Thallium-201 Myocardial Imaging for Evaluation of Right-Ventricular Overloading

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This study evaluated the specificity and sensitivity of Tl-201 myocardial imaging in the detection of right-ventricular (RV) overloading. Right-ventricular visualization (RVV) after administration of Tl-201 chloride was studied on 99 patients with various heart diseases. Tracer uptake in the free wall of the RV was graded in four degrees. The degree of RVV was compared with the findings of cardiac catheterization. The comparisons indicated that the uptake increased in step with the increases in RV systolic pressure, RV end-diastolic pressure, mean pulmonary arterial pressure, total pulmonary vascular resistance, and stroke-work index of the right ventricle (P < 0.05–P < 0.001). Of the patients with visible RV, all but three had RV overloading, and all but three of those without RVV had normal RV systolic pressure. Myocardial images also reflect the type of RV overloading. In patients with RV pressure overloading, the septum showed a tendency to appear straight. In patients with atrial septal defect leading to RV volume overloading, the RV cavity was dilated, the LV image small, and the septum convex toward the RV cavity. These results indicate that Tl-201 myocardial imaging is a sensitive and specific method for the study of RV overloading.

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Diagnosis of right-ventricular (RV) overloading is not always easy by conventional noninvasive methods such as x-ray, electrocardiographic, and echocardiographic examinations (*1–5*). The reliability of right-heart catheterization for detection of overloading is high, but repeated studies are undesirable.

Thallium-201 myocardial imaging has made possible the noninvasive evaluation of myocardial blood perfusion (*6–9*). At present, however, most myocardial imaging studies are concerned with left-ventricular (LV) perfusion defects caused by ischemic heart disease (*10–21*). Since perfusion of intravenously administered Tl-201 in the myocardium is proportional to the coronary blood flow, it has been assumed that enhancement of the right coronary blood flow would result in intensified perfusion of Tl-201 in the RV myocardium, and thus permit visualization of the RV free wall (*3,22,23*).

In line with this assumption, we sought to determine whether myocardial imaging would be effective in evaluating RV overloading by examining the incidence and degree of RV free-wall visualization, and by comparing the results with the findings of cardiac catheterization. We also wished to find out whether the scintigrams could distinguish between volume overloading and pressure overloading of the right ventricle.

MATERIALS AND METHODS

Myocardial imaging was performed on 99 adult patients, including 15 with coronary-artery disease,

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17 with cardiomyopathy, 22 with congenital heart disease, 32 with valvular heart disease, two with chronic cor pulmonale, one with primary pulmonary hypertension (PPH), and ten with normal hearts. Diagnosis was made on the basis of the patient's clinical history, clinical evaluation, electrocardiography, and cardiac catheterization. All but six normal subjects had cardiac catheterization with LV cineangiography and selective coronary arteriography. Cardiac catheterization was performed by the femoral approach. Intracardiac and vascular pressures were recorded with Statham 23-db transducers, placed 5 cm below Louis angle. Cardiac output was measured by combining the Fick method with a thermo-dilution technique using a Swan-Ganz thermo-dilution catheter.

The group with coronary-artery disease consisted of six patients with angina pectoris and nine with myocardial infarction. The cardiomyopathy cases included 14 of the hypertrophic type and three of the congestive type. In the congenital group there were eight with atrial septal defect (ASD), three with ventricular septal defect (VSD), two with VSD and Eisenmenger's syndrome, three with the tetralogy of Fallot, three with pulmonary stenosis, and three with other miscellaneous conditions. The group with valvular heart disease included 18 with mitral stenosis (MS), five with aortic regurgitation (AR), two with mitral regurgitation, four with MS and AR, and three with other combined valvular heart conditions. In 81 patients, cardiac catheterization was performed within 24 hr of the myocardial imaging, and the findings of the two studies were compared.

Myocardial imaging was performed on patients at rest. Ten minutes after i.v. injection of 2 mCi of Tl-201 chloride in the supine position, myocardial imaging was begun and completed within 60 min. Images were obtained with a gamma camera, using a low-energy high-resolution parallel-hole collimator. The 30% energy window was set symmetrically over the mercury x-ray peak. Five hundred thousand counts were recorded in the total image, with shielding of the abdomen to decrease background. A five-projection study was made with the detector placed in the anterior, left anterior oblique (LAO) 30°, 45°, 60°, and left lateral projections. Analog images were recorded with Polaroid film and a microdot imager without additional contrast enhancement or computer processing.

Unprocessed photoscans were read by two of the authors without reference to the clinical data. When Tl-201 activity was visible in the region of the right ventricle, concentration of the tracer activity was graded according to Cohen's criteria (*3*):

0 = activity in the region of the RV equal to that of the background;
1+ = RV activity less than that in the LV free wall;
2+ = RV activity equal to that of the LV myocardium;
3+ = RV activity greater than that of the LV free wall.

Tracer concentration in the RV free wall was judged at a spot near the region of the tricuspid valve to avoid interference from the liver. Measurement of the apparent thickness of the RV myocardium was made directly from the scintiphotos. Judgment and measurement of the visible RV free wall was made from the view in which the right ventricle was best separated from the left ventricle. At the same time, a thickness measurement of the LV free wall was made, both RV and LV being judged at the mid point of each ventricular free wall, and with magnification corrections calculated from the data of a phantom study. The RV cavity was judged to be dilated when it appeared as large as the LV cavity on the LAO view.

RESULTS

Incidence of RV visualization. The incidence of a visible RV free wall is tabulated in Table 1. The RV free wall was best separated from the left ven-

TABLE 1. INCIDENCE OF VISUALIZATION OF THE RIGHT-VENTRICULAR FREE WALL IN PATIENTS WITH VARIOUS HEART DISEASES

	Degree of right-ventricular visualization			
Disease	0	1+	2+	3+
Normal	9	1	0	0
Angina pectoris	6	0	0	0
Myocardial infarction	7	2	0	0
Hypertrophic cardiomyopathy	12	2	0	0
Congestive cardiomyopathy	0	3	0	0
Atrial septal defect	0	2	6	0
Ventricular septal defect	0	3*	1	1
Tetralogy of Fallot	0	0	2	1
Pulmonary stenosis	0	2	1	0
Other congenital heart diseases	3	0	0	0
Mitral stenosis	5	13	0	0
Aortic regurgitation	5	0	0	0
Mitral regurgitation	2	0	0	0
Mitral stenosis + aortic regurgitation	3	1	0	0
Other valvular heart diseases	2	0	0	1
Chronic cor pulmonale	0	2	0	0
Primary pulmonary hypertension	0	0	1	0

* In one patient the VSD was accompanied by aortic regurgitation.

TABLE 2. A COMPARISON OF DEGREE OF RIGHT-VENTRICULAR VISUALIZATION WITH FINDINGS OF CARDIAC CATHETERIZATION

Degree of right-ventricular visualization	Right-ventricular systolic pressure (mm Hg)	Right-ventricular end-diastolic pressure (mm Hg)	Mean pulmonary arterial pressure (mm Hg)
0	22.7 ± 5.2 (40)	4.3 ± 1.6 (39)	13.0 ± 3.6 (39)
1+	39.1 ± 13.8 (26)	6.5 ± 3.3* (26)	22.8 ± 8.8 # (25)
2+	74.1 ± 44.8 (11)	7.5 ± 3.2* (11)	33.9 ± 21.2 # (7)
3+	121.7 (3)	8.3 (3)	70.5 (2)
	Total pulmonary vascular resistance (dyne-sec/cm⁵)	**Stroke-work index of right ventricle (gram-meters/m²)**	**Stroke-work index of left ventricle (gram-meters/m²)**
0	224.7 ± 104.7 (35)	11.5 ± 4.7 (35)	70.5 ± 18.4 (36)
1+	455.3 ± 209.4 (21)	17.4 ± 6.6 (21)	56.2 ± 19.6 (20)
2+	379.3 ± 581.5 (5)	54.4 ± 33.4 (5)	74.8 ± 33.0 (5)
3+	1926.5 (2)	40.0 (2)	43 (1)

Each value is mean ± s.d. (number of cases).
The groups with a number of cases less than six are not used for Student's t test.
Student's t test shows significant differences in the range (P 0.05–P 0.001), with the exception of those marked * and #.

tricle in LAO 30° in three cases, in LAO 45° in 15 cases, in LAO 60° in 25 cases and in left lateral in two cases. Of the ten normal subjects, one with tachycardia at the time of imaging showed a grade 1+ RV free wall. Of the six patients with angina pectoris, none showed the RV free wall. Of the nine patients with myocardial infarction, two had a 1+ RV free wall. These two patients were suffering from heart failure and had a dilated LV cavity, as well as perfusion defects of the LV myocardium. Of the 14 patients with hypertrophic cardiomyopathy, two (14%) revealed a grade 1+ RV free wall. All three cases with congestive cardiomyopathy showed the RV free wall at grade 1+, with LV and RV cavities dilated. Of the 22 patients with congenital heart disease, a) seven (32%) visualized the RV free wall at grade 1+; b) ten (45%) at grade 2+; c) two (9%) at grade 3+; and d) in three the RV free wall was not seen (grade 0). Of the 32 cases with valvular heart disease, a) 14 (44%) revealed a grade 1+ RV free wall; b) one case (3%)—which had MS, mitral regurgitation and tricuspid regurgitation—showed the RV free wall at grade 3+; and c) in 17 (53%) the RV free wall was not visible. In the two patients with chronic cor pulmonale, myocardial imaging showed the RV free wall at grade 1+. The one patient with primary pulmonary hypertension revealed a grade 2+ RV free wall.

In the group with congenital heart disease, the RV free wall was seen in almost all cases. The degree of visualization, moreover, was high in this group, with 11 out of 18 patients showing the RV wall at grade 2+ or 3+. In the group with acquired heart disease, on the other hand, the RV wall was sometimes not seen at all and only once scored above grade 1+.

Correlation with hemodynamics. In Table 2 the data from cardiac catheterization are compared with the degree of visualization of the RV free wall. The group with 1+ visualization had higher RV systolic pressures than the group with nonvisualization ($P < 0.001$) (Fig. 1). This was true also of the 2+ group ($P < 0.005$), whose pressures were also higher than those of the 1+ group ($P < 0.05$). Of 41 patients with nonvisualization of the RV free wall, only three had RV systolic pressures of 30 mm Hg or more, including a normal subject, a patient with MS, and a patient with hypertrophic cardiomyopathy. Of 40 patients showing the RV free wall, ten had normal RV systolic pressures (<30 mm Hg), including three with ASD, two with MS and AR, one with MS, one with hypertrophic cardiomyopathy, one with VSD, one with VSD and AR, and a normal subject. Of these ten patients, seven had RV overloading, as suggested by other cardiac catheterization data: a) one with MS, and two with MS and AR, had significantly increased total pulmonary vascular resistance, and b) three with ASD, and one with VSD, had volume overloading, without pressure overloading, caused by a left-to-right shunt. The three patients with visualization of the RV free wall and normal catheterization data included one with hypertrophic cardiomyopathy, one with VSD and AR, and a normal subject.

The group visualizing the RV free wall had significantly higher values of RV end-diastolic pressure, mean pulmonary-arterial pressure, and total pulmonary vascular resistance than the nonvisualization

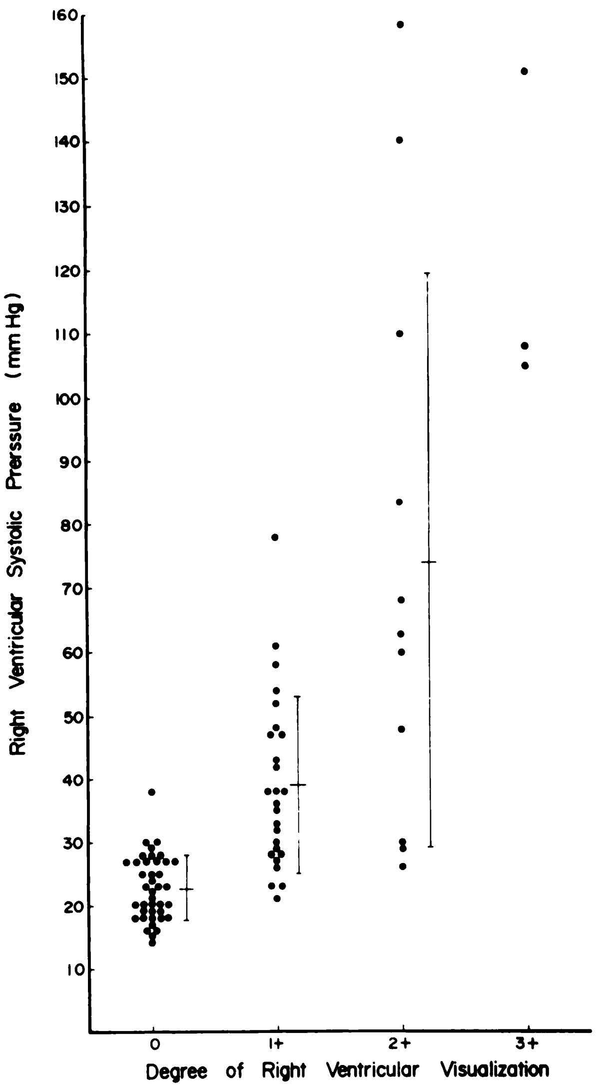

FIG. 1. Relationship between degree of right-ventricular visualization and right-ventricular systolic pressure. There were significant differences between 0 and 1+ visualization groups ($P < 0.001$), between 0 and 2+ groups ($P < 0.005$), and between 1+ and 2+ groups ($P < 0.05$).

group. Furthermore, RV stroke-work index was higher in the group with 1+ visualization than in group 0 ($P < 0.001$). On the other hand, the LV stroke-work index showed a higher value in group 0 than in the 1+ group ($P < 0.01$) (Fig. 2).

Subsequently the diseases were divided into three groups: one with RV pressure overloading, one with RV volume overloading, and one with both. The related characteristics of the myocardial images were studied.

RV pressure overloading. Of the 18 patients with MS, a) 13 (72%) showed the RV free wall at grade 1+ with a nondilated RV cavity; and b) seven (39%) showed a straight-looking septum on the LAO view (Fig. 3), with its axis tilting from (the patient's) upper right to lower left. On all three patients with pulmonary stenosis, a) the RV free wall was visualized at either grade 1+ or 2+; and b) the septum appeared straight and almost vertical.

A case with PPH showed the RV free wall at grade 2+ (Fig. 4). The septum appeared straight on the LAO view, with its axis tilting from upper right to lower left. The LV cavity was smaller than the RV cavity. This patient had cardiac failure with a low cardiac output. His condition continued to worsen, and he died 7 mo after the first scan. A repeat scan performed a few days before death showed the RV free wall at grade 3+, without visible change of its thickness, but the RV cavity was enlarged as compared with the previous scan. The LV cavity had contracted and was barely identifiable.

On both of the two patients with VSD and Eisenmenger's syndrome, a) the RV free wall was visualized at either grade 2+ or 3+; b) the septum

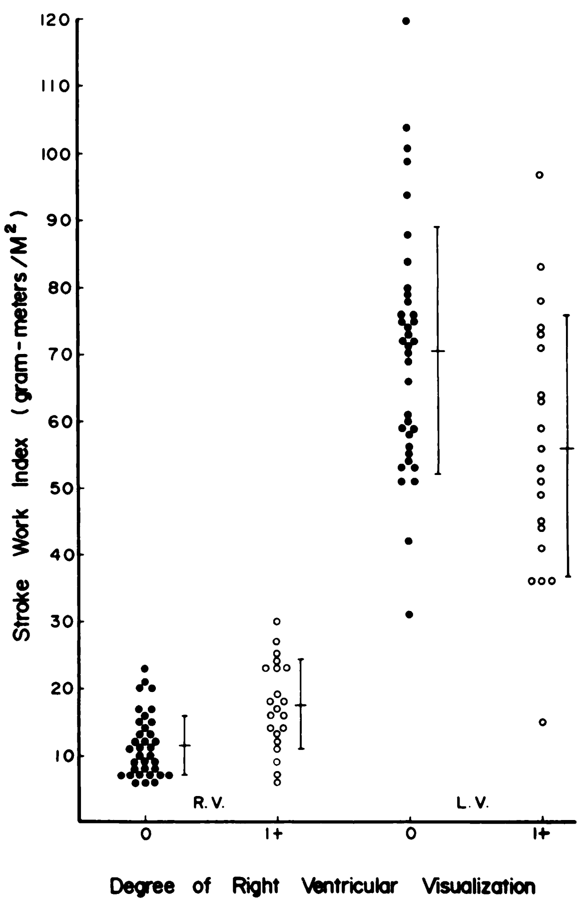

FIG. 2. Relationship between degree of right-ventricular visualization and stroke-work index of both left and right ventricles. Right ventricular stroke-work index showed significant differences between 0 and 1+ visualization groups ($P < 0.001$). Left-ventricular stroke-work index showed significant difference between 0 and 1+ visualization groups ($P < 0.01$).

FIG. 3. Myocardial scintigram (LAO 60° view) of patient with mitral stenosis. Note tilting of straight-looking septum, and right-ventricular free wall visualized at grade 1+.

FIG. 5. Myocardial scintigram of patient with ventricular septal defect and Eisenmenger's syndrome. LAO 30° view, showing straight-looking septum and dilatation of both ventricles.

appeared straight; and c) the RV cavity was markedly dilated (Fig. 5). The septum appeared either vertical or tilted in both cases.

Thus, in most cases with RV pressure overloading, the septum appeared straight on the myocardial images. Among the patients with MS, PPH, or VSD and Eisenmenger's syndrome, the axis of the RV free wall had a tendency to tilt from the upper right to the lower left.

RV volume overloading. On all eight patients with ASD, a) the RV free wall was visualized at either grade 1+ or 2+; b) the RV cavity appeared larger than the LV cavity; and c) the septum was convex toward the RV cavity in the LAO view. All patients with ASD revealed a left-to-right shunt and RV volume overloading. Radical operation was performed on three patients with ASD, and myocardial imaging was repeated postoperatively (Fig. 6). The new images revealed that the RV free wall was visualized at grade 1+, with the RV cavity appearing smaller than before, and the LV cavity larger.

On all three patients with VSD, the RV free wall was visualized at grade 1+. In two of the patients, however, the RV cavity was not dilated; one was associated with AR, and in the other the imaging was performed shortly after surgery.

RV pressure and volume overloading. On the three patients with tetralogy of Fallot, myocardial imaging revealed the RV free wall at either grade 2+ or 3+, a dilated RV cavity, and a straight-looking septum (Fig. 7).

Measurement of RV free-wall thickness. These measurements revealed a higher value in the grade 2+ group than in the 1+ group ($P < 0.005$) (Fig. 8). In seven cases out of 31 with 1+ visualization of the RV free wall, measurement of its thickness was difficult because the margins of the RV free wall were blurred.

Three patients with visualization of the RV free wall came to autopsy. The patient with PPH showed the RV and LV free walls to meaure 2.3 cm and 2.2 cm, respectively, on the LAO scintigram, but both free walls were 1.0 cm thick at autopsy. Another case with MS, mitral regurgitation, and tricuspid regurgitation showed the RV and LV free walls to measure 2.2 cm and 2.0 cm, respectively, by scintigram, whereas autopsy found them to be 1.2 cm and 1.4 cm thick, respectively. These two cases showed the RV free wall at either grade 2+ or 3+, so the in vivo thickness of the RV free wall satisfied the criterion of RV hypertrophy (RVH). The last patient with chronic cor pulmonale showed the RV free wall at grade 1+, but its thickness could not be measured because of the blurred margins. Autopsy showed the RV free wall to measure 0.6 cm thick, which satisfied the criterion of RVH.

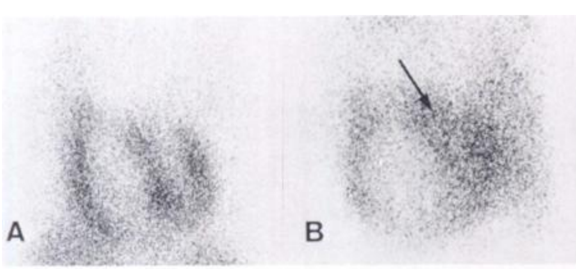

FIG. 4. Myocardial scintigrams of patient with primary pulmonary hypertension. (A) LAO 45° view, showing dilated right ventricle and small left ventricle, with straight-looking septum. (B) LAO 60° view made 7 mo after (A), showing markedly dilated right ventricle and contracted left ventricle (arrow).

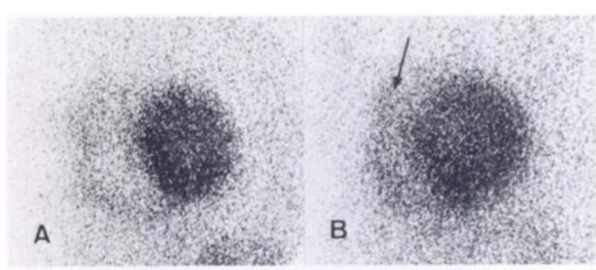

FIG. 6. Myocardial scintigrams of patient with atrial septal defect. (A) LAO 60° view, showing dilated right ventricle and septum convex toward right ventricle. (B) Postoperative LAO 60° view, showing right-ventricular free wall (arrow) with smaller cavity than before, and enlarged left ventricle.

DISCUSSION

This study establishes that myocardial imaging is a sensitive and specific method for detecting RV overloading. With earlier conventional methods, it was fairly difficult to diagnose RV overloading noninvasively. The standard chest x-ray permits only a guess regarding RV enlargement (*1*). Detection of RVH by electrocardiogram is insensitive, and often diagnosis is impossible, unless the condition is extreme (*2,3*). The ECG diagnosis is still more difficult when the case involves LV hypertrophy as well. The echocardiogram facilitates diagnosis of RV dilatation and advanced RVH, but detection of an early-stage RVH by this method is difficult (*4,5*). Moreover, when obesity or pulmonary emphysema is also present, recording of the echocardiogram becomes difficult. Since these conventional methods do not directly visualize the ventricular shape, the positional relationship between the two ventricles and the septum, and their exact form, cannot be ascertained. On the other hand, if Tl-201 myocardial imaging enables visualization of the RV free wall, the condition of both ventricles and the septum can be studied simultaneously. Few studies have been reported (*3,22,23*). Cohen et al. reported that the right ventricle was visible in Tl-201 images in patients with chronic pulmonary disease or left-ventricular dysfunction associated with pulmonary hypertension (*3*). The RV free wall was also seen in patients with valvular or congenital heart disease (*22,23*). The relationship between hemodynamics and RV visualization, however, has not been clearly demonstrated.

Among the patients with RV systolic pressure of 30 mm Hg or more, the RV free wall was visualized on all but three patients. In the visualized group, moreover, all but three patients had evidence of RV overloading. Thus it can be said that visualization of the RV free wall indicates RV overloading. Patients with grade 1+ RV free wall registered a higher RV stroke-work index than the grade 0 group. Since increased work requires a greater oxygen supply to the RV myocardium, right coronary blood flow increases, and this results in enhancement of Tl-201 uptake by the myocardium. Thus, the RV free wall visualization may occur in the presence of RV overloading without an accompanying increase in RV mass. This being so, the question is whether there is any way of distinguishing such cases from those of RVH.

One of the criteria for RVH is a RV free-wall thickness of 0.5 cm or more at autopsy (*24,25*). If the thickness of the RV free wall can be measured by myocardial imaging, judgment on RVH is easy. In the method employed in this study, however, it must be admitted that there was some error in the measurement of the RV free-wall thickness because a) gated myocardial imaging was not employed; b) the possibility of not observing the RV free wall in tangential view remains; and c) the analytical capability of the equipment is limited in defining thickness in millimeters. It may be possible in the future to estimate the RV free-wall thickness through ungated myocardial imaging when more autopsy cases are available.

Myocardial imaging provides distinguishing characteristics between RV pressure and volume over-

FIG. 7. Myocardial scintigram of patient with tetralogy of Fallot. Left lateral view, showing dilated right-ventricular cavity and straight-looking septum.

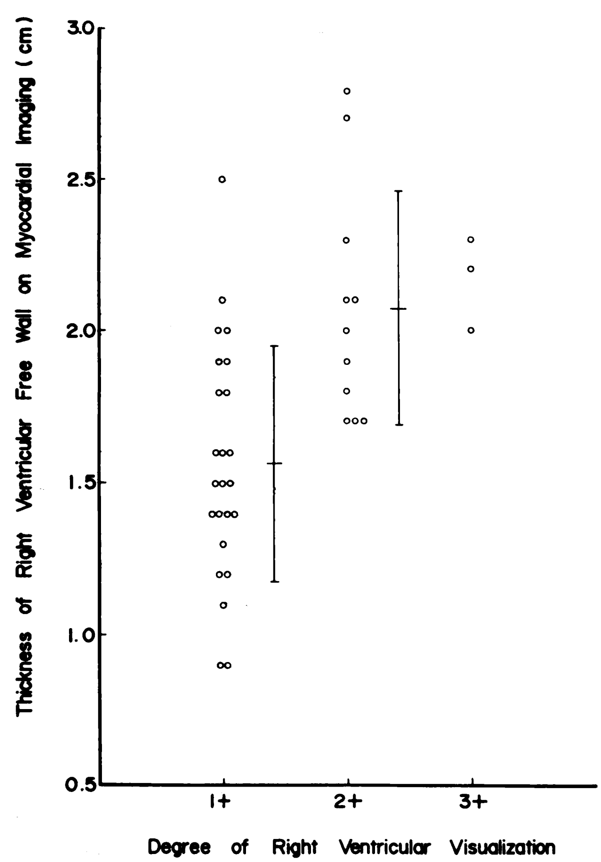

FIG. 8. Relationship between degree of right-ventricular visualization and thickness of right-ventricular free wall on myocardial image. There was significant difference between visualization groups 1+ and 2+ ($P < 0.005$).

loading. Among many of the cases with RV pressure overloading, the septum appeared straight. There were also occasional cases showing tilting of the straightened septum, which may be due to RV hypertrophy and/or dilatation. In the cases with MS, however, tilting may have been caused by enlargement of the left atrium.

In cases of RV volume overloading due to ASD, the RV cavity appeared dilated, and the septum displayed a convexity into the right ventricle, whereas the LV cavity appeared smaller than normal. Comparison of ASD cases before and after operation revealed that the RV cavity became narrower after operation, and the LV cavity wider. This indicates that RV volume overloading was corrected by elimination of the left-to-right shunt. Also, the fact that the RV wall remained visible after operation, despite elimination of the RV overload, again indicates enlargement of the RV myocardial mass.

Since myocardial imaging sensitively detects RV overloading, this method is expected to be used as an excellent method for determining RV overloading, for following postoperative progress of the patient, and for evaluating the changes in the disease.

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