**Stroke Volume Estimated at Aortic Root in M-Mode Echocardiography**

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**Summary**

A noninvasive method for the determination of stroke volume which can be applicable even to a heart contracting asymmetrically is desired. The momentum of blood ejected from heart will be divided into 2 forms; the one is that of blood running away distally and the other is the momentum of the aortic root. SV is estimated by an equation; \( SV_{ao} = k \times D^2 \times Vao^{1/2} \times AOT \), where \( D \) is the diameter of the aortic root, \( Vao \) is the mean velocity of the systolic movement of anterior aortic wall, and \( AOT \) is the duration of the valve opening of the aortic leaflets. A good correlation was found between \( SV_{ao} \) and SV measured by the thermodilution method \( (r=0.85, p<0.001) \). Since the parameters used in the present method are not affected directly by the mode of cardiac contraction; symmetrical or asymmetrical, it may be useful to determine SV in man.

**Additional Indexing Words:**
Stroke volume, Echocardiography, Aortic root motion, Momentum of blood

Several methods have been proposed for the determination of left ventricular stroke volume using M-mode echocardiography. The change of left ventricular dimension was used initially for this purpose.\(^1\)\(^-\)\(^4\) Though this method has gained a wide acceptance, its use may be limited only to a heart contracting almost symmetrically. To avoid this limitation, Lee et al or Lanai et al determined the left ventricular stroke volume from the motion of aortic or mitral leaflet.\(^5\)\(^,\)\(^6\) However, this method was criticized by Kronik et al who pointed out the difficulty in obtaining a reproducible opening or closing velocity of valve leaflet.\(^7\) A method for the determination of stroke volume which is applicable to a heart contracting asymmetrically is therefore desired.

This paper concerns a method to determine stroke volume from the

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aortic root motion, diameter of aortic root, and the ejection time in the M-mode echocardiography.

**SUBJECTS AND METHODS**

The subjects were 25 patients who were studied for the evaluation of cardiac function.

**Table I. Clinical Diagnosis of 25 Patients**

<table>
<thead>
<tr>
<th>Arrhythmia</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sino-atrial block or sick sinus syndrome</td>
<td>4</td>
</tr>
<tr>
<td>Atrio-ventricular block</td>
<td>2</td>
</tr>
<tr>
<td>LGL syndrome</td>
<td>1</td>
</tr>
<tr>
<td>Premature ventricular contraction</td>
<td>2</td>
</tr>
<tr>
<td>Ischemic heart disease</td>
<td></td>
</tr>
<tr>
<td>Angina pectoris</td>
<td>5</td>
</tr>
<tr>
<td>Old myocardial infarction</td>
<td>2</td>
</tr>
<tr>
<td>Hypertension</td>
<td>1</td>
</tr>
<tr>
<td>Functional heart murmur or straight back syndrome</td>
<td>8</td>
</tr>
</tbody>
</table>

**Total**                                           **25**

**Fig. 1.** The M-mode echocardiography of the aortic root (Left) and its schematic presentation (Right). The mean velocity of the aortic anterior movement (Vao), the diameter of the aortic root (D), and the duration of the valve opening (AOT) were measured as shown. Ao=aortic root; LA=left atrium.
disorders. The age ranged from 19 to 77 years. Their clinical diagnoses were summarized in Table I. The patients with aortic regurgitation, or other forms of valvular heart disease were excluded. Because of the difficulty in measuring cardiac output by the thermodilution method, tricuspid regurgitation or the atrial septal defect were also excluded.

Two dimensional echocardiograms and M-mode echocardiograms of the aortic root and the left ventricle were recorded in the standardized manner (Toshiba Co SSH-11A). They were recorded on a strip chart with a paper speed of 50 mm/sec.

As mentioned in the addendum, the stroke volume was estimated from the diameter of the aortic root (D), the duration of aortic valve opening (AOT), and the mean velocity of the anterior movement of the aortic wall (Vao) as shown in Fig. 1. Defining k as a constant having the dimension of (cm/sec)$^{1/2}$, stroke volume estimated from the aortic root motion was described as follows;

$$SV_{ao} = kD^2 \times Vao^{1/2} \times AOT$$

Stroke volume (SV) was measured then by the thermodilution method at catheterization or at bedside using Swan-Ganz catheter in these 25 patients. Four to 5 successive measurements of cardiac output were averaged and used for the calculation of stroke volume. Then SV by the thermodilution method was compared with SV estimated from the aortic root movement ($SV_{ao}/k$) where k was to be determined from the regression equation to see any validity of the present method. SV was also obtained from the left ventricular dimensions and compared with SV by the thermodilution method. Statistical analysis was done by Student’s t-test.

Fig. 2 (left). The relation between stroke volume measured by thermodilution method and that estimated by the present methods; $SV_{ao}/k$ divided by a constant k ($=D^2 \times Vao^{1/2} \times AOT$, see text). A good correlation was found ($r=0.85$, p<0.001).

Fig. 3 (right). The relation between stroke volume measured by thermodilution method and that obtained from the left ventricular dimensions. The relation is significant ($r=0.68$, p>0.001), but seems poorer than that found between SV by thermodilution and by the present method (Fig. 2).
RESULTS

1. The relation between SV measured by thermodilution method and the term, $D^2 \times Vao^{1/2} \times AOT$. The relation was shown in the Fig. 2. Both were found to be significantly correlated ($r=0.85$, $p<0.001$). The regression equation was; $SV$ by thermodilution $= 12 \times SV$ by the present method $+ 18$ (ml).

2. The relation between SV by thermodilution and that from the left ventricular dimensions. SV was routinely obtained from the left ventricular dimensions which was found to be fairly correlated with SV by thermodilution ($r=0.68$, $p<0.001$). The regression equation is; $SV$ by thermodilution $= 0.53 \times SV$ by left ventricular dimensions $+ 32$ (ml) (Fig. 3).

DISCUSSION

Stroke volume can be determined routinely from the dimensional change of left ventricle in the M-mode echocardiographic recordings.$^{1-4}$ However, its application is limited to the heart which contracts almost symmetrically and stroke volume could not be determined in the heart with abnormal wall motion as found in atrial septal defect or ischemia. Recently, Lee or Lalani tried the determination of stroke volume from the movement of aortic root or of mitral leaflet.$^{5,6}$ As pointed out by Kronik, the accurate determinations of the aortic or mitral opening or closing velocity are difficult and its applicability seems to be limited.$^{7}$ On the other hand, Pratt estimated stroke volume from the movement of posterior wall of aorta.$^{9}$ A fair correlation was observed between the stroke index and the posterior wall amplitude ($r=0.78$, $N=24$). Because of an easiness of recordings of the aortic root, they stressed its usefulness for estimating stroke volume. These findings were confirmed by Morioka et al who also observed a correlation between the slope of the aortic posterior wall during systole and the stroke volume or stroke index.$^{10,11}$ The reason of such correlations was however not discussed by these workers.

It is probable that the movement of the aortic root during systole is caused by the momentum of blood ejected from heart. The anterior movement of the aortic wall can be therefore related to the momentum of blood as discussed in the addendum. The term of stroke volume; $D^2 \times Vao^{1/2} \times AOT$, was found to be well correlated with stroke volume measured by thermodilution method (Fig. 2). This correlation seemed to be better than that found between stroke volume by thermodilution and that from left ventricular dimensional change.$^{11}$ The parameters required in the present method include the aortic wall motion, the diameter of the aortic root, and the opening dura-
tion of the aortic valve. The present method may be applicable even to a heart contracting asymmetrically.

**ADDENDUM**

The momentum of the blood ejected from heart into the aortic root will be divided into 2 components; the one of the blood running away distally, and the other of the aortic root movement. This relation can be expressed mathematically as follows;

\[ MV = mv - mv' \]

where \( M \) and \( V \) is the mass and the vector of the velocity of the aortic root. \( v \) and \( v' \) are the vectors of velocities of blood entering and leaving the part. \( m \) and \( m' \) are the blood entering and leaving the aortic root. The first equation will be expressed in scalars if the angle \( \theta \) between the 2 vectors is known. Assuming that an instantaneous accumulation of blood in the aortic root is small enough, then the scalars \( v \), and \( v' \) will be related to the cross sectional area of the aortic root \( A \) and the mass of blood as \( m = Av \) (\( = m' = Av' \)). The first equation is rewritten as follows;

\[ (MV)^2 = 2A^2 \times v^4 (1 - \cos \theta) \]

Since \( M \) is proportional to \( A \), the last equation can be expressed as

\[ \text{flow rate}(=Av) = kD^2 \times V^{1/2} \]

where \( k \) is a constant having the dimension of \( (\text{cm/sec})^{1/2} \), and \( D \) is the diameter of the aortic root. Intergrating the flow rate over the ejection time; here over the duration of the opening time of the aortic valve (AOT), stroke volume is obtained as follows;

\[ SV_{ao} = kD^2 \times (V_{ao})^{1/2} \times AOT \]

where \( D \) is regarded as fixed during the ejection and \( V_{ao} \) is the mean velocity of the movement of anterior aortic wall which is used as the representative velocity during systole.

**REFERENCES**


