Detection of Tricuspid Regurgitation with Two-dimensional Echocardiography and Peripheral Vein Injections

WILLIAM LIEPPE, M.D., VICTOR S. BEHAR, M.D., RALPH SCALLION, M.D., AND JOSEPH A. KISSLO, M.D.

SUMMARY “Contrast echocardiography,” utilizing a two-dimensional ultrasound system and peripheral venous injections, was used for the detection of tricuspid regurgitation in 30 patients. The appearance of contrast in the inferior vena cava and the back and forth movement of contrast across the tricuspid valve was considered evidence for tricuspid regurgitation. Echocardiographic findings were correlated with clinical and angiographic data. Patients were assigned on the basis of clinical data to one of three groups. Group I included five patients whose clinical findings were diagnostic for tricuspid regurgitation. Group II included patients (15) whose clinical findings were equivocal for tricuspid regurgitation and patients whose recognized primary problem is frequently associated with tricuspid regurgitation. Group III contained ten patients serving as controls. All group I patients had positive echocardiographic studies for tricuspid regurgitation, while all group III patients had negative studies, suggesting that this technique may be specific for tricuspid regurgitation. Among the group II patients, three who had positive echocardiographic studies despite the absence of specific clinical findings of tricuspid regurgitation, suggesting that this technique may be more sensitive than the methods in common use.

TRICUSPID REGURGITATION may be hemodynamically important and is relatively frequent in the presence of severe mitral valve disease, cardiomyopathy or pulmonary hypertension. Yet the diagnosis of tricuspid regurgitation, on the basis of clinical findings, is often difficult to make with certainty. An early, tall and broad V wave on the jugular venous pulse tracing is very helpful, but severe tricuspid regurgitation may occur in association with a relatively normal venous pulse tracing.1 In addition early, broad V waves may be seen in patients with congestive heart failure in whom there is no other evidence for tricuspid regurgitation.3 Right ventricular cineangiography is frequently inconclusive with regard to tricuspid regurgitation, due to the presence of a cardiac catheter across the tricuspid valve which may itself induce some degree of valvular incompetence. Thus, a technique for the detection of tricuspid regurgitation, which is more sensitive and specific than existing methods, would be of value.

Bove4 and Kremkau5 have shown that the rapid injection of liquid into the vascular system causes the development of tiny bubbles in the liquid, and that these microcavitations serve as excellent ultrasound targets. The utilization of microcavitations for “contrast echocardiography” has been described since 1968.6 Clouds of echo targets produced by the rapid injection of small boluses of indocyanine green dye, saline, 5% dextrose in water or the patient’s own blood have been utilized effectively for the demonstration of cardiac anatomy, aortic and mitral regurgitation and intracardiac shunts.6-10 Conventional M-mode echocardiography has been used in all previous studies. Most previous studies using this technique have required the placement of intracardiac or intra-aortic catheters at the time of cardiac catheterization and/or surgery. One recent study utilized peripheral vein injections of 5% dextrose in water or blood for the detection and localization of intracardiac right-to-left shunts.9

In the present study contrast echocardiography, utilizing a recently developed two-dimensional ultrasound system and peripheral venous injections of normal saline and/or indocyanine green dye, was evaluated as a technique for the detection of tricuspid regurgitation. Echocardiographic findings were correlated with physical signs, jugular venous pulse tracings and right ventricular cineangiograms.

Methods

Patients

The initial study group included 32 patients who were referred to the Duke Cardiovascular Laboratory for cardiac catheterization and/or two-dimensional echocardiography between August 1976 and March 1977. All patients underwent phonocardiography, including a jugular venous pulse recording. The presence of tricuspid regurgitation in 22 patients was suggested by physical signs and/or the clinical setting. Ten patients who served as controls for this study were referred to the Cardiovascular Laboratory for cardiac catheterization because of chest pain. None of the control group had physical findings suggesting the presence of tricuspid regurgitation.

On the basis of clinical data, each patient was assigned to one of three groups (table 1). Group I included five patients with physical findings and jugular pulse tracings that were diagnostic for tricuspid regurgitation (see phonocardiographic methods). Group II was composed of 17 patients: those in whom clinical findings were suggestive of, but not diagnostic for, tricuspid regurgitation, and those in whom physical findings were negative, but in whom the clinical setting (e.g., severe mitral valve disease) frequently is associated with tricuspid regurgitation. Group III included the ten control patients.

Two-dimensional echocardiography with peripheral venous injection of saline and/or indocyanine green dye was performed on all patients, as described below. For these studies to be considered technically acceptable, it was required that the microcavitations be visualized in the right
TABLE 1. Summary of Group Data

<table>
<thead>
<tr>
<th>Group</th>
<th>Number</th>
<th>Mean age (yr) (range)</th>
<th>Clinical setting</th>
<th>Criteria determining patient assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Holoystolic murmur</td>
<td>Murmur typical of TR</td>
</tr>
<tr>
<td>I</td>
<td>5</td>
<td>45 (28-54)</td>
<td>2 mitral valve disease</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 cardiomyopathy</td>
<td>1 pulmonary hypertension</td>
</tr>
<tr>
<td>II</td>
<td>17</td>
<td>47 (18-70)</td>
<td>3 cardiomyopathy</td>
<td>5 pulmonary hypertension</td>
</tr>
</tbody>
</table>

Abbreviations: TR = tricuspid regurgitation; JVP = jugular venous pulse; CHF = congestive heart failure.

atrium and right ventricle. In two patients (both in group II) microcavitations were not visualized, and these patients were excluded from the study population.

Cardiac catheterization with right ventricular angiography was performed in nine of the 22 patients in groups I and II. All group III patients underwent right and left heart catheterization, but none had right ventricular contrast injections. All studies were performed within three days of each other. Informed consent was obtained from every patient in the study before any peripheral venous injections were performed.

Phonocardiographic Methods

Phonocardiography and jugular venous pulse recordings were performed using standard techniques and a Siemens mingograf recorder. In patients who did not manifest overt congestive heart failure, the jugular pulse tracing was considered diagnostic for tricuspid regurgitation when the V wave was early-beginning, broad and more prominent than the A wave (Fig. 1). Broad, early-beginning V waves when recorded in patients with overt congestive heart failure were considered only suggestive for tricuspid regurgitation, because they have been observed in such patients in the absence of other evidence for tricuspid regurgitation. All patients in whom a V wave could be recorded over the liver were considered to have tricuspid regurgitation, even in the presence of congestive heart failure.

Echocardiographic Methods

Two-dimensional echocardiograms were obtained using a previously described real-time, focused, phased array imaging system developed in the Duke University Biomedical Engineering Department. Twenty-two of the patients included in the study were examined using the prototype of this device, while ten were examined using a commercially available model (Grumman RT-400). These systems produce high resolution images of cardiovascular structures which are presented in real-time, in a circular sector format, 50 to 90 degrees in azimuth. Images are permanently recorded on videotape for later playback and analysis. The ECG is displayed and recorded alongside the sector arc.

Two-dimensional images were routinely obtained in multiple cross-sectional planes through the heart, as previously described. Most pertinent to this report are the data obtained from images through the long axis of the tricuspid valve. In addition, with the transducer placed in the subxyphoid area, the right atrium, tricuspid valve, inferior vena cava (and hepatic veins) and sometimes the right ventricle were visualized simultaneously in the same plane. Images in these planes of view are illustrated in figure 2.

Bolus injections (4–5 cc) of normal saline and/or indocyanine green dye were injected rapidly by hand into an antecubital vein while viewing images in the plane of the right atrium and inferior vena cava. While continuously recording on videotape, observations were made for appearance of a cloud of echoes in the inferior vena cava. The transducer was then moved to obtain images in the long axis of the tricuspid valve, and additional injections were made to demonstrate the appearance of microcavitations in the right heart chambers. Patients were considered to have tricuspid regurgitation if microcavitations appeared in the

Figure 1. An example of the jugular venous pulse tracings considered diagnostic for tricuspid regurgitation. The V wave is early beginning and prominent. The phonocardiogram was obtained at the lower left sternal border. EKG = electrocardiogram; JVP = jugular venous pulse tracing; a, c and v refer to respective waves; PHONO = phonocardiogram.
inferior vena cava during ventricular systole (fig. 3), or if they passed back and forth across the tricuspid valve during successive cardiac cycles (fig. 4). The density of the microcavitations could be enhanced by having the patient perform a Valsalva maneuver with the injectate being delivered immediately after the release phase.

Catheterization Methods

Right and left heart catheterization was performed using standard techniques. Right ventricular cineangiograms were obtained by power injection of Renografin 76 through an 8 Fr Gensini catheter positioned across the tricuspid valve in the body of the right ventricle. Angiograms were considered positive for tricuspid regurgitation only when the regurgitant jet of contrast material was relatively pronounced and clearly not catheter-induced (fig. 5).

Results

In all five group I patients with definite clinical evidence of tricuspid regurgitation, the cloud of microcavitations was shown to appear in the inferior vena cava during ventricular systole and to pass back and forth across the tricuspid valve during successive cardiac cycles. Four of the five patients in group I underwent right ventricular cineangiography, which demonstrated severe tricuspid regurgitation in each case.

Of the 15 patients remaining in group II, eight had positive echocardiographic studies for tricuspid regurgitation, and seven had negative studies. Of particular note were three patients included in group II because their primary cardiac problems are frequently associated with tricuspid regurgitation. None of these three patients manifested the clinical findings of tricuspid regurgitation, but each of them demonstrated tricuspid regurgitation by contrast echo-

Figure 2. Frames showing examples of the planes of view employed in this study. Panels A and B show an image in the long axis of the tricuspid valve. Panels C and D show an image in the plane of the right atrium and inferior vena cava. RA = right atrium; RVC = right ventricular chamber; TL = tricuspid leaflet; IVS = interventricular septum; LVC = left ventricular chamber; ML = mitral leaflet; CS = coronary sinus; IVC = inferior vena cava; IAS = interatrial septum.

Figure 3. Frames in the plane of the right atrium and inferior vena cava, from a patient with tricuspid regurgitation. Panel A is a diastolic frame, before the injection of saline into an antecubital vein. Panel B is a systolic frame after the saline injection and demonstrates the appearance of microcavitations in the inferior vena cava and hepatic vein. Panel C is a schematic of panel B. D = diaphragm; K = kidney; RV = renal vein; L = liver; HV = hepatic vein.
cardiography. Since these patients demonstrate discordance between the clinical and echocardiographic findings, brief case histories will be described.

D. R. was a 46-year-old female with rheumatic heart disease, who had previously undergone a mitral commissurotomy. Physical examination demonstrated normal central venous pressure and a predominant A wave. There were murmurs of mitral stenosis, aortic regurgitation and a soft systolic murmur at the apex and lower left sternal border which did not vary with respiration. The liver was not enlarged. Phonocardiography and jugular venous pulse recording confirmed the physical findings. Contrast echocardiography was clearly positive for tricuspid regurgitation, and right ventricular cineangiography demonstrated moderate to severe tricuspid regurgitation.

J. W. was a 24-year-old female with a secundum atrial septal defect. A previous cardiac catheterization demonstrated elevated pulmonary vascular resistance and mitral prolapse with mild mitral regurgitation. Physical exam during the present admission demonstrated normal central venous pressure with a predominant A wave. There was a grade III/VI holosystolic murmur at the apex, which radiated to the axilla, and a grade III/VI pulmonary systolic ejection murmur. The liver was not enlarged. Phono-

cardiography with jugular venous pulse tracing confirmed these findings. Echocardiography demonstrated tricuspid regurgitation by the appearance of microcavitations in the inferior vena cava during ventricular systole and their back and forth movement across the tricuspid valve. No microcavitations were noted to appear in the left heart which would have suggested a right-to-left shunt. Cardiac catheterization on this admission demonstrated suprasystemic pressures in the pulmonary artery (104/44). Left ventricular cineangiography showed only mild mitral regurgitation, and a right ventricular contrast injection was equivocal for tricuspid regurgitation. There was no significant right-to-left shunt by oximetry.

J. H. was a 23-year-old male with overt congestive heart failure related to familial cardiomyopathy. His physical exam showed the jugular veins to be moderately distended, with a predominant A wave. There were no cardiac murmurs. The liver was not enlarged. Jugular venous pulse tracing demonstrated a predominant A wave, and the V wave was early-appearing and broad. Contrast echocardiography was positive for tricuspid regurgitation. Cardiac catheterization was not performed.

There were three patients in group II in whom right ventricular cineangiography was inconclusive for tricuspid regurgitation. Echocardiographic studies were clearly positive in two of these patients and negative in the other.

**FIGURE 4.** Frames in the long axis of the tricuspid valve from a patient with tricuspid regurgitation. Panel A is a diastolic frame before the bolus injection of saline. Panel B is an early systolic frame after the saline injection and shows microcavitations in both the right atrium and right ventricle. Panel C is a schematic of panel B. The open arrow in panel C shows the region of the foramen oval.

**FIGURE 5.** A right ventricular cineangiogram in the right anterior oblique projection, showing severe tricuspid regurgitation.

**FIGURE 6.** Bar graph illustrating the percentage of each patient group which had positive two-dimensional echo-contrast studies for tricuspid regurgitation.
In each of the ten group III patients, echocardiography with peripheral saline injection was negative for tricuspid regurgitation.

The results of two-dimensional echocardiographic contrast studies in each of the patient groups are represented graphically in figure 6. Every patient with a positive echocardiographic appearance of microcavitations in the inferior vena cava, in whom the tricuspid valve was clearly visualized, also showed movement of microcavitations back and forth across the tricuspid valve.

Discussion

Contrast echocardiography, using intravascular or intracardiac injections, has been shown to be a useful and safe technique for the delineation of cardiac anatomy and for the detection of intracardiac shunts and aortic and mitral regurgitation. All previously published studies have utilized M-mode echocardiography. The present study evaluates two-dimensional echocardiography and peripheral venous injections for the detection and confirmation of tricuspid regurgitation.

The 20 patients included in groups I and II represented a spectrum of the causes of tricuspid regurgitation, including cardiomyopathy, mitral valve disease, atrial septal defect and pulmonary hypertension. That this technique is specific for tricuspid regurgitation is suggested by the fact that it produced a positive result in all group I patients and a negative result in all group III patients. The sensitivity of the technique is more difficult to establish, since there is no completely reliable standard of reference for the detection of tricuspid regurgitation. However, the presence of three patients in this series in whom clinical findings for tricuspid regurgitation were absent and in whom contrast echocardiography produced a clearly positive result suggests that the technique is sensitive. Of particular importance are the three patients in this series in whom both physical findings and right ventricular angiography were inconclusive. Two of these three patients clearly demonstrated tricuspid regurgitation by contrast echocardiography while the other did not, suggesting that this technique may be both more sensitive and specific than currently used methods.

The potential limitations of this technique, like all those dependent on ultrasound, are related in part to the quality of sound transmission in any given patient. Such limitations were exemplified by the two patients who were excluded from our initial study population because microcavitations could not be visualized in either the inferior vena cava or right heart. Another limitation of the technique, as presently employed, is that it provides no quantitative information about tricuspid regurgitation. Thus it would be of value for determining the presence of tricuspid regurgitation but not its severity. The advantages of this technique for the detection of tricuspid regurgitation relate to the use of a two-dimensional ultrasound system which provides images in real-time. The utilization of ultrasound and peripheral venous injections makes possible study of the tricuspid valve without the presence of a catheter across the valve. The real-time format of the images allows one to appreciate the direction of movement of the microcavitations during each phase of the cardiac cycle. This is not possible with conventional M-mode techniques. The two-dimensional echocardiographic system provides spatial orientation which renders the inferior vena cava, hepatic veins and right atrium readily identifiable and allows them to be visualized simultaneously in the same cross-sectional plane. In fact, since the peritoneal cavity is normally free of air, high quality images of the inferior vena cava and right atrium, obtained by holding the two-dimensional transducer over the epigastrium, are often more readily produced than are high quality images in the long axis of the tricuspid valve, which must be obtained by holding the transducer over the chest. An added advantage of detecting tricuspid regurgitation by the appearance of contrast in the inferior vena cava is its simplicity, in that it makes unnecessary the distinction between true back and forth movement of microcavitations across the tricuspid valve and the slight backward movement of microcavitations in the right atrium consequent to the right atrial C wave.

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References

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