Diastolic Bulging of the Interventricular Septum Toward the Left Ventricle

An Echocardiographic Manifestation of Negative Interventricular Pressure Gradient Between Left and Right Ventricles During Diastole

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SUMMARY Diastolic bulging of the interventricular septum (IVS) toward the left ventricle was observed by real-time cross-sectional echocardiography in three patients with primary pulmonary hypertension and one patient with secondary pulmonary hypertension after closure of an atrial septal defect. M-mode echocardiography showed a characteristic abnormal pattern of septal motion in diastole and in systole. In two patients, we attempted to correlate M-mode motion to the interventricular pressure gradient. During diastole, the interventricular pressure gradient between the left and right ventricles was negative and the pressure gradient curve was very similar to the M-mode echogram of the IVS. Banding studies in which acute right ventricular hypertension was produced in dogs showed similar shape changes, suggesting that the diastolic shape and motion of the septum are determined by the interventricular pressure gradient between the ventricles. Diastolic bulging of the IVS toward the left ventricle in our patients results from negative interventricular pressure gradient between the left and right ventricles during diastole.

IN THE NORMAL HEART, the convexity of the interventricular septum (IVS) contributes to the circular shape of the left ventricular cavity during both systole and diastole. However, the IVS has been reported to alter its shape and motion in various conditions. Flattening of the IVS and reversal of the normal direction of the interventricular septum curvature were reported to occur in patients with right ventricular volume overload and in patients with mitral stenosis. In primary pulmonary hypertension, interventricular septal shape at postmortem study was found to be reversed, leading to protrusion of interventricular septal muscle into the left ventricular outflow tract.

During routine examination of the heart with phased-array, cross-sectional echocardiography, four patients showed marked bulging of the IVS toward the left ventricular outflow tract during diastole. This study was undertaken to clarify the cause of diastolic bulging of the IVS seen in our patients in clinical and experimental studies.

Materials and Methods

Clinical Studies

Four patients who showed marked diastolic bulging of the IVS on the cross-sectional echocardiography were included in this study. The clinical features of these patients are summarized in table 1. The diagnosis of primary pulmonary hypertension was made by history, conventional echocardiography and cardiac catheterization. In two patients, the diagnosis was later confirmed at postmortem examination. Patient 4, who had undergone closure of an atrial septal defect (ostium secundum type), later developed pulmonary hypertension, which was confirmed by cardiac catheterization.

Cross-sectional and M-mode echocardiographic examination of the IVS and the left ventricle was performed using a Toshiba SSH-11A electronic sector scanner with a 78° scanning angle. Cross-sectional echocardiograms were recorded with a movie camera and a Polaroid camera. M-mode echocardiograms were recorded with a strip-chart recorder at a paper speed of 25, 50 or 100 mm/sec from a cursor perpendicular to the IVS chosen from the real-time cross-sectional imaging.

In patients 1 and 2, who had primary pulmonary hypertension, simultaneous recordings of the right and left ventricular pressures and the interventricular pressure gradient between the left and right ventricles were performed, and the pressure gradient curves were compared with the echocardiograms. To obtain the ventricular pressure, we used two fluid-filled catheters of the same size and a strain gauge transducer (Statham P23-1D). Two catheters were introduced into the right ventricle and the pressures were made equisensitive. Then a catheter was withdrawn and was introduced into the left ventricle.

Experimental Studies

To investigate the mechanism of these echocardiographic findings, the relationship between the
echogram of the IVS and the interventricular pressure gradient between the left and right ventricles was examined in animal models of acute right ventricular hypertension. Six mongrel dogs that weighed 18–30 kg were anesthetized with i.v. pentobarbital (25 mg/kg) and ventilated with room air. The heart was exposed through a midsternal thoracotomy. Two catheter-tipped micromanometers (Millar) were positioned in the right ventricle, where micromanometric pressures were made equisensitive. A micromanometer was withdrawn and was positioned in the left ventricle. Simultaneous recordings of the right and left ventricular pressures and the pressure gradient between the left and right ventricles were performed simultaneously with the recordings of cross-sectional echocardiograms. The cross-sectional echocardiograms were recorded using the same type of apparatus as in clinical study. The transducer was positioned on the pericardial surface of the right ventricle. Various degrees of increase in right ventricular pressure were produced by changing degree of the constriction of the pulmonary artery using a Teflon tape around it.

Results

Clinical Studies

In the four patients, characteristic changes in the shape of the IVS were found to occur in the cross-sectional echocardiograms. In the long-axis plane, the upper portion of the IVS bulged toward the left ventricular outflow tract during diastole, resulting in a distorted left ventricular cavity and a narrowed left ventricular outflow tract (fig. 1A). Diastolic bulging of the IVS was observed in the short-axis plane as well (fig. 1B), and it was prominent in the region near the attachment of the septal leaflet of the tricuspid valve. On M-mode echocardiograms, abnormal motion of the IVS was observed in the upper portion, but the lower portion of the IVS showed less abnormal motion (fig. 2A).

The interventricular pressure gradient curves in the two patients who were catheterized showed a characteristic pattern (fig. 2B). The interventricular pressure gradient between the left and right ventricles was positive during systole. In early diastole, however, the left and right ventricular pressures crossed over each other in their descending limbs and the right ventricular pressure became higher than the left. As a result, the interventricular pressure gradient became negative in early diastole to form a negative dip on the pressure gradient curve. The onset of the negative dip in early diastole approximately coincided with the

<table>
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<th>Pt</th>
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Abbreviations: PPH = primary pulmonary hypertension; PH = pulmonary hypertension; ASD = atrial septal defect; max = maximum pressure; ED = end-diastolic pressure.

FIGURE 1. Long-axis (A) and short-axis (B) views of cross-sectional echocardiograms from patient 1. Left panels were recorded in end-systole and right panels in early diastole. While the interventricular septum (IVS) shows a smooth and flattened shape in end-systole, it bulges toward the left ventricular (LV) outflow tract in early diastole (arrows). Bulging is much more prominent in upper portion of the IVS. The LV cavity is distorted due to bulged IVS in early diastole. RV = right ventricle; MV = mitral valve; PW = posterior wall of the LV; LA = left atrium; A = anterior; P = posterior; L = left; R = right.
dicrotic notch of the pulmonary artery pressure curve. After the early diastolic negative dip, the pressure gradient curve leveled off during mid-diastole, forming a mid-diastolic plateau. After the P wave, the pressure gradient curve again showed a negative dip simultaneously with increased atrial kick in the right ventricular pressure curve. After an end-diastolic negative dip, the pressure gradient rapidly increased.

The rapid increase in the pressure gradient began significantly after the peak of the R wave.

The M-mode echocardiograms (fig. 3) revealed that the IVS moved posteriorly toward the left ventricle to form a dip in early diastole. The onset of early diastolic dip approximately coincided with the pulmonary component of the second heart sound. After the early diastolic dip, the IVS leveled off,
resulting in a mid-diastolic plateau. After the P wave of the ECG, the IVS moved again posteriorly to form a dip in end-diastole. Thus, the early diastolic dip, mid-diastolic plateau and end-diastolic dip occurred simultaneously on both the M-mode echogram of the IVS and the interventricular pressure gradient curve. Then the IVS moved rapidly anteriorly toward the right ventricle. This brisk anterior motion of the IVS began at the peak of R wave of ECG and terminated at the main deflection of the first heart sound. Therefore, the onset of brisk anterior motion of interventricular septal echogram was thought to precede that of the increase in the pressure gradient. During systole, the IVS showed gradual posterior motion.

**Experimental Studies**

With constriction of the pulmonary artery, we could produce hemodynamic states in which the right ventricular pressure was higher than the left during diastole in all six dogs (fig. 4). In the control state, the left ventricular pressure was always higher than the right during the cardiac cycle so that both curves never crossed over each other. With greater constriction of the pulmonary artery, a progressive increase in the right ventricular pressure, in association with a progressive decrease in the left ventricular pressure, occurred. As a result, both curves crossed over each other on their descending limbs in early diastole and the right ventricular pressure became higher than the left, resulting in an early diastolic negative dip in the interventricular pressure gradient curve. As the right ventricular pressure increased further, with increasing degree of constriction, a second negative dip appeared at end-diastole, when the atrial kick in the right ventricular pressure exceeded that in the left ventricular pressure curve.

The long-axis and short-axis cross-sectional echocardiograms obtained simultaneously with pressure recordings showed that during systole shapes of the IVS were not significantly different between the control state and constriction of the pulmonary artery. During diastole, the upper portion of the IVS was slightly convex toward the right ventricle before the constriction, while it markedly bulged toward the left ventricle when the interventricular pressure gradient between the left and right ventricles became negative during the constriction (fig. 5). Diastolic bulging of the IVS disappeared when the interventricular pressure gradient became positive in the course of releasing the constriction. These interventricular pressure gradient curves and the echocardiographic findings during diastole in experimental studies were very similar to those in the clinical studies.

In all dogs, the same relation was also observed...
between echocardiograms of the IVS and changing pattern of the interventricular pressure gradient.

Discussion

In the present study, we observed characteristic changes in the IVS shape during diastole; that is, diastolic bulging of the IVS toward the left ventricle. Weyman et al.\textsuperscript{22} described a similar echo pattern in patients with mitral stenosis. They suggested that the abnormal septal motion pattern was due to a change in left ventricular initial diastolic shape and that this change in shape reflected inequality of initial diastolic filling of the two ventricles.

Recently we reported that interatrial septal motion was mainly determined by the left-to-right interatrial pressure gradient.\textsuperscript{23, 24} Because the IVS is a muscular structure and is relaxed during ventricular diastole and because the IVS was reported to be altered in its shape during diastole in various conditions,\textsuperscript{5, 21, 22} shape and motion of the IVS during diastole are expected to be altered by the pressure gradient between both ventricles. Therefore, we attempted to correlate interventricular septal motion to the pressure gradient between both ventricles in the two patients who showed diastolic bulging of the IVS. The M-mode echocardiogram of the IVS of these patients showed a characteristic pattern that consisted of early diastolic dip, mid-diastolic plateau, end-diastolic dip, brisk and brief anterior motion and gradual posterior systolic motion. The similar pattern was described in the previous papers\textsuperscript{26, 28} in which detailed analysis of the motion was not performed. The echo-pressure study performed in two patients showed that the M-mode echocardiogram was very similar to the curve of the interventricular pressure gradient between the left and right ventricles in the pattern as well as timing. In animal experiments, interventricular septal shape during diastole was smooth and convex toward the right ventricle when the interventricular pressure gradient between the left and right ventricles was positive during diastole. When the interventricular pressure gradient became negative during diastole, the IVS was observed to bulge toward the left ventricle. These observations in animal experiments are thought to strongly support the results obtained by echo-pressure study performed in the two patients. Therefore, diastolic bulging of the IVS in these patients seems to result from negative interventricular pressure gradient between the left and right ventricles during diastole.

We think that the diastolic bulging of the IVS in patients with mitral stenosis reported by Weyman et al. might be caused by a negative interventricular pressure gradient in early diastole, which resulted from inequality of initial diastolic filling and distensibility of the two ventricles. Is the interventricular pressure gradient positive in the cases who do not show diastolic bulging? Although we have studied only five cases, we observed that the interventricular pressure gradient was positive in patients with various heart diseases, including atrial septal defect, who did not show diastolic bulging of the IVS. We have not observed diastolic bulging of the IVS in patients with a large atrial septal defect without pulmonary hypertension. This fact would add further strength to our thesis.

Park et al.\textsuperscript{27} suggested that bulging of the IVS to the left ventricular side seen in patients with transposition of the great arteries was related to a reversed pressure relationship in the ventricles during systole. As the IVS itself contracts during systole, the IVS may reflect the interventricular pressure gradient between both ventricles during systole to a lesser degree than during diastole.

In conclusion, diastolic bulging of the IVS seen in these patients results from negative interventricular pressure gradient between the left and right ventricles during diastole.

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