Pre-Fontan cardiac magnetic resonance predicts post-Fontan length of stay and avoids ionizing radiation

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Objective: Patients frequently undergo cardiac catheterization before the Fontan operation because of the limited echocardiographic windows in the region of the superior cavopulmonary connection and branch pulmonary arteries. Patients with obstruction to pulmonary blood flow are at increased risk for prolonged length of hospital stay after the Fontan operation. Cardiac magnetic resonance has unlimited imaging windows and can quantify both the branch pulmonary artery size and net flow distribution and thereby serve as a method for identifying patients at increased risk for prolonged length of stay.

Methods: We retrospectively reviewed 24 cardiac magnetic resonance studies of patients (mean age, 3.1 $\pm$ 1.0 years) referred before the Fontan operation. Cardiac magnetic resonance measured the cross-sectional area and flow to each branch pulmonary artery. Post-Fontan hospital course data were acquired from the medical record.

Results: Prolonged length of stay after the Fontan operation is observed among patients with one branch that is less than 25% of the total cross-sectional area (18.0 $\pm$ 5.5 vs 8.2 $\pm$ 3.8 days, $P = .01$) or with less than 40% flow to one branch (12.5 $\pm$ 6.9 vs 7.6 $\pm$ 1.5 days, $P = .04$). There is moderate correlation between the total branch pulmonary area and length of stay ($r = -0.75$).

Conclusions: Cardiac magnetic resonance noninvasively assesses the branch pulmonary area size and flow before the Fontan operation. These data predict which patients are more likely to experience a prolonged hospital course.

Video clip is available online.

The Fontan operation completes the process of converting a patient with a functional single ventricle from a circulation in parallel to a circulation in series. Investigators studying predictors of Fontan outcomes have considered the effect of many factors, including anatomic diagnosis, pulmonary artery size, ventricular size and function, and the presence of a reconstructed aortic arch.[1-12] Patient characteristics that had been thought of as high risk for Fontan completion have been found to produce acceptable intermediate outcomes in the current era of improved perioperative care.[13] However, there are still relatively few and at times conflicting data regarding the effect of these factors on the hospital length of stay (LoS).[7,10-12]

Before undergoing the Fontan operation, patients are commonly assessed with both noninvasive echocardiography and invasive diagnostic catheterization, with the occasional need for catheter intervention. Although noninvasive echocardiographic analysis might be sufficient to determine which patients will have a good outcome after the Fontan operation when unlimited echocardiographic windows are available, frequently the superior cavopulmonary connection and the branch pulmonary arteries (BPAs) are not adequately assessed.[14]

Cardiac magnetic resonance (CMR) provides quantitative measurements of the BPA size and flow distribution,[15-17] ventricular ejection,[18-20] and cardiac index.[21,22] With the exception of significant coil and stent artifacts, CMR provides unlimited imaging windows without the use of ionizing radiation. The purpose of this study was to investigate whether pre-Fontan CMR assessment can predict which patients will require a longer LoS.

MATERIALS AND METHODS

Patients

Twenty-four consecutive patients were referred for pre-Fontan CMR assessment on clinical grounds between April 2004 and September 2007 and have undergone Fontan completion. Their demographic data are described in Table 1.

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Abbreviations and Acronyms

AVV = atrioventricular valve
AVVR = atrioventricular valve regurgitation
BPA = branch pulmonary artery
CMR = cardiac magnetic resonance
EDV = end-diastolic volume
ESV = end-systolic volume
LoS = length of stay
LPA = left pulmonary artery
LV = left ventricular
RPA = right pulmonary artery
RV = right ventricular

MRI Protocol

CMR studies are monitored by our cardiac anesthesia service. Studies are conducted while patients are spontaneously breathing. Patients are anesthetized with propofol and generally do not require intubation or paralytics. The core of the CMR protocol involves assessment of BPA size and flow distribution, cardiac index, and ventricular size and function. CMR data were also reviewed for ventricular morphology, atrioventricular valve regurgitation (AVVR), and aortic arch obstruction.

BPA Size and Flow Distribution

The BPAs were measured in 2 orthogonal dimensions, and the cross-sectional area was calculated from the linear measurements. For each BPA, the smallest cross-sectional area along the segment from the superior cavopulmonary connection to the origin of the upper lobe branch, including the central pulmonary artery portion under the arch, was used for data analysis. By using phase-contrast magnetic resonance, the fractional BPA pulmonary blood flow is calculated as follows:

$$\textit{Fractional BPA pulmonary blood flow} = (\textit{Net BPA flow}/\textit{Net total pulmonary blood flow}) \times 100.$$

The single patient with a BPA endovascular stent was excluded from the BPA size and flow analysis.

Cardiac Index

Phase-contrast magnetic resonance acquisition was applied at the aortic valve for flow quantification and was indexed for body surface area. In patients who have a proximal reconstructive anastomosis of the great arteries without semilunar valve atresia, separate measurements of the native aortic and pulmonary valves were performed. The cardiac index was calculated as the sum of the 2 measurements. Phase-contrast magnetic resonance data analysis involved contouring regions of interest throughout all phases of the cardiac cycle. Forward, regurgitant (if applicable), and net flows were then automatically calculated from the resulting flow-time curves. The regurgitant fraction through a region of interest is defined as follows:

$$\textit{Regurgitant fraction} = (\textit{Reverse flow}/\textit{Forward flow}) \times 100.$$

One patient, who woke during the study and could not be resedated, did not have an aortic phase-contrast magnetic resonance measurement for analysis.

Ventricular Volume Analysis

Cine short-axis imaging of the functional single ventricle was acquired from the base to the apex of the heart by using 8 contiguous slices ranging from 6 to 8 mm in thickness, depending on heart size. The ventricular systolic function analysis involved contouring the blood pool at end-diastole and end-systole at each level of the volume data set, thereby quantifying the end-diastolic volume (EDV) and end-systolic volume (ESV). The stroke volume is defined as the difference between the EDV and ESV, and the ejection fraction is defined as follows:

$$\textit{Stroke volume}/\textit{EDV} \times 100.$$

For the purpose of comparison, the patients were grouped into those with a dominant, functional single right ventricle (Video 1) versus those with a dominant, functional single left ventricle (Video 2). There were 4 patients with indeterminate ventricular morphology who were excluded from the right ventricle versus left ventricle analysis.

TABLE 1. Characteristics of study patients

Parameters	Results
Age (y), mean ± SD (range)	2.7 ± 0.7 (1.5–5.2)
Male/female sex	13/11
BSA at CMR (m^2), mean ± SD (range)	0.59 ± 0.05 (0.47–0.67)
Cardiac anomaly (n = 24)	
Dominant, functional, single RV	n = 13
RV w/Norwood (HLHS, DORV/MA)	n = 11 (n = 10, n = 1)
RV w/normal aorta (single RV, unbalanced CCAVC)	n = 2 (n = 1, n = 1)
Dominant, functional, single LV	n = 7
LV w/Norwood (DILV/TGA)	n = 1
LV w/normal aorta (TA, DILV/TGA {S,L,L})	n = 6 (n = 5, n = 1)
Indeterminate ventricular morphology	n = 4
SCPC (n = 24)	
Age (y), mean ± SD [range]	0.5 ± 0.1 [0.3–0.7]
BDG (right bilateral)	n = 18 (n = 15, n = 3)
Hemi-Fontan	n = 6
Fontan (n = 24)	
Age (y), mean ± SD (range)	3.1 ± 1.0 (2–7.5)
Extracardiac conduit	n = 18
Lateral tunnel	n = 6
Fenestrations	n = 23

SD, Standard deviation; *BSA*, body surface area; *CMR*, cardiac magnetic resonance; *RV*, right ventricle; *HLHS*, hypoplastic left heart syndrome; *DORV*, double-outlet right ventricle; *MA*, mitral atresia; *CCAVC*, complete common atrioventricular canal; *LV*, left ventricle; *DILV*, double-inlet left ventricle; *TGA*, transposition of the great arteries; *TA*, tricuspid atresia; *TGA(S,L,L)*, situs solitus of the atria with right ventricular outlet chamber to the left of the dominant morphologic left ventricle, aorta (arising from the right ventricular outlet chamber) to the left of the pulmonary artery (arising from the dominant left ventricle); *SCPC*, superior cavopulmonary connection; *BDG*, bidirectional Glenn; *Hemi-Fontan*, patch closure of the superior vena cava–right atrial junction and side-to-side anastomosis of the superior vena cava–right pulmonary artery junction.

Atrioventricular Valve Regurgitation

The atrioventricular valve (AVV) regurgitant fraction was defined by using the following formula:

$$\textit{AVV regurgitant fraction}\ (\%) = (\textit{AVV regurgitant volume per heart beat}/\textit{AVV inflow per heart beat}) \times 100$$

The AVV regurgitant volume is equal to the difference between the ventricular stroke volume (derived from cine magnetic resonance) and the cardiac output per heart beat (derived from phase-contrast magnetic resonance). In the absence of semilunar valve regurgitation, the AVV inflow is equal to the ventricular stroke volume.

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