Study of Chronic Change of Hepatic Blood Flow Distribution of Fontan Patients

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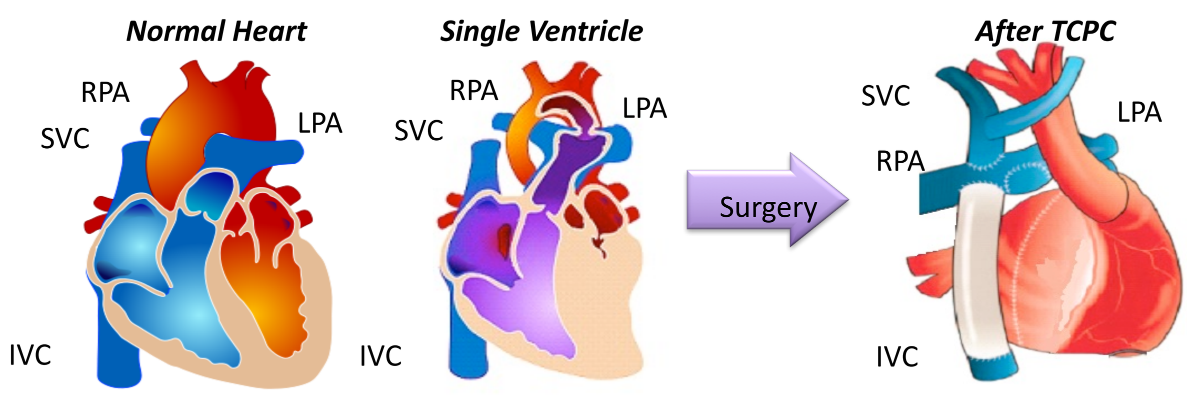
Introduction

• Children born with single ventricle (SV) congenital heart defects have single ventricle with a mixture of oxygenated and deoxygenated blood.
• Fontan surgery finalizes in the the Total Cavopulmonary Connection (TCPC)



•Adverse hemodynamics in the TCPC have been related to some long term complications:
- Limited exercise capacity: increased resistance to flow towards the lungs imposed by the connection, which has been linked to TCPC power loss (PL) during resting condition [1]
- Pulmonary arteriovenous malformations (PAVM): uneven hepatic flow distribution (HFD) to the lungs

•Computational fluid dynamics has been widely used to understand complex Fontan hemodynamics and optimize the surgical strategies/connections.
- Chronic changes are important since growth is unavoidable for our patients
- **Previous study has investigated chronic change of energy dissipation of TCPC [2];**

Objective
- Retrospectively analyze simulations of 33 serial Fontan patients and explore the chronic changes of hepatic blood flow distribution of the TCPC.
- Investigate the relationship of chronic changes of Fontan hemodynamics to patients' outcomes.

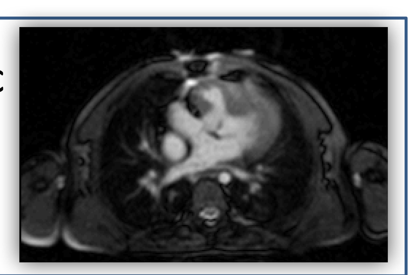
Methods

Patient Selection
- Completed Fontan surgery
- had at least two CMR scans in database (T1, T2)
- Completed questionnaire for quality of life.

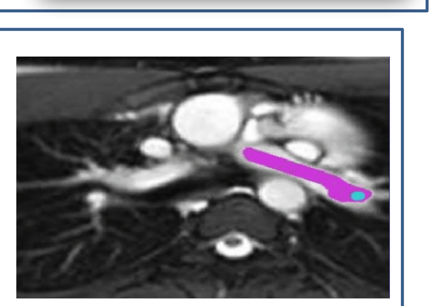
Time Point	Age (yr)	Body Surface Area (m2)
T1	11.8 ±4.5	**1.31±0.41**
T2	17.4±4.5	**1.65±0.29**

Anatomical and Flow Reconstruction

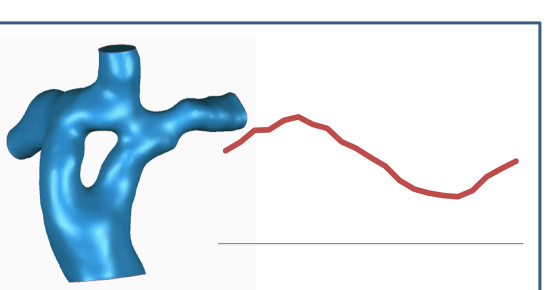
Cardiovascular magnetic Resonance Image acquisition



Vessel Segmentation from patient MRI [3]



Patient specific anatomy and flow reconstruction [4]



Methods (Contd.)

Computational Fluid Dynamics (CFD)
- Mesh were generated with Gambit or ANSYS Meshing module
- Patient-specific flows were used as boundary conditions
- In-house immersed-boundary method was used for simulations
- Blood flow: assumed to be Newtonian, density = 1060 kg/m^3, viscosity = 3.5×10^{-6} m^{2}s^{-1}

Quantification of hemodynamics
- Power loss was defined using a control volume energy analysis of the TCPC

$$PL=\sum_{inlets}P_{in}\times Q_{in}-\sum_{outlets}P_{out}\times Q_{out}$$

where P is total pressure and Q is mean flow at each inlet/outlet
- HFD was defined by the percentage of IVC flow to the left pulmonary artery, which is obtained by an in-house particle tracking code

Quality of Life (QoL) Score
- QoL reflects the impact of a specific illness, medical therapy, or health services policy on the child's ability to function in society and draw personal satisfaction from a physical, psychological, and social functioning perspective [4]
- A higher score means a better perceived QoL[4]
- **QoLs were only taken at T2**

Statistics
- Data normality: Anderson-Darling test
- Statistical Test: T-Test, Linear Regression (Significance: $p < 0.05$)
- Explored difference of QOL Score and HFD between different categories of patients (T-test)
- **Variables included in statistical analyses include: values at two time points as well as the chronic changes of HFD, flows, and geometric characteristics of TCPC.**

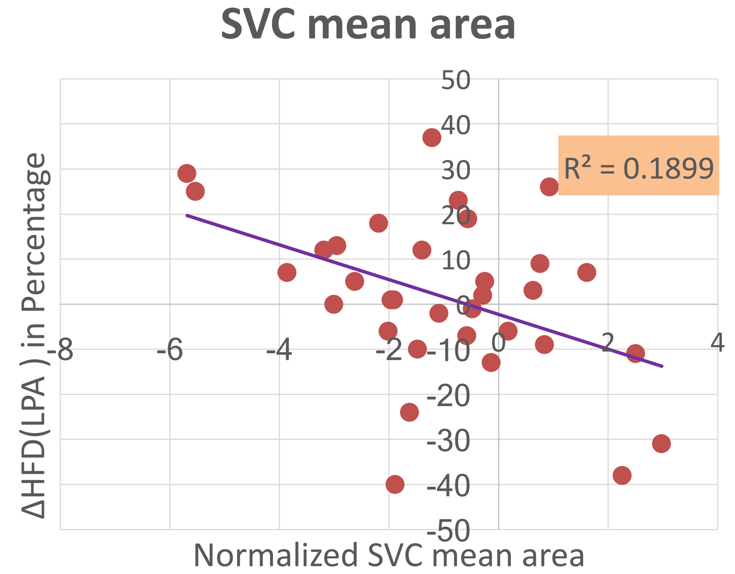
Result

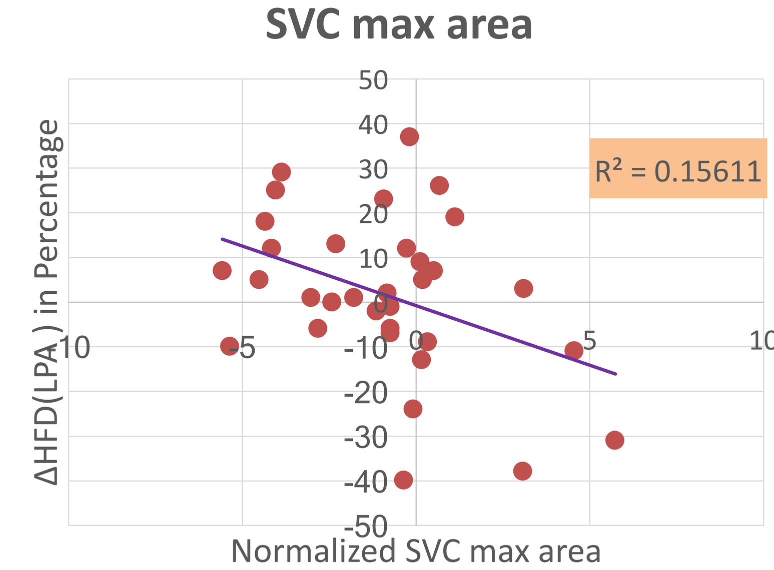
Hepatic Flow Distribution

Type	Time Points (T1, T2)		Change between T2 and T1
HFD (in %)	52.6±21.2	54.3±23.1	1.7 ± 18.4
P -value	0.60		NA

Type	Gender (Female, Male)	Fontan Type (EC, LT)	HLHS, non-HLHS	Bilateral, non-Bilateral	Reconstructed, non-Reconstructed
ΔHFD (in %)	-1.75±21.9 4.1±15.6	0.6±20.4 2.6±17.8	3.3±17.6 -5.2±22.8	2.7±5.7 1.9±19.2	5.2±18.6 0.3±18.4
p values	0.38	0.78	0.35	0.95	0.49

No difference in ΔHFD between patients in different clinical categories



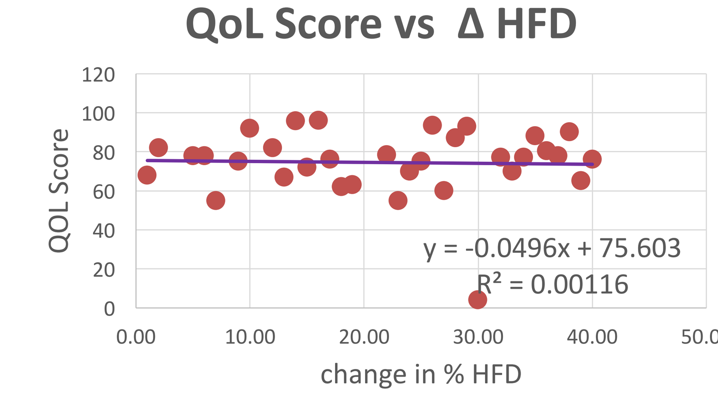


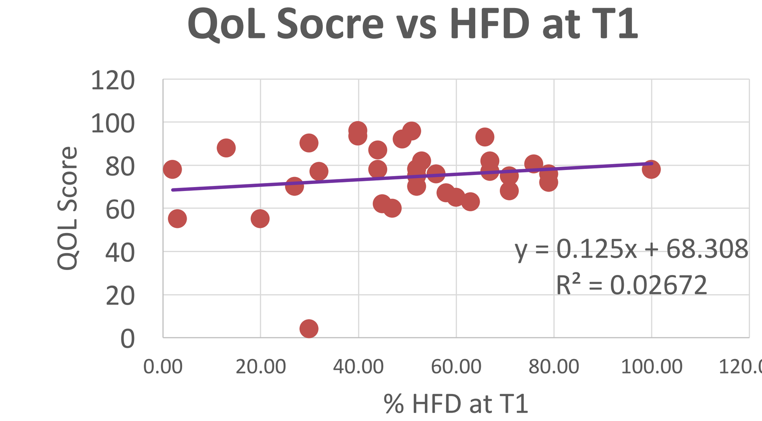
Results (Contd.)

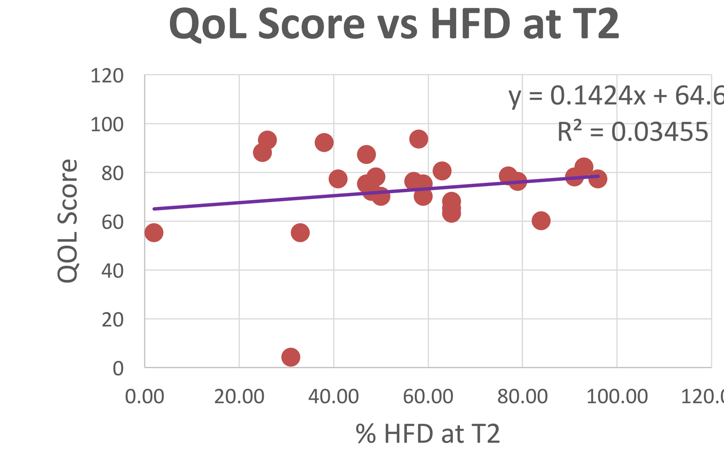
Quality of Life Score

Type	Gender (Female, Male)	Fontan Type (EC, LT)	HLHS, non-HLHS	Bilateral, non-Bilateral	Reconstructed, non-Reconstructed	Overall
QOL Score	75.0 ±12.6 78.4±10.7	73.0±13.3 78.3±10.7	77.5± 10.9 76.3±16.7	87.6±9.6 76.2±11.4	79.2±11.5 76.2±11.6	74.9±16.8
p values	0.4176	0.2523	0.8398	0.1070	0.4884	NA

No difference in QoL score between patients in different categories

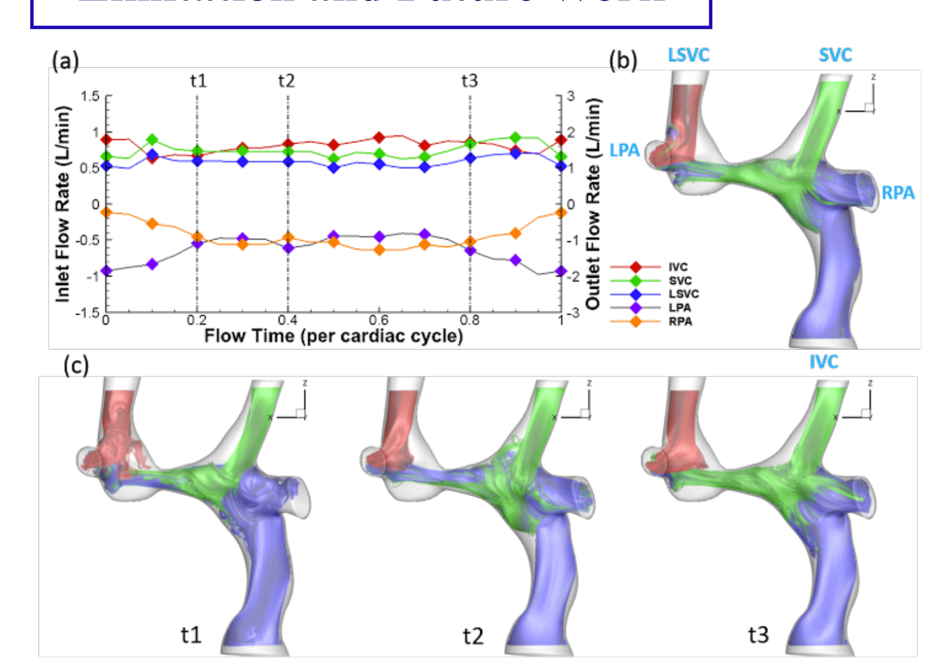






- According to R^2 above, there is no direct linear correlation between QOL Score, ΔHFD, HFD at T1 and HFD at T2.
- However, the simulation conducted using steady flow boundary condition may not be accurate and important information/characteristics may be lost.

Limitation and Future Work



(a) Flow rate is not constant in a cardiac cycle.
(b) Velocity Stream-traces of simulation result using mean flow rate boundary condition
(c) Velocity Stream-traces of simulation result under pulsatile boundary condition at three time points

- Blood flow in vessels are pulsatile, not steady.
- Future work will use pulsatile boundary conditions instead.

Acknowledgement

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Reference

[1] *Khiabani, R. H., K. K. Whitehead, D. Han, M. Restrepo, E. Tang, J. Bethel, S. M. Paridon, M. a. Fogel, and a. P. Yoganathan. 2015. "Exercise Capacity in Single-Ventricle Patients after Fontan Correlates with Haemodynamic Energy Loss in TCPC." Heart 101 (2): 139–43.*
[2] Frakes, D.H., C.P. Conrad, T.M. Healy, J.W. Monaco, M. Fogel, S. Sharma, M.J. Smith, and A.P. Yoganathan, *Application of an adaptive control grid interpolation technique to morphological vascular reconstruction. IEEE Trans Biomed Eng, 2003. 50(2): p. 197-206.*
[3] Frakes, D.H., M.J. Smith, J. Parks, S. Sharma, S.M. Fogel, and A.P. Yoganathan, *New techniques for the reconstruction of complex vascular anatomies from MRI images. J Cardiovasc Magn Reson, 2005. 7(2): p. 425-32*
[4] Drotar, D., Measuring Health-Related Quality of Life in Children and Adolescents. 1998: Mahwah, New Jersey: Lawrence Erlbaum Associates, Publishers.
[5] Frakes, D.H., M.J. Smith, D.A. de Zélicourt, K. Pekkan, and A.P. Yoganathan, *Three-dimensional velocity reconstruction. J Biomech Eng, 2004. 126(6): p. 727-35.*