

## Noninvasive Visualization and Measurement of Middle Cardiac Vein Flow by Transthoracic Doppler Echocardiography

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**Abstract** Transthoracic Doppler echocardiography offers a noninvasive approach for imaging posterior descending coronary artery (PD) running in the posterior longitudinal sulcus along the middle cardiac vein (MCV). To evaluate whether the MCV flow velocity reserve can reflect the PD flow reserve, 22 children with various heart diseases were examined using transthoracic Doppler echocardiography. Introduction of a modified transthoracic two chamber view with the transducer rotated counterclockwise and angulated posteriorly allows visualization of the MCV and PD. Peak systolic flow velocity and average peak systolic flow velocity in the MCV and peak diastolic flow velocity and average peak diastolic flow velocity in the PD were measured at rest and hyperemic conditions (intravenous administration of adenosine of 0.16 mg/kg/min). Coronary flow reserve was defined as the ratio of peak hyperemic to basal average peak flow velocity. ATP infusion induced significant increases in the peak systolic flow velocity and average peak systolic flow velocity in the MCV. The mean MCV flow velocity reserve in the patients was  $1.94 \pm 0.44$ . Significant increases in the peak diastolic flow velocity and the average peak diastolic flow velocity in the PD were also observed during ATP infusion, and the mean PD flow velocity reserve ( $2.19 \pm 0.62$ ) was significantly higher than the GCV flow velocity reserve ( $p < 0.0001$ ).

There was a good correlation between the MCV flow velocity reserve and PD flow velocity reserve ( $r = 0.86$ ,  $p < 0.0001$ ). This study demonstrated that it was possible to measure the MCV flow velocity and MCV flow velocity reserve in pediatric patients by transthoracic Doppler echocardiography. The MCV flow reserve correlated highly with the PD flow reserve. However, the degree of the MCV flow during hyperemia was less than that of the PD flow. This underestimation should be considered when the reactive hyperemic response is evaluated from the MCV flow velocity.

**Keywords** Transthoracic Doppler echocardiography · Coronary flow reserve · Posterior descending coronary artery · Middle cardiac vein

Monitoring of coronary vein flow and flow velocity reserve have been used as a measure of myocardial blood perfusion [3, 7]. Coronary vein blood flow and flow velocity reserve have been assessed by invasive techniques with thermodilution catheters [3, 7] and Doppler catheters [10]. Recent advances in Doppler and color echocardiographic techniques enable the measurements of flow velocities in the posterior descending coronary artery (PD) [1, 8, 9, 11]. It may be possible to extend the technique to the assessment of the middle cardiac vein (MCV) running in the posterior longitudinal sulcus in company with the PD. However, little published data exist on coronary flow velocities and coronary flow velocity reserves in MCV. This study assesses MCV flow velocity and flow velocity reserve in pediatric patients with various heart diseases, and compares flow velocity reserve in the MCV with flow velocity reserve in the PD.

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## Methods

### Study Subjects

Twenty-two patients aged 0.1 to 4 years ( $1.7 \pm 1.2$  years) with various heart diseases who underwent heart catheterization were examined in the study (ventricular septal defect with pulmonary hypertension in 5, tetralogy of Fallot in 4, aortic valve stenosis in 3, tricuspid atresia in 3, patent ductus arteriosus in 2, William syndrome with peripheral pulmonary stenosis in 2, Kawasaki disease in 3). All parents received an explanation of the study and gave informed consent.

### Echocardiography

Studies were performed in a quiet resting state. Echocardiographic examination on the patients was performed in the cardiac catheterization laboratory. Premedication consisted of pethidine hydrochloride administered subcutaneously 1 h before catheterization. Sedation with thiopental sodium (3 mg/kg) was administered intravenously when necessary.

Transthoracic Doppler echocardiographic examination was performed using an Aloka SSD-ProSound-5500 (Aloka, Tokyo, Japan) with a 5.0-MHz transducer. From the apical two-chamber view with the transducer rotated counterclockwise and angulated posteriorly, PD flow signals can be seen in the interventricular sulcus. Occasionally, the transducer was aimed posteriorly from the subcostal view, allowing the PD flow signals to be seen along the diaphragmatic surface of the heart. After demonstration of coronary flow signals, the pulsed Doppler sample volume was placed at the PD, and the sample volume decreased to 0.5 to 1.0 mm. Because the MCV is usually running in the interventricular groove along the PD [1], a careful search for color flow signals in the MCV was made. The sample volume was placed at the MCV after demonstration of coronary color flow signals. The velocity scale was decreased to the minimum range and then gradually increased until color signals were optimized within the vessel lumen. The color gain was also adjusted to minimize color flow scatter, and the Doppler filter was set at 200–400 Hz.

Measurement of peak flow velocity and average peak flow velocity in the MCV and peak flow velocity and average peak flow velocity in the PD were performed using the internal analysis package of the ultrasound unit. Measurements were calculated considering the angle between the Doppler beam and the coronary flow direction as determined by the two dimensional echocardiogram. Absolute velocity was

defined as the product of the measured velocity and the cosine of the angle between the Doppler beam and the direction of blood flow.

To assess coronary flow velocity reserve, adenosine triphosphate (ATP) was infused in the right antecubital vein at a dose of 0.16 mg/kg/min for 6 min. Data were obtained at rest and during ATP infusion. The ratio of the average peak flow velocity during hyperemia to baseline average peak systolic flow velocity was calculated as an index of flow velocity reserve.

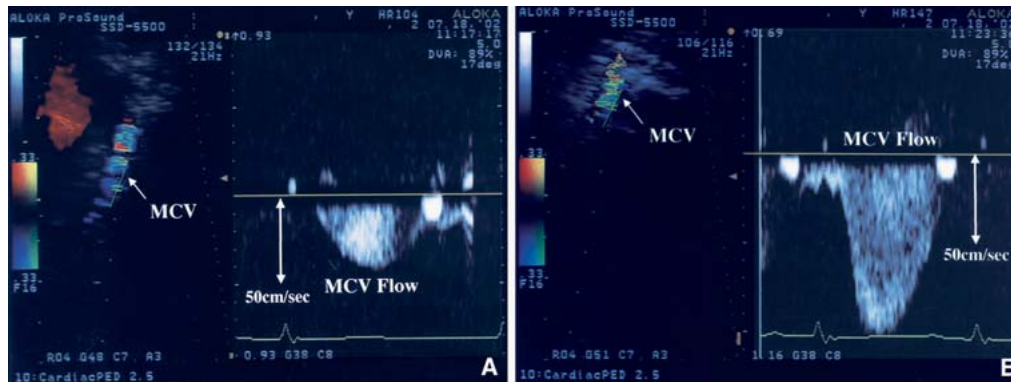
### Statistics

Data represent mean  $\pm$  SD, and were analyzed using paired *t* test. Correlations were determined using linear regression equations calculated using the least-squares method. Analysis of the difference in the measurements was performed according to the technique of Bland and Altman [2]. A *p* value  $< 0.05$  was considered statistically significant. To evaluate the effects of observational variability on the measurements of the MCV flow velocities, two independent observers analyzed 18 selected Doppler recordings. Intraobserver variability was assessed in 18 children who underwent the measurements by Doppler echocardiography. Analysis of the difference in the measurements was performed according to the technique of Bland and Altman [2]. The determinations of intraobserver and interobserver variabilities of the PD flow velocity measurements were described in our previous report [1].

## Results

The flow signals from the MCV and PD were recorded in 100% and 82% (18 of 22 subjects), respectively. Data from these 18 subjects were therefore analyzed. The flow velocity pattern of the MCV consisted of systolic component as shown in Fig. 1a. The mean angles between the Doppler beam and Doppler flow signals of the MCV and PD were  $23^\circ \pm 11^\circ$  and  $24^\circ \pm 10^\circ$ , respectively.

Table 1 shows hemodynamic and echocardiographic data at rest. The mean peak flow velocity in the MCV was  $36 \pm 9$  cm/s. The peak flow velocity in the MCV correlated with that in the PD ( $r = 0.79$ ,  $p < 0.0001$ ) (Fig. 2). The mean average peak flow velocity in the MCV was  $25 \pm 6$  cm/s. There was a good correlation between the average peak flow velocity in the MCV and the average peak flow velocity in the PD ( $r = 0.88$ ,  $p < 0.0001$ ) (Fig. 3).



**Fig. 1** An example of flow velocity changes in the middle cardiac vein at rest (a) and during hyperemia (b). MCV = middle cardiac vein

**Table 1** Echocardiographic measurements

	Mean	Range
Age (years)	1.7 ± 1.2	1 month–4 years
Heart rate (beats/min)	114 ± 24	86–147
Doppler measurements		
Angle between Doppler beam and Doppler flow signal of MCV (degrees)	25 ± 12	0–43
MCV peak flow velocity (cm/sec)	36 ± 9 <sup>a</sup>	24–58
MCV average peak flow velocity (cm/sec)	25 ± 6 <sup>b</sup>	16–38
Angle between Doppler beam and Doppler flow signal of PD (degrees)	25 ± 11	0–44
PD peak flow velocity (cm/sec)	33 ± 9	22–58
PD average peak flow velocity (cm/sec)	23 ± 6	17–36

MCV = middle cardiac vein, PD = posterior descending coronary artery

<sup>a</sup>  $p < 0.05$  vs. PD peak flow velocity <sup>b</sup>  $p < 0.05$  vs. PD average peak flow velocity

Table 2 shows changes in heart rate, systolic and diastolic blood pressures, and coronary flow velocities during ATP infusion. Figures 1a and 1b show examples of the MCV flow velocity changes during hyperemia. Heart rate was significantly increased during ATP infusion. Systolic and diastolic blood pressures were significantly decreased during hyperemia. ATP infusion induced significant increases in the peak flow velocity and the average peak flow velocity in the MCV. The mean flow velocity reserve in the MCV was as  $1.94 \pm 0.44$ . Significant increases in the peak flow velocity and the average peak flow velocity in the PD were also observed during ATP infusion, and the mean flow velocity reserve in the PD ( $2.19 \pm 0.62$ ) was significantly higher than that in the MCV ( $p < 0.0001$ ). There was a good correlation between the MCV flow velocity reserve and PD flow velocity reserve ( $r = 0.86$ ,  $p < 0.0001$ ) (Fig 4).

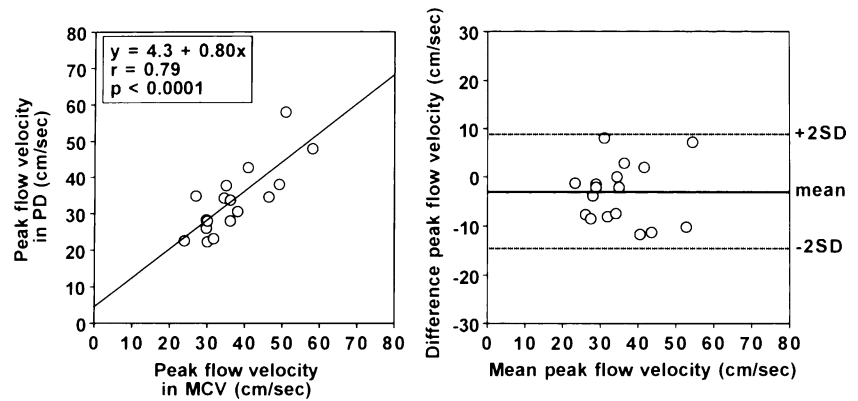
### Interobserver Variability and Reproducibility

There was good agreement between the two independent observers' measurements for MCV peak flow velocity, MCV average peak flow velocity, MCV average peak flow velocity during hyperemia, and MCV flow velocity reserve ( $r = 0.93, 0.93, 0.80$ , and  $0.97$ ). The absolute difference between observers was  $1.03 \pm 3.43$  cm/s for MCV peak flow velocity,  $0.17 \pm 2.25$  cm/s for MCV average peak flow velocity,  $-0.77 \pm 8.02$  cm/s for MCV average peak flow velocity during hyperemia, and  $-0.001 \pm 0.069$  for MCV flow velocity reserve. Excellent correlations were observed in the intraobserver measurements for MCV peak flow velocity, MCV average peak flow velocity, MCV average peak flow velocity during hyperemia, and MCV flow velocity reserve ( $r = 0.96, 0.97, 0.88$ , and  $0.99$ ). The absolute difference for the same observer was  $0.75 \pm 2.33$  cm/s for MCV peak flow velocity,  $0.05 \pm 1.61$  cm/s for MCV average peak flow velocity,  $-1.87 \pm 6.36$  cm/s for MCV average peak flow velocity during hyperemia, and  $-0.009 \pm 0.078$  for MCV flow velocity reserve.

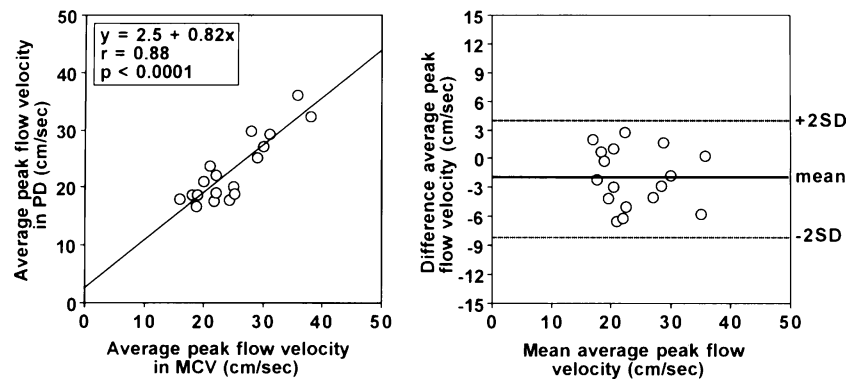
### Discussion

The current study demonstrated that it was possible to measure the MCV flow velocity and MCV flow velocity reserve in pediatric patients by transthoracic Doppler echocardiography. Assessment of MCV flow velocity and MCV flow velocity reserve was easily performed and was reproducible, as evidenced by the high degree of correlation between intraobserver and interobserver measurements. Thus, the transthoracic Doppler method appears suitable for the detection and evaluation of the MCV flow in children with various heart diseases. The approach for the assessment of the MCV flow

**Fig. 2** Regression (*left*) and mean difference (*right*) plots comparing PD peak flow velocity and MCV peak flow velocity



**Fig. 3** Regression (*left*) and mean difference (*right*) plots comparing PD average peak flow velocity and MCV average peak flow velocity



**Table 2** Hemodynamic and echocardiographic data during hyperemla

	Rest	ATP	P value
Heartrate (beats/min)	114 ± 24	131 ± 23	< 0.0001
Systolic blood pressure (mmHg)	90 ± 11	78 ± 10	< 0.0001
Diastolic blood pressure (mmHg)	49 ± 8	39 ± 8	< 0.0001
Doppler measurements			
MCV peak flow velocity (cm/sec)	36 ± 9 <sup>a</sup>	70 ± 15	< 0.0001
MCV average peak flow velocity (cm/sec)	25 ± 6 <sup>b</sup>	46 ± 11	< 0.0001
MCV flow velocity reserve		1.94 ± 0.44	
PD peak flow velocity (cm/sec)	33 ± 9	73 ± 17	< 0.0001
PD average peak flow velocity (cm/sec)	23 ± 6	48 ± 12	< 0.0001
PD flow velocity reserve		2.19 ± 0.62	

MCV = middle cardiac vein, PD = posterior descending coronary artery

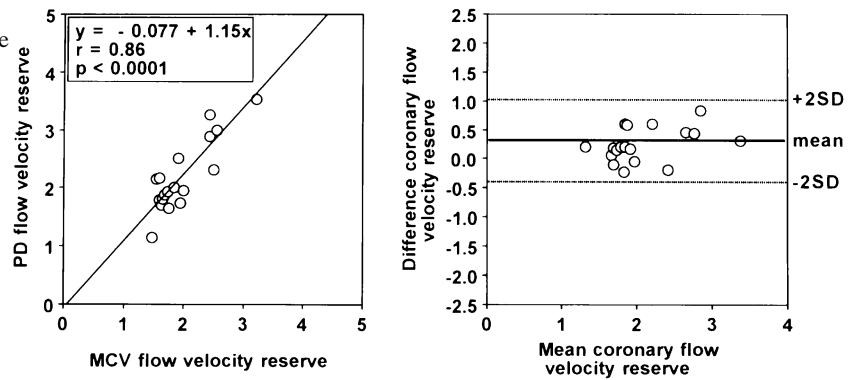
<sup>a</sup>  $p < 0.05$  vs. PD peak flow velocity, <sup>b</sup>  $p < 0.05$  vs. PD average peak flow velocity, <sup>c</sup>  $p < 0.01$  vs. PD flow velocity reserve

velocity reserve shows some advantages compared with the technique used for the PD. Success rate in the measurement of the MCV flow was high (100%) for the clinical application. However, there are some potential difficulties that have to be considered when recording Doppler flow signals of the PD. Individual coronary anatomy shows considerable patient-to-patient variability. In about 8% of the patients the coronary circulation is left dominant, which means that the PD and the posterolateral left ventricular branch are supplied by the left circumflex coronary artery [8]. In these cases the diameter of the PD might be too

small to acquire an accurate Doppler flow profile. Therefore, it may not be possible to visualize a segment of the distal right coronary artery in every patient. In fact, success rate in the measurement of the PD flow was relatively low in the present study as well as other studies [9, 11].

In the present study, we found a significant correlation between the MCV flow velocity and PD flow velocity. In addition, the MCV flow velocity reserve correlated highly with the PD flow velocity reserve. Thus, the MCV flow may be determined by the same factors that influence PD flow. However, the degree of

**Fig. 4** Regression (*left*) and mean difference (*right*) plots comparing PD flow velocity reserve and MCV flow velocity reserve



the MCV flow during hyperemia was less than that of the PD flow. This discrepancy between the coronary flow reserve in the MCV and PD is similar to the difference between the coronary flow reserve in the great cardiac vein and left anterior descending coronary artery [5, 6, 7]. Thus, this underestimation should be considered when the reactive hyperemic response is evaluated from the MCV flow velocity. The mechanism of this difference is unclear. The discrepancy between the flow velocity reserve in the MCV and PD may be also due at least in part to underestimation of flow changes. In the present study, we did not measure coronary flow volume but flow velocity. It is possible that the difference in flow velocity reserves between the MCV and PD found in the present study may relate to the difference in change of the lumen areas of the MCV and PD during hyperemia, however, we have no data regarding this.

It has been reported that coronary venous flow velocity increases around the onset of left ventricular ejection and decreases gradually toward the zero flow velocity line after the peak formation at mid- or late systole with one or two small wave components during atrial contraction and/or isovolumic contraction phase [6]. However, in the present study, MCV flow could be detected clearly only in the systolic phase, not in the atrial or isovolumic contraction phase. There are no correlative data in our study, using intravascular Doppler wire, flow probes, or other means, to support that these transthoracic Doppler velocities can be used to calculate MCV flow in children. Finally, the present study consisted of a small number of patients with each cardiac disease. Therefore, we could not compare the results in one type of heart disease to others. However, the purpose of the present study was to compare flow velocity reserve in the MCV with flow velocity reserve in the PD. In future studies, larger numbers of patients with various cardiac diseases should be examined by the

present method. These seem to be the limiting factors in the precise evaluation of the MCV flow dynamics in the present study.

## Conclusions

To assess blood flow velocity and flow velocity reserve in the middle cardiac vein and in the posterior descending coronary artery in patients with various heart diseases, high-frequency transthoracic two-dimensional Doppler echocardiography was performed. The present study demonstrated that the MCV flow reserve measured from the MCV is smaller than that determined from the PD, suggesting that it is necessary to consider the discrepancy between coronary flow velocity reserves in the MCV and PD when the MCV flow velocity measurements are used in the assessment of PD flow reserve.

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