CONTRACTILE RESERVE OF VALVULAR HEART DISEASES ECHOCARDIOGRAPHICALLY EVALUATED BY EPINEPHRINE LOADING BEFORE AND AFTER CARDIAC SURGERY

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In order to evaluate cardiac contractile reserve, echocardiographic studies were performed on 59 patients with acquired valvular heart disease and 13 patients with atrial septal defect. After epinephrine loading, the 59 patients were classified into three groups. In group I, echocardiographically-obtained left ventricular posterior wall excursion (PWE) remained below 10 mm after the administration of 2 μg/min epinephrine. This group included patients with PWE below 10 mm after 1 μg/min epinephrine loading but who could not endure the 2 μg/min infusion because of significant adverse effects. In group II, PWE was less than 10 mm before the loading, but exceeded 10 mm after the administration of 1 or 2 μg/min epinephrine loading. In group III, PWE exceeded 10 mm without stress.

The conclusions derived from our data are as follows: 1. The PWE and mean left ventricular posterior wall velocity (mPWV) obtained by echocardiography reflect the stroke volume derived from the thermodilution technique. It is possible to estimate the cardiac contractile force in patients who have a paradoxical motion of the interventricular septum, in the preoperative and even in the early postoperative periods. 2. Patients whose PWE and mPWV are less than 10 mm and 35 mm/sec, respectively, after 2 μg/min loading of epinephrine (group I), are likely to have severe cardiac failure after surgery. Inotropic stimulation is considered to be a very useful indicator for prediction of cardiac contractile reserve. 3. Patients having decreased PWE, mPWV, mVcf and EF before surgery may have arrested recovery in both short- or long-term follow-up. However, surgical treatment is recommended for these patients with low cardiac function, because some improvement can be expected after surgery.

It is generally agreed that the degree of myocardial damage influences postoperative recovery after repairs of cardiac anomaly and valves. Therefore, estimation of the degree of cardiac reserve before surgery is an important indicator for postoperative care and prediction of the later results. In order to evaluate a cardiac contractile reserve, exercise stress and medical loading are suitable for extracting a contractile force. Among them, epinephrine loading is easy to perform for patients before surgery and in the early stage of postoperation because it

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TABLE I NUMBER OF PATIENTS OF LOW OUTPUT SYNDROME AND HOSPITAL DEATHS IN EACH GROUP

<table>
<thead>
<tr>
<th>Group</th>
<th>Low output syndrome</th>
<th>Hospital death</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>8/11 (72.7%)</td>
<td>3/11 (27.3%)</td>
</tr>
<tr>
<td>Group II</td>
<td>3/18 (16.7%)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Group III</td>
<td>2/30 (6.6%)</td>
<td>1/30 (3.3%)</td>
</tr>
<tr>
<td>Total</td>
<td>13/59 (22.0%)</td>
<td>5/59 (8.5%)</td>
</tr>
</tbody>
</table>

Group I: the PWE remained below 10 mm after the loading of 2 μg/min epinephrine. And the patients with PWE below 10 mm after the 1 μg/min infusion, who could not endure 2 μg/min loading because of the significant adverse effects. Group II: the PWE exceeded 10 mm by the administration of 1 or 2 μg/min of epinephrine. Group III: the patients showed greater PWE than 10 mm without stress. The incidence of low output syndrome is high in group I and low in group III. And the mortality is also high in group I, however, the difference in hospital death is not significant among the groups.

Fig.1. Relation between stroke volume (thermodilution) and posterior wall excursion (echocardiogram) before and after surgery. Significant correlation coefficients were obtained between stroke volume and posterior wall excursion in mitral valve replacement, surgery for combined valvular diseases and open mitral commissurotomy. SV = stroke volume; AVR = aortic valve replacement; MVR = mitral valve replacement; CVD = surgery for combined valvular heart diseases; OMC = open mitral commissurotomy; ASD = closure of atrial septal defect

can be done at the patients bedside.

The authors studied various reactions of cardiac contraction using echocardiography and the Swan-Ganz thermodilution technique, and determined the reactions between hemodynamics and echocardiographic findings. Preoperative and postoperative data were compared in a short- and long-term follow-up.

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MATERIALS AND METHODS

1. Patients
From 1975 to 1983, 59 patients (29 men, 30 women), aged 22 to 63 years (mean 42.0) underwent aortic valve replacement (13); mitral valve replacement (10); multiple valve replacement (13); single valve replacement with tricuspid annuloplasty (9) and open mitral commissurotomy (OMC), (14). These procedures were compared with those of 13 adult patients (5 men, 8 women) aged 20 to 57 years (mean 36.9), who underwent closure of atrial septal defect (ASD). These patients underwent open heart surgery under cardiopulmonary bypass with a disposable bubble oxygenator diluted to 20–30% with lactated Ringer’s solution in a mild or milder hypothermia. A topical cooling with ice-slush of lactated Ringer’s solution and an infusion of cardioplegic solution consisting of glucose-insulin-potassium were also done for ischemic arrest.

A low output syndrome (LOS) was defined as a cardiac index of less than 2.0 L/min/m². Cathecolamines were required to maintain a blood pressure equal to or greater than 80 mmHg for more than three days, and an intra-aortic balloon pump was used to get a sufficient cardiac output.

2. Hemodynamic Study
Prior to the operation, a Swan-Ganz thermodilution catheter (93-122-7F) was inserted into the pulmonary artery and pressure was monitored at bedside. Cardiac output was measured with a Cardiac Output Computer (Model 9,000, Edwards Comp. U.S.A.) by an injection of 10 ml of chilled 5% dextrose in water into the right atrium. The cardiac index (CI) was calculated as CI = cardiac output/body surface area (L/min/m²), and stroke volume (SV) was calculated as SV = cardiac output/heart rate (ml/beat). Pulmonary arterial and pulmonary capillary pressures were measured with the catheter.

The left ventricular ejection time (LVET) was determined by an indirect carotidgram before surgery and pressure tracings of the radial artery after surgery, because LVET obtained by carotidgram has been reported to be nearly the same value as that determined by peripheral arteries.
Fig. 3. Early and late postoperative cardiac functions in each group. PWE and mPWV in group I are lower than those in group II and III throughout pre- and postoperation. EF and mVcf also showed almost the same tendency as PWE and mPWV, but a little different.

PWE = posterior wall excursion; mPWV = mean posterior wall velocity; mVcf = mean ventricular circumferential fiber-shortening; EF = ejection fraction; PRE = before operation; M = month; Y = year

3. Echocardiographic Study

M-mode echocardiograms were obtained with an Aloka Model 110 Ultrasound (Aloka Co., Japan) and ATL Mark V (Advanced Technical Laboratory, U.S.A.) using a transducer with a frequency of 2.25 or 3.0 MHz. The transducer was placed on the third or fourth intercostal space of the left sternal border. The largest diameter of the left ventricle from a view of the parasternal long axis was selected for examination of the left ventricular motion and dimensions. Special care was taken to direct the beam to the same location of the left ventricular wall in order to reduce the positional difference between before and after surgery. End-diastolic dimension (Dd), end-systolic dimension (Ds) and left ventricular ejection fraction (EF) were calculated by the Teichholz method. The total excursion of left ventricular posterior wall endocardium during systole (PWE), the mean rate of circumferential fiber shortening (mVcf = Dd–Ds/Dd/LVET) and the mean left ventricular posterior wall velocity (mPWV = PWE/LVET) were measured also.

Echocardiograms were recorded postoperatively every week for a month, and after one year.

* p<0.001  † p<0.005  ‡ p<0.025
4. Epinephrine Administration

Epinephrine was prepared for intravenous administration by diluting the epinephrine solution (Bosmin®) in a 20 ml syringe with 5% dextrose in water. Epinephrine was initially infused at a rate of 1 µg/min for more than ten minutes using a microinfuser. The parameters were determined by the Swan-Ganz catheter and echocardiography before and during the administration of epinephrine immediately after ten minutes infusion. After the measurements, epinephrine was increased to 2 and 4 µg/min respectively unless a significant increase occurred in mean pulmonary capillary pressure to 25 mmHg or more or significant adverse effects such as short breath, dyspnea or palpitation were noted. The other catecholamines were withheld during the study.

The left ventricular echograms were recorded at almost the same time as measurements were taken of cardiac output and pressure curves by the Swan-Ganz catheter. These parameters were measured one day before the operation and on the first postoperative day.

5. Patient Groups

Fifty-nine patients with acquired valvular heart diseases were classified into three groups by the reaction of PWE to epinephrine loading performed before surgery. Group I: the PWE of the examined patients remained below 10 mm after the loading of 2 µg/min epinephrine. And in this group were included those with PWE below 10 mm after the 1 µg/min infusion, who could not endure 2 µg/min loading because of the significant adverse effects. Group II: the PWE in this group exceeded 10 mm by the administration of 1 or 2 µg/min of epinephrine. Group III: the patients showed greater PWE than 10 mm without stress.

RESULTS

1. Clinical Results (Table I)

Eight of the 11 patients of group I developed LOS, and 3 died of cardiac failure. Three of the 18 patients of group II had LOS, and one of the three patients died of cardiac failure. Two of the 30 patients of group III developed LOS, and one of the two patients died of cerebral embolism. None of the patients with ASD appeared to have LOS.

2. Correlation between PWE and Stroke Volume
(thermodilution) (Fig. 1)

A total of 186 simultaneous measurements of echocardiography and cardiac output by the thermodilution were obtained from 72 patients. The cardiac output of the patients with ASD were not measured by the Swan-Ganz catheter before surgery because of the left-to-right atrial shunts.

The correlation coefficients between PWE and SV (thermodilution) were 0.78 for the mitral valve replacement, 0.64 for the combined valvular surgery and 0.75 for the OMC, respectively (p < 0.05). The postoperative coefficients were 0.90, 0.57 and 0.87, respectively (p < 0.01). The correlation coefficients for the aortic valve replacement were 0.37 before the surgery and 0.24 after the surgery (not significant). The correlation coefficient for the ASD after the surgery was 0.41 (not significant). However, an increase or decrease in PWE reflected the change of the stroke volume in an individual patient.

3. Reflection of PWE by Epinephrine Loading
(Fig. 2)

In 21 (29.2%) of the 72 patients echocardiographic cardiac functions could not be obtained on the first postoperative day, and these patients were excluded from the early postoperative data.

The PWE increased after the administration of 1 µg/min epinephrine in 65 (90.3%) of the 72 patients before surgery and in 45 (88.2%) of the 51 patients after surgery. There was no significant difference in the reactivity to epinephrine among the diseases or operative methods. The PWE of the patients who developed LOS was low both pre- and postoperatively, and its increase by the administration of epinephrine was minimal (closed circle). The postoperative convalescence was retarded for the patients whose preoperative PWE was below 10 mm after 2 µg/min epinephrine loading. Most LOS occurred in this group and the death rate tended to be high (Table 1 and Fig. 2).

4. Early and Late Results of Epinephrine Loading
(Fig. 3)

PWE and mPWV of all the groups increased after one month, and even more after one year.

Fig.5. Echocardiograms of a representative case of group I before and after epinephrine loading. The case is a 57-year-old male. He suffered from aortic regurgitation, mitral regurgitation and right coronary artery stenosis and underwent aortic and mitral valve replacements with aorta-to-right coronary artery bypass grafting. He died of severe cardiac failure on the first postoperative day. The PWE before epinephrine loading is 6 mm and after 2 µg/min loading is less than 10 mm.

ADR = epinephrine.
The other abbreviations are the same as in Fig. 3.
However, PWE and mPWV of group I remained consistently lower than those of groups II and III before and after surgery until long-term follow-up. Preoperative PWE and mPWV were different among the three groups (p < 0.025). The preoperative EF and mVcf were higher in group III than in group I (p < 0.001). Mvcf in group I, and EF in group I and group III decreased after one month, but increased after one year. Mvcf and EF in group II increased after one month but decreased after one year. However, these changes were not significant.

5. Early Postoperative Changes of PWE and mPWV (Table II and Fig. 4)

Early postoperative PWE and mPWV were obtained from a total of 51 patients who underwent aortic valve replacement (9); mitral valve replacement (6); open mitral commissurotomy (12); surgery for combined valvular heart diseases (11) and closure of atrial septal defect (13). LOS developed in 6 patients among this group. Early postoperative courses of PWE and mPWV in each operative procedure were followed for one month. Values of patients with LOS are drawn separately. There was no significant difference among the different operative procedures. The PWE and the mPWV of all the procedures decreased on the first postoperative day, but increased between one week and one month to the preoperative levels. PWE and mPWV in patients with LOS had a tendency to be lower throughout pre- and postoperation. Statistical data were discussed between LOS and each operative procedure group.

6. Representative Cases of Epinephrine Loading

Echocardiograms of a representative case of group I are shown in Fig. 5. This 57-year-old male suffered from severe aortic regurgitation, mitral regurgitation and right coronary artery stenosis. His PWE was 6 mm before epinephrine loading, and was increased to 7 mm by 1 μg/min epinephrine loading. The increase to 2 μg/min epinephrine loading, however, did not increase the PWE, but increased only the heart rate from 104/min to 124/min. He fell into LOS after the aortic valve replacement, mitral valve replacement and aorta-to-right coronary artery bypass surgery, and died of cardiac failure on the first postoperative day in spite of the intra-aortic balloon pumping.

Echocardiograms of a patient in group II are shown in Fig. 6. This 48-year-old female was diagnosed as mitral stenosis. Her PWE before the open mitral commissurotomy was 7 mm, and was increased to 9.5 mm by an administration of 1 μg/min epinephrine, and up to 12 mm by 2 μg/min epinephrine. Her postoperative recovery was uneventful and LOS did not appear.
DISCUSSION

1. Measurement of Cardiac Functions by Echocardiography

Echocardiographic detection of various cardiac functions is reliable and is easy to perform. It is generally accepted that left ventricular volume, EF and mVcf which are measured by echocardiography have a high correlation with those measurements derived from cineangiography. However, abnormal motion of the interventricular septum, which is often seen in the early postoperative stage, makes it impossible to use conventional formulae. On the other hand, a contractile pattern of the left ventricular posterior wall echo resembles the reversed left ventricular volume curve. A high correlation has been reported between the change of PWE and the stroke volume derived from the dye-dilution curve, and between mPWV and Vmax. This suggests that it is possible to estimate the left ventricular contractile force by the simple left ventricular posterior wall echo. Our study has also showed that there was a high correlation between the stroke volume derived from the thermodilution method and PWE or mPWV before and after surgery. Even in the cases with aortic regurgitation, mitral regurgitation or tricuspid regurgitation, the increase or decrease of PWE or mPWV by the epinephrine loading reflected that of the stroke volume by the thermodilution method in an individual patient. There is concern, however, that PWE does not reflect the stroke volume accurately in the case of mitral regurgitation, and that stroke volume derived from the thermodilution method is not correct in the case of tricuspid regurgitation.

To extract cardiac reserve, various stress tests are commonly adopted, such as ergometer, treadmill, cardiac pacing, drugs and others. Among them, a drug-induced stress test is considered to be the best for surgical patients. Most patients require bed rest and drug-induced tests can be performed at bedside. It has been reported that isoproterenol increases PWE, mPWV and max PWV, atropine decreases PWE slightly and methoxamine decreases mPWV. The increase of heart rate by atrial pacing makes PWE and mPWV low, and increase of heart rate by exercise increases PWE and mPWV. These facts suggest that a change of posterior wall reflects the left ventricular function, independent of heart rate. Therefore, it is reasonable to study PWE and mPWV even in cases which show a paradoxical motion of the interventricular septum. It has been shown that a change of PWE and mPWV reflects the results derived from the Swan-Ganz catheter and clinical data obtained before and after surgery.

When examining cardiac contractility, careful selection of a drug is important, because drugs that change cardiac contraction also change heart rate and pre- or afterload. We selected epinephrine, because the effect on afterload is less than that of isoproterenol. Neither afterload stress test by methoxamine nor exercise stress test can be used for early postoperative patients. Epinephrine stress is relatively easy to test even for patients with severe cardiac failure. Our data showed that an increase in cardiac contraction was obtained with minimal change in afterload and heart rate by loading one or two micrograms per minute of epinephrine. As shown in Fig. 3, the postoperative prognosis could be predicted by the reactivity of PWE to epinephrine when classified by 10 mm. When mPWV was classified by 35 mm/sec, it produced almost the same results as the PWE.

2. Follow-up Study

Nesto et al. reported that patients who had increased EF after administration of epinephrine or extrasystolic potentiation showed improvements of EF over a long period after the surgery for coronary heart disease. These results are adapted to other heart diseases, such as congenital heart and valvular heart diseases. It may be said that patients who showed better improvement by the epinephrine loading might have less myocardial disturbance. On the contrary, the patients who developed LOS showed lower cardiac functions before the surgery, and also showed less improvement of cardiac functions over a long period.

There was a little difference between the course of PWE and mPWV, and that of mVcf and EF. The discrepancy is considered to be due to abnormal interventricular septal motion often seen early after surgery. PWE and mPWV seem to reflect the postoperative course more than do mVcf and EF within a month after surgery. Over a long period, cardiac functions of all the groups, including the patients with LOS, improved to a point that was better than before surgery. These results indicate that even patients with poor cardiac function can survive cardiac surgery and improve cardiac function.

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REFERENCES
10. BURGGRAF GW, CRAIGE E: Echocardiographic studies of left ventricular motion and dimensions after valvular heart surgery. Am J Cardiol 36: 473, 1975
13. SMITHEY CS, WHARTON CFP, SOWTON E: Independent effects of heart rate and exercise on left ventricular wall movement measured by reflected ultrasound. Am J Cardiol 30: 43, 1972