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Noninvasive Doppler-derived myocardial performance index in children with single ventricular physiology

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Background : *Assessment of ventricular function in children who have single ventricle (SV) by standard conventional echocardiographic methods is invalid because of the unusual ventricular morphology. Myocardial performance index (MPI) is a Doppler index. It is independent on ventricular geometry and can be used to assess the global cardiac function. It may be better than conventional method in assessing ventricular function in patients with SV physiology*

Objective : *To assess the ventricular function measured by MPI and standard conventional echocardiography with cardiac catheterization in children with SV physiology.*

Methods : *Children with single ventricle physiology who underwent cardiac catheterization at Pediatric Cardiology Unit, Department of Pediatrics, Chulalongkorn University, between June-December 2001 was prospective recruited. Standard echocardiographic indices of myocardial performance and MPI were performed in these patients one day before their cardiac catheterization. Ventricular function was measured by area-length method during cardiac catheterization. Correlation between MPI and either echocardiographic indices or the data obtained from cardiac catheterization were analyzed by simple linear regression analysis.*

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Results : *Nineteen patients with single ventricular physiology were recruited into the study. Twelve patients had single left ventricle (LV) and 7 had single right ventricle (RV). Seven out of the 19 cases also had abnormal visceral situs. The myocardial performance index (MPI) ranged from 0.38-0.82 (0.48 $\pm$ 0.15). No significant difference in MPI between children with RV and LV morphology and between patients with systemic to pulmonary shunt and those without the shunt. There was no significantly correlation between MPI and ventricular function assessed either by standard conventional echocardiography or cardiac catheterization. In the interest of MPI adjusted to the patient's body surface area (BSA) was found to have a significant correlation with the mean pulmonary artery (PA) pressure and pulmonary to systemic vascular resistant (Rp/Rs). ($r = 0.66, p=0.003$ and $r = 0.68$, $p=0.002$). When this value was greater than1.0, it was predictive of PA pressure > 15 mmHg with a sensitivity of 60 % and specificity of 85 %.*

Conclusions : *Assessment of ventricular function in children with single ventricle by standard conventional echocardiography and MPI does not correlate the ejection fraction by cardiac catheterization. Myocardial performance indexed to BSA (MPI/BSA) may be a useful indicator to predict high mean PA pressure and high Rp/Rs ratio.*

Keywords : *Cardiac function, Myocardial performance index, Single ventricle, Doppler echocardiography.*

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หลักการและเหตุผล : *การประเมินประสิทธิภาพการทำงานของหัวใจด้วยคลื่นเสียงสะท้อนความถี่สูงโดยวิธีมาตรฐาน ในผู้ป่วยหัวใจพิการแต่กำเนิดชนิดที่มีหัวใจห้องล่างเพียงห้องเดียวมักขาดความแม่นยำจากข้อจำกัดในด้านกายวิภาคกายวิภาคของหัวใจดัชนี myocardial performance index (MPI) ซึ่งประเมินประสิทธิภาพการทำงานของหัวใจโดยรวมโดยใช้ Doppler echocardiography อาจเป็นการตรวจที่แม่นยำในผู้ป่วยกลุ่มนี้*

วัตถุประสงค์ : *เพื่อศึกษาการตรวจโดยวิธีมาตรฐานและดัชนี MPI ในการประเมินประสิทธิภาพการทำงานของหัวใจในผู้ป่วยเด็กโรคหัวใจพิการแต่กำเนิดที่มีหัวใจห้องล่างเพียงห้องเดียว เปรียบเทียบกับประสิทธิภาพการทำงานของหัวใจที่ได้จากการสวนหัวใจ*

วิธีการทำวิจัย : *ทำการศึกษาแบบไปข้างหน้าในผู้ป่วยเด็กหัวใจโรคพิการแต่กำเนิดชนิดที่มีหัวใจห้องล่างเพียงห้องเดียวที่เข้ารับการสวนหัวใจ ที่หน่วยกุมารเวชศาสตร์โรคหัวใจ ภาควิชากุมารเวชศาสตร์ คณะแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย ในระหว่างเดือนมิถุนายน 2544 ถึง ธันวาคม 2544 ผู้ป่วยทุกรายจะได้รับการตรวจประสิทธิภาพ การทำงานของหัวใจโดยคลื่นเสียงสะท้อนความถี่สูงด้วยวิธีดัชนี MPI และวิธีมาตรฐานเป็นเวลา 1 วันก่อนทำการสวนหัวใจ การประเมินประสิทธิภาพการทำงานของหัวใจในระหว่างการสวนหัวใจวัดโดยการวัดค่า ejection fraction โดยวิธี area length นำข้อมูลที่ได้มาวิเคราะห์โดยสหสัมพันธ์การถดถอยเชิงเส้น*

ผลการศึกษา : *ในระยะเวลาที่ทำการศึกษามีผู้ป่วยทั้งหมด 19 ราย ผู้ป่วย 12 รายมีหัวใจห้องล่างห้องเดียวชนิดด้านซ้าย ผู้ป่วย 7 ราย มีหัวใจห้องล่างห้องเดียวชนิดด้านขวา และผู้ป่วย 7 รายมีการจัดเรียงตัวของอวัยวะภายในผิดปกติร่วมด้วย ค่าดัชนี MPI ที่วัดได้มีค่าระหว่าง 0.30 - 0.82 (0.48 $\pm$ 1.5) พบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญ ทางสถิติของค่าดัชนี MPI ในผู้ป่วยที่หัวใจห้องล่างห้องเดียวชนิดซ้ายและขวา และในผู้ป่วยที่ได้รับ และไม่ได้รับการผ่าตัดทำ shunt ไม่พบความสัมพันธ์ของการประเมิน*

ประสิทธิภาพการทำงานของหัวใจโดยดัชนี MPI และการตรวจโดยวิธีมาตรฐานกับค่าที่ได้จากการสวนหัวใจ ค่าดัชนี MPI ต่อพื้นที่ผิวกาย (MPI/BSA) มีความสัมพันธ์กับความดันเฉลี่ยของหลอดเลือดแดงในปอดและอัตราส่วน Rp/Rs ($r = 0.66$, $p = 0.003$ และ $r = 0.68$, $p = 0.002$ ตามลำดับ) และค่าที่มากกว่า 1 บอกถึงการมีภาวะที่ความดันเฉลี่ยของหลอดเลือดแดงปอดที่สูงมากกว่า 15 มิลลิเมตรปรอท โดยมีความไวร้อยละ 60 และมีความจำเพาะร้อยละ 85

สรุป : การประเมินประสิทธิภาพการทำงานของหัวใจในผู้ป่วยหัวใจพิการแต่กำเนิดชนิดที่มีหัวใจห้องล่างเพียงห้องเดียวโดยการตรวจวัดวิธีมาตรฐานและดัชนี MPI ไม่มีความสัมพันธ์กับประสิทธิภาพการทำงานของหัวใจที่ได้จากการสวนหัวใจ ค่าดัชนีชี้วัด MPI ต่อพื้นที่ผิวกาย (MPI/BSA) อาจมีประโยชน์ในการบอกถึงการมีความดันเฉลี่ยในหลอดเลือดแดงปอดสูงและ อัตราความต้านทาน Rp/Rs ที่สูง

คำสำคัญ : Doppler echocardiography

The assessment of ventricular function in children with single ventricular physiology by traditional systolic ejection phase indexes, which based on geometric assumptions are invalid. [1] Myocardial performance index (MPI) has been reported as a good method to assess global cardiac function in adults and children. [1-24] The index is a Doppler-derived method and it is independent on ventricular geometry. It combines both systolic and diastolic time intervals to generate a combined index of global ventricular function. Although MPI has gained widespread acceptance for the evaluation of adults with congestive heart failure, [2] its use in pediatric population was limited. [1, 6, 15-21, 23] The purpose of this study is to examine the accuracy of MPI and other conventional methods employed to determine the ventricular function in children who have single ventricular physiology compared with the ventricular function measured by cardiac catheterization.

Patients and Method

Patients: Children with single ventricular physiology who underwent complete cardiac catheterization at Pediatric Cardiology Unit, Department of Pediatrics, Faculty of Medicine, Chulalongkorn University, Bangkok, Thailand during June -December 2001 were prospectively reviewed.

Clinical data: General demographic data, age, sex, weight, height, body surface area (BSA), pulse rate, respiratory rate, blood pressure, and preloaded condition were recorded one day before cardiac catheterization.

Echocardiographic data: Standard conventional two-dimensional echocardiography, M-Mode and Doppler echocardiography [3] were performed by an Aloka prosound SSD-5500 PHD (Aloka Inc, Tokyo, Japan) to completely examine and measure ventricular function. The following parameters were measured: ejection fraction (EF) and fractional shortening (FS) by M-mode echocardiography, EF by Simpson method, and mitral inflow Doppler E/A ratio. Myocardial performance index (MPI) [4] was calculated by subtracting ejection time (ET) from the interval between cessation and onset of mitral inflow velocity to give the sum of isovolumetric contraction time (ICT) and isovolumetric relaxation time (IRT) (Figure 1). The ejection time was determined from apical 5-chamber view using pulse-wave Doppler interrogation of systemic ventricular outflow with sample volume positioned just below the aortic valve. The time from the termination to the onset of ventricular inflow was determined from pulse-wave Doppler with the sample volume placed at the tips of the systemic atrioventricular valve, again in the apical imaging plane. The isovolumetric portion of the index (the sum of ICT + IRT) was calculated by subtracting the ET from the time from the end to the onset of ventricular inflow. Three to 5 cardiac cycles were measured and the average value was then obtained.

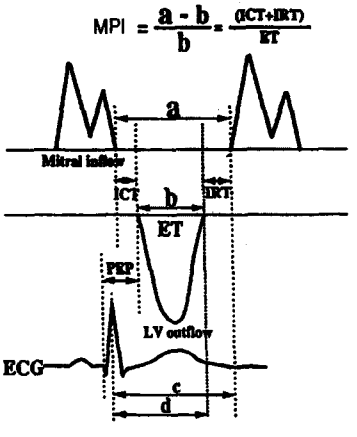

Figure 1. Schema Of Doppler time interval (Myocardial performance index, MPI) [4]

Cardiac catheterization data: The overall hemodynamic data, end-diastolic pressure of systemic single ventricle, mean pulmonary artery pressure, ejection fraction (EF) and stroke volume was measured. End-systolic and end-diastolic ventricular volume was obtained by area length method, using the antero-posterior (AP) projection and stroke volume was then calculated. Other important data from cardiac catheterization, such as ventricular end diastolic pressure, Qp/Qs, Rp /Rs, McGoon ratio and Nakata index were obtained for further determination of their correlation with MPI and other measurements from conventional echocardiographic methods.

Statistical analysis: Stepwise linear regression analysis was used to analyze the correlation between cardiac function measured by noninvasive conventional echocardiography and MPI and the data obtained by cardiac catheterization. A commercial statistical software package (SPSS version 11.0, SPSS Inc, Chicago, IL) was used for statistical evaluation.

Results

Nineteen children with single ventricular physiology were recruited into the study. There were 12 boys (63 %) and 7 girls (36 %). Their mean age was 32.6 $\pm$ 33.7 months (ranged 2 months to 120 months) Their cardiac lesions included tricuspid atresia (8 cases), double outlet right ventricle (5 cases), pulmonary atresia with intact ventricular septum (1 case), unbalance atrioventricular septal defect (2 cases) and double inlet left ventricle (DILV) (2 cases). There were 12 patients with single left ventricular morphology and 7 with single right ventricular morphology. Seven patients had abnormal visceral *situs* (*situs ambiguous* 3 cases, and *situs inversus* 4 cases) (Table 1).

The myocardial performance indexes (MPI) ranged from 0.30-0.82 (0.48 $\pm$ 0.15). There was no difference between the MPI of patients with single left ventricular morphology (0.48 $\pm$ 0.15) and patients with single right ventricular physiology (0.50 $\pm$ 0.17). Seven patients (37 %) underwent palliative systemic to pulmonary shunt and the values of MPI were not significantly different from those of patients who did not have shunt operation(r=0.51, p=0.38).

It was found that no significant correlation between Doppler-derived MPI from echocardiogram and measured EF from cardiac catheterization (Table 2, Figure 2 and 3). On the contrary, there were significant correlations between MPI and age, body surface area (BSA). (r = 0.88, p < 0.001 and r=0.78, p < 0.001)(Table 2). MPI tended to increase with age, body surface area. The ratio of MPI/BSA had a significant positive correlation with mean pulmonary artery (PA) pressure, and pulmonary to systemic vascular resistance (Rp/Rs) (r = 0.66, p = 0.003 and r = 0.68, p = 0.002 respectively) (Table 2). The ratio of MPI to BSA greater than 1.0 was predictive for a high PA pressure (greater than 15 mmHg) with a sensitivity of 60 % and specificity of 85 %.

It demonstrates that the accurate cardiac function could not be determined using standard conventional echocardiographic methods or MPI alone. This did not include FS from M-mode in which it had a significant correlation with EF from cardiac catheterization (r=0.53, p = 0.02) (Table 2, Figure 4).

Table 1. Summary clinical data and measurement from echocardiography and cardiac catheterization of SV patients in this study.

no.	age (mo)	Sex	BSA	M-mode EF	M-mode FS	EF simp	E/A	MPI	MPI/ BSA	LV EDP	M Pap	EF cath	Qp /Qs	Rp /Rs	Mc Goon	Nakata	Morpho	Surgery
1	84	m	0.81	70.2	34.6	51.2	1.17	0.69	0.86	17	13	64	1	0.1	3	688	RV	Fontan
2	96	m	0.73	64.6	28.2	40.9	0.88	0.76	1.04	16	15	63	0.8	0.1	2.8	630	RV	-
3	48	f	0.6	64.9	34.5	57.1	1.15	0.63	1.06	12	11	65	0.6	0.1	1.6	215	LV	Fontan*
4	36	m	0.47	73.7	36	52.4	1.21	0.48	1.02	11	14	70	0.9	0.1	2	355	LV	-
5	24	m	0.45	72.9	35.3	55.2	1.24	0.37	0.82	8	11	65	0.2	0.2	2	318	LV	Fontan*
6	5	f	0.34	70.3	33.6	51.3	0.96	0.34	0.98	12	13	56	0.6	0.2	2.5	406	RV	Glenn
7	24	f	0.55	65	31.2	54.9	2.25	0.4	0.73	19	12	73	1.5	0.1	2	247	RV	Fontan*
8	7	m	0.31	79.1	40.6	33	1.48	0.32	1.03	12	14	64	0.9	0.2	0.2	7	LV	-
9	120	m	0.96	73.4	35.8	78.5	1.02	0.82	0.85	11	34	67	2.4	0.2	2	351	LV	-
10	44	f	0.54	77.6	39.2	65.8	1.17	0.55	1.01	12	15	68	0.8	0.1	3.7	1059	LV	-
11	6	m	0.35	54.8	23.3	46.9	1.2	0.42	1.19	17	15	57	0.2	0.6	3.3	524	LV	-
12	7	m	0.31	63.6	28.6	60.8	0.85	0.56	1.81	8	35	63	1.4	0.3	1.8	205	LV	-
13	36	m	0.47	82.8	44.4	72.5	0.98	0.46	0.98	10	5	77	0.4	0.1	1.6	310	LV	-
14	18	m	0.4	64.3	29.1	62.5	0.85	0.44	1.1	12	-	71	0.1	-	0.8	46	LV	-
15	36	m	0.67	69	36.2	64.6	1.61	0.37	0.55	13	11	73	0.6	0.1	2.2	473	LV	Fontan
16	2	f	0.19	74	36	68.3	1.18	0.34	1.75	6	57	74	1.3	0.5	3.8	580	RV	-
17	11	f	0.35	64.1	28.8	65.4	1.05	0.51	1.44	20	24	60	0.4	0.5	1.5	186	RV	-
18	12	m	0.37	64.1	29.2	40.1	0.78	0.45	1.21	6	8	65	0.3	0.2	1.2	161	RV	Glenn
19	4	f	0.32	71.5	34.2	53.1	-	0.3	0.94	11	27	75	2.8	0.2	2.9	663	RV	-

Abbreviations : age(mo) = month old , BSA = body surface area, M-mode EF = M-mode ejection fraction by standard conventional echocardiography, M-mode FS = M-mode fractional shortening by standard conventional echocardiography, EF simp = ejection fraction from Simpson method, E/A = E/A ratio, MPI = myocardial performance index, MPI/BSA= the ratio of MPI to body surface area, LVEDP = left ventricular end-diastolic pressure, m Pap=mean pulmonary artery pressure, McGoon = McGoon ratio, Nakata = Nakata index, morpho = ventricular morphology of single ventricle, surgery = performed surgical treatment , Fontan = modified Fontan operation, Glenn = bidirectional Glenn operation Fontan* = Patient underwent operation and died.

Table 2. The linear regression analysis between Doppler myocardial performance index (MPI), MPI /BSA and ejection fraction (EF) from cardiac catheterization with independent variables.

Correlations	R	P value
MPI		
Age	0.87 *	< 0.001 *
Sex	0.24	0.31
Body surface area	0.78 *	< 0.001 *
Ejection Fraction(EF) M-mode	0.13	0.61
Fractional Shortening(FS) M-mode	0.12	0.62
Ejection Fraction(EF) Simpson	0.21	0.38
E/A ratio	0.34	0.17
End Diastolic Pressure(EDP)	0.23	0.34
EF from cardiac cath	0.22	0.38
Mean Pulmonary Pressure(MPA)	0.02	0.94
Qs/Qs	0.14	0.56
Rp/Rs	0.21	0.39
McGoon Index	0.09	0.71
Nakata Index	0.17	0.48
Hemoglobin level	0.35	0.14
Ventricular morphology(RV or LV)	0.07	0.78
Aortic valve regurgitation	0.03	0.92
MPI/BSA		
MPA	0.66 *	0.003 *
Rp/Rs	0.68 *	0.002 *
EF from cardiac cath		
Fractional Shortening(FS) M-mode	0.53 *	0.02 *

* = significant (p value < 0.05)

MPI = Doppler Myocardial Performance Index

MPI/BSA= Doppler Myocardial Performance Index ต่อ พื้นที่ผิวกาย

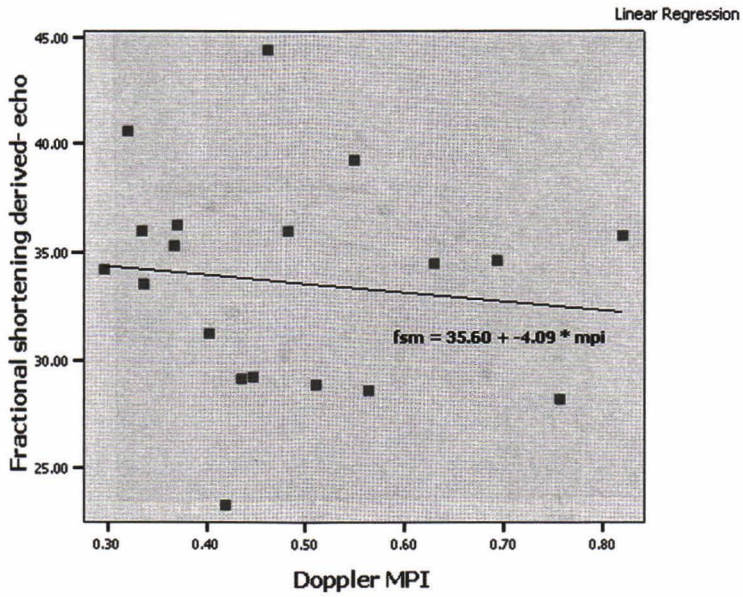

Figure 2. Correlation between Doppler myocardial performance index (MPI) and echocardiographic derived fractional shortening (FS).

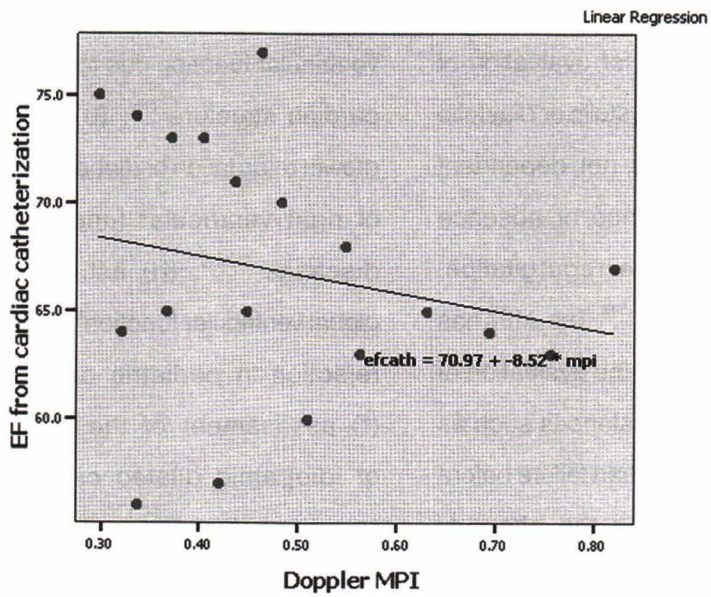

Figure 3. Correlation between Doppler myocardial performance index (MPI) and ejection fraction from cardiac catheterization.

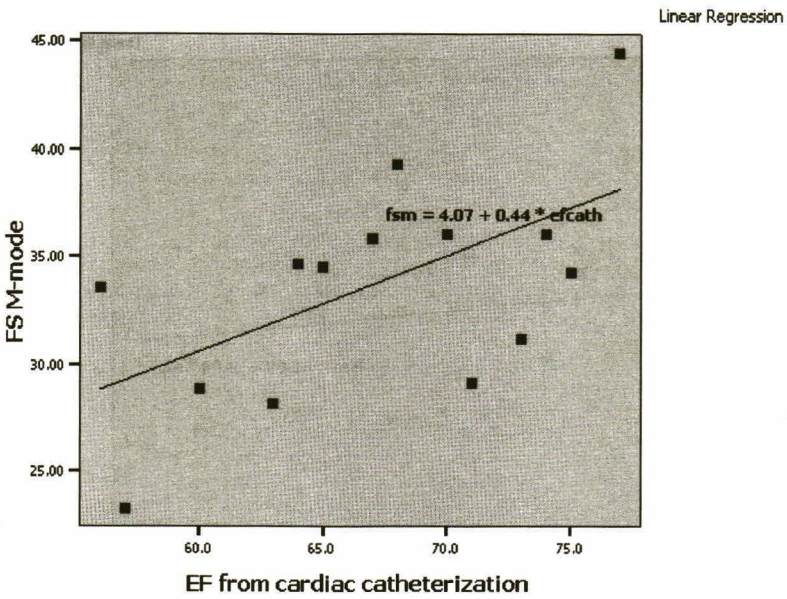

Figure 4. Correlation between echocardiographic derived fractional shortening (FS) and ejection fraction from cardiac catheterization.

Discussion

The MPI is more effective for evaluation of the global ventricular function than systolic or diastolic function alone.[1,2,4,6,17-19,21,22,25,26] It is not dependent on geometric assumption, presence or absence of systemic atrioventricular valve regurgitation, heart rate, and preload condition. [5-9] The MPI has gained widespread acceptance for the evaluation of ventricular function in many circumstances such as evaluation of adults with congestive heart failure before and after treatment[2], evaluation the effect of hypertension and its treatment [10], evaluation of the left ventricular dysfunction and the risk of heart failure in patients with myocardial infarction, [11,12] or evaluation of the right ventricular performance after myocardial infarction. [13] It may also be useful for evaluation of restenosis after percutaneous transluminal coronary angioplasty in patients with old myocardial infarction. [14] MPI is found useful in the following cases; (a) in pediatric population for assessment of fetal ventricular function due to atypical orientation of fetal cardiac structure [15], (b) detection of intrauterine growth retardation or diabetic infant [16], (c) assumption of right ventricular function in congenital heart diseases [6, 17], (d) estimation of postoperative global ventricular function[8], (e) predictor of moderate rejection in pediatric cardiac transplantation[18], (f) assessment of the severity and prognosis of idiopathic dilated cardiomyopathy [19-21], (g) assessment of RV and LV functions in primary pulmonary hypertension [22], (h) evaluation of RV dysfunction in patients with Ebstein's anomaly [23],(I) evaluation of preoperative and postoperative ventricular function in patients with single ventricular physiology because of unusual morphology.[1]

The study demonstrates that children with a functional single ventricle (SV) have high value of MPI (0.48 ± 0.15). The study of Williams RV, *et al* also

showed the same trend of higher MPI in SV physiology, compared to normal population (0.67 ± 0.14 Vs 0.39 ± 0.10).[1] We also found that the MPI in single ventricular physiology tended to increase with age. The finding is different from the MPI in normal heart population. In general, MPI decreases with age until 3 year old, and the value will remain constant afterward.[19] This finding supports the following ideas: (a) alteration in hemodynamic state (prolonged volume and pressure overload) and (b) chronic hypoxemia might decrease ventricular function in single ventricular physiology and cause a progressive depression of ventricular function with time. Thus, these patients should receive an early corrective surgery.

In reference to other researches, it was found that the preload condition and the degree of AV valve regurgitation had no significant effect on the MPI.[5,7-9,24] In our study, seven patients with minimal aortic valve regurgitation confirmed that no significant difference of MPI. (r =0.026, p = 0.91). (Table 2) The value of MPI alone could not definitely give all information about global cardiac function in single ventricular physiology as compared with EF from cardiac catheterization. This might be because MPI measures both systolic and diastolic function while EF from cardiac catheterization measures only systolic cardiac function. The ratio of MPI to BSA shows a significant correlation with important predictive factors for successful Fontan operation such as mean pulmonary arterial pressure and ratio of Rp/Rs. In the interest of MPI/BSA tends to increase with increasing mean PA pressure and Rp/Rs ratio. When this value is greater than1.0, it is indicative for high PA pressure greater than 15 mmHg. This may be an important indicator for patients, who need early Fontan operation. Therefore, if a child with single ventricular physiology has MPI/BSA greater than 1.0, the patient must urgently undergo cardiac catheterization to measure pulmonary artery pressure.

In addition, we conclude that true cardiac function in children with single ventricular physiology could not be definitely determined by standard conventional echocardiographic method except only by the fractional shortening (FS), which determined from M mode echocardiography.

Study limitation

Limitation of the study was the lack of an accepted gold standard of single ventricular function. By the reason of, the angiographic and echocardiographic ejection was limited by assumption regarding ventricular morphology and the point of ventricular function assessment from cardiac catheterization determined only systolic function. We need more sample size of children with SV physiology for establish a good significant correlation.

References

1. Williams RV, Ritter S, Tani LY, Pagoto LT, Minich LL. Quantitative assessment of ventricular function in children with single ventricles using the Doppler myocardial performance index. Am J Cardiol 2000 Nov 15; 86(10): 1106 - 10
2. St John Sutton M, Wiegers SE. The Tei index – role in the diagnosis of heart failure ? Eur Heart J 2000 Nov; 21(22):18722-4
3. Snider AR, Serwer GA, Ritter SB. Echocardiography in pediatric heart disease. 2nd ed.St. Louis : Mosby 1997 : 53 - 6

4. Oh JK, Seward JB, Tajik AJ. The echo manual. 2nd ed. Philadelphia: Lipincott-Raven, 1999: 55 - 6

5. Poulsen SL, Nielsen JC, Andersen HR. The influence of heart rate on the Doppler-derived myocardial performance index. J Am Soc Echocardiogr 2000 May; 13(5): 379 - 84

6. Eidem BW, O'Leary PW, Tei C ,Seward JB. Usefulness of the myocardial performance index for assessing right ventricular function in congenital heart disease. Am J Cardiol 2000 Sep 15; 86(6): 654 - 58

7. Eidem BW, O'Leary PW. The potential impact of alteration in preload on the myocardial performance index(MPI). J Am Soc Echocardiogr 2000 Jun; 13(6): 644

8. Timmis SB, Kirsh MM, Montgomery DG, starling MR. Evaluation of left ventricular ejection fractionas a measure of pump performance in patients with chronic mitral regurgitation. Catheter Cardiovasc Interv 2000 Mar; 49(3): 290 - 96

9. Takaki A, Sugi K, Sano T, Tanaka N, Matsuzaki M. Different responses of right and left ventricular diastolic function to pulmonary resection: echocardiographic study with leg elevation for preload augmentation. J Cardiol 2000 Oct; 36(4): 241 - 49

10. Yakabe K, Ikeda S, Naito T, Yamaguchi K, Iwasaki T, Nishimura E, Yoshinaga T, Furukawa K, Matsushita T, Shikuwa M, et al. Left ventricular mass and global function in essential hypertension after antihypertensive therapy. J Int Med Res 2000; 28(1): 9 - 19

11. Poulsen SH, Jensen SE, Tei C, Seward JB, Egstrup K. Value of the Doppler index of myocardial performance in the early phase of acute myocardial infarction. J Am Soc Echocardiogr 2000 Aug; 13 (8): 723 - 30

12. Lax JA, Bermann AM, Cianciulli TF, Morita LA, Masoli O, Prezioso HA. Estimation of the ejection fraction in patients with myocardial infarction obtained from the combined index of systolic and diastolic left ventricular function : a new method. J Am Soc Echocardiogr 2000 Feb; 13(2): 116 - 23

13. Mattioli AV, Vandelli R, Mattioli G. Doppler echocardiographic evaluation of right ventricular function in patients with right ventricular infraction. J Ultrasound Med 2000 Dec; 19(12): 831 - 6

14. Kamishirado H, Hayashi T, Hanato H, Kobayashi S, Maekawa Y, Ishiyama E, Akiya K, Fujito T, Takayanagi K, Morooka S. Evaluation of restenosis after percutaneous transluminal coronary angioplasty using a Doppler index, The Tei index. J Cardiol 1999 Mar; 33(3): 127 - 33

15. Eidem BW, Edwards JM, Cetta F. Quantitative assessment of fetal ventricular function: establishing normal values of the myocardial performance index in fetus. Echocardiography 2001 Jan; 18(1): 9 - 13

16. Tsutsumi T, Ishii M, Eto G, Hota M, Kato H. Serial evaluation for myocardial performance in fetuses and neonates using a new Doppler index. Pediatr Int 1999 Dec; 41(6): 722 - 27

17. Ishii M, Eto G, Tei C, Tsutsumi T, Hashino K, Sugahara Y, Himeno W, Muta H, Furui J,

Akagi T, 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 Sep-Oct; 21(5): 416 - 21

18. Mooradian SJ, Goldberg CS, Crowley DC, Ludomirsky A. Evaluation of noninvasive index of global ventricular function to predict rejection after pediatric cardiac transplantation. Am J Cardiol 2000 Aug 1; 86(3): 358 - 60
19. Eto G, Ishii M, Tei C, Tsutsumi T, Akagi T, Kato H. Assessment of global left ventricular function in normal children and in children with dilated cardiomyopathy. J Am Soc Echocardiogr 1999 Dec; 12(12): 1058 - 64
20. Dujardin KS, Tei C,Yeo TC, Hodge DO, Rossi A, Seward SB. Prognostic value of a Doppler index combining systolic and diastolic performance in idiopathic-dilated cardiomyopathy. Am J Cardiol 1998 Nov 1; 82(9): 1071 - 6
21. Tei C, Ling LH, Hodge DO, Bailey KR, OH JK, Rodeheffer RJ, Tajik AJ, Seward JB. New index of combined systolic and diastolic Myocardial performance : a simple and reproducible measure of cardiac function—a study in normals and dilated cardiomyopathy. J Cardiol 1995 Dec; 26(6): 357 - 66
22. Yeo TC, Dujardin KS,Tei C, Mahoney DW, McGoon MD, Seward JB. Value of a Doppler-derived index combining systolic and diastolic time intervals in predicting outcome in primary pulmonary hypertension. Am J Cardiol 1998 May 1; 81(9): 1157 - 61
23. Eidem BW, Tei C, O'Leary PW, Cetta F, Seward JB. Nongeometric quantitative assessment of right and left ventricular function: myocardial performance index in normal children and patients with Ebstein anomaly. J Am Soc Echocardiogr 1998 Sep; 11(9): 849 - 56
24. Kim WH, Otsuji Y, Seward JB, Tei C. Estimation of left ventricular function in right ventricular volume and pressure overload. Detection of early left ventricular dysfunction by Tei index. Jpn Heart J 1999 Mar; 40(2): 145 - 54.
25. Tei C, Nishimura RA, Seward JB, Tajik AJ. Noninvasive Doppler-derived myocardial performance index: correlation with simultaneous measurements of cardiac catheterization measurements. J Am Soc Echocardiogr 1997 Mar;10(2):169 - 78
26. Tei C, Dujardin KS, Hodge DO, Bailey KR, McGoon MD, Tajik AJ, Seward SB. Doppler echocardiographic index for assessment of global ventricular function. J Am Soc Echocardiogr 1996 Nov-Dec; 9(6): 838 - 47