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SUMMARY Real-time cross-sectional echocardiography was performed to record the interatrial septal echogram by right atrium-interatrial septum-left atrium (ASA) direction of the ultrasound beam by positioning the transducer to the right of the sternum. The configuration of the interatrial septum (IAS) and the change of the configuration through each cardiac cycle were studied in 10 normal subjects and 29 patients with left or right atrial overloading.

In normal subjects the IAS was slightly convex toward the right atrium (RA) in end-systole and slightly convex toward the left atrium (LA) in end-diastole, respectively. In patients with mitral stenosis, the IAS protruded archwise toward the RA both in end-systole and in end-diastole, and showed only minimum difference through each cardiac cycle. In patients with acute mitral regurgitation, the IAS was markedly convex toward the RA in end-systole and slightly convex toward the LA in end-diastole; thus, the difference of the configuration of the IAS was increased. In patients with chronic mitral regurgitation, the IAS was moderately convex toward the RA in end systole and flat or slightly convex toward the RA in end-diastole. In patients with tricuspid regurgitation, the interatrial septal echogram showed several patterns. However, the change in the configuration of the IAS throughout the cardiac cycle showed a characteristic pattern, i.e., it was more convex toward the LA or less convex toward the RA in end-systole than in end-diastole.

The observation of the change in the interatrial septal configuration may be useful in the diagnosis of right or left atrial overloading. The mechanism by which the configuration is altered seems to be the interatrial pressure gradient through each cardiac cycle.

ECHOCARDIOGRAPHY allows us to examine noninvasively the structure and function of the heart. However, the interatrial septum (IAS) has not been studied extensively by echocardiography. Very few reports on the cross-sectional echocardiographic examination of the IAS have appeared in the literature. In 1973, Matsumoto et al. studied the IAS by B-mode and conventional echocardiography, with the beam transmitted through the left sternal border.

They reported that the IAS was detected parallel to the anterior chest wall by B-mode echocardiography and that the defect in the IAS was visualized. In 1977, Dillon et al. examined the IAS by cross-sectional echocardiography with the transducer placed to the left of the sternum. They observed that the IAS appeared as a series of linear echoes extending from the aorta to the posterior wall of the atria in normal subjects. In patients with left atrial dilatation, the IAS curved slightly inward toward the right atrium (RA).

However, there have been problems with the methods in these reports, because the direction of the ultrasound beam was oblique or nearly parallel to the IAS.

We positioned the transducer to the right of the sternum to make the direction of the ultrasound beam perpendicular to the IAS, and could clearly observe the IAS by real-time, cross-sectional echocardiography. In this paper we describe 1) a new method to record the cross-sectional echocardiogram of the IAS and 2) the results of the initial application of the method to the patients with left or right atrial overloading.

Subjects and Methods

We studied the configuration of the IAS in 10 normal subjects and 29 patients with right or left atrial overloading whose cross-sectional echograms of the IAS were clearly recorded through each cardiac cycle. The study group consisted of 10 normal subjects, 10 patients with mitral stenosis, five with acute mitral regurgitation due to chordal rupture, five with chronic mitral regurgitation and nine with tricuspid regurgitation.

The diagnosis of mitral stenosis was made by echocardiography and cardiac catheterization. The diagnosis of acute mitral regurgitation due to chordal rupture was made by M-mode and cross-sectional echocardiography. The diagnosis was confirmed during surgery in two patients. Chronic mitral regurgitation was diagnosed by phonocardiography, echocardiography and left ventriculography. Tricuspid regurgitation was diagnosed by auscultatory findings, jugular phlebogram, contrast echocardiography and right ventriculography. The underlying heart diseases of patients with tricuspid regurgitation were mitral valve disease in five patients (four patients with mitral stenosis and one who underwent mitral valve replacement), congestive cardiomyopathy in two, primary pulmonary hypertension in one and Ebstein's anomaly in one.
The instrument used in this study was a commercially available Sonolayergraph Electronic Sector Scanning Type SSH-11A (Toshiba) with a 78° scanning angle. The transducer has 32 elements with a frequency of 2.4 MHz and an active area of 1.5 cm by 1.5 cm. The line density of the image was 112 lines/arc second and displayed at a tissue depth of 16 or 20 cm. The images were displayed on an oscilloscope screen at 30 frames/sec and recorded on a movie camera at a rate of 15 frames/sec. Single images could be recorded with a Polaroid camera mounted on a slave screen.

Cross-sectional echocardiographic studies were performed with the subject in either the supine or right lateral decubitus position. The recordings were performed during expiratory apnea. The transducer was placed in the third, fourth, or fifth intercostal space to the right of the sternum (transducer A in fig. 1) and was directed posteroanteriorly and superiorly with a horizontal plane. Then, the interatrial septal echogram was visualized together with the right and left atria as illustrated in figure 2A. We designated this direction of the ultrasound beam the right atrium-interatrial septum-left atrium (ASA) direction because a view of the RA, the IAS, and the LA can be obtained simultaneously. Contrast echo study was performed by injecting saline solution and indocyanine green into the antecubital vein during real-time cross-sectional echocardiograms.

Results

Normal Subjects

Figure 2A shows a single image of cross-sectional echocardiogram of the IAS from a normal subject. The interatrial septal echogram extended rightward from the interventricular septum to the junction of the right and left atrial walls. It ran slightly obliquely and right-posteriorly to the anterior chest wall (fig. 1). The right and left atria were seen anteriorly and posteriorly to the IAS, respectively. The IAS located posteriorly between the anterior wall of the RA and the posterior wall of the LA. The identification of the interatrial septal echogram was performed by contrast echo in all subjects studied (fig. 2B). The echo-dense material appeared in the RA anterior to the IAS after injection of saline solution and indocyanine green into the antecubital vein. The echogram of the IAS changed its configuration through each cardiac cycle (fig. 3). The IAS was slightly convex toward the RA in mid-systole, end-systole and early-diastole, and it was flat or slightly convex toward the LA in mid-diastole, end-diastole and early-systole. The cross-sectional echograms through each cardiac cycle showed similar patterns in each normal subject.

Mitral Stenosis

In patients with mitral stenosis, we saw characteristic findings. The IAS was convex toward the RA through each cardiac cycle in all patients. The change of the configurations of the IAS between end-systole and end-diastole was very much decreased. Figure 4 is a cross-sectional echocardiogram of a patient with severe mitral stenosis. The IAS protrudes prominently archwise toward the RA both in end-systole and end-diastole. The change of the configuration of the IAS is minimal. The IAS became less convex toward the RA after mitral valve replacement was successfully performed.

Acute Mitral Regurgitation due to Chordal Rupture

The impressive finding obtained by real-time observation was the increased and dynamic change in the interatrial septal configuration through each cardiac cycle. The IAS was moderately to markedly convex toward the RA in end-systole in all patients examined. In end-diastole, the IAS showed slightly convex curvature toward the LA. Figure 5 shows a cross-sectional echocardiogram of a patient with acute mitral regurgitation due to chordal rupture. In a patient with this disease who underwent mitral valve replacement successfully, such a typical pattern disappeared after the operation.

Chronic Mitral Regurgitation

The interatrial septal echograms of patients with
chronic mitral regurgitation were convex toward the RA in end-systole and less convex toward the RA or flat in end-diastole. In every case, the shape of the IAS in end-systole was more convex toward the RA than that in end-diastole. The change of the interatrial septal configuration through each cardiac cycle was not increased. Figure 6 is an echocardiogram of a patient with chronic mitral regurgitation.

Tricuspid Regurgitation

The interatrial septal echogram showed several patterns in these patients. In one patient with Ebstein's anomaly and one patient who had undergone mitral valvular replacement, the IAS was convex toward the LA in end-diastole, and it became more convex toward the LA in end-systole (fig. 7). In four patients with mitral stenosis and one patient with congestive cardiomyopathy without mitral regurgitation, the IAS was convex toward the RA in end-diastole and it became less convex toward the RA in end-systole (fig. 8). To summarize, the IAS became more convex toward the LA or less convex toward the RA in end-systole than in end-diastole. This characteristic finding was not observed in two patients. In a patient with primary pulmonary hypertension, the IAS was convex toward the LA through each cardiac cycle and the change of the IAS between end-systole and end-diastole was minimal. In a patient with congestive cardiomyopathy complicated by mitral regurgitation, the IAS was convex toward the RA in end-diastole and became more convex in end-systole.

Discussion

By applying cross-sectional echocardiography, we can obtain the interatrial septal echogram by left sternal or subxiphoid approach. However, in our experience, the cross-sectional echogram of the IAS by these methods often has echo dropout in some part of the IAS, perhaps related to the direction of ultrasound beam. The direction of the beam is not perpendicular, but oblique or nearly parallel to the IAS when the left sternal approach is used (transducer B in fig. 1). Therefore, the beam must be nearly perpendicular to the IAS through each cardiac cycle to get accurate recordings of the IAS. If the transducer is positioned to the right of the sternum (transducer A in fig. 1), the direction might be nearly perpendicular to the IAS. However, the recording of the echocardiogram by right sternal approach has not been used often, probably because it was generally considered difficult to perform. We performed cross-sectional echocardiography of the IAS using a phased-array electronic sector scanner by positioning the transducer to the right of the sternum (the ASA direction). Thus, we
FIGURE 3. A series of cross-sectional echocardiograms in one cardiac cycle from a normal subject. Two illustrations of the lowest panel are schematic drawings of echocardiograms C and F. Panels A, B and C are echocardiograms recorded in systole (A — early systole; B — mid-systole; C — end-systole), and panels D, E and F are those recorded in diastole (D — early diastole; E — mid-diastole; F — end-diastole). Note that the interatrial septum (IAS) is slightly convex toward the right atrium (RA) in end-systole (arrows in panel C) and that it is slightly convex toward the left atrium (LA) in end-diastole (arrows in panel F). IVS = interventricular septum.

FIGURE 4. Cross-sectional echocardiograms from a patient with severe mitral stenosis. Panel A was recorded in end-systole and panel B in end-diastole. Note the interatrial septum (IAS) protruded archwise toward the right atrium (RA) (arrows) and markedly enlarged left atrium (LA).
have recorded good echograms of the IAS in approximately 200 of 500 consecutive subjects with or without heart disease. The recording of the IAS was especially difficult in normal subjects and in patients without cardiomegaly. In 20% of these subjects we obtained good echograms; but the recording was relatively easier in patients with right or left atrial overloading. In patients who had bulging of the right border of the heart to the right side on the chest x-ray film, the recording could almost always be obtained. It was usually easier to record the echogram with the subjects in the right lateral decubitus position.

Although our study is preliminary, the results seem very interesting. In normal subjects, the IAS protruded slightly toward the right atrium in mid-systole, end-systole and early-diastole. However, it flattened or retracted slightly toward the left atrium in mid-diastole, end-diastole and early-systole. We believe this is the first report on the change of the interatrial septal configuration through each cardiac cycle.

What is the mechanism by which the interatrial septal configuration is altered? Because the IAS is a thin membranous structure between the left and right atria, its configuration may be altered by the interatrial pressure gradient. Braunwald et al. showed that the left-to-right interatrial pressure gradient was higher in end-systole than in end-diastole in patients without any clinical evidence of cardiovascular disease. This observation may explain the mechanism of the change in the interatrial septal configuration between end-systole and end-diastole. We hypothesize that the configuration of the IAS and its change through each cardiac cycle are determined primarily by the interatrial pressure gradient. When the left atrial pressure is higher than the right, the interatrial septal configuration may be convex toward the RA. The more the interatrial left-to-right pressure gradient increases, the more convex toward the RA the IAS may be. When the right atrial pressure is higher than the left, the IAS may be convex toward the LA. The more right-to-left pressure gradient increases, the more convex toward the LA the IAS may be. When the interatrial pressure gradient is almost zero, the IAS may show an almost flat configuration.

In mitral stenosis, the IAS showed marked protrusion toward the RA, with minimal change in its configuration through each cardiac cycle. The protrusion of the IAS toward the RA can be explained by the increase in the left-to-right interatrial pressure gradient due to increased left atrial pressure. The pulse pressure of the LA in patients with mitral stenosis is reported to be about the same or higher than that of
Figure 6. Cross-sectional echocardiograms and their schematic representations from a patient with mitral regurgitation due to rheumatic heart disease. Panel A was recorded in end-systole and panel B in end-diastole. The interatrial septum (IAS) is convex toward the left atrium (LA) both in end-systole and in end-diastole, but it is less convex in end-diastole. The LA is enlarged. RA = right atrium.
normal subjects. Therefore, the pulse pressure in the left-to-right interatrial pressure gradient may increase. A possible explanation of the minimum change of the interatrial septal configuration between end-systole and end-diastole is that the IAS is protruded almost to its maximum limit, even in its minimum pressure gradient and that, therefore, the IAS cannot protrude further in response to the increment of the pressure gradient.

The configuration of the IAS in end-systole was markedly convex toward the RA in acute mitral regurgitation, while it was slightly to moderately convex toward the RA in chronic mitral regurgitation. The configuration of the IAS in end-diastole was convex toward the LA in acute mitral regurgitation, and it was almost flat or slightly convex toward the RA in chronic mitral regurgitation. Therefore, the difference of the configurations between end-systole and end-diastole was increased in acute mitral regurgitation, while the difference was not increased in chronic mitral regurgitation. Hemodynamic study by Baxley et al. showed that the volume change of the LA was smaller in the ruptured chordae group than in the rheumatic mitral regurgitation group, and that the pulse pressure of the LA was larger in the ruptured chordae group than in rheumatic mitral regurgitation group. The increase in the pressure pulse of the LA may result in the increment of the left-to-right interatrial pressure gradient. In fact we have observed in studies with open-chest dogs that the interatrial left-to-right pressure gradient was increased when acute mitral regurgitation was produced by cutting the chordae tendineae (fig. 9). In this experiment, an increase in the left atrial pressure by the production of acute mitral regurgitation was dominant in systole, but not as clear in end-diastole, while the right atrial pressure was unchanged both in end-systole and in end-diastole. Thus, the left-to-right pressure gradient was

FIGURE 7. Cross-sectional echocardiograms and their schematic representations from a patient with tricuspid regurgitation who underwent mitral valve replacement. Panel A was recorded in end-systole and panel B in end-diastole. Note that the interatrial septum (IAS) is more convex toward the left atrium (LA) in end-systole than in end-diastole. RA = right atrium; IVS = interventricular septum.

FIGURE 8. Cross-sectional echocardiograms and their schematic representations from a patient with mitral stenosis complicated by tricuspid regurgitation. Panel A was recorded in end-systole and panel B in end-diastole. The interatrial septum (IAS) is less convex toward the right atrium (RA) in end-systole than in end-diastole. The convex curvature toward the RA both in end-systole and in end-diastole is due to mitral stenosis. IVS = interventricular septum; LA = left atrium.
Increased, especially in end-systole. These observations support our hypothesis that the interatrial septal configuration is determined mainly by the interatrial pressure gradient.

Patients who had tricuspid regurgitation in the present study had various underlying heart disease that caused it. Therefore, the interatrial septal configuration and its change through each cardiac cycle showed several features. However, seven of nine patients with tricuspid regurgitation had a characteristic finding: The IAS became more convex toward the LA or less convex toward the RA in end-systole than in end-diastole. It may result from the increment of the right-to-left interatrial pressure gradient during systole due to regurgitant flow across the tricuspid valve. Two patients in this group did not show the characteristic finding of tricuspid regurgitation. In the patient with primary pulmonary hypertension, the IAS might protrude toward the LA to its nearly maximum limit, even in diastole. Therefore, the IAS might be unable to protrude any more in response to tricuspid regurgitation. In the patient with cardiomyopathy who had mitral and tricuspid regurgitation, the IAS became more convex toward the RA in end-systole than in end-diastole, indicating that the elevation of the left atrial pressure due to mitral regurgitation may have been greater than that of the right atrial pressure due to tricuspid regurgitation.

This new ASA directional technique may have a further application; that is, to measure precisely the anteroposterior dimension of the RA which has been considered to be difficult to estimate echocardiographically. The left atrial dimension, which is estimated by an almost right-angled direction to the conventional one, can also be measured, together with the measurement of the right atrial dimension, in a cross-sectional echocardiogram.

In conclusion, the observation of the interatrial septal configuration by the new method introduced in this study is very useful in the diagnosis of the left or right atrial overloading. The major factor that changes the IAS configuration seems to be the pressure gradient between both atria.

References
Real-time cross-sectional echocardiographic evaluation of the interatrial septum by right atrium-interatrial septum-left atrium direction of ultrasound beam.
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