ECHOCARDIOGRAPHIC ESTIMATION OF FORWARD STROKE VOLUME AND MITRAL REGURGITANT VOLUME IN PATIENTS WITH OR WITHOUT LEFT VENTRICULAR DYSSYNERGY

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In order to estimate forward stroke volume (FSV) and mitral regurgitant volume (MRV) by echocardiography, the relationship between FSV or the severity of mitral regurgitation (MR) determined by conventional methods and those measured by aortic-left atrial echogram was investigated in 119 subjects, consisting of 88 patients without MR (no-MR group) and 31 patients with MR (MR group).

The most adequate echocardiographic measurement for estimating FSV in the no-MR group was the product of posterior aortic wall excursiion (Ao-PWE) and left atrial dimension (LAD); i.e., Ao-PWE × LAD. Further sophistication in estimating FSV was achieved by separating the subjects with LAD ≤ 40 mm from those with LAD > 40 mm.

MRV was estimated by subtracting the FSV determined directly by either Fick or thermodilution method from the stroke volume determined by echocardiography. MRV so obtained was compatible with the severity of MR determined by LV cineangiography.

The FSV in the no-MR group and the MRV in the MR group could be estimated with reliable accuracy by echocardiography alone (in the former) and by echocardiography plus a simple procedure such as Fick or thermodilution method (in the latter). Furthermore, this method was found to be free of influence from left ventricular dyssynergy or aortic regurgitation.

ECHOCARDIOGRAPHY is a rapid and safe method for estimating cardiac stroke volume. Many studies have been done on estimating total stroke volume using the left ventricular (LV) echogram. However, employing these methods for estimating forward stroke volume (FSV) in patients with LV dyssynergy or valvular regurgitation have frequently led to misleading results. The mitral valve echogram or aortic wall echogram has also been used to estimate FSV. Investigators so doing, postulate that FSV obtained by this way is not influenced by coexisting aortic regurgitation (AR) or LV dyssynergy. However in patients with mitral regurgitation (MR), for instance, the use of the mitral valve echogram overestimates FSV, and the use of the aortic wall echogram is also less accurate than the others mentioned above, probably because of (1) the assumption that the motion of the aortic root reflects FSV and (2) the inadequate characterization of the subjects studied. The motion of the posterior aortic wall is

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- Posterior aortic wall echogram
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primarily determined by left atrial volume change rather than the effects of the ejection phase of LV contraction. The relation between FSV and the motion of the posterior aortic wall should be examined by separating the patients without MR (no-MR group) from those with MR (MR group). A method to estimate FSV in the no-MR group and mitral regurgitant volume (MRV) in the MR group using the motion of the posterior aortic wall echogram was reported previously by Yorozu et al. The purpose of this study is to extend further the previous study in order to establish the practical usefulness of this study.

MATERIALS AND METHODS

The subjects in this study consisted of 88 patients without MR (57 males and 31 females, mean aged 45.6 with a range from 14 - 67 years), "no-MR group", and 31 patients with MR (19 males and 12 females, mean aged 47.8 with a range from 19 - 72 years), "MR group". In the no-MR group, 15 patients had AR and 19 patients had LV dyssnergy. In the MR group, 5 patients were combined with AR and one patient with LV dyssnergy. Patients with shunt diseases were excluded in this study.

Right-sided cardiac catheterization was performed in all patients following a standard procedure, and LV cineangiography was performed in all patients with MR or coronary heart disease. The severity of MR was classified according to

![Fig 2. Relationship between FSVd and Ao-PWE in the no-MR group.](image)

The solid line indicates the regression in the group with LAD ≤ 40 mm; the regression equation is

$$\text{FSVd} = 9.33 \times (\text{Ao-PWE}) - 2.0$$

(\(n = 60, r = 0.762\)).

The dotted line indicates the regression in that with LAD > 40 mm; the regression equation is

$$\text{FSVd} = 15.28 \times (\text{Ao-PWE}) - 35.0$$

(\(n = 28, r = 0.833\))

FSVd: forward stroke volume determined by either Fick or thermodilution method.

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the criteria by Sellers et al.17 and the patients were divided into four groups as follows: grade 1, 16 patients; grade 2, 6 patients; grade 3, 8 patients; grade 4, one patient. AR was judged by aortography.

All echocardiograms were obtained within one week of catheterization using an Aloka SSD-80 or an Aloka SSD-110S echocardiograph utilizing a 10 mm, 2.25 MHz, non-focused transducer (Aloka Industries Ltd., Tokyo). The patients were studied in the supine or left decubitus position with the transducer placed in the third or fourth intercostal space at the left sternal border in order to obtain both the aortic root echo-gram (at the level of the valve) and the left atrial echo-gram. The recordings with simultaneous electrocardiograms were made on a strip chart recorder (ECO-125, Fukuda Denshi Co. Ltd., Tokyo) at a paper speed of 50 mm/sec or 100 mm/sec. Fig. 1 shows diagramatic cross-section of the heart (A) and corresponding aortic — left atrial echo-gram (B). The posterior aortic wall excursion (Ao-PWE) is determined as the perpendicular distance in millimeters from the level of the maximum posterior motion of the posterior aortic wall to the level of the maximum anterior motion. The left atrial dimension (LAD) is obtained by the maximum distance between the posterior aortic wall and the left atrial posterior wall in millimeters (Fig. 1-B). The average values of 5 consecutive cardiac cycles were used to determine the Ao-PWE and LAD, while in patients with atrial fibrillation, at least 10 cardiac cycles were averaged.3,4 The mean heart rate was 65.2 with a range from 35—105 beats/min during the echocardiographic studies and 66.8 with a range from 32—110 beats/min during cardiac catheterization. In the same patient studied, the difference of heart rates between during the echocardiographic study and during the cardiac catheterization was less than 10 beats/min.

**RESULTS**

FSVd determined by either Fick or thermodilution method (FSVD) ranged from 21—131 ml/beat (70±24 ml/beat, mean±1 SD). LAD ranged from 23—60 mm (38±8.7 mm), and Ao-PWE ranged from 4.1—13.2 mm (7.7±1.9 mm).

(1) FSVd and posterior aortic wall motion in the no-MR group

FSVd, which means mitral flow volume (MFV) in the no-MR group, correlated positively with Ao-PWE (Fig. 2). The correlation coefficient (r) was 0.748, and the regression equation was

FSVd = 10.19 × (Ao-PWE) - 5.8

As shown in the figure, the dissociation of the regression lines was clear between the group with LAD ≤ 40 mm and that with LAD > 40 mm, particularly when the Ao-PWE was 7 mm or more, so that the group with large LAD showed smaller Ao-PWE than that with small LAD for the same FSVd (Fig. 2). This resulted in a relatively constant value of a product of Ao-PWE and LAD, Ao-PWE × LAD, among the patients with the same FSVd.

The correlation coefficient (r) between FSVd and (Ao-PWE × LAD) in all subjects was 0.755, but the regression was clearly different between the group with LAD ≤ 40 mm and that with LAD > 40 mm, resulting in a good correlation coefficient in both groups, r = 0.924 in that with LAD ≤ 40 mm and r = 0.928 in that with LAD 40 mm (Fig. 3). The regression equation in that with LAD ≤ 40 mm was

FSVd = 0.364 × (Ao-PWE × LAD) - 18.4

and in that with LAD > 40 mm was

FSVd = 0.428 × (Ao-PWE × LAD) - 68.7

As shown in the figure, the group with LAD > 40 mm showed larger value of (Ao-PWE × LAD) for the same FSVd (Fig. 3). Examples are shown in Fig. 4 (Case 1 and Case 2).

Influence of LV dysynergy upon the FSVd and (Ao-PWE × LAD) relationship in the both groups (that with LAD ≤ 40 mm and that with LAD > 40 mm) was not apparent, so was it in

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patients with AR (Fig. 5).

(2) FSVd and (Ao-PWE x LAD) in the MR group

It was observed that the MR group showed larger value of (Ao-PWE x LAD) than the no-MR group for the same FSVd. An example is shown in Fig. 4 (case 3). When the relationship of the FSVd and (Ao-PWE x LAD) in the MR group was compared with that in the no-MR
Fig. 5. Relationship between FSVd and (Ao-PWE x LAD) in the no-MR group with LAD $\leq 40$ mm (A) and that with LAD $> 40$ mm (B).
There was no influence of LV dyssynergy and AR on the relation between FSVd and (Ao-PWE x LAD).

Fig. 6. Relationship between FSVd and (Ao-PWE x LAD) in the MR group with LAD $\leq 40$ mm (A) and that with LAD $> 40$ mm (B).
The regression line of FSVd and (Ao-PWE x LAD) in the no-MR group is shown by the solid line, and one standard deviation of FSVd is shown by the dotted lines. MR patients in grade 1 do not show deviation from the regression line in the MR group except 3 cases with LAD $> 40$ mm. All of the advanced MR patients (grade 2-4) show deviation from the regression line.

group (as illustrated in Fig. 6), all of the advanced MR patients (grade 2-4) showed smaller FSVd than the no-MR group for the same value of (Ao-PWE x LAD). MR patients in grade 1 did not show deviation from the regression line of the no-MR group except 3 patients with LAD $> 40$ mm.

In Fig. 7, the relation between FSVd and the stroke volume calculated from the echocardiographic measurements (SVE) using the equation 1 or 2 is shown. All of the advanced MR patients showed larger SVE for the same FSVd. Since the difference between SVE and FSVd gives an estimate of the mitral regurgitant volume (MRV) in these patients, MRV is able to be calculated by

Fig. 7. Relationship between FSVd and SVE.
SVE: stroke volume calculated from the echocardiographic measurements, Ao-PWE x LAD.
the following equations:
in the group with $LAD \leq 40$ mm,
\[ MRV = [0.364 \times (Ao-PWE \times LAD) - 18.4] - FSVd \] \hspace{1cm} (3)
in the group with $LAD > 40$ mm,
\[ MRV = [0.428 \times (Ao-PWE \times LAD) - 68.7] - FSVd \] \hspace{1cm} (4)
Thus, the mean value of MRV in grade 1 was $1.4 \pm 19.5$ ml/beat ($\pm$ 1 SD); in grade 2, $28.8 \pm 8.8$ ml/beat and in grade 3, $59.3 \pm 11.8$ ml/beat. The MRV in grade 4 was $157.8$ ml/beat. In the no-MR group, the mean difference between FSVd and SVE was $0.3 \pm 8.8$ ml/beat, and this difference was termed "false MRV" (Fig. 8).

Fig. 8. Comparison of MRV (by the present method) with the severity of MR determined by LV cineangiography.
The bars and open circles indicate one standard deviation and the mean values of MRV. Statistical significance was assessed by unpaired t-test.
MRV: mitral regurgitant volume,
ns: not significant,
*: $p < 0.001$, **: $p < 0.01$.

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Fig. 9. Aortic-left atrial echogram of a patient with MR in grade 3.
In this patient, FSV determined by thermodilution method is 92 ml/beat. Ao-PWE and LAD determined by echocardiography are 11 mm and 45 mm, respectively.
The difference between the false MRV and the MRV in grade 1 was not statistically significant. The differences between the false MRV and the MRV in grade 2 or 3, and between grade 1 and grade 2 or 3 were statistically significant (p < 0.001). The difference between the MRV in grade 2 and grade 3 was also statistically significant (p < 0.01) (Fig. 8). One patient in grade 4 was excluded from this statistical analysis.

Fig. 9 demonstrates a representative example of one patient with MR. In this patient, FSV determined by thermodilution method is 92 ml/beat. LAD and Ao-PWE by echocardiography are 45 mm and 11 mm, respectively. MRV is given by using the equation 4:

\[
MRV = [0.428 \times (Ao-PWE \times LAD) - 68.7] - FSVd
\]

\[
= [0.428 \times (11 \times 45) - 68.7] - 92
\]

\[
= 51 \text{ ml/beat.}
\]

Therefore, the severity of this patient is classified as grade 3 by echocardiography (Fig. 8) and this grade was compatible with the severity determined by LV cineangiography.

DISCUSSION

(1) Calculation of FSV in the no-MR group

The patients with large LAD were found to have smaller Ao-PWE than those with small LAD for the same FSVd, and a product of Ao-PWE and LAD tended to be a nearly constant value among patients with the same FSVd. There were good correlations between FSVd and this product when the subjects were divided into two groups. Furthermore, the FSVd and (Ao-PWE \times LAD) relationship was not influenced by LV dyssnergy or AR. These results demonstrate that FSVd in the no-MR group (FSVd = MFV in the no-MR group) is predictable by echocardiography insofar as Ao-PWE and LAD are accurately determined, and that this method is not influenced by LV dyssnergy or AR.

In the no-MR group, the product of Ao-PWE and LAD was larger in those with LAD > 40 mm than those with LAD \leq 40 mm for the same FSVd (Fig. 3 and Fig. 4). One of the most possible interpretations of this discrepancy is that the cyclic change of left atrial size does not occur proportionally in all directions, but may be exaggerated by the systolic anterior motion of the aortic root in antero-posterior direction especially when LAD is over 40 mm, although the meaning of the value “40 mm” itself should be investigated further because this value was arbitrary determined in this study as a critical value for LAD.

(2) Estimation of MRV

Angiography has been an indispensable method for the diagnosis of valvular heart disease, and many methods have been reported previously for determining the severity of valvular regurgitation.\(^7,19--25\) However, angiography is an invasive procedure, performed at the cost of pain to the patient and possible hazardous complications even when done with skilled hands. Echocardiography, on the other hand, is a non-invasive, safe and repeatable procedure. The practical usefulness of echocardiography in estimating the severity of MR has been demonstrated by previous investigators\(^2,16,26,27\) Popp et al.\(^2\), for example, reported a method to evaluate valvular regurgitation using the difference between FSV determined by Fick method and total stroke volume determined by the LV dimension on echocardiogram. However, this method provides inaccurate estimation of the severity of MR where MR is complicated with LV dyssnergy or AR. Patton et al.\(^26\) estimated the severity of MR using a posterior left atrial echogram, and Strunk et al.\(^27\) estimated the severity of MR using a regurgitant index, dividing the difference between the cubes of the minimum and maximum LA dimension on echocardiogram by the FSV determined by Fick method. Although these two methods are not influenced by LV dyssnergy or AR, they could not evaluate MRV.

In this study, mitral flow volume (MFV) could be estimated by echocardiographic measurements, Ao-PWE \times \text{LAD}, using the equation 1 or 2. Since FSV is equal to the MFV in the no-MR group, it is reasonable to consider that the difference between the stroke volume determined by echocardiography (SVE = MFV) and FSV determined by either Fick or thermodilution method (FSVd) should give an estimate of the mitral regurgitant volume (MRV) in patients with MR. The MRV so obtained was compatible with the severity determined by LV cineangiography.

The advantage of this method over those postulated by previous investigators is that FSV and the severity of MR determined by this method are not influenced by LV dyssnergy or AR. Another advantage is that determination of MRV is possible by this method.
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