Contrast M-mode Ultrasonography of the Inferior Vena Cava

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SUMMARY Contrast M-mode and two-dimensional ultrasonography of the inferior vena cava were performed in 65 patients with various acquired and congenital cardiac disorders. After saline was injected into a peripheral arm vein, the inferior vena cava was visualized by both methods in 60 patients (92%). The M-mode approach was better for correlating the appearance of contrast within the inferior vena cava with the ECG. This precise correlation served as the basis for differentiating patients with tricuspid insufficiency (visualization of contrast after the QRS) from those with impaired right ventricular filling (visualization of contrast before the QRS) or arrhythmia. Results with the M-mode approach suggest that conditions other than tricuspid insufficiency may cause the appearance of contrast within the inferior vena cava. M-mode echocardiography should be used to further investigate patients with impaired right ventricular filling.

CONTRAST ECHOCARDIOGRAPHY is a useful technique for verifying cardiac anatomic structure, evaluating intracardiac shunts and detecting valvular insufficiency.1-10 Lieppe et al.11 showed that two-dimensional echocardiography is a sensitive technique for detecting tricuspid regurgitation by visualizing within the inferior vena cava contrast that was injected peripherally. The major advantages of the two-dimensional approach are spatial anatomic identification of the inferior vena cava and recognition of the direction in which contrast moved within this vessel.

Clinical experience with ultrasonography of the vena cava leads us to believe that conditions other than tricuspid insufficiency cause the appearance of the contrast within this vessel. These may not be readily apparent if the two-dimensional approach alone is used. Two-dimensional echocardiography suffers from time-domain sampling rates restricted to television frame rates (30 frames/sec). Such low sampling rates make it difficult to time precisely the appearance of contrast in relation to the cardiac cycle. The higher time-domain sampling rates of M-mode (1,000 or more samples/sec) displayed on the familiar strip-chart recording make it quite easy to relate the time of contrast appearance to the ECG. The present study addressed the hypotheses that M-mode echocardiography is a useful alternative to the two-dimensional approach for detecting contrast within the inferior vena cava, and for purposes of obtaining critical timing information, M-mode ultrasonography is superior.

Methods

Ultrasonography of the inferior vena cava was performed by standard M-mode and two-dimensional techniques in 65 consecutive patients referred to the Duke University Clinical Cardiology Laboratory for evaluation of chest pain or possible pericardial, congenital or valvular heart disease. M-mode and two-dimensional examinations were performed by independent operators unbiased by the results from the alternate technique. Two-dimensional images were obtained using a focused, phased-array system.12 M-mode recordings were performed with commercially available equipment using a 7.5-cm focused, 2.25-MHz transducer. All patients were examined in the supine position; two were also examined in the left lateral position.

To obtain images of the inferior vena cava the two-dimensional echo transducer was placed in a subcostal position to yield a long-axis view of the right atrium, inferior vena cava and hepatic vein13 (fig. 1). The inferior vena cava appeared as a tubular structure, devoid of pulsations, that collapsed during a rapid brief inspiration. It was 1–2 cm in diameter and was located 8–10 cm from the abdominal surface, depending on the girth of the patient.

The M-mode transducer was placed by an operator, unbiased by the results of the two-dimensional approach, in a subcostal position and was directed slightly to the right of the midline. The inferior vena cava appeared posterior to the liver as a nonpulsatile, echo-free space that collapsed during rapid inspiration. The proper position for the M-mode beam is determined by sweeping from the right atrium to the insertion of the common hepatic vein to avoid detection of small amounts of contrast that swirl about the junction of the right atrium and inferior vena cava in normal subjects. When the M-mode beam was directed too far to the right of the midline, it visualized the gall bladder, which was closer to the abdominal surface.

Normal saline (10 ml) was rapidly injected into a superficial arm vein to produce contrast for visualiza-
tion by both ultrasonic methods. Peripheral injections were made during suspended respiration. M-mode and two-dimensional echocardiographic recordings were compared regarding the presence of contrast within the inferior vena cava and the timing of its appearance in relation to the cardiac cycle. Tricuspid regurgitation was considered present when contrast appeared in the inferior vena cava during ventricular systole (after the QRS complex) (fig. 2).11

Results

The inferior vena cava was identified by both M-mode and two-dimensional methods in 60 of 65 patients (92%). In three patients (5%) the inferior vena cava could not be identified by either method; in two others (3%) it was seen by two-dimensional ultrasonography alone. In each of these latter cases, the inferior vena cava was difficult to detect by the two-dimensional approach and was tortuous and narrow (less than 0.5 cm in diameter).

Neither ultrasonic approach detected contrast within the inferior vena cava in 19 of 60 patients. These patients had no clinical evidence of tricuspid regurgitation or right-sided heart disease.

Both M-mode and two-dimensional approaches detected contrast within the inferior vena cava in 36 other patients. In 25 of these, contrast appeared after the QRS complex, which was consistent with clinical and auscultatory evidence of tricuspid regurgitation. Contrast appeared at other times during the cardiac cycle in 11 others. The timing of the appearance of contrast within the inferior vena cava was related most easily to the phases of the cardiac cycle by using the M-mode approach. In three patients with pericardial disease, contrast appeared before the QRS complex (fig. 3). In six patients with arrhythmias, contrast appeared at the time of aberrant ventricular beats (fig. 4). In two patients, contrast appeared before the QRS when the patients changed from the supine to the left lateral position (fig. 5).

In five patients, contrast was visualized by only one ultrasonic method. Four patients had contrast appear with atrial systole in the proximal 2 cm of the inferior vena cava when examined with two-dimensional echo-

Figure 1. Cephalic-to-caudal M-mode sweep from the subxiphoid area in a normal subject. On the left the transducer beam is angled superiorly into the thorax, visualizing the abdominal wall (AW), moving portions of the right atrial wall and right atrium (RA) itself. As the transducer is swept caudally, the junction of the RA and inferior vena cava (IVC) is seen (solid arrow). At the proper level for interrogating the IVC, the liver is anterior and the IVC appears as a tubular structure 1–2 cm in diameter. The hepatic vein (HV) lies just anterior to the vena cava. The open arrow indicates normal collapse (nearly 50%) of the IVC with rapid inspiration. Systolic pulsations of the liver are found in most normal subjects. Range marks are 1 cm; paper speed is 25 mm/sec.

Figure 2. Microcavitations appear in the inferior vena cava (IVC) in a patient with severe tricuspid regurgitation. The arrow and vertical white line indicate onset of the QRS complex, followed by dense microcavitations. Paper speed is 50 mm/sec. HV = hepatic vein.

Figure 3. Microcavitations appear before systole in the inferior vena cava (IVC) of a patient with pericardial constriction. Respiration is suspended. The arrows and vertical white line indicate onset of QRS complex. Paper speed is 50 mm/sec. HV = hepatic vein.
cardiography, but not with M-mode. None of these patients had clinical or auscultatory evidence of right-sided heart disease. In one patient with paroxysmal atrial fibrillation, the M-mode examination was positive for systolic contrast during the arrhythmia, and the two-dimensional approach was negative during normal sinus rhythm.

Discussion

The results of this study indicate that M-mode ultrasonography can be used in most patients to inspect the inferior vena cava. Sweeping the transducer from the right atrium in a caudal direction helps assure the luminal continuity of right-sided cardiac structures. Because M-mode does not provide the lateral spatial target information of the two-dimensional approach, the inferior vena cava must be differentiated from the aorta by observing the collapse of the vena cava during rapid inspiration and its lack of systolic pulsations. The gall bladder or hepatic veins may produce an echo-free space similar to the inferior vena cava, but both are closer to the abdominal surface and do not collapse during rapid inspiration. Occasionally, these intraabdominal targets may rotate slightly in and out of view with rapid inspiration and appear to collapse by ultrasound. Thus, identification of the collapse of the inferior vena cava should be from more than one interrogating angle.

Although the inferior vena cava did not fail to collapse with rapid inspiration in this study, we have since seen several patients with markedly elevated right-sided pressure in whom it did fail to collapse. In each, contrast was detected within this structure before the onset of the QRS complex in patients with sinus rhythm on ECG.

The limited spatial characteristics of M-mode echo also make it difficult to identify accurately the level at which the echo beam intersects the inferior vena cava. This problem occurred in four patients in whom contrast was visualized by the two-dimensional approach, but not by M-mode. In each of these patients, contrast appeared with each atrial systole only in the proximal inferior vena cava adjacent to the junction of the right atrium and inferior vena cava. The M-mode beam was directed too far caudal to detect the contrast. This problem may be eliminated by angling the M-mode transducer cephalad to locate the right atrium and then returning the beam to the area just distal to the junction of the right atrium and inferior vena cava at or slightly below its junction with the common hepatic vein (fig. 2).

Two-dimensional ultrasonography failed to detect contrast that was seen during the M-mode examination in a subject who had paroxysmal atrial fibrillation during the M-mode study. The patient was in normal sinus rhythm during the two-dimensional examination, which accounts for the disparate results.

The M-mode approach is also better than the two-dimensional in displaying critical timing information regarding the appearance of microcavitations. The familiar time-histogram display of M-mode data facilitates the correlation of contrast appearance with the sequence of the cardiac and/or respiratory cycle. Such information could not be obtained easily using the two-dimensional approach.

The M-mode display indicated that there were other reasons than tricuspid insufficiency for microcavitations to appear in the inferior vena cava. These include phases of respiration, alterations in right ventricular filling pressure, patient position, and abnor-

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**Figure 4.** Appearance of microcavitations in the inferior vena cava (IVC) with cardiac arrhythmia. The patient is in ventricular bigeminy. Microcavitations appear after onset of the premature complexes (arrows and vertical white line). Reverberant artifacts from the dense microcavitations are seen posterior to the IVC. Paper speed is 50 mm/sec. HV = hepatic vein.

**Figure 5.** Spurious appearance of microcavitations in the inferior vena cava (IVC) because of improper technique in a normal subject in the left lateral position. After normal inspiration (open arrow), microcavitations appear before the QRS complex (closed arrows and vertical white line). The anterior wall of the IVC is not clearly recorded, and the absence of the hepatic vein indicates this tracing was taken at the improper level. Paper speed is 50 mm/sec.
malities in the sequence of atrial-ventricular contraction.

If injections are made into an arm vein during a rapid, brief inspiration, contrast may appear in the inferior vena cava with atrial systole at end-inspiration or the beginning of expiration. This respiratory phenomenon occurred in all patients and may be due to phasic changes in the inferior vena caval flow relative to the respiratory cycle. Because it did not occur when patients held their breath, it also illustrates the importance of injecting contrast during suspended respiration.

Contrast appeared in the inferior vena cava after atrial contraction but before the QRS complex in three patients with pericardial disease (fig. 3) who had documented elevation of right ventricular end-diastolic pressures at catheterization (one with constrictive pericarditis and two with cardiac tamponade). This presumably occurred because of forceful atrial contraction coincident with marked elevation of right ventricular end-diastolic pressure.

Two patients were examined in both the supine and the left lateral decubitus positions to determine the effect of altered position. Contrast appeared in the inferior vena cava before ventricular systole, when the patients were in the left lateral position. When they were examined in the supine position, contrast was uniformly absent from the inferior vena cava, although we do not know why. By two-dimensional echocardiography, these microcavitations could be seen trapped in the hepatic veins. To avoid errors introduced by this factor, studies should be performed only in the supine position.

The electrocardiographic rhythm strip recorded with the M-mode echo allowed display of systolic events not readily appreciated on the two-dimensional echo. Exact timing of ventricular contraction and detection of arrhythmias are critical, because various arrhythmias may affect the appearance of systolic contrast (fig. 4). Six patients had contrast appear in the inferior vena cava in conjunction with cardiac arrhythmias (four had atrial fibrillation and two had premature ventricular contractions).

M-mode echo should be considered as an alternative to two-dimensional ultrasonography for detecting contrast within the inferior vena cava. Despite the lack of lateral spatial integration, the location of the M-mode beam can usually be verified by careful attention to technique. Compared with the two-dimensional approach, M-mode echo is more widely available and less expensive. Recognition of temporal cardiac events relative to the electrocardiogram is more readily achieved by M-mode. This study expands the scope of uses of M-mode and provides an explanation for the appearance of contrast within the inferior vena cava in patients who do not have tricuspid insufficiency. This technique may also add to the understanding of the complex dynamics of flow in the inferior vena cava in normal subjects and in those with restrictive or right-sided heart disease. When M-mode and two-dimensional echocardiography are used together, the reliability of results for detecting the inferior vena cava and timing of appearance of contrast within it should be enhanced.

References

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