral intravenous line for all computed tomography studies. Median age- and size-adjusted radiation dose was 14.0 mSv for cardiac catheterization and 1.1 mSv for computed tomography. Contrast dose was 4.8 mL/kg for the cardiac catheterization group and 2 mL/kg for the computed tomography group. There were no computed tomography discrepancies and 1 discrepancy between cardiac catheterization and surgical findings. There were 8 adverse events in 6 patients in the cardiac catheterization group and 1 adverse event in the computed tomography group. There was no difference between groups in postoperative course or need for repeat intervention.

Conclusions: Cardiac computed tomography and cardiac catheterization are equally accurate for evaluation of anatomy before second-stage single ventricle palliation when compared with surgical findings. Computed tomography may be the preferred test in select patients because of decreased vascular access and anesthesia risk, lower radiation and contrast exposure, and fewer adverse events. (J Thorac Cardiovasc Surg 2014;148:1548-54)

Advances in the surgical and medical treatment of patients with single ventricle heart disease have resulted in improved clinical outcomes.[1,2] Historically, interstage evaluation has included echocardiography and cardiac catheterization (CC). In select groups, noninvasive evaluation may be diagnostically sufficient without affecting outcomes before second-stage surgical palliation. Cardiac magnetic resonance imaging (MRI) has been described for this indication but requires general anesthesia with suspended respiration in all patients and prolonged imaging time.[3-5]

Recent advances in computed tomography (CT) technology have resulted in important improvements in temporal (as low as 75 m seconds) and spatial resolution (0.3-0.6 mm) that allow detailed visualization of cardiac anatomy at the higher heart rates of infants and children. The image acquisition time has decreased to less than 1 second on many scanner platforms, allowing scans to be performed free breathing without significant motion artifacts.[6,7] Radiation reduction and postprocessing techniques also have significantly reduced the radiation exposure while maintaining image quality using current CT compared with previous generation scanners.[8] These advances have decreased the risk and expanded the usefulness of CT for patients with congenital heart disease. The accuracy and risk of cardiac CT as an alternate diagnostic modality to CC for evaluation of anatomy before second-stage single ventricle palliation have not been reported.

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METHODS

Institutional review board approval was obtained for retrospective review of all diagnostic CC and CT procedures performed before second-stage single ventricle palliation at a single institution from March 2010 to July 2012. The CC, CT, anesthesia, surgical, and postoperative hospital data were reviewed. Patient clinical characteristics, general anesthesia and sedation use, vascular access, radiation exposure, contrast administration, image quality, adverse events, hospital course, and diagnostic accuracy as determined by surgical findings were compared between groups.

Abbreviations and Acronyms

- CC = cardiac catheterization
- CT = computed tomography
- CTA = computed tomography angiography
- CTDI = computed tomography dose index
- $CTDI_{vol}$ = volume computed tomography dose index
- DAP = dose area product
- DLP = dose-length product
- IV = intravenous
- MRI = magnetic resonance imaging
- ROI = region of interest

Patient Selection

All consecutive patients with single ventricle physiology who underwent diagnostic CC or CT during the time of review were included in the study. Patients who underwent intervention at the time of pre-Glenn catheterization were excluded (n = 9). All patients had an initial pre-Glenn echocardiogram, and patients were selected to have a CC or CT on the basis of the attending pediatric cardiologist's decision. Early in the cohort, as the technology was being introduced, the choice of imaging modality was based on referring physician preference. Later in the cohort, patients were triaged by clinical protocol to catheterization if intervention was anticipated on the basis of a detailed echocardiogram or they had moderate to severe atrioventricular valve regurgitation or ventricular dysfunction.

Anesthesia and Procedural Time Measurements

All CC and CT studies were performed under the supervision of a dedicated pediatric cardiac anesthesia team. Patients were categorized as having received general anesthesia with intubation, free breathing with intravenous (IV) or oral sedation, or free breathing with no sedation. The CT procedural time was determined from the time stamps on the first and last images acquired. CT scan acquisition time was determined by the table speed divided by the scan length. For CC, the procedural time was defined as the time from sheath insertion to sheath removal.

Computed Tomography Angiography Protocol

All studies were performed on a second-generation dual-source CT scanner (Definition Flash; Siemens Healthcare, Forschheim, Germany; gantry rotation time = 280 ms, collimated detector-row width 64 × 0.6 mm). A pediatric (BKH) or adult cardiologist (JRL) was in attendance for all scans. Scans were performed using high-pitch (3.4) helical techniques with prospective electrocardiogram triggering and a tube potential equal to 80 kV. Reference tube current was selected according to a locally developed algorithm that is based on the selected tube voltage, patient age, and weight. Attenuation-based online tube current modulation of the reference tube current time product also was used according to patient size and anatomic region (CARE Dose4D; Siemens Healthcare). Localizer images were obtained, and the scan range was adjusted to cover the thorax; 2 mL/kg of contrast were diluted with 2 mL/kg of saline and injected through a 22- or 24-gauge peripheral IV via a power injector at a rate of 1 to 2 mL/sec. Monitoring scans were started approximately 5 seconds after initiation of contrast injection, and diagnostic image acquisition was initiated when adequate opacification of the systemic arterial system was determined visually. Scan length, tube potential, effective tube-current time product, volume computed tomography dose index ($CTDI_{vol}$), scan dose-length product (DLP), total DLP, number of angiograms, total amount of contrast, IV site and gauge, and any adverse events were recorded.

All raw datasets were reconstructed with a thickness of 0.6 mm using filtered back projection with a medium-sharp reconstruction kernel developed specifically for cardiac applications (B36) and using an iterative reconstruction algorithm (SAFIRE, Siemens Healthcare, Forschheim Germany) for studies performed after March 2012. The reconstructed CT images were transferred to a standard workstation for image analysis (Vitrea, Vital Images, Minnetonka Minn).

Cardiac Catheterization Protocol

All catheterization studies were performed by an attending pediatric CC physician under anesthesia. A Toshiba INFINX biplane lab (Tustin, Calif) was used, with the "small" cardiac settings for all fluoroscopy and angiograms. The frame rate was 7.5 frames/sec for fluoroscopy and 15 frames/sec for cine angiography. Central venous and/or arterial access was obtained as clinically indicated. Systemic venous, pulmonary arterial, and systemic arterial angiography were performed. Systemic venous, atrial, ventricular, pulmonary venous wedge or pulmonary artery, and aortic pressures were measured.

Measurement of Radiation Dose

Computed tomography. The $CTDI_{vol}$, scan length, and DLP values provided by the scanner were recorded for each patient on the basis of a standard 32-cm CTDI phantom. The total procedural DLP includes localizer images, bolus monitoring images, and diagnostic images from the helical scan. The size- and age-unadjusted effective radiation dose in millisieverts for CT procedures is typically obtained by multiplying the total DLP by a conversion factor for the chest in adult-sized patients: 0.014 mSv/(mGy × cm).[9,10]

The estimate of effective CT radiation dose used for comparison with catheterization was adjusted for both patient size and age by converting from 32-cm to 16-cm phantom estimates of DLP and by converting the chest conversion by an age-adjusted factor.[11] DLP_{32cm} measurements were first adjusted to correspond to 16-cm CTDI phantom-based measurements ($DLP_{16cm} = DLP_{32cm} \times 2.06$)[12] and then multiplied by an age-appropriate conversion factor for the chest, 0.039 mSv/(mGy × cm) for patients aged less than 6 months.[13] By using these conversions, the age- and size-adjusted estimate of CT effective dose is 5.7-fold higher than an unadjusted dose.

Catheterization. The dose area product (DAP) provided by the catheterization system, number of angiograms, and minutes of fluoroscopy was recorded at the end of each case. Age-adjusted effective dose was calculated by multiplying the DAP by a conversion factor of 2.337 mSv/(Gy × cm^2). This conversion factor was obtained from tabular data applicable to neonates infants aged less than 1 year for the lateral projection.[14]

Contrast administration. The total contrast amount used for the CT or CC was recorded and divided by patient weight to determine the contrast volume in milliliters/kilogram.

Definition of Image Quality and Accuracy

Computed tomography quantitative. A region of interest (ROI) was defined to calculate contrast, image noise, contrast-to-noise ratio, and signal-to-noise ratio from the B36 kernel reconstruction.[8,15] The systemic venous (ROI = 10-15 mm^2), pulmonary arterial (ROI = 15 mm^2), and systemic arterial systems (ROI = 25 mm^2) and myocardium (10 mm^2) were evaluated.

Computed tomography and cardiac catheterization qualitative. All catheterization and CT studies were reviewed by a pediatric cardiologist (BKH and MV) and judged on an image-quality

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TABLE 1. Patient characteristics

	Cardiac CTA (n = 16)	CC (n = 16)	*P* value
Gender (male/female)	(8/8)	(10/6)	.4760
Age at time of imaging procedure, mo	3.7 (2.6-5.4)	3.6 (3.3-5.0)	.6144
Weight, kg	5.3 (4.5-6.8)	5.6 (5.3-6.4)	.7650
Body surface area, m^2	0.29 (0.25-0.32)	0.30 (0.27-0.32)	.6409
Time between imaging procedure and Glenn surgery, d	37.5 (10.5-71.5)	36.5 (23.0-51.0)	.5786
Primary diagnosis			
HLHS	7	8	
Unbalanced AV canal	3		
DILV	1	2	
DORV	2	1	
TA	1	4	
Heterotaxy	2	1	

Values are expressed as median, 25th percentile, 75th percentile. *AV*, Atrioventricular; *CC*, cardiac catheterization; *CTA*, computed tomography angiography; *DILV*, double inlet left ventricle; *DORV*, double outlet right ventricle; *HLHS*, hypoplastic left heart syndrome; *TA*, tricuspid atresia.

datasheet modified from the *European Guidelines on Quality Criteria For Diagnostic Radiographic Images*.[16] Anatomic details specifically evaluated were visually sharp definition of systemic venous anatomy, proximal and distal aortopulmonary or Sano shunt anatomy, proximal and distal branch pulmonary artery anatomy, and aortic arch anatomy. CT datasets were evaluated for coronary artery anatomy, intracardiac anatomy, atrial septal and coronary sinus anatomy, and tracheobronchial anatomy. Studies were judged on a 4-point scale, with 1 being optimal and 4 being nondiagnostic. Significant findings were listed, and areas not fully evaluated were documented.

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Adverse Events

All procedure and anesthesia reports were reviewed by a pediatric anesthesiologist (JM and DD) for the adverse events of contrast extravasation or IV infiltration, allergic reaction to contrast administration, sustained procedural desaturation with pulse oximetry more than 15 points below admission oxygen saturations for 10 minutes or more, acidosis, unplanned intensive care unit admission, arrhythmia, blood transfusion secondary to decreased hemoglobin during the procedure, transient vascular injury, unplanned intubation, initiation of inotropic support, or heart block.

Surgical Correlation

An experienced pediatric cardiac surgeon (DO) reviewed the operative records for all patients and determined whether anatomic findings at the time of second-stage palliation agreed with the preoperative study. Any diagnostic discrepancy between the preoperative evaluation and the surgical findings was recorded.

Hospital Course

The age at the time of second-stage surgery, cardiopulmonary bypass time, length of intubation, chest tube duration, additional interventions or advanced diagnostic studies required, length of hospital stay, and oxygen saturations at the time of discharge were recorded on all patients and compared between the 2 groups.

Statistical Analysis

Nonparametric analysis was performed on continuous variables using the Wilcoxon rank-sum test. Categoric variables were compared using the Fisher exact test.

RESULTS

A total of 32 pre-Glenn studies were performed on 31 patients during the time of review. Underlying diagnosis and patient characteristics are shown in Table 1. One patient was referred for CT for further definition of complex anatomy subsequent to CC and is included in both groups (computed tomography angiography [CTA], n = 16; CC, n = 16). One patient was referred to catheterization after CT for balloon angioplasty of severe aortic coarctation at the distal Norwood anastomosis. This patient is included in the CT group but not the CC group. Procedures performed before imaging included a first-stage Norwood procedure with an aortopulmonary shunt (n = 5) or Sano modification (n = 13), Damus–Kaye–Stansel and shunt (n = 1), or aortopulmonary shunt (n = 10). Additional procedures performed at the time of shunt included total anomalous pulmonary venous return repair (n = 1), pulmonary arterioplasty (n = 1), main pulmonary artery ligation (n = 3), ligation of a left superior vena cava (n = 1), and pulmonary artery banding (n = 1). Two patients were referred to the Glenn as the primary procedure without prior palliation.

Significant findings at the time of CTA included severe aortic coarctation (n = 1), internal jugular vein occlusion (n = 1), pulmonary artery narrowing (mild = 3, moderate-severe = 6), and narrowing of the Sano conduit (n = 1). All pulmonary arterial stenoses were confirmed surgically, and arterioplasty was performed at the time of second-stage palliation. Visual inspection at the time of shunt removal verified proximal shunt narrowing.

Findings at the time of catheterization included pulmonary stenosis (mild = 1, moderate to severe = 3), proximal Norwood narrowing (n = 1), and coronary sinus stenosis (n = 1). One patient was thought to have femoral arterial and venous occlusion and was referred to CT for evaluation subsequent to catheterization. All moderate to severe pulmonary artery narrowings were confirmed at surgery, and arterioplasty was performed. One central arterial narrowing considered mild was found to be more significant surgically, and an extended patch augmentation of the central pulmonary artery confluence was performed. One patient underwent coronary sinus unroofing. The patient who was referred to CTA for evaluation of femoral vessel anatomy had patency of both femoral arteries and veins.

Second-stage palliation was a superior cavopulmonary anastomosis (n = 29) or an aortopulmonary shunt (n = 1). One patient was referred for cardiac transplantation.

Anesthesia/Sedation

General anesthesia was used for all patients undergoing catheterization and 1 of 16 patients undergoing CTA. One patient received CT under anesthesia because of the

TABLE 2. Comparison of diagnostic risk

	Cardiac CTA (n = 16)	Diagnostic CC (n = 16)	*P* value
Anesthesia and procedural time			
Procedural time (min)	8 (6-12)	81.5 (64.5-111)	<.0001
Image acquisition time	0.25 sec		
General anesthesia (N/total)	1/16	16/16	<.0001
Vascular access			
Peripheral IV (22 g, 24 g)	16/16		—
Central venous	0/16	16/16	—
Central arterial	0/16	12/16	—
Radiation dose			
Radiation dose adjusted for age/size, mSv	1.12 (0.96-1.31)	13.95 (8.86-17.93)	<.0001
Fluoroscopy (min)		19.5 (16.5-29.0)	—
Contrast			
Volume contrast administered in mL/kg	2.06 (1.98-2.20)	4.82 (3.78-5.90)	<.0001
Adverse events	1	8	<.0001

Values are expressed as median, 25th percentile, 75th percentile. *CC*, Cardiac catheterization; *CTA*, computed tomography angiography; *IV*, intravenous.

anesthesiologist's preference. Fourteen patients undergoing CTA were sedated but free breathing during scan acquisition, and 1 patient received no sedation or anesthesia. Procedural time for CT was 8 minutes with image acquisition time of 0.25 seconds. Median CC procedural time was 81.5 minutes (Table 2).

Computed Tomography and Catheterization Study Parameters

The average CT scan length was 11.75 cm, median procedural DLP was 14, scan DLP was 8, and scan $CTDI_{vol}$ was 0.47. Thirteen of 16 patients had 1 CTA, and 3 of 16 patients had 2 CTAs performed. Two patients had a planned delayed phase scan because of high suspicion of systemic venous occlusion, and 1 patient had a repeat scan because of poor timing of the initial contrast bolus. The number of biplane angiograms performed during catheterization was 7.5 (5-10), and fluoroscopy time was 19.5 minutes (16.5-29.0 minutes). Catheterization procedural DAP was 5.97 (3.8-7.7) (Table 2).

Radiation Dose

The age- and size-adjusted radiation dose was 1.12 mSv for CT and 13.95 mSv for catheterization (Table 2).

Contrast Administration

Median contrast administration was 2.3-fold higher in the catheterization group than in the CT group (Table 2).

Qualitative Image Quality

All CTA scans were found to be diagnostically acceptable, with 14 of 16 being optimal (image quality = 1) and 2 of 16 being adequate (image quality = 2) (Figures 1 and 2). One unsedated patient moved between the localizer images and the helical scan acquisition, and the scan was diagnostic but with a different scan range than expected, and 1 scan had suboptimal opacification of the systemic venous system. All catheterization studies were found to be diagnostically acceptable, with 11 considered optimal (image quality = 1) and 5 considered adequate (image quality = 2); 4 of those were due to incomplete visualization of the systemic venous system, and 1 study had inadequate opacification of a branch pulmonary artery.

Quantitative Image Quality (Computed Tomography Angiography)

The image noise in the aorta, pulmonary artery, and central venous system was 41.4 ± 10.6, 40.9 ± 11.5, and 41.2 ± 15.4, respectively. Contrast-to-noise ratio in the

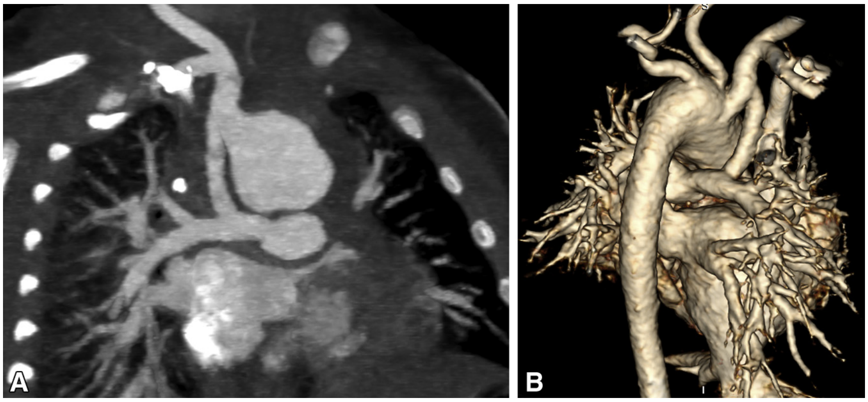

FIGURE 1. A, Two-dimensional image of a widely patent aortopulmonary shunt arising from the base of the right-sided innominate artery. B, Posterior view of a 3-dimensional reconstruction in the same patient. Note the visualization of the branch pulmonary arteries and reconstructed aorta.

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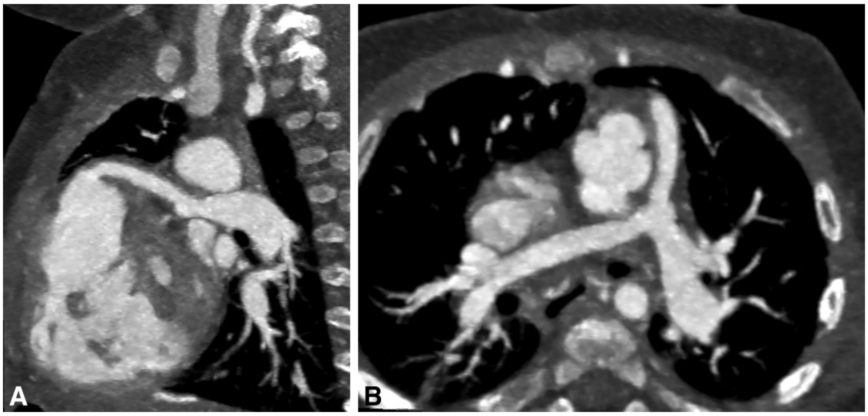

FIGURE 2. A, Two-dimensional sagittal view of a Sano shunt from the anterior surface of the right ventricle. The shunt is patent throughout its length to the left pulmonary artery. B, Axial 2-dimensional image in the same patient further illustrating the visualization of the distal shunt and branch pulmonary arteries.

aorta, pulmonary artery, and central venous system was 13.6 ± 4.6, 14.5 ± 4.5, and 7.9 ± 3.5, respectively. Signal-to-noise ratio in the aorta, pulmonary artery, and central venous system was 14.5 ± 4.6, 14.5 ± 4.5, and 8.9 ± 3.4, respectively. No quantitative measure of image quality for CC angiography was performed.

Adverse Events and Complications

There were 8 adverse events in 6 patients in the diagnostic catheterization group (vascular injury n = 2, hypoxia requiring oxygen overnight n = 3, atrial flutter requiring cardioversion n = 1, and packed red blood cells transfusion secondary to decreased hemoglobin during procedure n = 2). Four patients in the CC group were planned admissions, and there were 6 unplanned admissions because of the adverse events listed. The adverse event and unplanned admission in the CT group were secondary to increased cyanosis over baseline that required overnight observation and discharge to home oxygen.

Hospital Course

Table 3 contains postoperative clinical data. There was no statistically significant difference among the groups in duration of chest tube or intubation, hospital length of stay, or need for additional interventions.

Accuracy

There were no major discrepancies between any CTA and surgical findings. There was 1 discrepancy between CC and surgical review regarding the judgment of severity of pulmonary arterial narrowing. In this case, the angiogram underestimated the narrowing compared with surgical inspection, and arterioplasty was performed at the time of second-stage palliation. See detailed findings in the "Results" section.

DISCUSSION

Our study shows that both CC and CT are highly accurate for evaluation of anatomy before second-stage single ventricle palliation, with no difference in clinical outcome between diagnostic groups at the time of hospital discharge after surgical intervention. The risk profile favors CT because of decreased vascular access and anesthesia risk, lower radiation and contrast exposure, and fewer adverse events.

Diagnostically precise information is required to optimize clinical outcomes in this patient population. Minimizing risk associated with diagnostic evaluation is critically important in a hemodynamically disadvantaged cohort, such as those undergoing staged palliation for single ventricle congenital heart disease. It has been shown that echocardiography alone is insufficient for a complete diagnostic assessment before second- or third-stage single ventricle palliation and that advanced diagnostics are needed for this indication.[17,18] A high-quality echocardiogram is necessary to triage patients at the highest risk of requiring an intervention to catheterization, however, or the proposed diagnostic algorithm would add to the diagnostic burden in the subset of patients who undergo both noninvasive and invasive evaluations. This is true for the single crossover patient in our group who underwent CT and required subsequent balloon angioplasty of aortic coarctation. A successful noninvasive evaluation before second-stage single ventricle palliation requires careful clinical evaluation and echocardiographic screening for proper patient selection.

CC has been the normative modality for interstage evaluation. This study supports the diagnostic accuracy of well-performed diagnostic catheterization. However, it is important to note that the hemodynamic information from CC, which is commonly thought to be critical to the interstage evaluation, did not alter the treatment strategy in a

TABLE 3. Clinical outcomes at the time of second-stage palliation

	Cardiac CTA (n = 16)	Diagnostic CC (n = 15)	*P* value
Age at date of surgery, mo	5.7 (4.3-7.1)	5.1 (4.5-7.5)	.8371
Length of inpatient stay, d	7.7 (6.1-15.1)	8.4 (7.2-36)	.3697
Days with chest tube	2 (1-2)	2 (2-3)	.1644
Days intubated	1 (0-1)	1 (1-6)	.2222
Chest x-rays during hospitalization	9 (7-19)	11 (8-37)	.1463
Cardiopulmonary bypass time for second-stage palliation, min	63 (32-78)	69.5 (36-90)	.7134
Oxygen saturation at discharge, %	76 (72-80)	76 (75-82)	.6344
No. of patients who underwent subsequent intervention during same inpatient hospital stay	2	6	.2200
No. of procedures subsequent to second-stage palliation (performed in 8 patients)			
Diaphragm plication	1	3	
Tricuspid valve repair/ replacement	1	1	
Revision with larger patch augmentation of Glenn		1	
Catheterization	1	5	
Placement of RV to PA conduit after shunt		1	
ECMO		1	
Incidence of pleural effusions requiring CT	2	2	1.0

Values are expressed as median (25th percentile, 75th percentile). *CC*, Cardiac catheterization; *CTA*, computed tomography angiography; *CT*, computed tomography; *ECMO*, extracorporeal membrane oxygenation; *PA*, pulmonary artery; *RV*, right ventricle.

single patient in this cohort, suggesting that many patients may forego invasive hemodynamic assessment if accurate noninvasive imaging is available. A prior study that randomized patients pre-Glenn to noninvasive evaluation with MRI or CC also showed no difference in hospital course after the Glenn procedure and no difference between this same patient cohort 8 years after Fontan completion.[3,19] Several authors propose a completely noninvasive evaluation through the Fontan in low-risk patients.[3,18-20]

MRI has been proposed as a feasible noninvasive method of interstage evaluation and is the standard noninvasive imaging modality for evaluation of congenital heart disease. MRI requires general anesthesia and suspended respiration with an average scan time of 45 to 70 minutes and is contraindicated in some patients.[3,21] The risk of anesthesia is highest for pediatric patients with single ventricle heart disease and when performed outside the operating room.[22,23] The relative risk of adverse event with MRI is 3.9 times higher if performed with anesthesia.[24] There are additional concerns regarding the potential negative effects of prolonged or repeat anesthesia on neurodevelopment in the youngest patients.[25-28]

CTA use in patients with congenital heart disease has historically been limited by poor temporal and spatial resolution, and the relatively high radiation doses of previous generation scanners. Recent advances in CT scanning technology and techniques have resulted in improved image quality and image acquisition speed with dramatically lower radiation doses. In light of these recent developments, CT may be a reasonable alternate diagnostic modality to catheterization when assessment of complex cardiac anatomy is required for clinical decision-making and a young patient is considered high risk for anesthesia required for MRI. This study demonstrates that CT is diagnostically accurate, can be performed without general anesthesia in most patients using only a peripheral IV line, and has lower radiation doses and fewer adverse events when compared with CC.

In our practice, all patients pre-Glenn are now routinely prescreened with echocardiography before triaging to CT or CC. Only patients found to have risk factors for second-stage palliation, such as significant atrioventricular valve regurgitation or ventricular dysfunction, or those who require catheter-based intervention undergo CC. All other patients undergo interstage evaluation using CT. We believe the decreased anesthesia risk compared with both catheterization and MRI favors the modality for this specific indication. The radiation doses reported are less than for previous generations of technology, even when the estimated dose is adjusted for age and size. Even so, aggressive dose reduction is required to minimalize risk in this population. Historically, patients who undergo multiple and repeat catheterization procedures report high cumulative doses.[29,30]

Pediatric medical radiation exposure has been under considerable and appropriate scrutiny because of the increased radiation sensitivity and longer expected lifespan of a pediatric patient.[31,32] The majority of patients born with single ventricle physiology in the current era will reach adulthood.[1,33,34] Careful attention to all the details of CT image acquisition and aggressive radiation dose is required to optimize the safety profile of this diagnostic modality.

Study Limitations

This is a single-institution, retrospective study. There was no randomization of patients to diagnostic modality, and the decision to perform a catheterization or CT was based primarily on referring physician preference. These findings only apply to a strict echocardiography screening protocol that has the highest likelihood of finding pathology that requires catheter-based intervention. The diagnostic accuracy was limited to the confirmation of anatomy visualized within the surgical field. Only immediate and short-term clinical outcomes are compared, and no follow-up after

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hospital discharge has been conducted. The CT risk is specific to the scanner and modes of image acquisition used. The findings may not be applicable to other institutions with different technical capabilities.

CONCLUSIONS

In selected patients undergoing second stage palliation of single ventricle heart disease CT angiography provides equivalent diagnostic accuracy and improved safety profile when compared with traditional cardiac catheterization. Our experience suggests that non-invasive diagnostic evaluation using CTA is preferable to cardiac catheterization in favorable risk patients.

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