The Tricuspid Valve Annulus: Study of Size and Motion in Normal Subjects and in Patients with Tricuspid Regurgitation

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SUMMARY The tricuspid valve leaflets and their annular attachments were recorded by two-dimensional echocardiography from a view of the right ventricular inflow tract obtained by placing the transducer at an intermediate position between the left ventricular apex and the left lower sternal border. The transducer was rotated, and recordings were made at 30° rotational intervals around the circumference of the tricuspid valve annulus. The cyclical pattern of variations in tricuspid annular size was studied with 12 measurements made during the cardiac cycle in five normal subjects. Annular areas and circumferences were measured. The overall motion pattern was similar to that reported in normal mitral valve annular study. Subsequently, in 16 normal subjects and 18 patients with tricuspid regurgitation, the maximum and minimum tricuspid annular sizes and their percent reduction were measured. The mean maximum annular circumference and area were 11.9 ± 0.9 cm (mean ± sd) and 11.3 ± 1.8 cm² in normal subjects. They were significantly greater in tricuspid regurgitation (14.0 ± 0.7 cm and 15.8 ± 1.8 cm², respectively). The mean minimum annular sizes were much larger in tricuspid regurgitation (12.5 ± 0.6 cm and 13.0 ± 1.4 cm²) than in normal subjects (9.6 ± 0.9 cm, 7.6 ± 1.4 cm²). Thus, the percent reduction of annular circumference and area were significantly decreased in tricuspid regurgitation. For anatomic correlations, measurements of the tricuspid annular circumference were made at autopsy in 18 hearts without underlying valvular disease. The annular circumference was measured in the fresh and fixed states. The measurement in the fresh state was 13.5 ± 0.8 cm and in the fixed state was 12.0 ± 0.8 cm. The values measured in the fixed hearts were more similar to measurements obtained by echocardiography in a group of normal subjects.

Thus, tricuspid annular reconstruction by the new two-dimensional echocardiographic method provides additional information about normal and abnormal size and function of the tricuspid valve annulus.

THE MOST COMMON cause of tricuspid regurgitation (TR) is not intrinsic involvement of the valve itself, but dilatation of the tricuspid valve annulus. The results of tricuspid annuloplasty for correction of significant tricuspid regurgitation have usually been successful. No technique is available to measure tricuspid annular size and assess annular function, and no reports have described the tricuspid annular size and motion in intact man. In a study using two-dimensional echocardiography from our laboratory, we described a method of reconstructing the mitral annulus using multiple apical planes obtained by 30° rotations of the transducer. In the present report, we used a similar method to reconstruct the tricuspid annulus using multiple echocardiographic planes obtained from another transducer location.

In the present paper we describe a noninvasive method of evaluating the size of the tricuspid valve annulus and its variations during the cardiac cycle in normal subjects and in patients with TR. Measurements of the tricuspid valve annulus in autopsy hearts with normal tricuspid valves were made in the fresh and fixed state. The echocardiographic findings in a group of normal subjects were compared with the autopsy measurements.

Clinical Study

Patients

Eighteen of 23 patients with clinical TR examined by echocardiography between May 1980 and February 1981 had high-quality echocardiograms of the right ventricular inflow tract, which are necessary for measuring the tricuspid annulus. All 18 patients were diagnosed as having TR. The clinical diagnosis in each case was supported by contrast echocardiographic appearance in the inferior vena cava throughout systole after a peripheral venous injection of 5% dextrose in water. The underlying conditions were pulmonary hypertension in five patients, congestive cardiomyopathy in five, rheumatic valvular disease in four and previous myocardial infarction with ventricular failure in four. All patients were males, ages 35–86 years (mean 63.0 years). A control group consisted of 16 normal male subjects from 28 examined, and these were selected on the basis of the quality of the echocardiograms required for accurate measurements. All were males, ages 17–57 years (mean 34.5 years).

Two-dimensional Echocardiographic Methods

All subjects were studied in the partial left lateral decubitus position. A commercially available wide-angle, phased-array system (Varian 3000) was used.
The studies were recorded on half-inch videotape using a Sanyo video recorder. The images could be redisplayed in real-time, slow motion or as single frames. Still frames were recorded on 90-mm film during real-time studies and are used as illustrations in this paper. The transducer was mounted on an inclinometer,\textsuperscript{11} which has a circular, fluid-filled chamber that contains an air bubble to allow measurement of 30° transducer rotational intervals.

We have described in detail the method designed to reconstruct the mitral annulus from diameters measured in the multiple apical views obtained at 30° rotational intervals by appropriate manipulations of the transducer.\textsuperscript{7} A similar approach was used to reconstruct the tricuspid valve annulus. The transducer was held at an intermediate position between the left ventricular apex and the left lower sternal border to obtain the long-axis plane of the right ventricular inflow tract (fig. 1). A plane between 11 and 5 o'clock was used as the initial plane of examination (fig. 2). In this position, the transducer was angled back and forth in an arc perpendicular to the plane of the beam for identifying the maximum orifice diameter. During held expiration, five to 10 cardiac cycles were recorded on videotape. The transducer was then rotated 30° clockwise, and the widest annular diameter at this rotation identified, and recordings were made. Thus, recordings were made at 30° rotational intervals around the circumference of the tricuspid annulus.

A reference line drawn on a strip of clear plastic was taped to the video monitor screen so that it bisected the annular diameter perpendicular to the plane of the tricuspid annulus. After the videotape was advanced to selected times during the cardiac cycle, the annular diameters and the distance from the reference line were measured. Thus, the tricuspid annulus was reconstructed for 12 selected times during the cardiac cycle.

**FIGURE 1.** Mounted on the echocardiographic transducer (T) is an inclinometer.\textsuperscript{11} This device has a circular, fluid-filled chamber that contains an air bubble, which allows measurement of 30° transducer rotations. The shaded area represents a plane of the two-dimensional echocardiographic beam that slices the tricuspid annulus in two places.

**FIGURE 2.** Cross section of the heart and six planes recorded by a rotational system. The numbers represent locations of transducer during the cross sections. A = anterior tricuspid leaflet; S = septal tricuspid leaflet; P = posterior tricuspid leaflet; MV = mitral valve; AV = aortic valve; PV = pulmonary valve.

**FIGURE 3.** The changes in tricuspid annular area index during the cardiac cycle in a representative normal subject.
in five initial normal subjects. Preliminary observations showed that the annular size was maximum in late diastole, at the end of the P wave and minimum in midsystole. In the subsequent analysis of the data, the maximum annular size was measured in late diastole, at the end of P wave and minimum size in midsystole in the normal subjects and in 12 of the patients with TR.

In six cases of TR with atrial fibrillation, the maximum annular size was measured at the onset of the Q wave. Each measurement represented a mean value from four to five cardiac cycles. The reconstructed tricuspid annular area was planimetered, and the resulting area was divided by the body surface area and expressed as tricuspid annular area index. Tricuspid annular cir-

**Figure 4.** Composites of still frames taken in late diastole (top) and midsystole (bottom) in a normal subject from six planes at 30° rotational intervals. Black arrows indicate hinge points of the tricuspid valve leaflets identified at each rotation. The structures around the tricuspid annulus are changing in each plane. The two-dimensional echo beam slices the annulus (top) at 11 and 5 o'clock and (bottom) at 12 and 6 o'clock, and so on, for each of the six planes. LV = left ventricle; RV = right ventricle; RA = right atrium; Ao = aortic valve; ocl = o'clock.
Circumferences were measured with a mapping wheel from the reconstructed annuli. The percent reduction of annular size was measured by the formula \((\text{maximum size} - \text{minimum size}) / \text{maximum size} \times 100\).

**Autopsy Study**

Hearts were obtained from 18 consecutive autopsies in which there was no evidence of underlying valvular disease or heart failure. These autopsies were all performed by one person. The hearts were from males, ages 28–93 years (mean 63.3 years).

The tricuspid valve was opened by a single incision passing from the right atrium to the apex of the right ventricle through its lateral border. The circumference of the tricuspid valve annulus was then measured using a metric ruler with subdivisions of 0.1 cm. Rusted et al.\(^{12}\) suggested that this measurement technique results in a measurement error of no more than 0.02–0.03 cm. The mitral valve was opened in a similar manner by a single incision. The circumference of the mitral valve annulus was measured by the same method. After measurement in the fresh state, all hearts were fixed in 10% formaldehyde for 24 hours. The tricuspid and mitral annuli were then remeasured in the manner described for the fresh state.

The height and weight of each subject were recorded and the body surface area was calculated from these figures. The surface area was then used to calculate the mean circumference index (cm/m\(^2\)).

**Results**

**Clinical Study**

The size of the tricuspid annulus was observed to change dynamically during cardiac cycle in our study. Figure 3 shows the tricuspid annulus changing in a normal subject during one cardiac cycle. In late diastole, at the end of the P wave, the annulus increased in size to reach a maximum. Then there was a presystolic narrowing, and minimum size was reached in mid-systole. The annulus then enlarged before end-systole, and further increased in early diastole. The annulus change from early to mid-diastole was small. Similar cyclical variations of tricuspid annular size were seen in all five normal subjects whose recordings were reconstructed for 12 times during a cardiac cycle.

Figure 4 shows composites of still frames taken in late diastole and mid-systole in a normal subject from six planes at 30° rotational intervals. Black arrows indicate the leaflet annular attachments that were identified at each rotation. The structures around the tricuspid valve differ depending on the plane of orientation of the echo beam. Figure 5 shows a composite of still
Composites of still frames taken in late diastole (far left) and mid-systole (left) in a patient with tricuspid regurgitation. Black arrows indicate hinge points of the tricuspid valve leaflets identified at each rotation as described in figure 4. IVS = interventricular septum; RV = right ventricle; RA = right atrium. Ao = aortic valve; o'clock.

Figure 5.

frames taken from a patient with TR. Tricuspid annular size and percent reduction in normal subjects and in TR are summarized in table 1. The maximum tricuspid annular circumference and area in normal subjects were 11.9 ± 0.9 cm and 11.3 ± 1.8 cm², respectively (mean ± sd). The indexes were 7.8 ± 0.7 cm/m² and 6.1 ± 0.9 cm²/m², respectively. Tricuspid annular circumference and area were significantly larger in patients with TR than in normal subjects (p < 0.001). The maximum tricuspid annular circumference and area in TR were 14.0 ± 0.7 cm and 15.8 ± 1.8 cm², respectively. The percent reductions of annular circumference and area were significantly lower in TR compared with normal (p < 0.001) (table 1).

Autopsy Study

The mean tricuspid valve annular circumference in the fresh state was 13.5 ± 0.8 cm (mean ± sd), and the mean circumference index was 7.3 ± 0.9 cm/m². The mean tricuspid valve annular circumference in the fixed state was 12.2 ± 0.8 cm, and the mean circumference index was 6.5 ± 0.9 cm/m². In these same autopsied hearts, the mean mitral valve annular circumference in the fresh state was 11.4 ± 0.7 cm and in the fixed state, 10.7 ± 0.5 cm. Comparisons of measurements in the normal subjects with those in the autopsied hearts are listed in table 2.

Discussion

Motion and Percent Reduction of Tricuspid Valve Annulus

Using a new rotational two-dimensional echocardiographic technique, we showed that the tricuspid annular size varied during the cardiac cycle. The motion of the tricuspid valve annulus in normal subjects was similar to that of the mitral valve annulus reported in a previous study. Earlier experimental observations on the beating, exposed heart have suggested a definite sphincter-like action of the mitral and tricuspid valve annuli. Tsakiris et al. studied dogs with lead beads sutured to their tricuspid annuli. The changes in the size and motion of the tricuspid annuli in the present study of human subjects were similar to their experimental observations. In the study of Tsakiris et al., the size of the tricuspid annulus increased in diastole until a plateau was reached that was approximately before the onset of the P wave of the ECG, and a smaller increase in annular size occurred during the early phase of atrial contraction. Progressive narrowing of the annulus then occurred during the end of atrial
contraction and throughout ventricular systole. Finally, annular size increased during ventricular isovolumic relaxation.

The pattern in experimental studies on dogs was similar to that in the present clinical study, except during end-systole. In our study, tricuspid annular size began increasing in the latter half of the ventricular systole and increased further during isovolumic relaxation. This finding was similar to that in previous studies of the mitral valve annulus. This increase in the tricuspid annular size during late systole may be caused by the effects of increasing right atrial size. Furthermore, the maximal diastolic area of tricuspid annulus in resting normal subjects in the present study was reduced by 33% (range 26–39%) during the cardiac cycle, which is similar to the 29% reduction (range 20–39%) reported in an experimental study of anesthetized intact dogs. The mean reduction of tricuspid annulus size in resting normal subjects in the present study is somewhat larger than that of the mitral annulus (mean 26%, range 23–31%) reported in our previous study.

The anatomic structures surrounding the annulus may influence the reduction in the annular size. The mitral annulus has two major collagenous structures, the right and left fibrous trigones; however, the tricuspid annulus has only a single right fibrous trigone. The mitral valve annulus is not in contact with the myocardium across the base of the anterior mitral leaflet between the fibrous trigones. Therefore, the tricuspid annulus, with more of its circumference in contact with the myocardium, exhibits increased systolic reduction. The percent reduction of the tricuspid annulus size in TR was significantly decreased compared with that in normal subjects. The mechanism of this finding remains speculative and may be related to reduced right ventricular ejection fraction.

Size of the Tricuspid Annulus

Since this is the first report on tricuspid annular size in the intact human subject, it is difficult to assess the accuracy of tricuspid annular size measured in the present study by two-dimensional echocardiography.

A comparison of the tricuspid valve annulus measured during life using two-dimensional echocardiography with the measurement obtained at autopsy may raise several questions. The method by which the heart is preserved may produce different annular measurements. Apparently, examination of the valve annuli in the fixed state results in a smaller annular size than in the fresh hearts. The formalin-preserved annulus appears to compare more closely with the maximum size in a group of normal subjects. Smaller measurements obtained by two-dimensional echocardiographic techniques compared with freshly opened hearts may be related to less precise lateral resolution of the ultrasonic method, which tends to underestimate cavity size. Echocardiographic measurements of the mitral valve annulus compared with autopsy measurements show a similar discrepancy: The autopsied hearts are consistently larger in both the fresh and fixed states. The tricuspid annulus is larger than the mitral annulus.

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<tr>
<th>Table 1. Echocardiographic Data of the Tricuspid Annular Sizes and Percentage Reduction</th>
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<td>Annular circumference (cm)</td>
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<td>---------------------------------------------------------------</td>
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<td>Normal (n = 16)</td>
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<td>Tricuspid regurgitation</td>
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<td>Maximum Measurement</td>
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Values are mean ± SD.

*Significantly different from normals (p < 0.001).

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<th>Table 2. Comparisons of Echocardiographic and Autopsy Measurements of Tricuspid and Mitral Annuli</th>
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<tr>
<td>Tricuspid annular circumference (cm) Mean and range</td>
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*Previously published observations.7
The two-dimensional echocardiographic and the autopsy measurements in the present study confirm this observation.

The tricuspid annulus in TR was significantly larger than that in normal subjects. Because percent reduction of the annulus was reduced, the minimum systolic tricuspid annular size was markedly larger than that in normal subjects — almost twice normal. The exact mechanism for larger systolic size is not known. It may be speculated that right ventricular enlargement results in dilatation of the annular size. Furthermore, a decrease in right ventricular function may account at least in part for less-than-normal systolic reduction of annular size.

The choice of surgical management of "secondary" TR appears to be controversial, and several kinds of reconstruction methods are used. Preoperative evaluation of the annular size may be helpful in planning the reconstruction procedure or the use of a prosthetic device. This method would also provide, for the first time, a method for assessing preoperative size and function of the tricuspid annulus.

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