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Brief Report

Feasibility of conductance catheter-derived pressure–volume loops to investigate ventricular mechanics in shunted single ventricles

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Abstract We present pressure–volume loops obtained from two patients with single-ventricle physiology, one with a modified Blalock–Taussig shunt and one with a right ventricle-to-pulmonary artery shunt. The dissimilarities in pressure–volume loop contour and related indices highlight potentially important differences in ventricular mechanics between the shunt types.

Keywords: Single ventricle; RV–PA shunt; Norwood procedure; pressure–volume loop; ventricular mechanics

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THE TWO MOST POPULAR SURGICAL TECHNIQUES for providing controlled pulmonary blood flow in children with single ventricles are the modified Blalock–Taussig shunt and the right ventricle-to-pulmonary artery shunt. By eliminating the obligatory diastolic run-off in the Blalock–Taussig shunt, the main proposed benefits of the right ventricle-to-pulmonary artery shunt are better coronary and systemic perfusion, more balanced and predictable pulmonary-to-systemic flow ratio, and decreased ventricular volume loading.[1,2]

Although there have been numerous studies investigating the clinical and echocardiographic differences between the two shunts, little is known about the differences in ventricular mechanics between the shunt types.[1,3,4] The advent of smaller conductance catheters approved for use in humans now allows for examination of ventricular mechanics using pressure–volume loop analysis in this population. This report highlights the feasibility of using conductance catheters to help elucidate potential differences between shunt types using pressure–volume loop analysis.

Case presentations with pressure–volume loop analysis

The protocol was approved by the institutional review board and informed consent obtained for the patients. Pressure–volume loops were obtained through direct measurement using microconductance catheters (CD Leycom, Zoetermeer, The Netherlands) in two patients presenting for catheterisation before stage 2 palliation. Patient information and haemodynamic data of each patient are summarised in Table 1.

Pressure–volume loop analysis was performed off-line using specialised software (ConductNT® version 3.18; CD Leycom). Conductance volumes were calibrated using end-systolic and end-diastolic volumes obtained from magnetic resonance imaging performed on the same day. Patients were transported directly from the catheterisation laboratory to the magnetic resonance suite and were cared for by the same anaesthesia team. The anaesthetic regimen was not standardised for each patient.

In each patient, a 4-Fr microconductance catheter was placed in the systemic ventricle using an antegrade approach through the atrioventricular valve. A 5-Fr transseptal sheath was used to aid in

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Table 1. Patient information and catheterisation findings.

	Patient 1	Patient 2
Age (months)	5	3
Weight (kg)	5.9	4.5
Diagnosis	HLHS	TA
Initial palliative surgery	Norwood, 5 mm RV–PA shunt	3.5 mm BT shunt
Ventricular function by echo	Normal	Normal
Atrioventricular valve Regurgitation	Mild	None
Systemic saturation	78%	82%
Pulmonary flow:systemic flow	0.54:1	1.15:1
Ventricular end-diastolic pressure	7	10
Significant catheterisation findings	Coarctation: 9 mmHg	LPA stenosis: 3 mmHg

BT = Blalock–Taussig; HLHS = hypoplastic left heart syndrome; LPA = left pulmonary artery; RV–PA = right ventricle to pulmonary artery; TA = tricuspid atresia

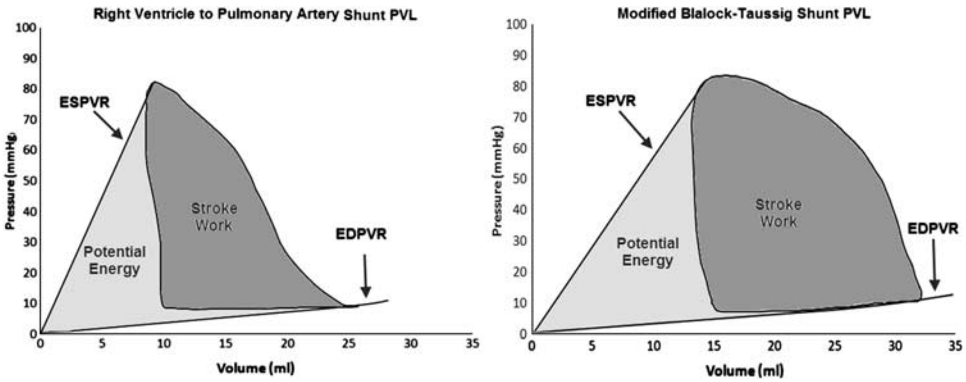

Figure 1.

Pressure–volume loops of the right ventricle-to-pulmonary artery shunt (left) and modified Blalock–Taussig Shunt (right). End-Systolic Pressure–Volume Relationship (ESPVR) and End-Diastolic Pressure–Volume Relationship (EDPVR) lines are marked. Stroke work (shaded blue) and potential energy (shaded red) are illustrated. Potential energy + stroke work = pressure–volume area. PVL = pressure–volume loops.

stable positioning of the catheter. Pressure–volume loops were obtained under general anaesthesia during expiratory hold for 10 s. Careful attention was given to place the catheter in centre of the ventricle and eliminate volume segments outside of the ventricle. Pressure–volume loop indices were calculated using averaged single-beat methods to avoid the risks involved with load alteration.

Averaged pressure–volume loops for the two patients are displayed in Figure 1 with the calculated indices displayed in Table 2. Most noticeably, the patient with right ventricle-to-pulmonary artery shunt had an absence of isovolumic contraction, whereas the patient with the modified Blalock–Taussig shunt displayed preservation of the isovolumic contraction phase. This difference is most apparent in indices related to pressure–volume loop area such as ventricular stroke work and pressure–volume area, both of which were lower in the patient with a right ventricle-to-pulmonary artery shunt.

Table 2. Comparison of pressure–volume loop indices.

Index	RV–PA shunt	mBT shunt
Heart rate (bpm)	150	135
Stroke work (ml × mmHg)	629	1204
Pressure volume area (ml × mmHg)	1007	1836
dP/dt_{max} (mmHg/s)	1027	813
dP/dt_{min} (mmHg/s)	−2505	−1184
tPER (ms)	61	136
PRSW (mmHg)	24	38

dP/dt = change in pressure over change in time; mBT = modified Blalock–Taussig; PRSW = preload-recruitable stroke work; RV–PA = right ventricle to pulmonary artery; tPER = time to peak ejection rate

Discussion

To the best of our knowledge, this report is the first to utilise conductance catheter-derived pressure–volume loops in single-ventricle patients to examine differences in ventricular mechanics between these two shunt types. This report demonstrates that quality pressure–volume loop data can be obtained. The use of an antegrade approach is feasible in this population. The use of an antegrade approach for conductance catheter placement into the single ventricle can cause iatrogenic atrioventricular valve regurgitation and confound results. However, in our two patients no haemodynamic deterioration was observed following catheter placement. Echocardiogram performed at the end of the catheterisation showed no change in atrioventricular valve regurgitation from baseline.

These pressure–volume loops suggest an important potential dissimilarity in the isovolumic contraction phase of these two patients, illustrated by the differing shape of the two pressure–volume loops. The patient with right ventricle-to-pulmonary artery shunt had a near elimination of isovolumic contraction leading to a decrease in stroke work. In the patient with the modified Blalock–Taussig shunt, the isovolumic phase was well preserved. Pressure:volume area, which is defined as the sum of stroke work and potential energy, can be represented on the pressure–volume loop diagram as the area enclosed within the end-systolic pressure–volume line, end-diastolic pressure–volume line, and the isovolumic contraction line. In the patient with right ventricle-to-pulmonary artery shunt, the end-systolic pressure–volume relationship slope was higher, which decreased the potential energy. Therefore, the patient with right ventricle-to-pulmonary artery shunt had a lower pressure:volume area owing to a decrease in both stroke work and potential energy. Pressure:volume area and stroke work positively correlate with myocardial oxygen demand.[5] This suggests that, at the same heart rate, the myocardial oxygen consumption is lower in the single ventricle with a right ventricle-to-pulmonary artery shunt compared with a modified Blalock–Taussig shunt.

These findings are in agreement with recent reports using computational modelling to simulate flow dynamics of the right ventricle-to-pulmonary artery shunt. These reports found that forward flow in the right ventricle-to-pulmonary artery shunt occupied 80% of the cardiac cycle, and that stroke work was lower in the right ventricle-to-pulmonary artery shunt, supporting the lack of isovolumic contraction phase.[6,7]

It is important to consider some possible limitations to these observations. A very important consideration is the underlying diagnoses of these two patients – hypoplastic left heart versus tricuspid atresia. The difference in ventricular dominance complicates comparisons as ventricular dominance may affect contractility and myocardial function. However, a previous study of biventricular circulation demonstrated that the pressure–volume loops of morphologic right ventricles become very similar to that of a morphologic left ventricle when exposed to systemic pressures.[8]

In conclusion, this novel case comparison demonstrates the feasibility of using conductance catheters to investigate ventricular mechanics in infants with single ventricles and highlights a potentially important difference in ventricular mechanics between the two shunt types. Further investigations to confirm these findings in a larger cohort are warranted.

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