Motion of the Interatrial Septum in Acute Mitral Regurgitation

Clinical and Experimental Echocardiographic Studies

CHUWA TEI, M.D., HIROMITSU TANAKA, M.D., SHOICHIRO NAKAO, M.D.,
HISAKAZU YOSHIMURA, M.D., SHINICHI MINAGOE, M.D., TOMOYOSHI KASHIMA, M.D.,
AND TAKUYA KANEHISA, M.D.

SUMMARY The interatrial septal echocardiograms from 15 patients with acute mitral regurgitation due to ruptured chordae tendineae were compared with those from 14 normal subjects. On the cross-sectional echocardiogram, the interatrial septal configuration in patients with chordal rupture showed a characteristic pattern in which the interatrial septum (IAS) was flat or slightly convex toward the left atrium at end-diastole and became markedly convex toward the right atrium at end-systole. On the M-mode echocardiogram, the interatrial septal amplitude was greater in patients with chordal rupture (12.4 ± 1.9 mm) than in normal subjects (9.4 ± 0.9 mm). Systolic fluttering of the IAS was found in five of 10 patients with rupture of the chordae attached to the posterior mitral leaflet. This finding was thought to be specific for acute mitral regurgitation due to ruptured chordae to the posterior mitral leaflet. After operation, the amplitude of the IAS became normal or diminished and systolic fluttering of the IAS disappeared.

Animal experiments performed to clarify the mechanism of these findings showed that increased systolic motion of the IAS resulted from an increase in the systolic left atrial-to-right atrial pressure gradient due to acute mitral regurgitation. The systolic fluttering of the IAS was thought to represent a jet stream against the IAS due to rupture of the chordae tendineae to the lateral half of the posterior mitral leaflet.

We conclude that the interatrial septal echocardiogram reflects the hemodynamic changes due to acute mitral regurgitation and direction of the regurgitant jet against the IAS. This finding may prove to be important in diagnosing acute mitral regurgitation secondary to ruptured chordae tendineae.

IN ACUTE severe mitral regurgitation, marked increases in the left atrial mean and peak pressure result from severe mitral regurgitation in a less compliant left atrium (LA). These hemodynamic changes in the LA may be expected to alter motion of the interatrial septum (IAS), which is a thin structure in the absence of chronic disease. In addition, a jet lesion on the IAS has been observed in patients with acute mitral regurgitation due to chordal rupture.

Despite numerous reports on the echocardiographic findings in acute mitral regurgitation due to chordal rupture, the analysis of interatrial septal motion has not been reported. We recently developed a new method to obtain the interatrial septal echocardiogram from a right sternal approach. With this method, the interatrial septal configuration can be observed and recorded during each cardiac cycle on cross-sectional echocardiogram, and motion analysis of the IAS is made by placing a cursor to record the M-mode echocardiogram. Our preliminary studies showed that the interatrial septal echocardiogram can detect hemodynamic changes in both atria in normal subjects and in patients with various heart diseases.

In this investigation, we evaluated the interatrial septal echocardiogram in the diagnosis of acute mitral regurgitation due to chordal rupture and performed experiments in animals to clarify the mechanisms of our findings.

Materials and Methods

Clinical Study

Interatrial septal echocardiograms of 15 patients with acute mitral regurgitation due to chordal rupture were analyzed and compared with those of 14 normal subjects (mean age 27 ± 10 years). Chordal rupture was confirmed in six of the 15 patients with acute mitral regurgitation during open heart surgery (table 1). In patients 1 and 2, the chordae tendineae attached to the posterior mitral leaflet (PML) and to the anterolateral papillary muscle had ruptured. In patients 3 and 4, the chordae from the posteromedial papillary muscle to the PML had ruptured. In patient 11, the chordae attached to the anterior mitral leaflet (AML) and to the posteromedial papillary muscle had ruptured. In patient 12, the chordae tendineae attached to the AML and to the posteromedial and anterolateral papillary muscles had ruptured. Chordal rupture was thought to be spontaneous in five of these six patients and due to subacute bacterial endocarditis in one. In the remaining nine patients, acute mitral regurgitation due to ruptured chordae was diagnosed on the basis of clinical history, phonocardiography and conventional echocardiography and was supported by cardiac catheterization and angiography. All nine patients had an apical holosystolic murmur associated with the sudden onset of con-
gestive heart failure within 2 years before the examination. No patient had a history of acute rheumatic fever. The characteristic M-mode echocardiographic findings of mitral regurgitation due to chordal rupture were present in all patients. Left ventriculography showed severe mitral regurgitation in five patients and moderate mitral regurgitation in eight patients. The V wave of pulmonary artery wedge pressure was more than 30 mm Hg in eight of nine patients in whom the wedge pressure could be obtained. According to the cross-sectional echocardiographic criteria reported by Mintz et al.,10 10 patients had flail PML and five patients had flail AML.

Our technique for recording interatrial septal echocardiograms has been reported.11, 12 A commercially available Sonolayergraphy Electronic Sector Scanning Type SSH-11A (Toshiba) with a pulse repetition rate of 500 Hz was used. M-mode echocardiograms were recorded on a strip-chart recorder (Honeywell 11A) at a paper speed of 50 or 100 mm/sec simultaneously with ECGs and phonocardiograms. The cross-sectional echocardiograms were recorded at 15 frames/sec using a movie camera, and single images were recorded with a Polaroid camera mounted on a slave screen. The interatrial septal echocardiograms were recorded with the patient in the supine or right lateral decubitus position. The transducer was positioned in the third or fourth intercostal space to the right of the sternum and was angled slightly superiorly and medially until the IAS was visualized. During observation of the cross-sectional echocardiography, the M-mode echocardiograms were obtained with known spatial orientation from a cursor chosen from the real-time cross-sectional imaging. The amplitude of the interatrial septal echocardiogram was measured from the most anterior portion to the most posterior portion of the IAS during the cardiac cycle.

### Experimental Study

Seven mongrel dogs that weighed 20–29 kg were studied. The heart was exposed through a midsternal thoracotomy under anesthesia with intravenous pentobarbital and ventilation with room air. Echocardiograms were obtained with the same type of apparatus used in the clinical study. The interatrial septal echocardiogram was obtained from the pericardial surface of the right atrium (RA). A transducer-tipped pressure catheter (Millar) was introduced via the pulmonary vein and positioned in the LA. Another catheter (Millar) was introduced via the right jugular vein into the RA. The left and right atrial pressures and the LA-to-RA pressure gradient were recorded simultaneously with M-mode and cross-

### Table 1. Clinical Data of 15 Patients with Acute Mitral Regurgitation Due to Chordal Rupture

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*The degree of mitral regurgitation was judged by Seller's criteria." Abbreviations: PA = pulmonary artery; CTR = cardiothoracic ratio; SBE = subacute bacterial endocarditis; PML = posterior mitral leaflet; ALPM = anterolateral papillary muscle; PMPM = posteromedial papillary muscle; AML = anterior mitral leaflet; NYHA = New York Heart Association; (+) = present; (−) = not available or not performed.
sectional echocardiograms of the IAS and ECGs using a strain-gauge transducer (Statham P23-2D) and Biophysiograph 180 system (Sanei Sokki). Acute mitral regurgitation was produced by cutting the chordae tendineae using a hook introduced via the apex. The simultaneous recordings of the M-mode and cross-sectional echocardiograms and hemodynamic data were performed in the control state and after production of acute mitral regurgitation. To elevate right atrial pressure after production of acute mitral regurgitation, the pulmonary artery was constricted to various degrees by means of a Teflon tape. Simultaneous recordings of the right atrial and left atrial pressures, the LA-RA pressure gradient and the interatrial septal echocardiogram were made before and during the constriction as well as during release of the constriction.

Results

Clinical Study

**Interatrial Septal Echocardiograms in Normal Subjects** (fig. 1) and in Acute Mitral Regurgitation Due to Chordal Rupture (figs. 2 and 3)

In all normal subjects studied, cross-sectional echocardiograms of the IAS showed a characteristic configuration and pattern of change during the cardiac cycle. The interatrial septal configuration was slightly convex toward the LA or flat at end-diastole and convex toward the RA at end-systole. The M-mode echocardiogram of the IAS was characterized by a pattern in which eight distinct points (a–h) were identified. In some normal subjects, points g and h were not differentiated from each other. The IAS showed a gradual anterior motion toward the RA during systole. The amplitude of the IAS was 9.4 ± 0.9 mm (mean ± SD).

In all 15 patients with acute mitral regurgitation due to chordal rupture, the interatrial septal configuration was almost flat or slightly convex toward the LA at end-diastole, with or without an irregular line echo. The IAS protruded markedly toward the RA at end-systole. The change of the interatrial septal configuration during the cardiac cycle was markedly increased in these patients. But the change of the interatrial septal configuration did not significantly differ between patients with ruptured chordae to the PML and those with ruptured chordae to the AML.

The M-mode echocardiograms of the IAS of patients with ruptured chordae showed increased systolic anterior motion compared with normal subjects. The amplitude of the interatrial septal echocardiogram was 12.4 ± 1.9 mm in the 15 patients with ruptured chordae (12.7 ± 2.0 mm in patients with ruptured chordae to the PML and 11.8 ± 1.9 mm in patients with ruptured chordae to the AML; there was no significant difference between these two values).

Systolic fluttering of the interatrial septal echogram was observed in five of 10 patients with ruptured chordae to the PML (fig. 2). Two patients who had shown systolic fluttering were proved during open heart surgery to have ruptured chordae tendineae from the anterolateral papillary muscle to the PML. In contrast, two patients with ruptured chordae tendineae from the posteromedial papillary muscle to the PML did not show systolic fluttering of the IAS.

**Figure 1.** Cross-sectional and M-mode echocardiograms of the interatrial septum (IAS) from a normal subject. (above) Cross-sectional echocardiograms of the IAS recorded at end-diastole (A) and at end-systole (B). The interatrial septal configuration is slightly convex toward the left atrium (LA) at end-diastole and slightly convex toward the right atrium (RA) at end-systole. (below) M-mode echocardiogram of the IAS showing a characteristic pattern in which eight distinct points (a–h) are identified. The IAS shows a gradual anterior (toward the RA) motion during systole. A = anterior; P = posterior; L = left; R = right; PCG = phonocardiogram.
Pre- and Postoperative Echocardiograms of the IAS in Patients with Acute Mitral Regurgitation Due to Chordal Rupture (fig. 4)

In all six patients in whom the pre- and postoperative echocardiograms were recorded, a significant change was noted in the interatrial septal echocardiograms. Marked protrusion toward the RA during systole preoperatively was improved and the configuration during the cardiac cycle changed toward normal. The M-mode echocardiogram of the IAS showed a reduction in amplitude, often to normal, after the operation. Systolic fluttering of the IAS also disappeared postoperatively.

Experimental Study

Echocardiograms of the IAS and the LA-to-RA Pressure Gradient Curve in the Control State (figs. 5 and 6)

In all seven dogs studied, control M-mode and cross-sectional echocardiograms of the IAS showed a pattern similar to that in normal human subjects. On the M-mode echocardiograms of the IAS from the dogs, seven points could be identified in the control state, as in the normal human subjects (fig. 5). Comparison of the M-mode echocardiographic patterns of the IAS and the LA-to-RA pressure gradient curve revealed very similar patterns and timings.

Interatrial Septal Echocardiograms and the LA-to-RA Pressure Gradient Curve in Acute Mitral Regurgitation (figs. 5 and 6)

In three dogs the chordae tendineae to the PML were cut and in four dogs the chordae to the AML were cut. The amplitude of the interatrial septal echocardiogram was markedly increased in all seven dogs after this intervention. On cross-sectional echocardiogram, the change of the interatrial septal configuration during the cardiac cycle was also markedly increased when acute mitral regurgitation was produced. Thus, the interatrial septal echocardiograms recorded in dogs after the chordae were cut were very similar to those recorded in patients with acute mitral regurgitation due to chordal rupture.

Analysis of the pressure curve recorded simultaneously with the interatrial septal echocardiogram showed that a marked increase in the left atrial pressure with only slightly increased or unchanged right atrial pressure occurred during ventricular systole, resulting in a marked systolic increase in the
FIGURE 3. Cross-sectional and M-mode echocardiograms of the interatrial septum (IAS) from a patient with acute mitral regurgitation due to torn chordae tendineae to the anterior mitral leaflet (patient 12). (above) Cross-sectional echocardiograms of the IAS recorded at end-diastole (A) and at end-systole (B). The interatrial septal configuration is almost flat at end-diastole, whereas it becomes markedly convex toward the right atrium (RA) at end-systole. The change of the interatrial septal configuration between end-diastole and end-systole is increased. (below) M-mode echocardiogram of the IAS showing increased amplitude of the IAS but no systolic fluttering of the IAS. A = anterior; P = posterior; L = left; R = right; LA = left atrium; PCG = phonocardiogram.

LA-to-RA pressure gradient after the chordae tendineae were cut. Thus, the increased systolic amplitude of the IAS and systolic increase in the LA-to-RA pressure gradient occurred simultaneously, suggesting a cause-and-effect relationship (figs. 5 and 6).

In two dogs, systolic fluttering of the IAS was observed after acute mitral regurgitation was produced (fig. 5). At autopsy, the chordae tendineae from the anterolateral papillary muscle to the PML were torn in both dogs. In one dog in which the chordae tendineae from the posteromedial papillary muscle to the

FIGURE 4. Cross-sectional and M-mode echocardiograms of the interatrial septum (IAS) recorded before and after an operation in a patient with acute mitral regurgitation due to chordal rupture (patient 11). (above) Cross-sectional echocardiograms of the IAS recorded during systole. The interatrial septal configuration is markedly convex toward the right atrium (RA) before the operation (A) but it is slightly convex toward the RA after the operation (B). (below) M-mode echocardiograms of the IAS before (left) and after (right) the operation. The increased amplitude of the IAS becomes normal after the operation. A = anterior; P = posterior; L = left; R = right; LA = left atrium; PCG = phonocardiogram.
PML were cut and in four dogs with torn chordae tendineae to the AML, systolic fluttering of the IAS was not observed.

Interatrial Septal Echocardiograms and the LA-to-RA Pressure Gradient Curves Before and After Constriction of the Pulmonary Artery After Rupture of the Chordae Tendineae (fig. 7).

With increasing constriction of the pulmonary artery after rupture of the chordae tendineae, the increased amplitude of the IAS and the increased LA-to-RA pressure gradient progressively decreased in parallel in all seven dogs. With more advanced degree of constriction, systolic anterior motion of the IAS and the systolic increase of the LA-to-RA pressure gradient curve disappeared. These changes in the LA-to-RA pressure gradient during constriction resulted from the progressive decrease in the left atrial pressure and the progressive rise in the right atrial pressure.

When the progressive release of the constriction started, the amplitude of the IAS began to increase and returned to the initial level. Thus, changes in the interatrial septal echocardiograms and the LA-to-RA pressure gradient curve were similar before, during and after the constriction of the pulmonary artery in all seven dogs.

Discussion

The present study shows that the interatrial septal echocardiogram shows two characteristic features in patients with acute mitral regurgitation due to chordal rupture: increased systolic motion and systolic fluttering of the IAS.

The mechanism of increased systolic motion of the IAS in acute mitral regurgitation due to chordal rupture was examined in the animal models of acute mitral regurgitation by cutting the chordae tendineae in seven dogs. The interatrial septal echocardiograms...
of these dogs obtained in the control state were very similar to those of normal human subjects, and the echocardiograms obtained after the production of acute mitral regurgitation were also very similar to those of patients with acute mitral regurgitation. Using this model, the simultaneous recordings of the LA-to-RA pressure gradient curve and the interatrial septal echocardiogram showed that both were similar and changed in parallel with each other as well in various hemodynamic states, i.e., control state, acute mitral regurgitation and constriction of the pulmonary artery after cutting of the chordae tendineae. These results strongly support the hypothesis that the change of the interatrial septal echocardiogram may be determined mainly by the LA-to-RA pressure gradient during the cardiac cycle.\(^1\)\(^,\)\(^2\) We conclude that increased systolic motion of the IAS in acute mitral regurgitation may result from the increase in the LA-to-RA pressure gradient during systole due to mitral regurgitation.

Systolic fluttering of the IAS was present in five of 10 patients with ruptured chordae to the PML and in none of the patients with ruptured chordae tendineae to the AML or the patients with chronic rheumatic mitral regurgitation. Our experience indicates that systolic fluttering of the IAS is pathognomonic for acute mitral regurgitation due to rupture of the chordae tendineae attached to the PML. In the experimental study, we did not observe systolic fluttering of the IAS in the four dogs in which the chordae tendineae attached to the AML were cut. In contrast, systolic fluttering of the IAS occurred in two of three dogs in which the chordae tendineae to the PML were cut. Therefore, a regurgitant jet appears to be responsible for the systolic fluttering of the IAS. In a pathologic study, Edwards and Burchell\(^7\) showed that the jet lesion was located in the IAS in patients with rupture of the chordae to the PML. The jet lesion was considered to be caused by a stream against the IAS. In these patients, the systolic murmur and thrill may yield

\[ \text{FIGURE 6. Simultaneous recordings of interatrial septal echocardiogram, left and right atrial pressures (LA pre. and RA pre., respectively), left atrium-to-right atrium pressure gradient (LA-RA pre. gra.) and ECG in a dog before and after the chordae tendineae to the anterior mitral leaflet were cut. (above) Recording obtained in the control state. The interatrial septal echocardiogram and the LA-RA pressure gradient curve show similar patterns and timings. The echocardiogram of the interatrial septum (IAS) is similar to that of normal human subjects. (below) Recording in chordal rupture. The amplitudes of the interatrial septal echocardiogram and the LA-RA pressure gradient curve are increased and the curves are similar. There is no systolic fluttering of the IAS.} \]
clinical signs that mimic aortic stenosis.14 When the chordae to the AML were ruptured, the jet lesion was located at the posterior wall.2 The systolic murmur may be transmitted to the left axilla and back.14 Selzer et al.14 reported that there was a jet lesion in the IAS in a patient with ruptured chordae tendineae to the PML. In our clinical study, all 10 patients with torn chordae tendineae to the PML had a systolic murmur that transmitted to the cardiac base, and all five patients with torn chordae to the AML had a systolic murmur that transmitted to the left axilla and back.

On the basis of these reports and the results of our own study, we strongly suggest that systolic fluttering of the IAS represents vibration caused by a jet stream against the IAS.

Systolic fluttering of the IAS was found only in patients with rupture of the chordae tendineae to the PML, but it was not found in all of the dogs in which chordae tendineae to the PML were cut. Because the PML occupies two-thirds of the circumference of the mitral ring,18 the direction of the regurgitant jet may depend on the location of the PML to which the ruptured chordae tendineae are attached. The lateral half of the PML is attached by the chordae tendineae from the anterolateral papillary muscle and the medial half of the PML is attached by the chordae from the posteromedial papillary muscle. Torn chordae tendineae from the anterolateral papillary muscle to the

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**Figure 7.** Continuous recording of the interatrial septal echocardiogram, the left and right atrial pressures, the left atrium-to-right atrium (LA-RA) pressure gradient and the ECG in a dog with chordal rupture before and during the increasing constriction of pulmonary artery and during the release of constriction. The interatrial septal echocardiogram and the LA-RA pressure gradient curve change parallel each other before, during and after the constriction of the pulmonary artery. RA = right atrial; LA = left atrial.

**Figure 8.** Schematic drawing showing relationship between the localization of mitral leaflet to which the torn chordae tendineae attached and the direction of a regurgitant stream caused by the torn chordae. When the chordae tendineae to the anterior mitral leaflet (AML) were torn, the regurgitant stream may have been directed toward the posterior wall of the left atrium (arrow 1). When the chordae tendineae to the medial half of the posterior mitral leaflet were torn, the regurgitant jet may have been directed toward the anterior wall of the left atrium and the posterior wall of the aorta (arrow 2). When the chordae to the lateral half of the posterior mitral leaflet were torn, the regurgitant jet may have been directed toward the interatrial septum (IAS) (arrow 3). RV = right ventricle; TV = tricuspid valve; PA = pulmonary artery; LV = left ventricle; PML = posterior mitral valve.
PML were found at open heart surgery in two patients who had systolic fluttering of the IAS. Systolic fluttering was not observed in two patients with torn chordae tendineae attached to the PML and the posteromedial papillary muscle. In two of three dogs in which the chordae tendineae to the PML were cut, systolic fluttering of the IAS was observed and the torn chordae tendineae were found at autopsy to originate from the anterolateral papillary muscle. In the remaining dog with ruptured chordae tendineae to the PML, systolic fluttering was not present and the torn chordae were found to originate from the posteromedial papillary muscle. Therefore, the regurgitant jet may have been directed toward the IAS when the chordae tendineae from the anterolateral papillary muscle to the PML were cut (fig. 8). When the chordae from the posteromedial papillary muscle to the PML were cut, the regurgitant jet may have been directed toward the posterior aortic wall and the anterior wall of the LA.

Thus, systolic fluttering of the IAS results from a regurgitant jet against the IAS and occurs in patients with the torn chordae from the anterolateral papillary muscle to the lateral half of the PML. Antman et al. reported a case with high-frequency vibration of structures constituting the posterior aortic and anterior atrial regions on conventional M-mode echocardiogram. At operation, all of the chordae tendineae toward the medial half of the posterior leaflet were found to be ruptured.

We conclude that interatrial septal echocardiography may well reflect the hemodynamic changes due to regurgitation and a regurgitant jet and therefore may provide important clues for the diagnosis of acute mitral regurgitation due to ruptured chordae tendineae.

Acknowledgment

The authors gratefully acknowledge the critical review of this manuscript by Dr. Pravin M. Shah, Professor of Medicine, University of California, Los Angeles. We are indebted to Kaye Cherry for typing the manuscript.

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Motion of the interatrial septum in acute mitral regurgitation. Clinical and experimental echocardiographic studies.

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_Circulation_. 1980;62:1080-1088
doi: 10.1161/01.CIR.62.5.1080

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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