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弁エコーと拍動流速の対比検討

Correlative study of valve echograms with phasic blood flow in man

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Summary

In order to attempt noninvasive estimation of phasic blood flow using echocardiography, simultaneous recordings of flow velocity and the valve echogram were obtained in 47 children with various types of heart disease. Echocardiographic measurement was quantitatively compared with the flow variable of the pulmonary artery, the aorta and the tricuspid valve, respectively.

Maximum opening velocity (b-c slope) of the pulmonary valve echogram was correlated with peak pulmonary flow velocity (r=0.72) and peak pulmonary acceleration (r=0.76), but no significant relation was found between pulmonary b-c slope and pulmonary diastolic pressure. The correlation between aortic opening slope and peak aortic flow velocity was not so good (r=0.48), but peak aortic acceleration was linearly related to the b-c slope of the aortic valve echogram (r=0.72). Both tricuspid D-E slope and E amplitude were correlated closely with peak initial tricuspid flow velocity (r=0.76, r=0.88 resp.). There were less significant relationship between mitral B-C slope and peak aortic flow velocity (r=0.55) and peak aortic acceleration (r=0.60).

These results suggest that blood flow dynamics is reflected to some extent by echocardiographic valve motion. Thus we can obtain quantitative information relating to phasic blood flow from the echocardiogram noninvasively.

Key words

Opening slope of the semilunar valve　Peak flow velocity　Peak flow acceleration　Tricuspid flow velocity　Mitral B-C slope

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Echocardiography is widely utilized to measure the size of cardiac chambers and great vessels, and several recent investigators[1,2] have reported the feasibility of echocardiographic estimation of intracardiac pressure. There is however, a paucity in studies[3~5] which correlate instantaneous blood flow with the echocardiogram. The purpose of the present paper is to compare phasic blood flow with the valve motion, and to examine whether it is possible to obtain quantitative information relating to blood flow noninvasively from echocardiograms.

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Materials and Methods

The clinical materials consisted of 47 child patients in all of whom both instantaneous flow velocity and the valve echogram were recorded simultaneously. There were 24 boys and 23 girls, ranging in age from 1 year and 9 months to 16 years and 9 months, the average being 5 years and 10 months. They included eight normal children, 13 with secundum atrial septal defect, 16 with ventricular septal defect, four with patent ductus arteriosus, three with tetralogy of Fallot and three with other heart disease.

Instantaneous phasic flow velocity was measured with a catheter-tip flow probe (VPC–663A, Millar instruments) and a square wave electromagnetic flowmeter (model 601D, Carolina Medical Electronics). Echocardiograms were obtained using a commercially available ultrasonoscope (Ekoline 20A, Smith-Klein Instruments) with a 3.5 MHz or 5 MHz nonfocused transducer. Flow velocity tracings and echocardiograms were recorded simultaneously in all cases on a multichannel photographic recorder (VR–12, Electronics for Medicine) at paper speed of 100 mm/sec with time signals of 40 msec. Flow acceleration, the first time derivative of flow velocity, was electronically determined by the R-C circuit of time constant of 1 msec. Fundamental characteristics of velocity probe and flowmeter were previously reported in detail elsewhere[6].

Peak velocity within the great vessels was measured directly from the velocity record and peak acceleration was also obtained from the acceleration curve. Peak value of tricuspid flow velocity was measured at the initial portion during the ventricular rapid filling phase. Echocardiographic measurements were obtained

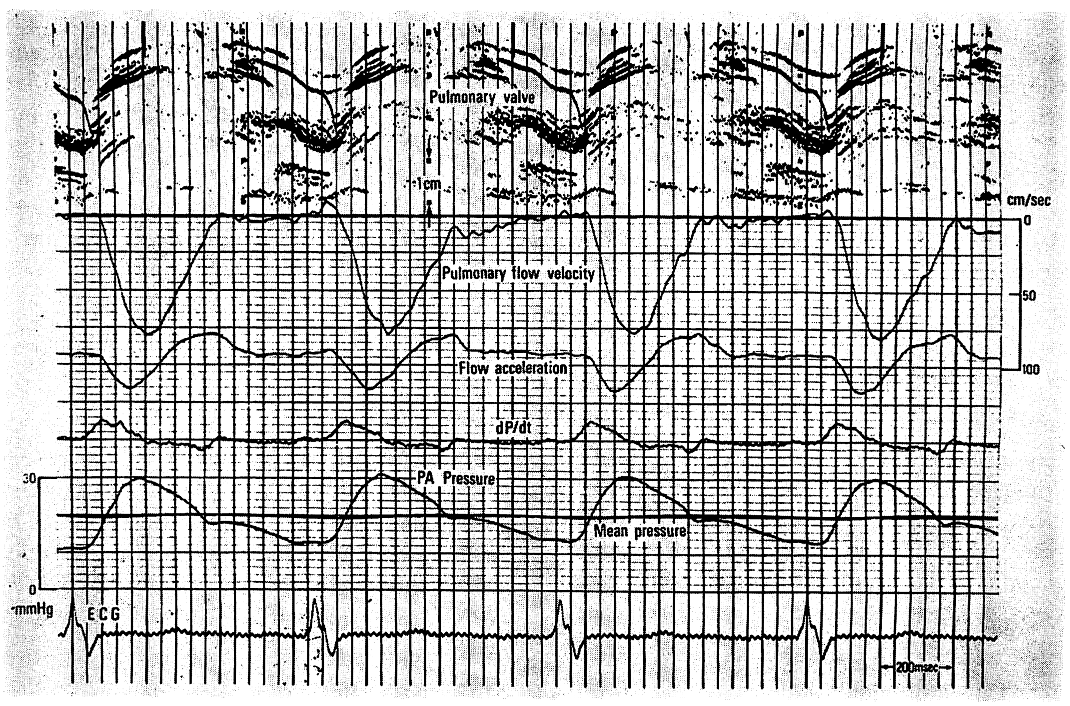

Fig. 1. Simultaneous recordings of the pulmonary valve echo, pulmonary flow velocity, flow acceleration and PA pressure in a patient with atrial septal defect.
PA=pulmonary artery.

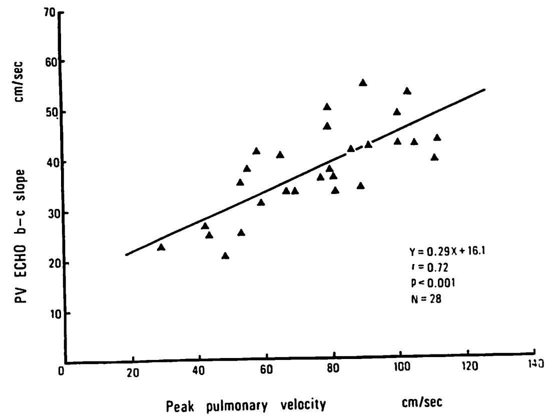

Fig. 2A. Correlation between maximum b-c slope of the pulmonary valve echogram and the peak pulmonary velocity.
PV=pulmonary valve.

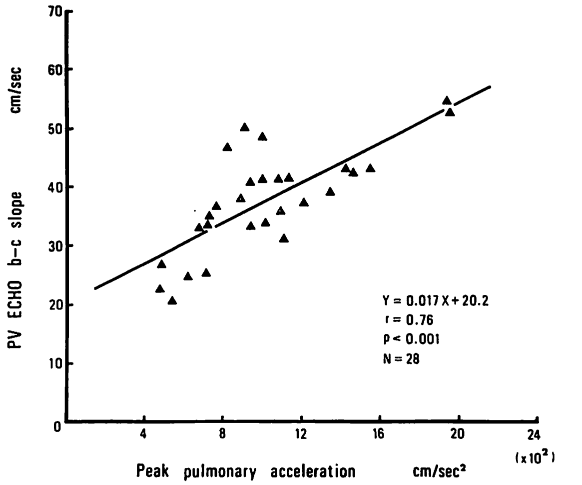

Fig. 2B. Correlation between the maximum b-c slope of the pulmonary valve echogram and the peak pulmonary acceleration.
PV=pulmonary valve.

from maximum opening velocity (b-c slope) of the pulmonary and the aortic valve. Maximum opening velocity (D-E slope) and the largest distance of the initial opening (E amplitude) were measured from the tricuspid valve echogram and the final mitral closure (B-C slope) was measured from the mitral valve echogram. Both measurements of velocity variables and echocardiograms were obtained and averaged in five beats except during inspiratory phase.

Results

1. Pulmonary valve echogram vs phasic pulmonary flow

Simultaneous recordings of the pulmonary valve echogram and phasic flow velocity were obtained in 28 children (**Fig. 1**). Values of the maximum b-c slope of the pulmonary valve echograms were linearly related to the peak pulmonary velocity (r=0.72) and the peak pulmonary acceleration (r=0.76) (**Fig. 2A** & 2B). However, as shown in **Fig. 3**, no significant relationship was observed in these patients between b-c slope and pulmonary arterial diastolic pressure measured by a micromanometer. Thus opening velocity was thought to be dependent on flow rather than pressure in the pulmonary artery.

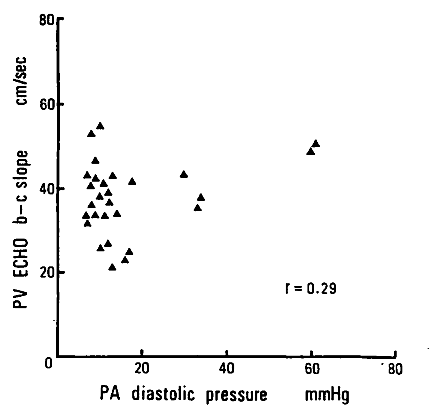

Fig. 3. Correlation between the maximum b-c slope of the pulmonary valve echogram and the pulmonary diastolic pressure.
PV=pulmonary valve; PA=pulmonary artery.

2. Aortic valve echogram vs phasic aortic flow

Phasic aortic flow was simultaneously rec-

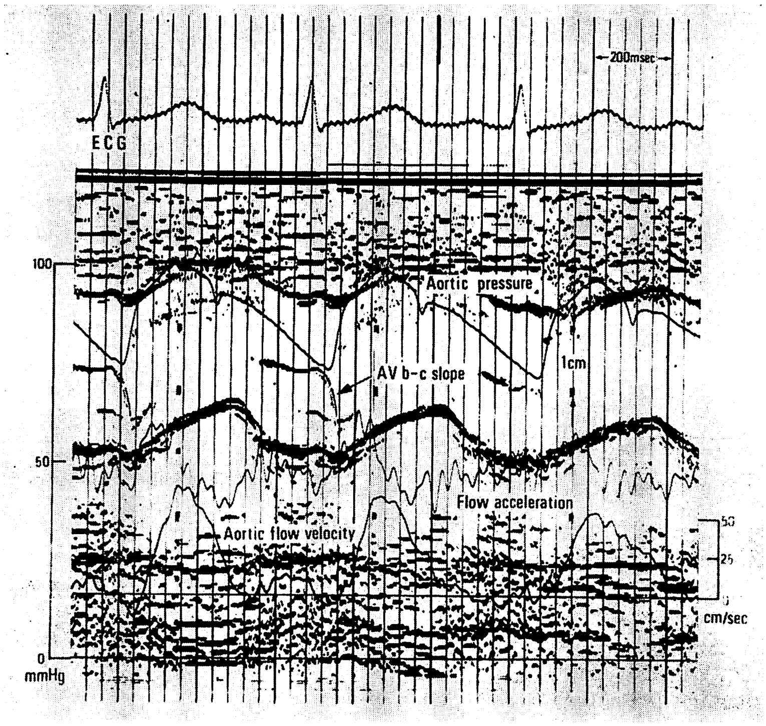

Fig. 4. Simultaneous recordings of the aortic valve echogram, aortic pressure, aortic flow velocity and flow acceleration in a patient with ventricular septal defect.
AV=aortic valve.

orded with aortic valve echogram in 12 patients (**Fig. 4**). The maximum opening velocity of the aortic valve echogram was poorly correlated (r=0.48) with the peak aortic velocity (**Fig. 5**A), but it was significantly correlated (r=0.72) with the peak aortic acceleration (**Fig. 5**B). It is considered that the echocardiographic tracing of the opening valve is more faithfully reflected by flow acceleration than flow velocity.

3. Tricuspid valve echogram vs tricuspid flow velocity

Instantaneous tricuspid flow velocity can be obtained by positioning the catheter probe across the tricuspid valve. Twenty-two patients had simultaneous recordings of flow velocity and the echogram of the tricuspid valve (**Fig. 6**). Each maximum opening velocity (D-E slope) and E amplitude derived from the tricuspid valve echogram were compared with the peak initial flow velocity of the tricuspid valve. As indicated in **Fig. 7**A & **7**B, both echocardiographic measurements of the tricuspid valve were well correlated with the peak initial tricuspid flow velocity, respectively (r=0.76, r=0.88).

4. Mitral valve echogram vs phasic aortic flow

Simultaneous recordings of phasic aortic flow and the mitral valve echogram were obtained in 21 patients (**Fig. 8**). The final closing velocity (B-C slope) of the mitral valve was less significantly correlated with the peak aortic velocity (r=0.55) (**Fig. 9**A) and the peak aortic acceleration (r=0.60) (**Fig. 9**B).

Discussion

Previous studies[3,7] have shown a similar pattern between transmitral blood flow and dias-

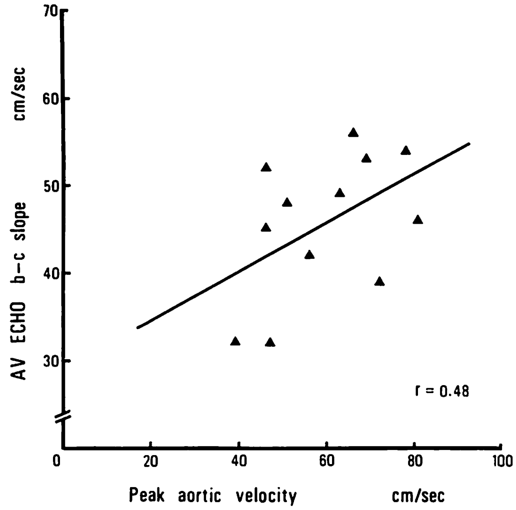

Fig. 5A. Correlation between the maximum b-c slope of the aortic valve echogram and the peak aortic velocity.

AV=aortic valve.

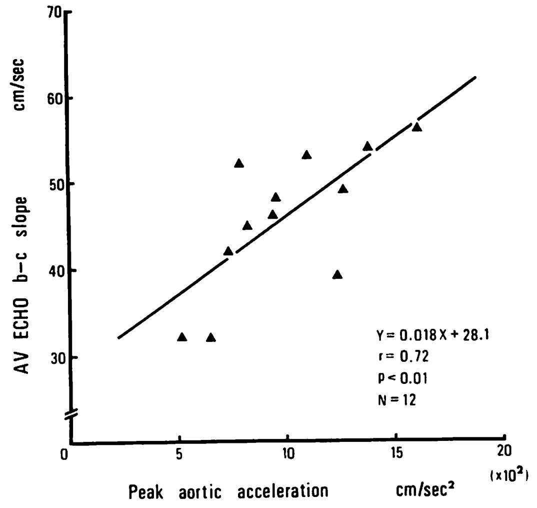

Fig. 5B. Correlation between the maximum b-c slope of the aortic valve echogram and the peak aortic acceleration.

AV=aortic valve.

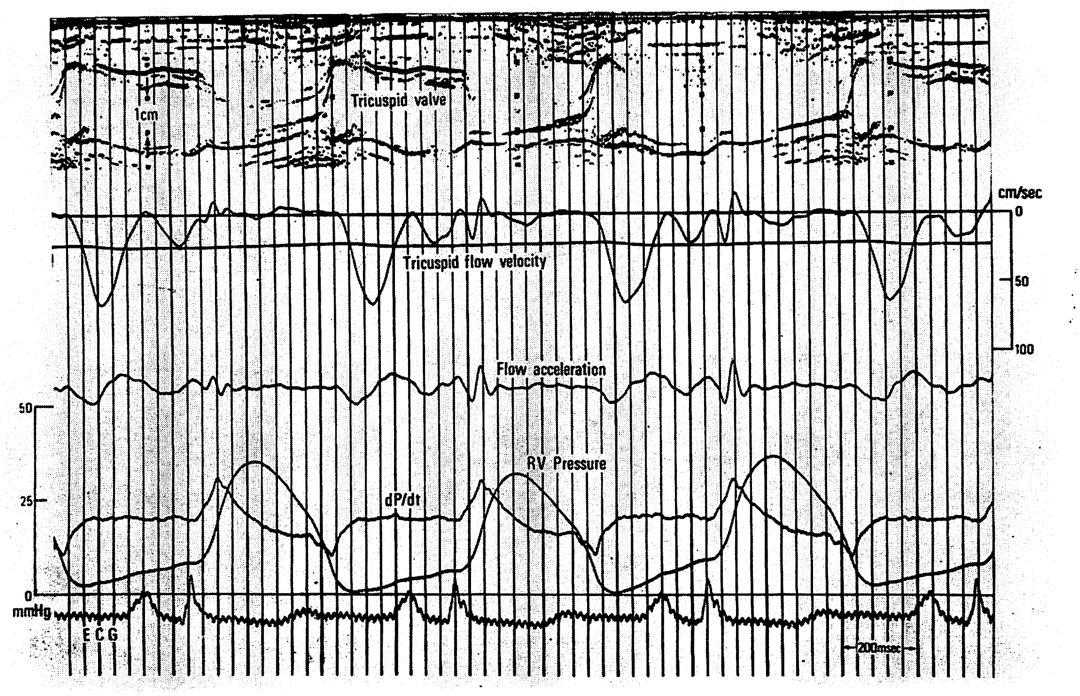

Fig. 6. Simultaneous recordings of the tricuspid valve echo, tricuspid flow velocity, flow acceleration and RV pressure in a patient with mucocutaneous lymph node syndrome without cardiac involvement.

RV=right ventricle.

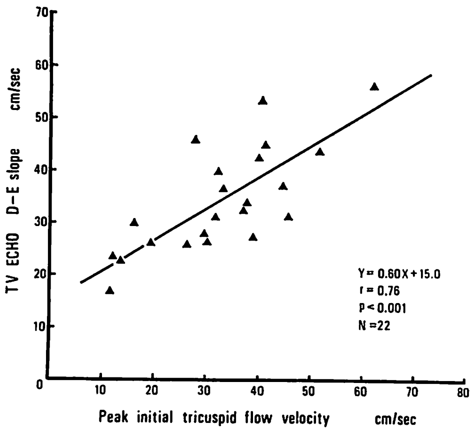

Fig. 7A. Correlation between the maximum D-E slope of the tricuspid valve echogram and the peak initial tricuspid flow velocity.
TV=tricuspid valve.

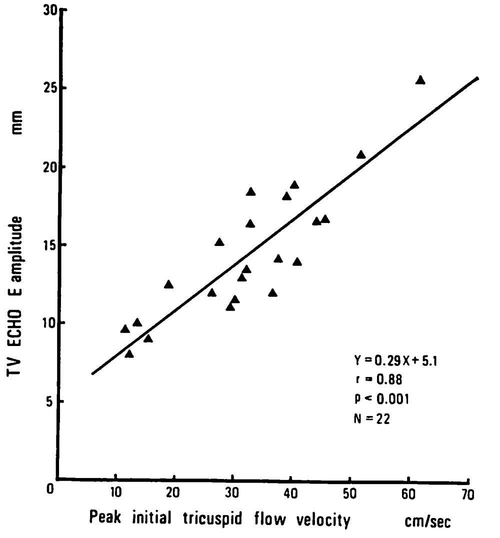

Fig. 7B. Correlation between the E amplitude of the tricuspid valve echogram and the peak initial tricuspid flow velocity.
TV=tricuspid valve.

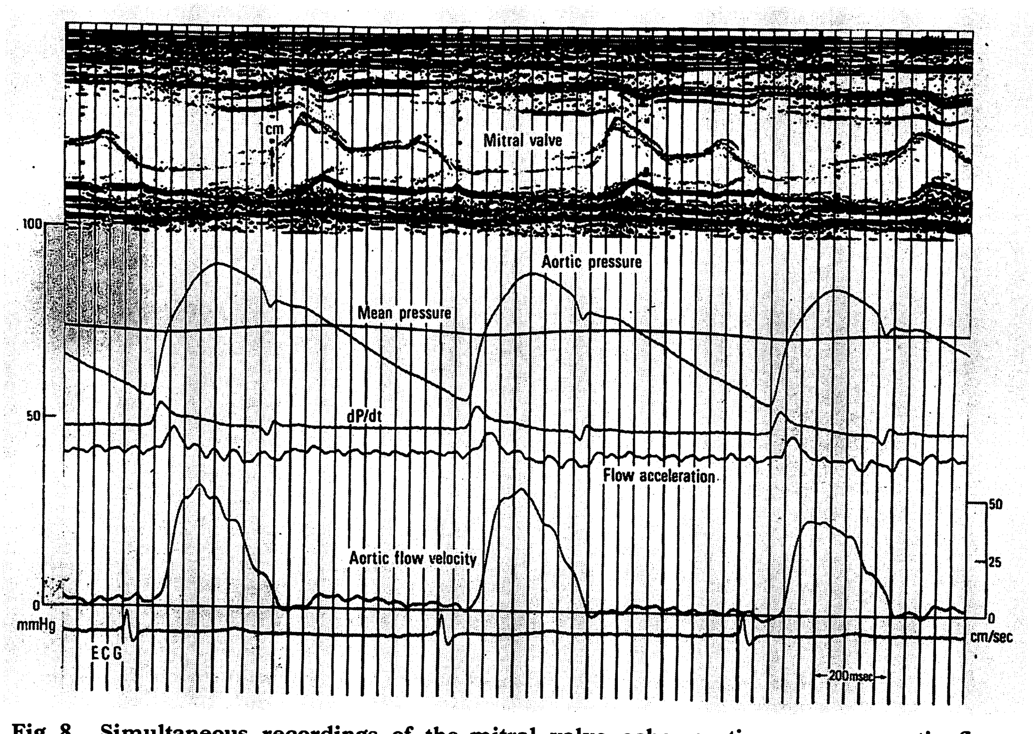

Fig. 8. Simultaneous recordings of the mitral valve echo, aortic pressure, aortic flow velocity and flow acceleration in a normal child.

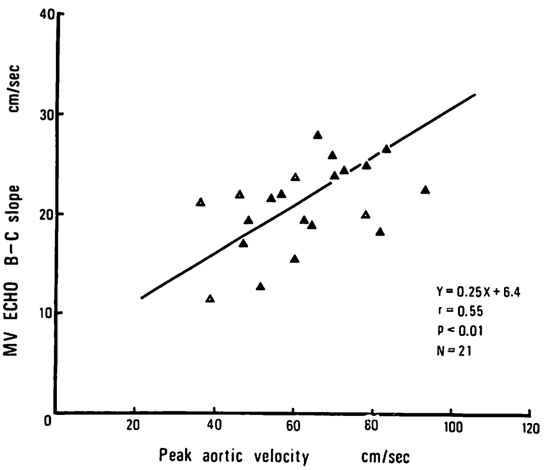

Fig. 9A. **Correlation between the maximum B-C slope of the mitral valve echogram and the peak aortic velocity.**
MV=mitral valve.

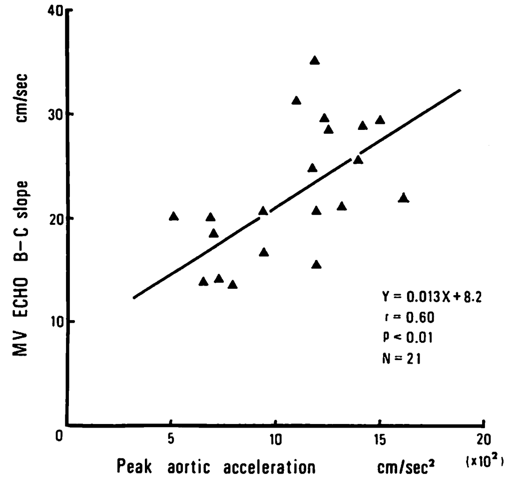

Fig. 9B. **Correlation between the maximum B-C slope of the mitral valve echogram and the peak aortic acceleration.**
MV=mitral valve.

tolic anterior leaflet motion of the mitral valve. Mitral flow velocity in such studies on human subjects was derived from numerical differentiation of left ventricular volume[5,7], or electromagnetic flowmeter was sutured to the mitral annulus in experimental animals[3]. In this report, we have obtained instantaneous flow velocity by using a catheter-tip probe during cardiac catheterization which was recorded simultaneously with the valve echogram. As shown in **Fig. 10** which represents simultaneous recordings of the mitral valve echo and transmitral blood flow, it is obvious that the motion of the valve echo strikingly resembles instantaneous flow velocity tracings. Thus, we have investigated the quantitative relationship between the pattern of phasic blood flow and the valve echogram in the present study.

Little is reported on the opening velocity of the pulmonary valve echogram relating to hemodynamic significance. Nanda and his associates[8] pointed out that the pulmonary opening velocity increased in patients with pulmonary hypertension, but Weyman and his associates[9] did not observe such findings. The present study demonstrated that although the maximum opening velocity of the pulmonary valve echogram was generally increased in patients with high diastolic pressure of the pulmonary artery, there was a wide scatter of values for the opening velocity in low diastolic pressure. More important observation is that the maximum opening velocity of the pulmonary valve was linearly related to flow variables such as the peak pulmonary velocity and acceleration. similar finding has been recently reported[10] in animal experiments using simultaneous recordings of the pulmonary valve echogram and flow acceleration obtained with electromagnetic flowmeter. Based on these results we can quantify the echocardiographic data in terms of the pulmonary blood flow, but care should be taken for quantitative evaluation because opening slope was frequently influenced by the position of the ultrasonic transducer and the direction of echo beam[10].

While the maximum opening velocity of the aortic valve echogram did not have a good correlation with the peak aortic flow velocity, it correlated fairly well with the peak aortic acce-

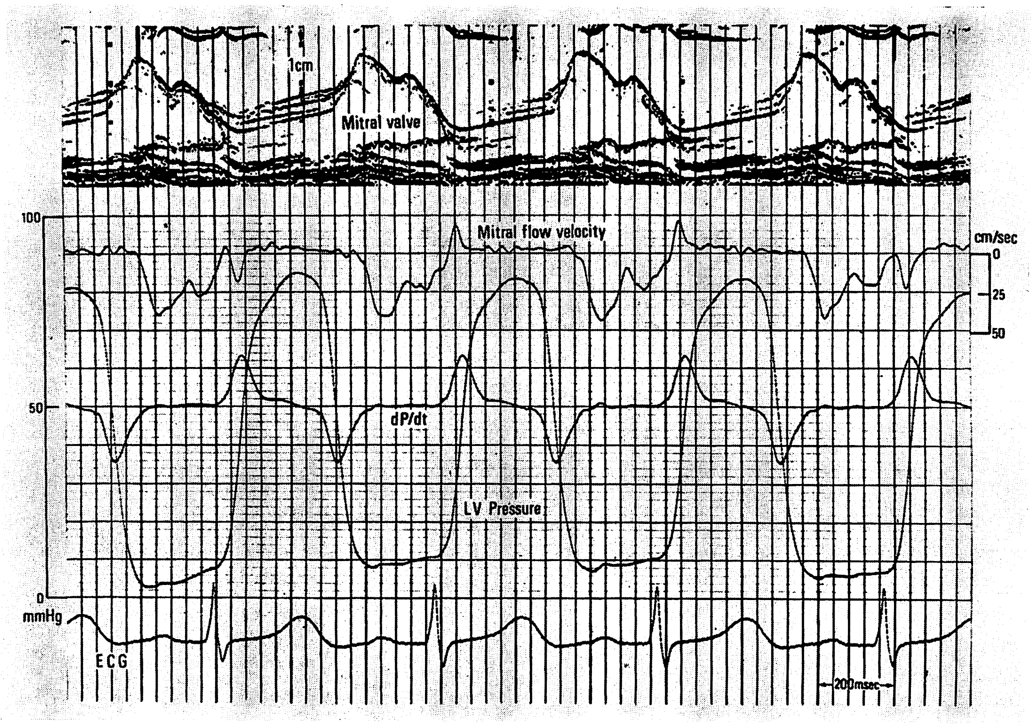

Fig. 10. Simultaneous recordings of the mitral valve echo, mitral flow velocity and LV pressure in a patient with ventricular septal defect.

The similar pattern is observed between the mitral valve echogram and mitral flow velocity. LV=left ventricle.

leration. This may be partly because there is a relatively narrower scatter of the value for the peak aortic velocity than that for acceleration in the subjects selected in this study. In addition, it is reasonable to consider that the maximum slope of the valve echogram is represented by flow acceleration since valve motion may reflect flow velocity curve as described earlier. Echocardiographic measurement of the aortic valve is used for the evaluation of cardiac output in aortic stenosis[11].

Employment of a catheter-tip velocity probe made it possible to obtain easily transtricuspid flow velocity during cardiac catheterization[6]. The D-E slope and E amplitude derived from the initial portion of the tricuspid valve were shown to be correlated with the peak initial tricuspid flow velocity, respectively. Since tricuspid flow provides valuable information in regard to right ventricular compliance and stroke volume, noninvasive evaluation of right ventricular performance can be performed by analyzing the tricuspid valve echogram.

Several investigators[4,12] have recently suggested that the B-C slope of the anterior mitral leaflet may provide an index of left ventricular function. According to Jugdutt and his associates[4], anterior mitral valve leaflet closing velocity was well correlated with the peak aortic velocity, but was not significantly correlated with the peak aortic acceleration. On the contrary, our results demonstrated that there was only slight significant relation between the B-C slope of the mitral valve and peak aortic velocity and acceleration, respectively. The mitral valve B-C slope is thought to be influenced by the conditions of the ultrasonic record as well as other hemodynamic factors than left ventricular function.

In summary, the analysis of the simultaneous recordings of the valve echogram and phasic blood flow revealed that valve motion was dependent on blood flow, and echocardiographic measurement allows for noninvasive assessment of flow variables quantitatively. It may be expected to obtain more useful and fruitful information about phasic blood flow from echocardiography by further investigations on the relationship between flow and valve echogram.

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