Doppler myocardial performance index in assessment of ventricular function in children with single ventricles

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Background: **Quantitative assessment of ventricular function in children with single ventricles is both difficult and subjective because of asymmetric ventricular geometry. The Doppler myocardial performance index (MPI) allows the assessment regardless of ventricular shape. This study was designed to evaluate the feasibility of MPI in assessing ventricular function in children with single ventricles before and after total cavopulmonary connection (TCPC).**

Methods: **Subjects consisted of 161 pediatric patients with single ventricles and 80 normal children without heart disease. The maximum positive rate of ventricular pressure change (Max dp/dt) was obtained in 58 patients by cardiac catheterization. Sixty-eight children with single ventricles received TCPC. MPI was calculated from Doppler tracings of ventricular inflow and outflow, then MPI of single ventricles before and after surgery and normal heart were compared.**

Results: **Normal MPI value was 0.30±0.08 in the left ventricle and 0.26±0.08 in the right ventricle. Compared to normal children, MPI was significantly higher in 161 children with single ventricles (0.54±0.11, $P<0.001$). MPI correlated inversely with Max (dp/dt) ($r=-0.77$, $P<0.01$), and was positively related to age ($r=0.54$, $P<0.01$) in patients with single ventricles. MPI did not differ significantly before and after surgery in 68 patients with single ventricles (0.55±0.21 vs 0.51±0.20, $P>0.05$). However, MPI in 48 patients of <6 years old decreased significantly (0.55±0.21 vs 0.48±0.18, $P<0.05$), suggesting improved ventricular function.**

Conclusions: **Compared to normal children, ventricular function is impaired in patients with single ventricles and may worsen with age. MPI provides an accurate method for assessing ventricular function in children with single ventricles before and after TCPC.**

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Introduction

Single ventricle is very common in patients with complex congenital heart disease. Quantitative assessment of their ventricular function is important for preoperative evaluation and serial postoperative follow-up. However, the assessment of ventricular function in children with single ventricles is very difficult and subjective.[1] Traditional systolic ejection phase indexes are based on geometric assumptions that are frequently invalid in these patients because of their unusual ventricular geometry.[2] Magnetic resonance imaging has proven useful in assessing single ventricular function, but these techniques are inappropriate for small children because they require deep sedation due to the loud noise of operation.[3] Three-dimensional echocardiography seems ideal for estimating volume since it does not require any assumptions about chamber shape and has been successfully applied in assessing left and right ventricular function. However, these studies depend on expensive equipment, and sometimes single ventricle is too large to be completely contained. So far, a simple, reliable and reproducible echocardiographic measure of univentricular performance has not been available. Myocardial performance index (MPI), combining Doppler-derived systolic and diastolic time intervals to generate a combined index of global ventricular function, has been proposed recently. This index, essentially a time ratio independent of ventricular shape, may be used to assess the performance of ventricles of unusual geometry.[4] Although MPI is widely accepted in the evaluation of adult patients,[5,6] its use in children with congenital heart disease is limited. This study aimed to explore the feasibility of MPI in assessing univentricular function and investigate the influence of total cavopulmonary connection (TCPC) procedure on cardiac performance.

Methods

Patients

From April 1988 to December 2006, clinical records of 241 children were studied retrospectively who were treated at the Department of Pediatric Cardiology, Shanghai Children's Medical Center. Informed consents were obtained from their parents, and the study was approved by the Hospital Institutional Review Board. Among them, 80 children were controls with normal echocardiogram and electrocardiogram, 41 males and 39 females, aged from 4 days to 18 years (average: 5.2±0.9 years). The study group included 161 children with single ventricles, including 93 males and 68 females, aged from 1 day to 18 years (average: 5.1±0.8 years). Of these patients, 81 had single right ventricle, 48 had single left ventricle, and 32 had single ventricle of mixed morphology. The maximum positive rate of ventricular pressure change (Max dp/dt) was obtained in 58 patients by cardiac catheterization. TCPC was performed in 68 patients, including 48 patients who underwent surgery at <6 years and 20 patients who underwent TCPC at >6 years of age. All subjects were in sinus rhythm during echocardiogram recording.

Doppler echocardiography

All patients were studied with an HP SONOS 5500 system (Hewlett-Packard Andover, MA) with an S4 transducer in left lateral position. An electrocardiographic signal with 0.04-second marks was displayed with Doppler signals for event timing. Sample volume was set at an axial length of 0.35 cm. In the control group, the mitral inflow velocity pattern was recorded from the apical four chamber view with the sample volume between the tips of the mitral leaflets. The left ventricular outflow was recorded by Doppler with the sample volume positioned above the aortic valve. The tricuspid inflow was recorded by Doppler with the sample volume positioned between the tips of the tricuspid leaflets and the right ventricular outflow with the sample volume above the pulmonic valve. In the study group, systemic ventricular outflow was recorded by Doppler with the sample volume positioned above the aortic valve; ventricular inflow was recorded with the sample volume positioned between the tips of the systemic atrioventricular valve. Images were recorded on MO disk, and off-line analysis of the recorded images was performed using the same ultrasound system.

Doppler echocardiography was performed within 24 hours of the catheterization studies and TCPC procedure. All patients were clinically stable during the noninvasive and invasive studies. During examination, the patients were at rest and quiet, and some of them were sedated with oral chloral hydrated (50 mg/kg) if necessary.

Measurement of MPI

MPI was calculated as previously described (Fig. 1). Ejection time was measured from the onset to the end of ventricular outflow. Isovolumic relaxation time was calculated by subtracting ejection time from the end to onset of ventricular inflow. MPI was calculated by dividing isovolumic portion by ejection time.[1,3] Mean values were obtained by averaging at least 5 consecutive beats.

Cardiac catheterization

Hemodynamic measurements were performed using standard techniques. Briefly, single ventricular pressure was recorded during catheterization with a fluid-filled catheter system and a strain-gauge manometer (GE-Vascular ADV/LV/LP/DLX, GE Healthcare, Chalfont

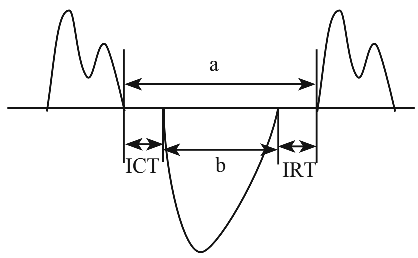

Fig. 1. MPI is calculated as (a-b)/b, where a is the interval between cessation and onset of the atrioventricular inflow and b is the ventricular ejection time. ICT: isovolumic contraction time; IRT: isovolumic relaxation time.

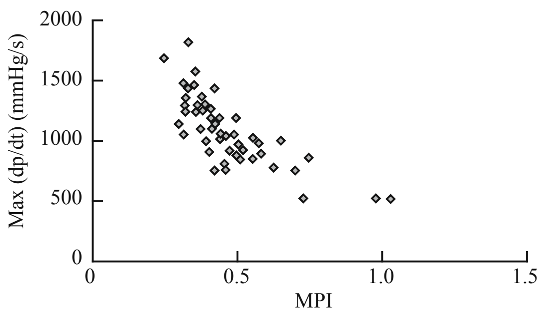

Fig. 2. Correlation between MPI and Max (dp/dt) in 58 children with functionally single ventricles.

St Giles, UK). Max (dp/dt) was determined with data from single ventricular pressure. Mean values were obtained by averaging at least 5 consecutive beats.

Reproducibility analysis

The repeatability of interobserver and intraobserver was studied in 10 patients with single ventricles by Bland-Altman analysis.[7] Each observer individually selected the frames to measure and had no knowledge of the results obtained by the other observer.

Statistical analysis

The data were expressed as means ± SD or percentages as appropriate. Differences in continuous variables between the patients with single ventricles and controls were assessed using unpaired Student's *t* test. Paired *t* test was used to assess difference in continuous variables in the single ventricle group before and after TCPC. Linear regression analysis was used to assess the relation of MPI to age in both single ventricle and control groups. Statistical significance was set at $P<0.05$, and all P values are two-sided. Statpal software (Chalmer BJ, Whitmore DG; distributed by Marcel Dekker, Inc., New York, NY) was used for all analyses.

Results

The single ventricle group consisted of 161 patients; of these, 68 underwent TCPC procedure and 58 underwent cardiac catheterization. The control group consisted of 80 children with normal hearts. There were no significant differences in age, weight, gender, or heart rate between the two groups ($P>0.05$).

In the control group, the normal value of the left ventricular MPI was 0.30±0.08; MPI of the right ventricle was 0.26±0.08. MPI was independent of age and heart rate ($P>0.05$), left and right ventricular MPIs were not affected by age and heart rate in normal children.

The data of patients with single ventricle are shown in Table 1. The results showed that MPI of single ventricle was 0.54±0.11, higher than that in the control group ($P<0.001$). MPI of single ventricle of left ventricular type was 0.56±0.15, of right ventricular type was 0.56±0.11, and of indeterminate type was 0.54 ±0.14. There was no significant difference in types of single ventricle ($P>0.05$). MPI was positively related to patient's age ($r=0.54$, $P<0.01$). Max (dp/dt) was 1105 ±275 (range: 528-1824) mmHg/s, correlated inversely with MPI ($r=-0.77$, $P<0.001$) (Fig. 2).

Demographic data of 68 patients with single ventricles before and after TCPC are shown in Table 2. There was no significant difference in MPI in these patients before and after surgery (0.55±0.21 vs 0.51±0.20, $P>0.05$). However, MPI in 48 patients who underwent surgery at <6 years old decreased significantly (0.55±0.21 vs 0.48±0.18, $P<0.05$), suggesting an improvement in ventricular function. There was no significant change in the MPI in 20 patients who underwent TCPC at >6 years old (0.57± 0.17 vs 0.58±0.21, $P>0.05$).

There was an acceptable, nonsignificant difference in MPI values obtained by the two independent observers ($P=0.76$), and a mean percentage error of 6.4 ±2.1% was obtained by intraobservers.

Table 1. Clinical profile, Doppler intervals and MPI in 161 children with functionally single ventricle (means ± SD)

	LV type	RV type	Un type	Total SV
n	48	81	32	161
a (s)	0.31±0.05	0.32±0.05	0.32±0.06	0.31±0.05
b (s)	0.19±0.03	0.20±0.02	0.20±0.04	0.20±0.03
MPI	0.56±0.15	0.56±0.11	0.54±0.14	0.54±0.11

a: interval between cessation and onset of atrioventricular inflow; b: ventricular ejection time; MPI: myocardial performance index; LV: left ventricular; RV: right ventricular; Un: indetermined; SV: single ventricle.

Table 2. Changes in MPI in 68 patients before and after TCPC in patients who underwent surgery at <6 years old and at 7-18 years old (means ± SD)

	<6 years	>6 years	Total
No.	48	20	68
MPI_{pre-op}	0.55±0.21	0.57±0.17	0.55±0.21
MPI_{pos-op}	0.48±0.18*	0.58±0.21	0.51±0.20

*: $P<0.05$. MPI_{pre-op}: MPI before operation; MPI_{pos-op}: MPI after operation.

Discussion

A wide variety of congenital defects share the common characteristics of single ventricular chamber: single left ventricle, single right ventricle, etc. Previous studies suggest that long-term volume overload of single ventricles and persistent cyanosis adversely affect ventricular function,[8-10] and that early procedures to relieve volume overload in these patients may be beneficial.[11,12] So quantitative assessment of their ventricular function is important for preoperative evaluation and serial postoperative follow-up.

Ejection phase indexes, although used to evaluate single ventricular function, rely on geometric assumptions that are not valid for the single ventricle. Since MPI, as a time ratio, is both independent of ventricular geometry and the presence of systemic atrioventricular valve regurgitation, it may be particularly useful in assessing univentricular function.[1,13]

LaCorte et al[14] used a porcine model to directly correlate MPI with invasive indices of systolic and diastolic function. They found a statistically significant inverse relationship between percent change in MPI and percent change in cardiac output (r=-0.65, P=0.03) and a direct correlation between the value of Tei and the ventricular stiffness constant at baseline (r=0.63, P <0.05). This invasive experiment supports the clinical use of this index as a measure of global ventricular function.[15,16] In our study, there was a good correlation between MPI and invasive measurements of Max (dp/dt) (r=-0.77, P<0.01), suggesting that MPI could be used to estimate single ventricular function. Further, the left and right ventricular MPIs in controls were similar to the previously reported normal values. Patients with single ventricles had a higher MPI (0.54±0.11) than normal patients (P<0.001), and this was positively related to age (r=0.54, P<0.01), suggesting adverse effects of long-term volume overload and decreased ventricular function.[17]

Single ventricles are of three types: left ventricular type, right ventricular type, and indeterminate type. The modified Fontan procedure has been applied to the management of all forms of single ventricle anomaly. The modified Fontan procedure is characterized by low early mortality, excellent mid-term survival, and improved single ventricular function.[8] Nevertheless, a morphologic right ventricle is a risk factor for prolonged hospitalization of in-patients and may influence the long-term survival because of intrinsic geometric functional and pathophysiologic differences between the morphologic right ventricle and the morphologic left ventricle.[18] In our study, however, there was no significant difference among MPI of the three types, suggesting ventricular morphology does not influence univentricular function. Whether ventricular morphology will influence postoperative outcomes requires further study.

In our study, MPI in 48 patients who underwent surgery at <6 years old decreased significantly (0.55±0.21 vs 0.48±0.18, P<0.05), but no significant decrease was found in 20 patients who underwent TCPC at >6 years old (0.57±0.17 vs 0.58±0.21, P>0.05). Our findings support the hypothesis that early reduction of volume load may preserve and even improve ventricular function,[11] suggesting that TCPC should be performed as early as possible.

This study has some limitations. First, the intervals between the onset and end of atrioventricular flow and ejection time are measured sequentially and not on the same cardiac cycle.[19] Second, the cessation of atrioventricular inflow may be significantly affected by atrioventricular block and atrial flutter. Further study is needed to clarify the effects of arrhythmias on MPI. Third, the load dependence of MPI has to be completely evaluated,[20] and further study is necessary to clarify the effects of loading conditions on MPI. Compared to normal children, ventricular function is impaired in patients with single ventricles and may worsen with age.

In conclusion, MPI provides an accurate method for assessing ventricular function in children with single ventricles before and after TCPC procedure. The TCPC procedure should be performed early to improve univentricular function. When MPI is used to evaluate cardiac function, the effect of ventricular preload and afterload should be considered.

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References

1 Williams RV, Ritter S, Tani LY, Pagotto LT, Minich LL. Quantitative assessment of ventricular function in children with single ventricles using the doppler myocardial performance index. Am J Cardiol 2000;86:1106-1110.
2 Donofrio MT, Jacobs ML, Spray TL, Rychik J. Acute changes in preload, afterload, and systolic function after superior cavopulmonary connection. Ann Thorac Surg 1998;65:503-508.
3 Zhang YQ, Chen SB, Sun K, Chen S, Shen R, Zhang ZF, et al. Study on right ventricular function in children with normal heart and congenital heart disease using the Doppler Tei index (chin). Chin J Med Imaging Techol 2003;19:1669-1671.
4 Tei C. New noninvasive index for combined systolic and diastolic ventricular function. J Cardiol 1995;26:135-136.
5 Bruch C, Schmermund A, Dagres N, Katz M, Bartel T, Erbel R. Severe aortic valve stenosis with preserved and reduced systolic left ventricular function: diagnostic usefulness of the Tei index. J Am Soc Echocardiogr 2002;15:869-876.
6 Ishii M, Eto G, Tei C, Tsutsumi T, Hashino K, Sugahara Y, et al. Quantitation of the global right ventricular function in children with normal heart and congenital heart disease: a right ventricular myocardial performance index. Pediatr Cardiol 2000;21:416-421.
7 Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-310.
8 McGuirk SP, Winlaw DS, Langley SM, Stumper OF, de Giovanni JV, Wright JG, et al. The impact of ventricular morphology on midterm outcome following completion

total cavopulmonary connection. Eur J Cardiothorac Surg 2003;24:37-46.
9 Piran S, Veldtman G, Siu S, Webb GD, Liu PP. Heart failure and ventricular dysfunction in patients with single or systemic right ventricles. Circulation 2002;105:1189-1194.
10 Ricci M, Lombardi P, Galindo A, Vasquez A, Zuccarelli J, Rosenkranz E. Distribution of cardiac output and oxygen delivery in an acute animal model of single-ventricle physiology. J Thorac Cardiovasc Surg 2005;130:1062-1070.
11 Milanesi O, Stellin G, Colan SD, Facchin P, Crepaz R, Biffanti R, et al. Systolic and diastolic performance late after the Fontan procedure for a single ventricle and comparison of those undergoing operation at <12 months of age and at >12 months of age. Am J Cardiol 2002;89:276-280.
12 Mahle WT, Coon PD, Wernovsky G, Rychink J. Quantitative echocardiographic assessment of the performance of the functionally single right ventricle after the fontan operation. Cardiol Young 2001;11:399-406.
13 Murphy GS, Marymont JH, Szokol JW, Avram MJ, Vender JS. Correlation of the myocardial performance index with conventional echocardiographic indices of systolic and diastolic function: a study in cardiac surgical patients. Echocardiography 2007;24:26-33.
14 LaCorte JC, Cabreriza SE, Rabkin DG, Printz BF, Coku L, Weinberg A, et al. Correlation of the Tei index with invasive measurements of ventricular function in a porcine model. J Am Soc Echocardiogr 2003;16:442-447.
15 Ozkan M, Uzun M, Erinc K, Koz C, Baysan O, Sag C. Utility of myocardial performance index measured by left ventricular catheterization. Acta Cardiol 2005;60:415-420.
16 Teshima K, Asano K, Iwanaga K, Koie H, Uechi M, Kato Y, et al. Evaluation of left ventricular Tei index (index of myocardial performance) in healthy dogs and dogs with mitral regurgitation. J Vet Med Sci 2007;69:117-123.
17 Spencer KT, Kirkpatrick JN, Mor-Avi V, Decara JM, Lang RM. Age dependency of the Tei index of myocardial performance. J Am Soc Echocardiogr 2004;17:350-352.
18 Hori Y, Uechi M, Indou A. Effects of changes in loading conditions and heart rate on the myocardial performance index in cats. Am J Vet Res 2007;68:1183-1187.
19 Voon WC, Su HM, Yen HW, Lin TH, Lai WT, Sheu SH. Left ventricular Tei index: comparison between flow and tissue Doppler analyses. Echocardiography 2005;22:730-735.
20 Mahle WT, Cohen MS, Spray TL, Rychik J. Atrioventricular valve regurgitation in patients with single ventricle: impact of the bidirectional cavopulmonary anastomosis. Ann Thorac Surg 2001;72:831-835.

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