

Associations between pre-Fontan cardiovascular magnetic resonance and catheterization data with Fontan failure at a moderate-altitude surgical center

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Abbreviations and Acronyms:

CC (cardiac catheterization), CMR (cardiovascular magnetic resonance), RPA (right pulmonary artery), SVR (systemic vascular resistance), PVR (pulmonary vascular resistance), EDP (end diastolic pressure), ESV (end systolic volume), EDV (end diastolic volume), AAO (ascending aorta), SVC (superior vena cava), PAP (pulmonary artery pressure), DAO (descending aorta), IVC (inferior vena cava), LPA (left pulmonary artery), RPA (right pulmonary artery),

CENTRAL MESSAGE

We found RPA mean pressure, SVR, peak systolic pressure of the systemic ventricle, and EDP of the AAO to be associated with Fontan failure in pre-Fontan CC at a moderate altitude center.

PERSPECTIVE STATEMENT

Despite many advancements in the field, long-term survival rates of the Fontan procedure range from 61-83% at 20 years. This study aims to provide further data to determine suitability and readiness to proceed with Fontan at altitude using pre-Fontan hemodynamic assessment with CC and CMR to provide key anatomic and physiologic data points to guide decision making.

ABSTRACT

Objective: While post-Fontan survival metrics have improved in recent decades, there remains a gap in understanding how pre-Fontan hemodynamic factors relate to long-term clinical outcomes, particularly in patients living at altitude. This study aimed to investigate the association between pre-Fontan hemodynamic parameters, and the likelihood of post-Fontan death or heart transplant.

Methods: A retrospective cohort study was performed in Fontan patients who underwent cardiac catheterization (CC) and cardiovascular magnetic resonance (CMR) between 1999-2021 at a single moderate-altitude surgical center. CMR and CC data from the Glenn stage was analyzed. Univariate logistic regression modeling was used to model the relationship between the probability of transplant or death, whichever came first.

Results: 240 unique patients were included. The mean age at time of Fontan was 3.4 ± 1.2 years. Mean home elevation was 5109.3 ± 1294.3 feet. Most patients had a fenestrated external conduit type Fontan. The mean follow-up time post-Fontan at the time of data collection was 9.7 ± 5.8 years. **(Table 1)**

The following variables were associated with increased odds ratio (OR) for death/transplant: elevated systemic vascular resistance (SVR), elevated right pulmonary artery (RPA) mean pressure, elevated peak systolic pressure of the systemic ventricle, and end diastolic pressure of the ascending aorta (AAO). **(Table 2)**

Conclusion: While elevated pre-Fontan SVR was significantly associated with increased OR for death/transplant, interestingly, elevated PVR was not. We additionally found elevated RPA mean pressure, elevated peak systolic pressure of the systemic ventricle, and EDP of the AAO to be significantly associated with the primary outcome.

Table 1: Study Participant Characteristics.

Variable	Total (N=240)
Sex	
Female	136 (43.3%)
Male	104 (56.7%)
Age at time of Fontan (years)	3.4 ± 1.2
Height at time of Fontan (cm)	93.0 ± 8.2
Weight at time of Fontan (kg)	13.9 ± 2.5
Home Elevation (feet)	5109.3 ± 1294.3
Mortality Status	
Alive	230 (95.8%)
Deceased	10 (4.2%)
SV Morphology	
RV	131 (55.3%)
LV	106 (44.7%)
HLHS	114 (47.5%)
DKS Anastomosis	117 (48.8%)
SCPC Type	
Unilateral Bidirectional Glenn	196 (82.4%)
Bilateral Bidirectional Glenn	27 (11.3%)
Hemi-fontan	13 (5.5%)
Kawashima	2 (0.8%)
Fontan Type	
External Conduit	213 (88.8%)
Lateral Tunnel	25 (10.4%)
Fenestrated	229 (95.4%)
Post-Fontan follow-up time (years)	9.7 ± 5.8
*Continuous data are represented as means (± standard deviation), and categorical data as numbers (% of total). SV: single ventricle; RV: right ventricle; LV: left ventricle; HLHS: hypoplastic left heart syndrome; DKS: Damus-Kaye-Stansel; SCPC: superior cavopulmonary connection	

Table 2: Summary Statistics of Pre-Fontan Cardiac Catheterization

<u>Pre-Fontan Cardiac Catheterization Data Summary</u>	
Variable	Mean (SD) Overall N=220
Mean Pressure (mmHg)	
AAO	56.8 (8.2)
DAO	56.7 (8.2)
SVC	11.1 (3.1)
LA	5.5 (2.0)

LPA	10.3 (2.1)
RPA	10.5 (2.2)
Peak Systolic Pressure (mmHg)	
Systemic Ventricle	80.2 (12.5)
AAO	78.8 (10.5)
DAO	78.8 (11.6)
End Diastolic Pressure (mmHg)	
Systemic Ventricle	6.6 (5.4)
AAO	41.6 (8.6)
DAO	42.4 (7.8)
Indexed PVR	2.0 (0.9)
SVR	12.6 (4.0)
Qp (L/min/m²)	2.9 (4.6)
Qs (L/min/m²)	4.4 (1.5)
Heart rate (beat/min)	98.4 (16.3)
VO2 (ml/kg/min)	157.1 (12.9)
<u>Pre-Fontan CMR Data Summary</u>	
Variable	Mean (SD) Overall N=56
Indexed Vessel Area (cm²/m²)	
AAO	3.6 (1.4)
DAO	0.8 (0.2)
LPA	0.7 (0.4)
RPA	0.9 (0.3)
Indexed Vessel Flow (ml/beat/m²)	
Aorta net flow	27.5 (8.9)
LPA net flow	4.4 (2.3)
RPA net flow	6.3 (2.2)
IVC flow	10.4 (7.0)
SVC flow	9.5 (3.7)
Systemic Ventricle Indexed ESV (ml/m²)	61.0 (24.5)
Systemic Ventricle Indexed EDV (ml/m²)	117.8 (38.3)
Ejection Fraction of Systemic Ventricle (%)	49.1 (7.7)
*Data are represented as means ($\pm$ standard deviation), AAO: ascending aorta; DAO: descending aorta; SVC: superior vena cava; LA: left atrium; LPA: left pulmonary artery; RPA: right pulmonary artery; PVR: pulmonary vascular resistance; SVR: systemic vascular resistance; Qs: systemic flow; Qp: pulmonary flow; CMR: cardiac magnetic resonance; ESV: end systolic volume; EDV: end diastolic volume.	

Table 3: Results of Univariate Logistic Regression Predicting Fontan Failure from Cardiac Catheterization Data

Variable	N	OR	95% CI	p-value
Mean Pressure (mmHg)				
AAO	130	1.06	(1, 1.13)	0.051
DAO	213	0.99	(0.93, 1.04)	0.671
IVC	9	1.72	(0.91, 6.83)	0.202
SVC	201	1.03	(0.88, 1.16)	0.598
LPA	208	1.08	(0.85, 1.37)	0.523
LA	192	1.23	(0.98, 1.54)	0.065
RPA	207	1.29	(1.05, 1.62)	0.021
Peak Systolic Pressure (mmHg)				
Systemic Ventricle	203	1.05	(1.01, 1.08)	0.009
AAO	131	1.04	(0.99, 1.09)	0.072
DAO	211	1.02	(0.99, 1.06)	0.205
End Diastolic Pressure (mmHg)				
Systemic Ventricle	200	1.00	(0.88, 1.07)	0.986
AAO	131	1.06	(1, 1.12)	0.038
DAO	211	1.00	(0.93, 1.05)	0.912
Indexed PVR	167	0.76	(0.35, 1.44)	0.459
SVR	198	1.16	(1.04, 1.3)	0.007
Qp (L/min/m²)	173	0.55	(0.2, 1.01)	0.220
Qs (L/min/m²)	199	0.86	(0.56, 1.22)	0.461
Heart Rate (beat/min)	216	0.99	(0.96, 1.02)	0.386
VO2 (ml/kg/min)	215	1.00	(0.96, 1.03)	0.789
OR: odds ratio; CI: confidence interval; AAO: ascending aorta; DAO: descending aorta; SVC: superior vena cava; LA: left atrium; LPA: left pulmonary artery; RPA: right pulmonary artery; PVR: pulmonary vascular resistance; SVR: systemic vascular resistance; Qs: systemic flow; Qp: pulmonary flow.				

Table 4: Results of Univariate Logistic Regression Predicting Fontan Failure from Cardiac Magnetic Resonance Data

Variable	N	OR	95% CI	p-value
Indexed Vessel Area (cm²/m²)				
AAO	46	0.68	(0.2, 1.6)	0.442
DAO				
LPA	45	2.47	(0.12, 23.22)	0.450

RPA	43	0.19	(0, 6.24)	0.356
Indexed Vessel Flow (ml/beat/m²)				
Aorta net flow	52	0.88	(0.75, 1.01)	0.089
LPA net flow	49	1.30	(0.71, 2.42)	0.361
RPA net flow	48	0.63	(0.24, 1.29)	0.266
IVC flow	41	1.00	(0.74, 1.16)	0.998
SVC flow	47	0.67	(0.25, 1.17)	0.215
Systemic Ventricle Indexed ESV (ml/m²)	55	1.03	(0.98, 1.08)	0.246
Systemic Ventricle Indexed EDV(ml/m²)	55	1.02	(0.99, 1.05)	0.125
Ejection Fraction of Systemic Ventricle (%)	55	0.98	(0.85, 1.12)	0.759
Cardiac Index	49	1.40	(0.78, 2.56)	0.233
OR: odds ratio; CI: confidence interval; AAO: ascending aorta; DAO: descending aorta; SVC: superior vena cava; LPA: left pulmonary artery; RPA: right pulmonary artery; ESV: end systolic volume; EDV: end diastolic volume.				

Table 5: Results of COX PH analyses of statistically significant findings on univariate analysis. Estimates displayed as hazard ratios with 95% CI's and p-values.

Variable	HR	95% CI	p-value
SVR	4.3	(1.7,11.1)	<0.001
RPA mean pressure	4.9	(1.1,21.1)	0.03
Peak Systolic pressure of systemic ventricle	2.7	(1.0,6.9)	0.05

Table 6: Summary of time-to-event, in years, from Fontan date, in patients with CC data

Min	Q1	Median	Mean	Q3	Max	# Patients meeting primary outcome
0.03	0.37	1.57	5.63	10.73	16.36	22

Figure 1: Kaplan-Meier Analysis of time-to-event from date of Fontan to May 2024, in patients with SVR < 15.71 vs patients with SVR > 15.71 on CC data.

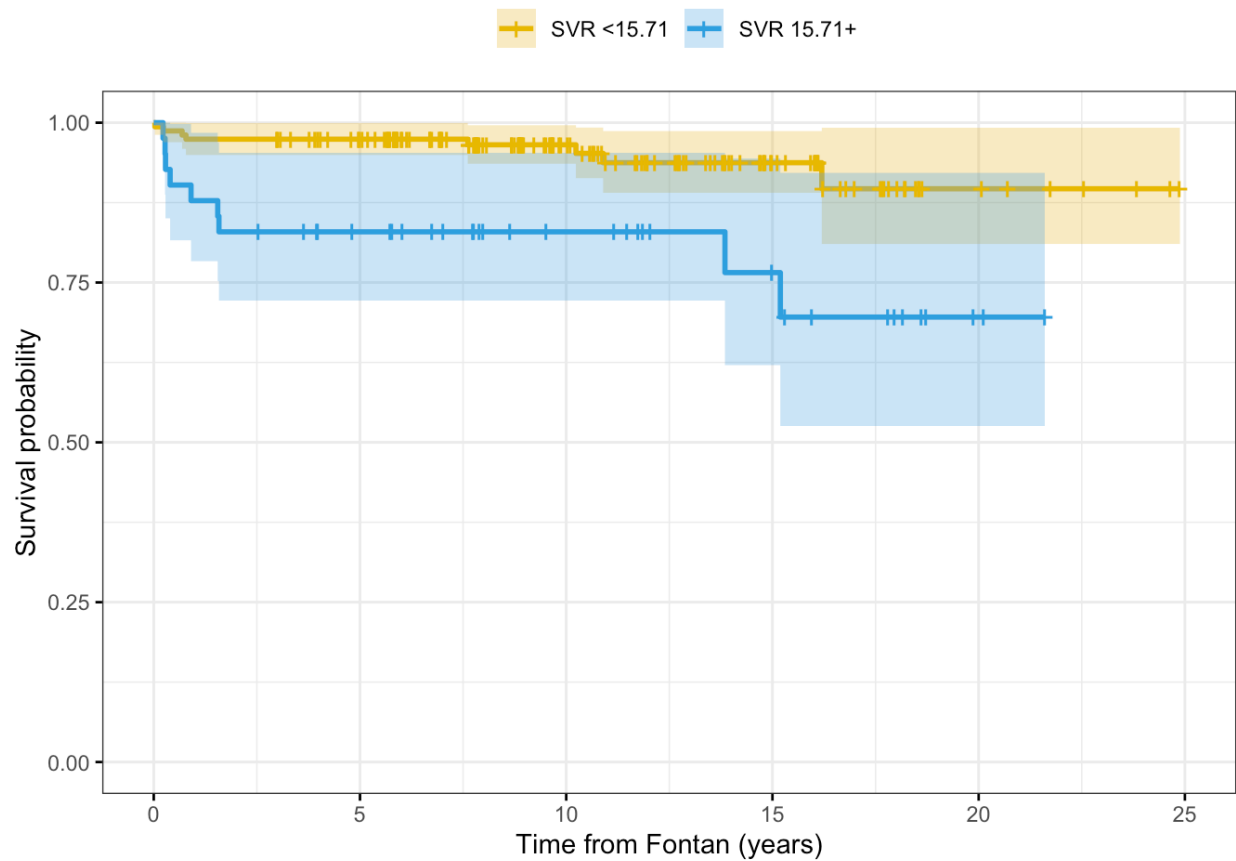


Figure 2: Kaplan-Meier Analysis of time-to-event from date of Fontan to May 2024, in patients with mean RPA pressure < 9 vs patients with mean RPA pressure > 9.

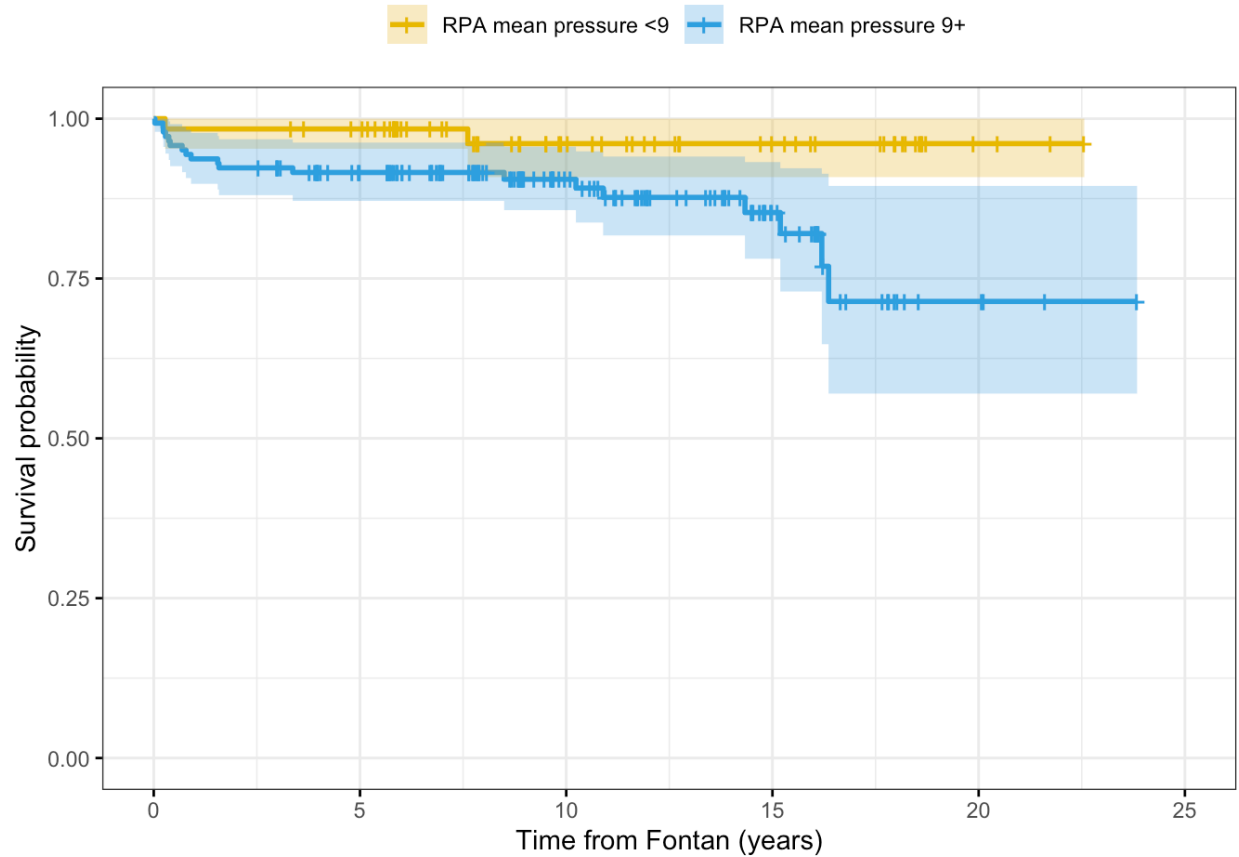


Figure 3: Kaplan-Meier Analysis of time-to-event from date of Fontan to May 2024, in patients with peak systolic pressure of the systemic ventricle < 79 vs patients with peak systolic pressure of the systemic ventricle > 79 .

