

Quantitative Evaluation of the Hemodynamics in Fontan Circulation

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Objectives: Detecting early ventricular dysfunction and introducing medication therapies with adequate timing are essential to improve long-term outcomes after Fontan procedures. There have been several numerical studies on Fontan circulation discussing the flow energy loss (EL) that reflects the hemodynamic stabilities and which would lead to increase the cardiac workload. However, due to the definition of EL, which requires information of both pressure and velocity distributions, in-vivo clinical measurements of EL have never been reported, and its effects on heart failure were unclear. In the present study, we measured EL in Fontan patients with simultaneous measurements of pressure and velocity, and revealed the influence to the systolic and diastolic functions of the single ventricle.

Methods: Catheter exams measuring pressure and velocity simultaneously were performed 1 year after the Fontan procedure in 8 patients. EL was calculated using the averaged pressure and velocity data of 20 cardiac cycles in the superior and inferior vena cava and the bilateral pulmonary arteries. Blood flow amounts were approximated using cross-sectional areas obtained from cineangiograms. The ventricular systolic functions were evaluated with max dp/dt during the isovolumic systolic phase (Sdpdt), and the ejection fraction (EF) in volumetry; whereas the diastolic functions were evaluated with max -dp/dt (Ddpdt), and time constant tau in the isovolumic diastolic phase. The ratio of Ddpdt/Sdpdt was examined to investigate the impaired phase in one cardiac cycle. The echocardiographic Tei index was also examined.

Results: EL significantly correlated with Sdpdt ($r=0.827$), but not with the EF ($r=0.472$), indicating that high EL reflected afterload increase. EL significantly correlated with tau and tei index ($r=0.755$ and 0.705 , respectively), but weakly with Ddpdt ($r=-0.581$). EL strongly correlated with Ddpdt/Sdpdt ($r=0.886$), indicating that EL increased when the diastolic function was impaired, while the systolic function was preserved.

Conclusions: EL is a novel and sensitive parameter not only reflecting flow efficiencies in cavopulmonary anastomosis sites but also detecting early heart failure with preserved systolic function with increased afterload and impaired diastolic function of the single ventricle. Quantitative evaluation of the hemodynamics is useful to manage patients with Fontan palliation.