Journal of Cardiography 11: 1147-1157, 1981

Transesophageal echocardiographic evaluation of left ventricular function at rest and during dynamic exercise in aortic insufficiency

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Summary

Transthoracic echocardiography is often of limited value for the evaluation of left ventricular (LV) performance during dynamic exercise (E). Therefore, we studied LV function during maximal E by supine ergometry in 10 normal subjects (N) and 15 patients of aortic regurgitation (AR) with (8) and without (7) symptoms with transesophageal M-mode echocardiography. With this transesophageal approach, where an esophageal transducer is incorporated at the tip of a commercially available gastroscope, good continuous recordings of LV diameter were obtained without being disturbed by respiration or thoracic movement during E. Systolic blood pressure was measured by cuff method and echocardiographic indices such as heart rate, enddiastolic dimension (ED), and fractional shortening (FS) were determined at rest (R) and during maximal E. In N the following significant changes were observed during maximal E; pressure rate biproduct (13 ± 2 mmHg$\cdot$min$^{-1}\cdot 10^3 \rightarrow 20\pm3$ mmHg$\cdot$min$^{-1}\cdot 10^3$, $p<0.001$), ED (51 ± 5 mm $\rightarrow 48\pm6$ mm, $p<0.05$), and FS ($37\pm4\% \rightarrow 43\pm5\%$, $p<0.001$). In AR no significant change was observed between pressure-rate products in symptomatic and asymptomatic groups at R and during E, respectively. Significant changes in ED during E was observed only in asymptomatic AR (55 ± 4 mm $\rightarrow 51\pm6$, $p<0.05$). FS was within a normal range in both groups of AR at R. During maximal E, however, symptomatic group exhibited a decrease of FS ($33\pm7\% \rightarrow 28\pm5$, $p<0.05$), whereas the asymptomatic group showed a significant increase ($34\pm5\% \rightarrow 37\pm6\%$, $p<0.01$). Thus the present study revealed the different response of LV in symptomatic and asymp-

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Presented at the 23rd Meeting of the Japanese Soceity of Cardiovascular Sound held in Kurume, October 8-10, 1981
Received for publication October 30, 1981

tomatic AR to E in terms of ED and FS.

Key words
Transesophageal echocardiography Dynamic exercise Left ventricular performance Aortic regurgitation

Dynamic exercise echocardiography provides important informations concerning the response and cardiac reserve of the left ventricle against exercise.[1~8] During dynamic exercise, however, transthoracic echocardiography is often of limited value for the evaluation of left ventricular performance due to the disturbance in obtaining good quality image because of exaggerated

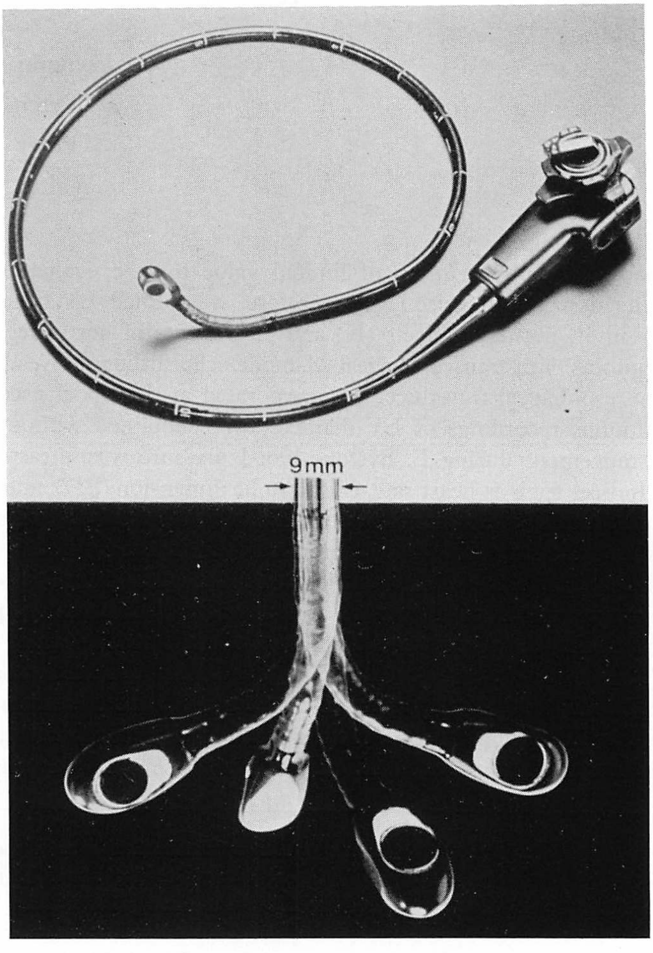


Fig. 1. Our newly developed transesophageal ultrasound transducer system for M-mode echocardiograms using a gastroscope.
The internal fiber optic system is removed and replaced with an ultrasound transducer cable. An esophageal 3.5 MHz transducer is incorporated into the tip of a commercially available gastroscope covered with soft plastic material. The outer diameter of the shaft of the gastroscope is 9 mm. The angulation and rotation is possible by turning the control knob.

respiration and chest wall motion. In order to overcome these difficulties during dynamic exercise the authors have developed a new transesophageal ultrasound transducer system using a gastroscope and applied it for the evaluation of left ventricular response to dynamic exercise in aortic regurgitation.

Materials and Methods

The study population consisted of 10 healthy subjects (5 males and 5 females, age 38±14 years) and 15 patients of aortic regurgitation with and without symptoms (9 males and 6 females ranging from 19 to 61 years in age with a mean of 36±12). Eight patients who were judged symptomatic had at least one of symptoms such as congestive heart failure, syncopy, lightheadedness, exercise intolerance and angina.

Transesophageal echocardiography:

A commercially available medium focused esophageal transducer (10 mm diameter, 3.5 MHz) was incorporated into the tip of the shaft of a gastroscope (**Fig. 1**). The manipulation of the ultrasound transducer such as the angulation, rotation and up and down movement of the probe, was under the examiner's control. Transesophageal M-mode echocardiograms were recorded with a Picker Echoview System 80 C on a high resolution fiber-optic continuous strip chart recorder (Honeywell visicorder Model 1856) at a paper speed of 50 and/or 100 mm/sec. Prior to the insertion of the probe atropine sulfate (0.5 mg) was administered intravenously in order to prevent bradycardia and hypersalivation. Shortly before the insertion of the probe local anesthesia of the throat was performed with xylocaine spray. A transesophageal M-mode echocardiogram of the left ventricle was obtained after proceeding the probe to a depth of about 40 cm, where the aortic valve was visualized, and by further counterclockwise rotation plus downward movement of the probe within

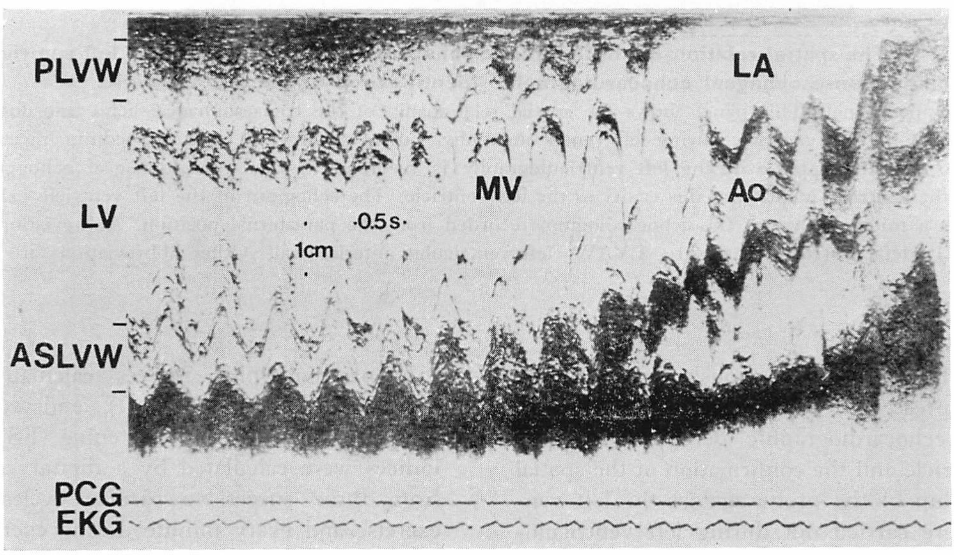


Fig. 2. Transesophageal echocardiographic M-mode scan from the left ventricle to the aorta.

By advancing the transducer system to a depth of about 40 cm after insertion, the aortic root is visualized. By a counterclokwise rotation and further downward movement of the gastroscope the left ventricle appears at the level of mitral valve leaflets. Abbreviations: PLVW=posterior left ventricular wall, LV=left ventricle, ASLVW=anteroseptal left ventricular wall, MV=mitral valve, LA=left atrium, Ao=aorta, PCG=phonocardiogram, EKG=electrocardiogram.

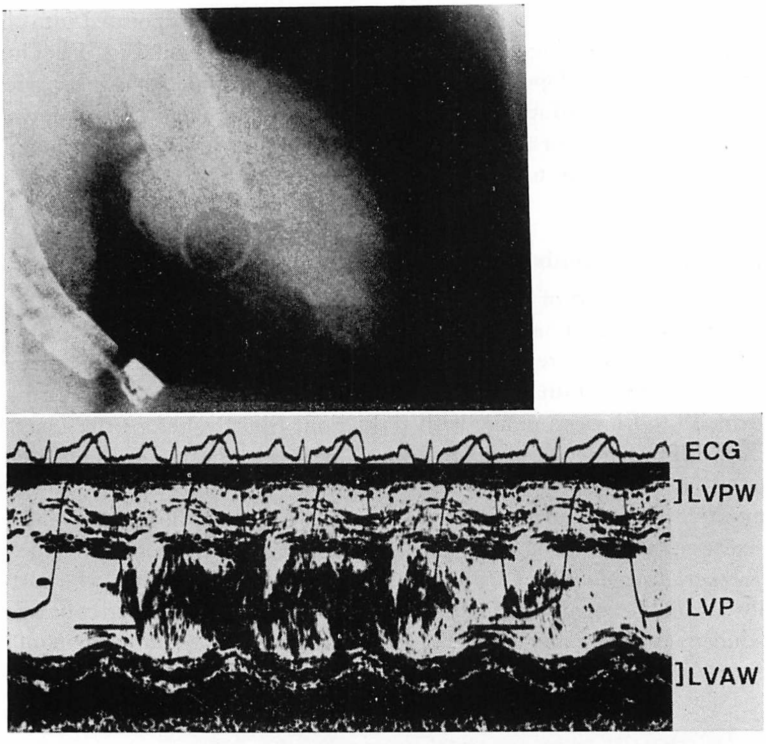


Fig. 3. The spatial relationship of the transesophageal echo probe against the left ventricle and the transesophageal echocardiographic identification of the left ventricle.

Upper panel: This panel shows the spatial relationship of the transesophageal echo transducer against the left ventricle during left ventriculography. Lower panel: The contrast medium injected into the left ventricle during left ventriculography is recorded in the transesophageal echogram of the ventricle identifying this cavity as the left ventricle. The echogram of the left ventricle exhibits a mirror image of the echocardiogram recorded from the parasternal position. Abbreviations: LVP=left ventricular pressure, LVAW=left ventricular anterior wall. Other abbreviations are as for figure 2.

the esophagus as has previously been reported by the present[9~11] and other authors[12] (**Fig. 2**). The echocardiographic identification of the left ventricle and the confirmation of the spatial relationship of the probe against the left ventricle were carried out during left ventriculography in a limited number of patients (**Fig. 3**). It should be noted that transesophageal M-mode echocardiograms of the left ventricle exhibit a mirror image of the echocardiogram recorded from the parasternal position as shown in **Fig. 4** since the ultrasound is emitted from behind the posterior left ventricular wall.

Echocardiographic indices calculated were enddiastolic dimension (ED), endsystolic dimension and fractional shortening (FS). These indices were calculated by a digital computer from three successive cardiac cycles before exercise and every minute during exercise.

Bicycle exercise test:

Supine bicycle exercise was initiated at a work load of 150 kpm/min. The load was increased by 150 kpm/min every three minutes until either one of angina, limiting dyspnea and fatigue was developed.

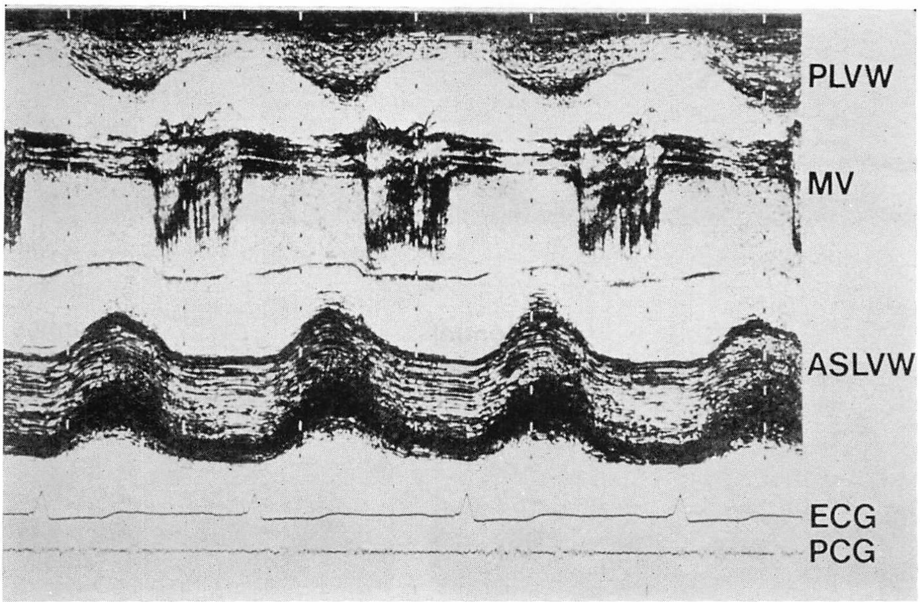


Fig. 4. An example of the transesophageal echocardiogram (TEE) of the left ventricle in a case with aortic regurgitation.

TEE of the left ventricle exhibits a mirror image of the echocardiogram recorded from the parasternal position. High frequency oscillations on both mitral leaflets indicate the high quality of TEE recordings. Abbreviations are as for figure 2.

Results

1. Normal control subjects:

Recordings of in-exercise transesophageal echograms of the left ventricle were satisfactory at all stages of work load as seen in **Fig. 5**. The influences of dynamic exercise in 10 normal subjects are summarized in **Fig. 6**. In accordance with the increase in heart rate, left ventricular enddiastolic diameter decreased continuously from 51 mm at rest to 48 mm under maximal exercise (**Fig. 6**, middle panel). The fractional shortening increased continuously from 37% at rest to 43% at the end of exercise.

2. Aortic regurgitation:

The in-exercise left ventricular echograms by the transesophageal method were also satisfactory at all stages of work load in both symptomatic and asymptomatic groups with aortic regurgitation (**Figs. 7, 8**). Echocardiograms in a case with symptomatic aortic regurgitation at rest and maximal exercise are shown in **Fig. 7**. The left ventricular enddiastolic diameter was markedly increased at rest to 76 mm and was further increased to 82 mm at maximal exercise. Fractional shortening decreased from 41% at rest to 37% at end point of exercise. In **Fig. 8** echocardiograms in a representative case of asymptomatic aortic regurgitation at rest and maximal exercise are shown. As before exercise the endocardium of both posterior and anterolateral left ventricular walls could be clearly recorded even under severe exercise. The enddiastolic diameter decreased from 74 mm to 69 mm and the fractional shortening increased from 36% to 38%.

The hemodynamic data of the two subsets of patients with aortic regurgitation are shown in **Fig. 9** through **11**. Mean arterial pressure and heart rate at rest and during exercise were not different between the two groups, and as a result the pressure-rate product showed no significant

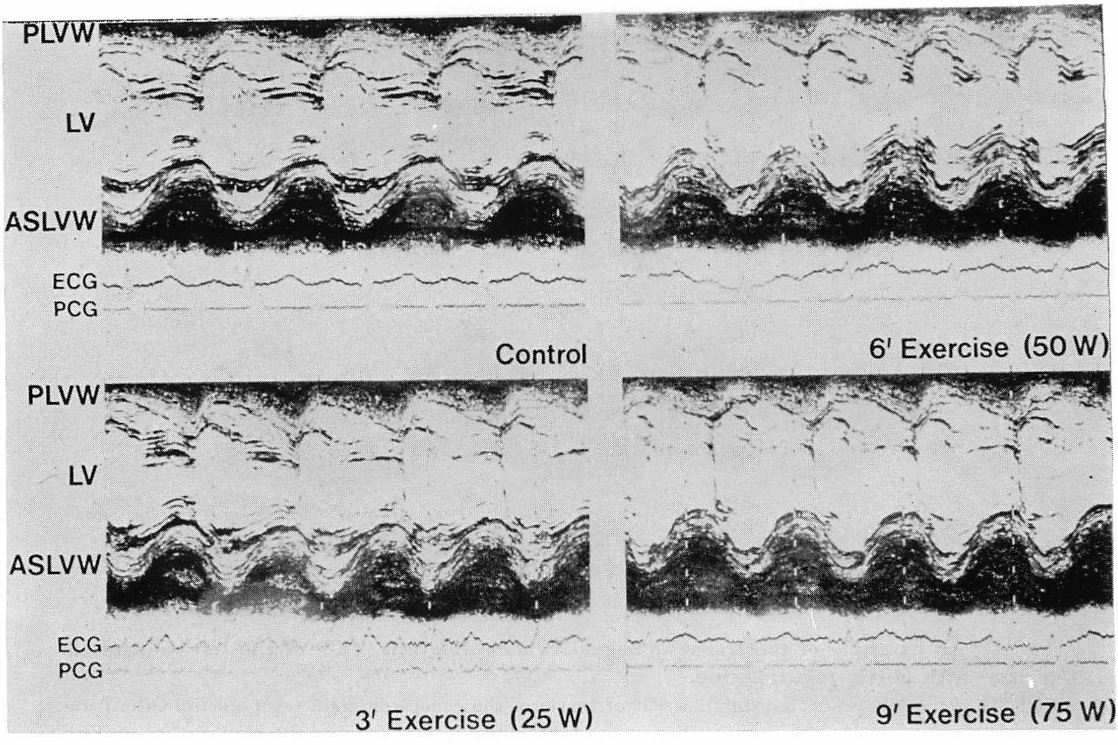
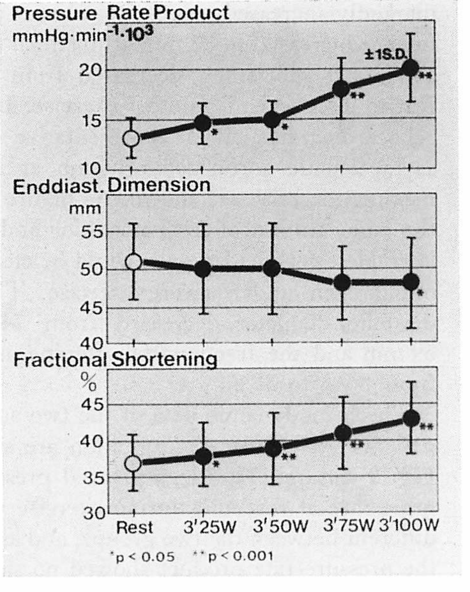


Fig. 5. TEE recordings of the left ventricle at different stages of exercise in a normal subject.

In this figure TEEs of the left ventricle at rest (control), during exercise at 25, 50 and 75 Watts are exhibited. Abbreviation are as for figure 2.



←**Fig. 6. Effects of dynamic exercise in 10 normal subjects.**

Top panel: The pressure rate product increased from 13 ± 2 mmHg·min^{-1}·10^3 to 20 ± 3 mmHg·min^{-1}·10^3 ($p<0.001$) at maximal exercise.

Center panel: Enddiastolic dimension decreased from 51 ± 5 mm to 48 ± 6 mm ($p<0.05$) at maximal exercise.

Bottom panel: Fractional shortening increased from $37 \pm 4\%$ at rest to $43 \pm 5\%$ ($p<0.001$) at maximal exercise.

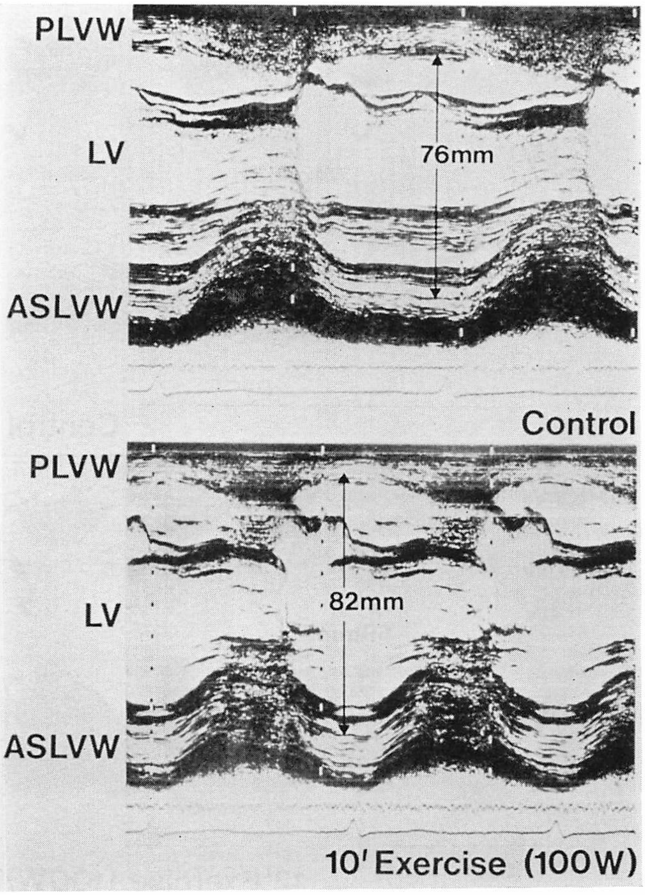


Fig. 7. Transesophageal echograms of the left ventricle at rest and maximal exercise in a symptomatic patient with aortic regurgitation.
The enddiastolic diameter is markedly increased already at rest to 76 mm (upper panel) and is further increased to 82 mm at maximal exercise (lower panel). The fractional shortening decreased from 41% to 37%. Abbreviations are same as for figure 2.

difference in these two subsets (**Fig. 9**). Left ventricular enddiastolic diameter at rest in symptomatic patients with aortic regurgitation was 69 mm in average and was significantly larger than that of 55 mm in asymptomatic patients. A significant decrease in the left ventricular enddiastolic diameter like in the asymptomatic group was not observed in the symptomatic group (**Fig. 10**).

Fractional shortening was within a normal range at rest in both symptomatic and asymptomatic groups except one symptomatic case (**Fig. 11**). During maximal exercise fractional shortening became subnormal in four patients and the mean value of fractional shortening fell significantly from 33±7% to 28±5% ($p<0.05$) in the symptomatic group (**Fig. 11**). In contrast to the symptomatic patients a significant increase in fractional shortening was observed in the asymptomatic group (34±5% → 37±6%, $p<0.01$) (**Fig. 11**). However, the fractional shortening in 3 of 7 asymptomatic patients remained unchanged.

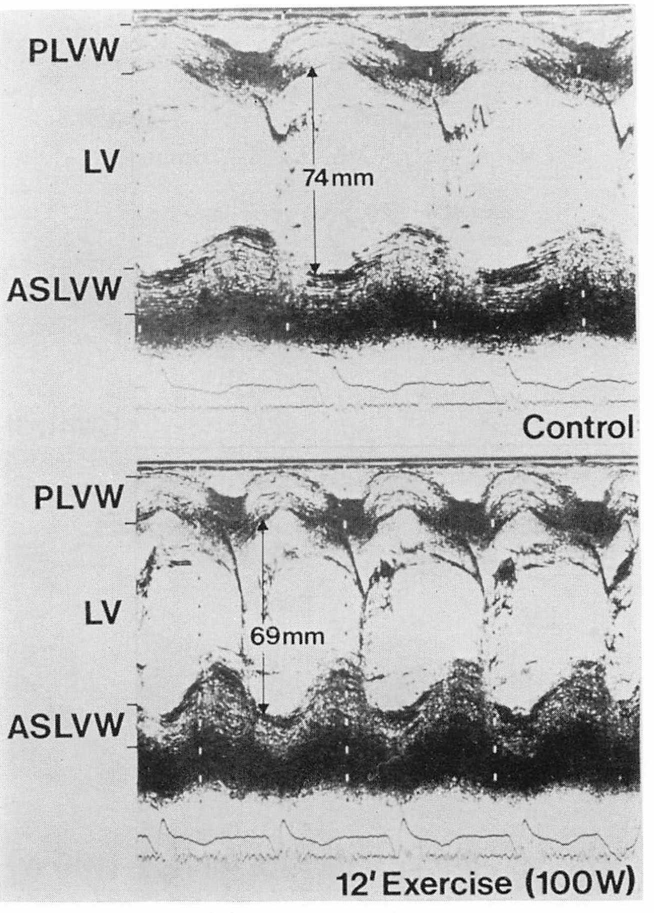


Fig. 8. Transesophageal echograms of the left ventricle at rest and maximal exercise in an asymptomatic patient with aortic regurgitation.

The enddiastolic dimension is 74 mm at rest (upper panel) and is decreased to 69 mm at maximal exerxise (lower panel). Fractional shortening increased from 36% to 38%. Abbreviations are same as for figure 2.

Discussion

Recently several reports have been made on exercise echocardiography to assess left ventricular performance.[1~8] Application of echocardiography to evaluate left ventricular size and performance during exercise possesses the advantages of noninvasiveness and repeatability. Left ventricular diameter, wall thickness changes and the time point of mitral valve opening and closing can be measuresd continuously by echocardiography, in contrast to left ventriculography, before, during and after interventions without any risk and alteration of the physiologic response of the myocardium to the examination. However, exercise echocardiography reported in the literature[2~8] using the parasternal approach reveals not a few technical problems in obtaining adequate images. This is mainly caused by an exaggerated chest wall motion and interposition of lung tissue in the path of ultrasound beam due to exercise induced hyperventilation. Three different postures for exercise have been adopted among investigators.

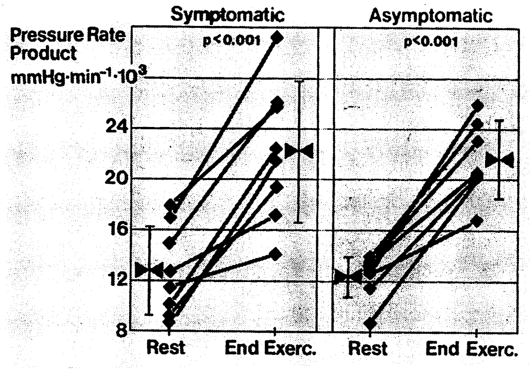


Fig. 9. Pressure rate product at rest and maximal exercise in symptomatic and asymptomatic patient groups of aortic regurgitation.

Left panel: In symptomatic patients pressure rate product increased significantly from 13 ± 3 mmHg·min^{-1}·10^3 at rest to 22 ± 6 mmHg·min^{-1}·10^3 at maximal exercise ($p < 0.001$). Right panel: In asymptomatic patients pressure rate product increased significantly from 12.5 ± 2 mmHg·min^{-1}·10^3 at rest to 21.5 ± 3 mmHg·min^{-1}·10^3. No significant difference is shown in pressure rate products between the two groups at rest and maximal exercise, respectively.

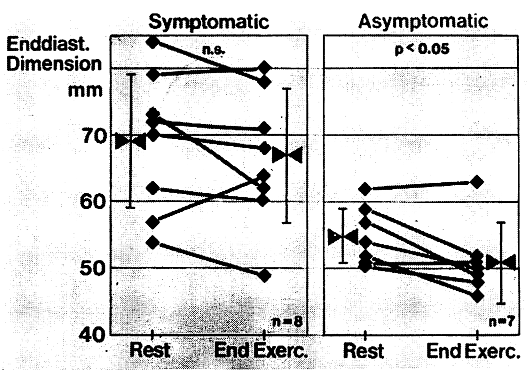


Fig. 10. Enddiastolic dimension at rest and maximal exercise in symptomatic and asymptomatic patient groups of aortic regurgitation.

Left panel: In the symptomatic patients group enddiastolic dimension shows no significant change between control stage (69 ± 10 mm) and end of exercise (67 ± 10 mm). Right panel: In asymptomatic patients group enddiastolic dimension shows a significant decrease between the control stage (55 ± 4 mm) and end of exercise (51 ± 6 mm) ($p < 0.05$).

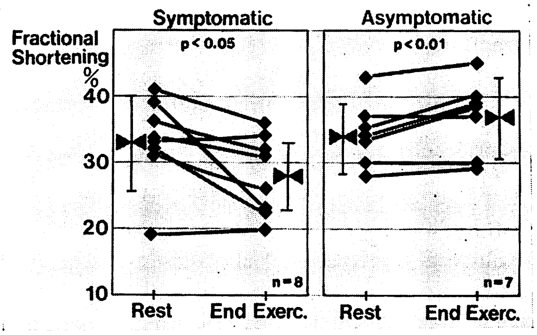


Fig. 11. Fractional shortening at rest and maximal exercise in symptomatic and asymptomatic patient groups of aortic regurgitation.

Left panel: In the symptomatic patients group fractional shortening fell from $33 \pm 7\%$ at rest to $28 \pm 5\%$ at maximal exercise ($p < 0.05$).

Right panel: In the asymptomatic patients group the fractional shortening increased to the contrary from $34 \pm 5\%$ at rest to $37 \pm 6\%$ at maximal exercise ($p < 0.01$).

Since the clinical application of transesophageal echocardiography by Frazin et al.[13] only several studies[9~12,14,15] have been made because of the uniqueness of the technique and also the difficulty to control the transducer. One of the present authors could sucessfully apply this technique to the assessment of left ventricular performance during open heart surgery. However, in order to apply this technique further to the exercise test of the left ventricle the transducer system had to be imporved for a better control of the probe. The incorporation of the ultrasound transducer into the tip of a gastroscope facilitated the positioning, rotation and angulation of the transducer, so that the transducer was always under the examiner's control.

In the present study a decrease in enddiastolic diameter was shown at the maximal point of dynamic exercise in normal subjects and asymptomatic aortic regurgitation indicating good reserve of left ventricular pump function. In symptomatic aortic regurgitation no significant decrease was observed in the enddiastolic diameter at the endpoint of exercise revealing a decrease in the reserve of left ventricular pump function.

In the present study changes in fractional shortening during maximal exercise in symptomatic and asymptomatic aortic regurgitation showed the same tendency as the exercise ejection fraction reported by Borer and associates[16]. Although exercise-induced dysfunction could be evaluated by fractional shortening in the present study, it should be carefully considered whether the abnormality in exercise ejection fraction indicates the impairment in the intrinsic contractile state of the myocardium. As previously reported exercise fractional shortening is affected by alteration in preload and afterload.[17,18]. However Borer and associates showed in their preliminary studies the presence of an intrinsic left ventricular dysfunction and an abnormal exercise ejection fraction in patients with aortic regurgitation based on the fact that ejection fraction during exercise often did not revert to normal even after the preload and afterload were reduced or after the replacement of aortic valve.[19]

Even after considering the above discussion the potential usefulness of exercise transesophageal echocardiography was demonstrated in this study. A decrease in the cardiac reserve was clearly been shown in symptomatic patients. In 3 patients with asymptomatic aortic regurgitation fractional shortening remained unchanged during maximal exercise and this indicates the possibility of detecting reduced functional reserve at the early stage by the present method. Thus the present method seems to offer a helpful guide to the prognosis of the present morbus.

要　　約

経食道心エコー図法による大動脈弁閉鎖不全症の安静時および運動負荷時左室機能評価

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通常の経胸壁心エコー図法による運動負荷時左室機能評価には，少なからぬ問題点がある．そこで我々は経食道 M モード心エコー図法を用い，自転車エルゴメーターによる最大運動負荷時左室機能を，健常 (N) 10 例，大動脈弁閉鎖不全症 (AR) 15 例にて検討した．AR 群は有症状群 (SAR) 8 例と無症状群 (AAR) 7 例に分け検討した．市販の食道用探触子をガストロスコープ先端に装着した装置を用いることにより，運動負荷に伴う過大呼吸，胸郭運動などに障害されずに，良質の左室エコー図を連続的に記録し得た．収縮期血圧はカフ圧にて測定し，心拍数，拡張末期径 (ED)，径短縮率 (FS) 等の心エコー図による指標を，安静時および最大運動負荷時にて求めた．N 群では最大運動負荷時ダブルプロダクトが 13 ± 2 mmHg・$min^{-1}\cdot10^3 \rightarrow 20\pm3$ mmHg・$min^{-1}\cdot10^3$, $p<0.001$; ED が 51 ± 5 mm $\rightarrow 48\pm6$ mm ($p<0.05$), FS は $37\pm4\% \rightarrow 43\pm5\%$ ($p<0.001$) と，有意な変化が認められた．AR 群にて安静時および運動負荷時それぞれにおけるダブルプロダクトは，SAR 群，AAR 群間で有意差がなかった．運動負荷による ED の有意な変化は，AAR 群にのみみられた (55 ± 4 mm $\rightarrow 51\pm6$ mm, $p<0.05$)．EF は安静時，AAR, SAF 両群ともに正常範囲にあったが，最大運動負荷時に SAR 群で有意に減少し ($33\pm7\% \rightarrow 28\pm5\%$, $p<0.05$)，AAR 群では有意に増加した ($34\pm5\% \rightarrow 37\pm6\%$, $p<0.01$)．本研究により，SAR 群と AAR 群における左室の運動負荷に対する反応が異なることが，ED, FS の指標を通して示された．

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