Regional differences in myocardial work of the left ventricle in patients with idiopathic dilated cardiomyopathy: Implications for the surgical technique used for left ventriculoplasty

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Objectives: In this study we measured regional myocardial work of the left ventricle in patients with dilated cardiomyopathy and examined the existence of regional differences in myocardial work.

Background: Left ventriculoplasty aims to improve the ejection fraction by excluding a region with decreased wall motion and decreasing wall tension. If regional differences in myocardial work are present, left ventriculoplasty will be more effective when a region with decreased myocardial work is excluded.

Methods: The study group consisted of 10 patients with idiopathic dilated cardiomyopathy. Regional work of the ventricle normalized to a unit volume of myocardium (RWM) is given as follows: RWM = –∫σd[ln(1/H)], where σ is mean wall stress, and H is wall thickness of the region. After right-sided catheterization, left ventricular pressure was measured with a 3F micromanometer catheter. Echocardiography was performed simultaneously, and a short-axis view of the left ventricle at the level of the papillary muscles was obtained. The derived M-mode image was recorded with left ventricular pressure. σ – ln(1/H) relations for the ventricle were delineated, and regional work of the interventricular septum and posteriorinferior wall were determined. Relationships between regional work of the myocardium and wall thickness, interventricular septal regional work of the myocardium and right ventricular systolic pressure, and right ventricular ejection fraction were also studied.

Results: Interventricular septal regional work ranged from –0.84 to 3.34 mJ/cm³ (0.74 ± 1.51 mJ/cm³). Postero Inferior wall regional work ranged from 1.59 to 4.29 mJ/cm³ (2.77 ± 0.86 mJ/cm³). In the study group, interventricular septal regional work was lower than postero inferi or wall regional work (P < .05). In 8 of these 10 patients, interventricular septal regional work was lower than postero inferior wall regional work. In the other 2 patients, conversely, interventricular septal regional work was higher than postero inferior wall regional work.

Conclusions: The existence of differences in regional work between the interventricular septum and the postero inferior wall suggests the importance of the evaluation of regional work in the selection of an effective treatment for dilated cardiomyopathy.
left ventriculoplasty (Batista operation and modified Dor operation) is recognized as one option for the surgical treatment of dilated cardiomyopathy (DCM).5-7 Left ventriculoplasty aims to improve the ejection fraction by excluding a region with decreased wall motion and decreasing wall tension. Myocardial damage in DCM is assumed to be diffuse, regardless of the region.8,9 Wherever the left ventricular (LV) wall is excised, as long as the diameter after the ventriculoplasty is the same, the result of left ventriculoplasty is expected to be the same if the degree of myocardial damage is uniform and all regions are working uniformly. However, if regional differences in myocardial work are present, left ventriculoplasty will be more effective if a region with decreased myocardial work is excluded. In this study we measured regional myocardial work of the left ventricle in patients with DCM and examined the existence of regional differences in myocardial work.

Methods

Study Patients

From July 1999 to January 2000, 15 subjects in whom DCM was suspected underwent cardiac catheterization at our institute. Five of the subjects were excluded from the study group: 2 with suspected secondary DCM; 2 with poor echocardiographic visibility; and 1 with total occlusion of the left anterior descending artery revealed by means of arteriography. The study group consisted of 10 patients with idiopathic DCM. The patients (9 men and 1 woman; mean age, 40.9 ± 16.1 years; age range, 16-68 years) were enrolled according to the following criteria: (1) LV end-diastolic dimension of greater than 60 mm; (2) global LV hypokinesia and fractional shortening of less than 0.20; (3) intact coronary arteries; (4) endomyocardial biopsy; and (5) clinical history that was not contradictory to the diagnosis of DCM. The patients were scheduled for cardiac catheterization mainly to obtain a definitive diagnosis of DCM, as well as for this study. Informed consent was obtained from all subjects.

Methodology

The method of measurement of regional myocardial work in this study was previously described by Nakano and colleagues10,11 and Sugawara and colleagues.12 The normalized unit volume of regional work of the myocardium (RWM) is given as follows:

$$RWM = -\frac{d}{\partial(\ln(1/H))}$$

where $\sigma$ is mean wall stress and $H$ is wall thickness of the region.

Assuming the left ventricle to be a spherical model, $\sigma$ is expressed as follows:

$$\sigma = PD/4H$$

where $P$ is LV pressure, and $D$ is LV short-axis diameter. Hence, RWM can be measured with the changes in wall thickness and the short-axis diameter and the pressure of the left ventricle. The changes in $H$ and $D$ can be easily measured by conventional echocardiography.

Cardiac Catheterization

Cardiac catheterization was performed in the catheterization laboratory of The Heart Institute of Japan, Tokyo Women's Medical University. The subjects were in the fasting state, and previous medications had not been discontinued before the examination. All subjects were being treated with oral medications only and were in stable condition.

The right and left sides of the heart were catheterized through the femoral vein and artery. A 7F triple-lumen thermistor catheter (Harmac Medical Products, Inc, Buffalo, NY) was positioned in the pulmonary artery, and pulmonary capillary wedge pressure was measured. Then pulmonary arterial pressure was measured. The thermodilution method was used to determine cardiac output and stroke volume. The catheter was connected to a cardiac output computer (Baxter Com-1; Baxter Healthcare Corporation, Irvine, Calif). After cardiac output had been measured, right ventricular and right atrial pressure were measured. After right-sided catheterization, LV pressure was measured with a 3F micromanometer catheter (Millar Instruments, Inc, Houston, Tex), which was inserted through a pigtail catheter positioned in the left ventricle. Echocardiography was performed, simultaneously, by means of a 2.5-MHz transducer (Hewlett-Packard Co, Andover, Mass) connected to SONOS 1000 (Hewlett-Packard). The transducer was placed on the third or fourth intercostal space at the left sternal border, and a short-axis view of the left ventricle at the level of the papillary muscles was obtained. The cursor was positioned centrally in the 2-dimensional image of the short-axis cross section of the left ventricle, and the derived M-mode image was recorded with the LV pressure on a strip chart at a paper speed of 100 mm/s. The measurements were recorded while the patients held their breath after expiration. After the recording, left ventriculography, if hemodynamically acceptable, was performed. After selective coronary angiography and right ventriculography, endomyocardial biopsy of the right ventricle was performed for the definitive diagnosis of DCM.

Data Analysis

On the strip chart, on which the short-axis M-mode view of the left ventricle was recorded simultaneously with LV pressure, the right ventricular and LV endocardium of the interventricular septum and the endocardium and epicardium of the posteroinferior wall were traced manually over one cardiac cycle. Then motions of the interventricular septum and posteroinferior wall and LV pressure were digitized with optical graph recognition software (Flexitrace version 1.03; Tree Star Inc, San Carlos, Calif). The data were fed into a computer system, $\sigma = \ln(I/H)$ relations for the ventricle were delineated, and RWM of the interventricular septum (RWMs) and the posteroinferior wall (RWMp) were determined. The area that is surrounded by the $\sigma = \ln(I/H)$ loop during one cardiac cycle is equal to RWM. If the loop rotates counterclockwise, the region performs positive work. If the loop rotates clockwise, the region performs negative work (ie, work is done on that region by the surrounding myocardium). RWMs and RWMp were then compared. Relationships between RWM and wall thickness, RWMs and right ventricular systolic pressure, and right ventricular ejection fraction were also studied.
LV mass was calculated from echocardiographic data by the method of Devereux and Reichek.13

**Statistical Analysis**
For each subject, data obtained from 3 measurements were averaged. Values were expressed as the mean value ± 1 standard deviation. A matched paired t test was used for the comparison between RWMs and RWMp in the study group. SAS version 6.12 (SAS Institute, Inc, Cary, NC) was used as statistical software for the analysis.

**Results**
Figure 1, A, shows a representative recording of an M-mode short-axis echocardiographic image at the level of the papillary muscles with a simultaneous LV pressure recording in a patient with DCM. Figure 1, B, shows manually traced lines of the wall motions and the LV pressure. Figure 1, C, shows \( \sigma – \ln(1/H) \) loops. The area of the loop of the interventricular septum is smaller than that of the posteroinferior wall. Also, it rotates clockwise. RWMs was –1.47 mJ/cm³, and RWMp was 4.20 mJ/cm³.

Tables 1 and 2 show data of echocardiography and catheterization, respectively, in 10 patients with DCM. The LV diastolic dimension was increased to 68 ± 6.3 mm. The fractional shortening and the ejection fraction were decreased to 0.104 ± 0.035 and 27.1% ± 9.7%, respectively. The ejection fraction and the systolic pressure of the right ventricle were 41.4% ± 14.2% and 33.4 ± 11.7 mm Hg, respectively. RWMs ranged from –0.84 to 3.34 mJ/cm³ (0.74 ± 1.51 mJ/cm³). RWMp ranged from 1.59 to 4.29 mJ/cm³ (2.77 ± 0.86 mJ/cm³). In the study group RWMs was lower than RWMp (\( P < .05 \)).
Among these 10 patients, RWMs was lower than RWMp in 8 patients. In the other 2 patients, conversely, RWMs was higher than RWMp. In 4 of the 8 patients in whom RWMs was smaller than RWMp, the RWMs value was negative. Neither of the 2 patients in whom RWMs was higher than RWMp had negative RWMp values.

Figure 2 shows relationships between the thickness of the interventricular septum and RWMs and the thickness of the posteroinferior wall and RWMp. No correlation was found.

Figure 3 shows relationships between right ventricular ejection fraction, right ventricular systolic pressure, and RWMs. Right ventricular ejection fraction was evaluated by means of scintigraphy. No correlation was found.

The total work (TW) was derived as the product of stroke volume and mean arterial pressure:

\[ TW = \text{Stroke Volume} \times \text{Mean Arterial Pressure} \]

Figure 4 shows the product of RWMs and LV mass and that of RWMp and LV mass and TW of the left ventricle in each patient (where the density of myocardium is regarded as 1 g/cm³).

Discussion

The validity of this method has already been discussed by Nakano and colleagues and Sugawara and colleagues. Because RWM can be measured when an M-mode short-axis view of the left ventricle and LV pressure are obtained, this method is clinically applicable. Also, because RWM is derived as a value per unit volume of myocardium, comparison of RWM between different regions in the same ventricle and that among different regions in different ventricles is possible.

TABLE 1. Demographic and echocardiographic data

<table>
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<th>Patient No.</th>
<th>Sex</th>
<th>Age (y)</th>
<th>NYHA</th>
<th>LVDd (mm)</th>
<th>LVDs (mm)</th>
<th>LVFS</th>
<th>IVST (mm)</th>
<th>PWT (mm)</th>
<th>LV mass (g)</th>
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NYHA, New York Heart Association classification; LVDd, LV diastolic diameter; LVDs, LV systolic diameter; LVFS, LV fractional shortening; IVST, interventricular septal thickness; PWT, posteroinferior wall thickness.

TABLE 2. Catheterization data

<table>
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<tr>
<th>Patient No.</th>
<th>SV (mL)</th>
<th>MAP (mm Hg)</th>
<th>CI (L · min⁻¹ · m⁻²)</th>
<th>LVEF (%)</th>
<th>RVEF (%)</th>
<th>RVsp (mm Hg)</th>
<th>HR (beats/min)</th>
<th>RWMs (mJ/cm³)</th>
<th>RWMp (mJ/cm³)</th>
<th>Basic rhythm</th>
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<td>84</td>
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<td>2.96</td>
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<td>1.51</td>
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SV, Stroke volume; MAP, mean arterial pressure; CI, cardiac index; LVEF, LV ejection fraction; RVEF, right ventricular ejection fraction; RVsp, right ventricular systolic pressure; HR, heart rate; Af, atrial fibrillation; SR, sinus rhythm; AFL, atrial flutter; PVC, premature ventricular contraction.
Comparison Between the Normal Group and the Study Patients

Figure 5 shows the comparison of RWM between a group of normal subjects and the group of our study patients with DCM. The normal group data were taken from the article by Nakano and colleagues. In the normal group RWMs is slightly smaller than RWMp, but the difference is not significant. In the DCM group RWMs and RWMp values are smaller than those of the normal group \( P < .05 \). In this comparison, adjustments of age and sex were not conducted.

Validity of the RWM Values

It is known that the product of RWM and LV mass correlates well with the TW in normal subjects. In patients in whom RWMs was lower than RWMp, TW had a value between RWMp \( \times \) LV mass and RWMs \( \times \) LV mass (Figure 4). This relationship showed that RWMs is lower than RWM averaged over the whole left ventricle, and RWMp is higher. In the 2 patients (patients 3 and 9) in whom RWMs was higher than RWMp, TW had a value between RWMs \( \times \) LV mass and RWMp \( \times \) LV mass in one patient, but TW was higher than both RWMp \( \times \) LV mass and RWMs \( \times \) LV mass.
Regional Differences of Myocardial Work in Patients with DCM

It is generally thought that the degree of myocardial damage in patients with DCM is uniform, regardless of the region. However, recent studies suggest that LV wall motion is not always diffusely hypokinetic and that regional differences in the degree of myocardial damage are present. In our study in 8 of 10 patients with DCM, RWMs was lower than RWMp.

In patients with DCM, paradoxical motion of the interventricular septum is sometimes identified. This can be partly attributed to decreased contractility of the interventricular septum in systole and elevation of right ventricular pressure and decreased diastolic function caused by LV failure in diastole. In our 10 patients no apparent paradoxical motion of the interventricular septum was identified. The influence of elevated right ventricular pressure on RWMs was anticipated, but no significant correlation was found. Godoy and colleagues evaluated LV filling by means of color kinesis in patients with DCM and revealed differences in regional diastolic function. Diastolic function of the interventricular septum was decreased in their recording.

In our study no correlation between wall thickness and RWM was identified. It might have been due to the inability of echocardiography to distinguish between a normal thick muscle pulled by adjacent muscle versus one that is distorted by contraction. Maehashi and colleagues discussed relationships between segmental LV wall motion abnormalities and pathologic findings in patients with DCM. In their study, patients were categorized into uniform and nonuniform groups on the basis of the patterns of myocardial fibrosis. No significant correlation was found between the degree of wall motion abnormality and fibrosis in the former group, and the wall motion abnormality correlated with the degree of fibrosis in the latter group. Of the 12 patients with DCM in their study, 8 belonged to the uniform group, in which more severe segmental wall motion abnormalities were found in the interventricular septum than in the LV free wall, although no significant difference was observed in the fibrosis ratio among these regions.

Relation to Left Ventriculoplasty

Recently, left ventriculoplasty is being performed as one option for surgical treatment for DCM. If regional differences in myocardial work were present, and if a region with

Figure 4. Relationships between RWMs × LV mass, RWMp × LV mass, and TW of the left ventricle in 10 patients.

Figure 5. Regional work of the myocardium in the normal and DCM groups. The difference between the 2 groups was statistically significant (P < .05) in both walls. Values for the normal group are from J Am Coll Cardiol. 1988;12:1442-8.
decreased myocardial work was excluded, left ventriculoplasty would be effective. In contrast, if a region with greater myocardial work was excluded, the TW would be decreased. The Batista operation excludes the free wall between the 2 papillary muscles (the same region in which we evaluated RWm) and reduces LV diameter, which is expected to decrease wall tension and increase ejection fraction. Another important role of this operation is to reduce mitral regurgitation, which should lead to improvement in overall cardiac function. However, application of this procedure to a heart with cardiac function mainly dependent on the postero-inferior wall of the left ventricle should be considered carefully. In fact, in 8 of 10 patients in our study, this region was doing regional work higher than the average regional work (TW/LV mass; Figure 4). In the modified Dor operation, ejection fraction is improved by excluding a region extending from the anterior wall of the left ventricle to the interventricular septum by use of an endoventricular circular patch. The area of exclusion is located more basally than in the original Dor operation. The patch, which now forms a part of the LV wall, does not do any work. When the loss of regional work caused by the patch is overweighed by a decrease in wall tension and the improvement of ejection fraction caused by the reduction of LV diameter, this operation is expected to have a good effect on overall cardiac function. A heart with decreased RWms may be a suitable case for this operation. The evaluation of RWM in the left ventricle by this method should be of value when deciding whether to perform left ventriculoplasty.

Suma and colleagues7 performed the volume reduction test. When the left ventricle was decompressed during cardiopulmonary bypass, they assessed the LV wall thickening by means of echocardiography to decide which region should be excluded in the left ventricle. In our study RWM was measured by means of the changes in wall thickness and LV pressure. A common feature of the 2 methods is that wall thickening is related to regional function. Our method may enable us to decide which region should be excluded before cardiopulmonary bypass.

Study Limitations

At present, this method enables us to evaluate RWM in only 2 regions of the left ventricle. However, tagged magnetic resonance imaging has the potential for evaluating RWM in various regions of the left ventricle because it can estimate the positions of the epicardial and endocardial surfaces.21,22 The accuracy of calculating regional work is limited by the accuracy in determining the mean wall stress. The assumption that the whole ventricle is spherical may include a certain amount of error in mean wall stress.10 If the radius of local curvature of the ventricular wall in the beating heart can be measured, it is possible to improve the accuracy in
terpreting mean wall stress. Tagged magnetic resonance imaging also has potential in this respect.

In conclusion, in this study RWM was evaluated in patients with idiopathic DCM. In 8 of 10 patients, RWms was lower than RWmp. In the other 2 patients, RWms was higher than RWmp. The existence of the differences in regional work between the interventricular septum and the postero-inferior wall suggests the importance of the evaluation of regional work in the selection of an effective treatment for DCM.

References


