Hepatic Venous Flow Assessed by Transesophageal Echocardiography

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Systemic venous flow patterns are easily assessed by transthoracic echocardiography for evaluation of right heart dynamics. However, the transthoracic approach cannot be used in patients undergoing thoracic surgery. The present study describes a method for obtaining hepatic venous flow velocity with transesophageal Doppler echocardiography. Twenty-nine patients were studied with transthoracic echocardiography just before cardiac surgery and with transesophageal echocardiography during surgery. Hepatic venous flow velocity recordings were obtained in 14 of 29 patients with the transthoracic and in all 29 with the transesophageal approach.

Timing of flow pattern was similar with the two methods, but recordings obtained with transesophageal echocardiography were inverted compared with those obtained with transthoracic echocardiography as a result of the difference in probe location in relation to flow direction. The time-velocity integrals obtained with the two techniques did not differ significantly; for the transthoracic and transesophageal approaches, they were, respectively, 7.3 ± 3.4 versus 5.7 ± 4.4 for systolic flow; 1.0 ± 1.6 versus 0.5 ± 0.6 for end-systolic flow reversal; 4.7 ± 2.3 versus 3.7 ± 1.7 for diastolic flow; 2.0 ± 1.8 versus 1.5 ± 1.5 for atrial flow reversal and 1.9 ± 1.0 versus 1.7 ± 1.1 for systolic/diastolic ratio.

In conclusion, hepatic venous flow values are obtained more frequently and with better quality by transesophageal than by transthoracic echocardiography. The flow patterns and velocity integrals are similar with both methods and previous experience with transthoracic echocardiography should be applicable to the transesophageal technique. Transesophageal Doppler echocardiography therefore has potential for studying right heart dynamics during anesthesia and surgery.

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Recordings of flow velocity in the superior vena cava and hepatic veins are helpful in assessing right heart dynamics in health and disease (1–4). Various techniques, including differential manometers (5), bristle flow meter (6), electromagnetic flow probes (7,8) and implanted pulsed ultrasound flow meters (9,10), have been used to record venous flow velocities. More recently, pulsed wave Doppler ultrasound (1) has been introduced as a noninvasive measuring method. However, in patients undergoing abdominal or thoracic surgery, hepatic venous flow cannot be assessed with this method because of interference with the surgical field. Transesophageal echocardiography is an established operating room technique for assessing mitral valve function before and after repair, left ventricular wall motion and function and repair of congenital heart disease, but it has not been used for assessing right heart dynamics. In this study we describe a method for recording hepatic venous flow with transesophageal echocardiography and comment on the patterns observed.

Methods

Study subjects. Hepatic venous flow velocity recordings were studied in 29 adult patients (mean age 55 years, range 20 to 82) undergoing open heart surgery; 20 were male and 9 female. Twenty-two patients were having a first cardiac operation; 7 had had a previous cardiac operation. All tracings were obtained while patients were under general anesthesia and receiving mechanical ventilation. Clinical diagnoses were coronary artery disease in 13 patients (including 3 who also had had mitral valve repair); mitral valve disease in 5; aortic valve disease in 7; mitral and aortic valve disease in 1; and Wolff-Parkinson-White syndrome requiring ablative surgery of an accessory bundle in 3. All patients had a transthoracic Doppler echocardiographic examination on the day before surgery and were in sinus rhythm at the time of both recordings. All patients gave informed written consent to the protocol approved by the Committee for the Protection of Human Subjects at the Stanford University Medical Center.

Doppler Ultrasound Recordings

Transthoracic recordings. Transthoracic recordings were made with patients in the supine position using a Hewlett-

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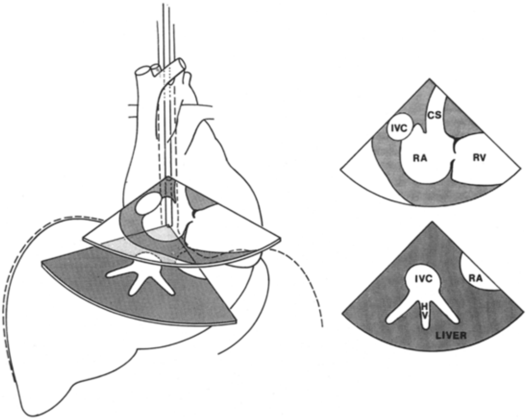

Figure 1. Schematic representation of hepatic veins obtained by the transesophageal approach. The probe is introduced into the esophagus and advanced until the right chambers are visualized. The **upper right panel** shows the coronary sinus (CS), the entrance of the inferior vena cava (IVC), the right atrium (RA) and the right ventricle (RV). Then the probe is advanced, rotating and angulating as necessary until the junction of the inferior vena cava with the hepatic veins (HV) is visualized (**inferior right panel**).

Packard ultrasonograph (Ultrasonograph model 1000) with simultaneous recording of the electrocardiogram and respiration. From a subcostal view, pulsed wave recordings were made with a 2.5 or 3.5 MHz transducer, as previously described by our laboratory (1). In some cases a more lateral thoracic approach was also attempted.

Transesophageal recordings. All transesophageal recordings were obtained with use of a Hewlett-Packard ultrasonograph (Sonus model 500) with a 5 MHz transducer mounted at the tip of a 14 mm adult gastroscope (model 21362A, HP echoscope). Studies were performed in the operating room immediately after induction of general anesthesia and establishment of mechanical ventilation with the patients supine and hemodynamically stable. The echoscope was introduced into the esophagus with the transducer facing anteriorly. Tomographic planes were obtained in the usual fashion by translating and rotating the echoscope within the esophagus while observing the ultrasound image for reference (11). To visualize the hepatic veins, the right atrium was imaged and the transducer was advanced until the entrance of the inferior vena cava could be clearly seen (Fig. 1). The probe was then rotated clockwise and angulated as necessary to follow the lumen of the inferior vena cava until its junction with the hepatic veins was visualized (Fig. 2A). It was often helpful to superimpose the color flow velocity image on the two-dimensional echocardiogram so that flow within the hepatic veins could be identified (Fig. 2B). The pulsed wave Doppler sample volume was then placed in the hepatic vein where the clearest Doppler signal could be obtained with distinctive wave contours and the least background noise. The filter setting was set at 50 Hz to include low velocity signals; angle correction was not used. After hepatic venous flow was recorded, the transducer was repositioned for the four chamber view and the opening and closure of the tricuspid valve were recorded for timing, with use of pulsed wave Doppler echocardiography, with the sample volume placed at the tips of the tricuspid leaflets. Each study, including a simultaneous electrocardiogram (ECG), was recorded on videotape and strip chart at a velocity of 50 mm/s for later review.

Analysis of Doppler recordings. Hepatic venous flow during each beat was analyzed by dividing the cardiac cycle into systole and diastole. Systole was identified as the interval from tricuspid valve closure to tricuspid valve opening, as determined by Doppler ultrasound tricuspid flow velocity recordings (1). Diastole was defined from tricuspid valve opening to tricuspid valve closure. In both phases peak flow velocities and flow velocity integrals were measured by manual planimetry as an average of three beats. The end-expiratory phase of the respiratory cycle was noted during recording and was used for selection of beats for analysis. Heart rate was determined from the ECG.

Interobserver variability. Ten transesophageal Doppler recordings were randomly selected and measured by a second observer to determine interobserver variability for quantitating hepatic venous flow velocity tracings. This was expressed as a linear regression between the two observations and as percent error, derived as the absolute difference between observations divided by the initial measurement (12).

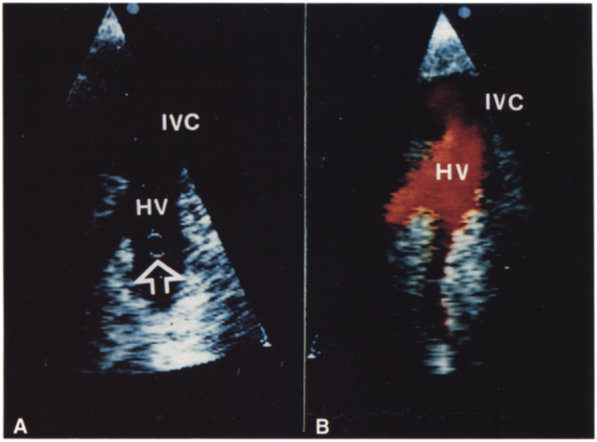

Figure 2. A, Two-dimensional echocardiogram of the liver and hepatic veins (HV) obtained with the transesophageal approach. *The location of the sample volume is also indicated (arrow).* **B,** A similar image in the same patient with superimposed Doppler color flow information. The red indicates flow toward the heart. IVC = inferior vena cava.

Data analysis. Peak flow velocity and velocity integrals are expressed as mean values ± 1 SD. Differences between transthoracic and transesophageal mean values were compared by using a two-tailed paired Student's t test. Statistical significance was defined as $p < 0.05$.

Results

Hepatic venous flow recordings. All 29 patients had adequate transesophageal tracings for analysis. Figure 3 shows a normal pulsed wave Doppler flow velocity curve of the hepatic veins obtained with transesophageal echocardiography. The normal forward flow velocity pattern is a biphasic forward flow usually with systolic predominance. This pattern was recorded in 24 of our patients with the transesophageal approach. Flows were opposite in direction from those obtained with use of the transthoracic subcostal view because of the different probe location in relation to flow direction. With transesophageal echocardiography, filling velocities (flow toward the heart) are recorded as a positive deflection, reversed velocities (toward the hepatic veins) as a negative deflection.

In two patients the general approach just described did not yield adequate recordings. The echoscope was then advanced further into the stomach, rotated and flexed toward the liver, yielding adequate recordings in these patients also. This view is similar to the transgastric view used to image the left ventricular short axis (11), with Doppler velocities shown as mirror images of the typical transesophageal recordings described above.

In five patients the transesophageal tracing presented a predominant diastolic filling pattern, with a decreased systolic component (Fig. 4). Only three of these five patients had adequate preoperative transthoracic tracings for comparison. In two of these three the preoperative flow velocity pattern was characterized by diastolic predominance and both patients had had previous cardiac surgery. The other patient had normal findings on the transthoracic preoperative recording that became abnormal on the transesophageal study after induction of anesthesia. In addition, hepatic venous flow was recorded during a short period of ventricular fibrillation before establishment of cardiopulmonary bypass (Fig. 5).

Transesophageal versus transthoracic hepatic venous flow velocity recordings (Table 1). Fourteen (48%) of the 29 patients had hepatic venous flow tracings obtained by the transthoracic approach that were adequate for measurement of flow velocity integrals. Peak flow velocity could be measured in 16 patients. Table 1 shows the range and mean

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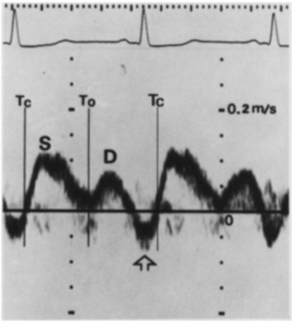

Figure 3. Normal hepatic venous flow tracing obtained with the transesophageal approach. Positive velocities represent flow toward the heart. D = diastolic forward flow; **open arrow** = reversed flow during atrial contraction; S = systolic forward flow; Tc = tricuspid valve closure; To = tricuspid valve opening.

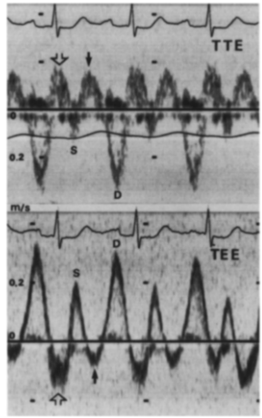

Figure 4. Abnormal hepatic venous flow tracing in a patient with previous heart surgery. The peak velocity and time integral of the diastolic wave are larger than the corresponding systolic wave, with both the transthoracic (TTE) **(upper)** and the transesophageal (TEE) **(lower)** approach. **Open arrow** = reversed flow during atrial contraction; **black arrow** = reversed flow during ventricular end-systole; abbreviations as in Figure 3.

of peak flow velocities and flow velocity integrals of hepatic venous flow recordings obtained with transesophageal and transthoracic approaches. With the transesophageal approach a systolic/diastolic time-velocity integral ratio > 1 was observed in 24 patients (83%); in 15 (52%) flow reversal occurred at the end of ventricular systole and in 25 (86%) it was associated with atrial contraction. With the transthoracic approach a systolic/diastolic velocity-time integral ratio > 1 was observed in 11 (79%) of 14 patients; flow reversal occurred in 11 (79%) at the end of ventricular systole and in 12 (86%) it was associated with atrial contraction. The differences in mean values between the two approaches were not statistically significant except for the peak flow velocities of the small waves representing atrial reversal of flow and ventricular end-systolic reversal. The absolute values obtained by the transthoracic approach were generally larger although these differences were not statistically significant. Patients who had both adequate transesophageal and adequate transthoracic tracings showed no significant difference between systolic/diastolic ratios for either peak flow velocities or flow velocity integrals (1.83 ± 1.5 vs. 1.77 ± 0.7, p = NS and 1.62 ± 1.2 vs. 1.87 ± 1.0, p = NS, respectively).

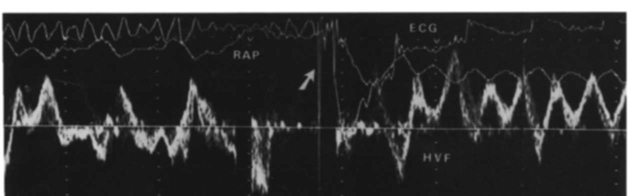

Figure 5. Hepatic venous flow (HVF) tracing from a patient with a short episode of ventricular fibrillation **(left)**. The recording was obtained with the chest open. The apparently rather discrete flow velocity waves **(left)** suggest atrial contraction and relaxation in the absence of organized ventricular activity. A periodic atrial pressure wave also is noted in the right atrium (RAP). ECG = electrocardiogram; **white arrow** = countershock.

Table 1. Hepatic Venous Flow Peak Velocities and Flow Velocity Integrals With Transesophageal (n = 29) and Transthoracic (n = 14) Echocardiography

	Peak Vel (cm/s)		Vel Int (cm)	
	TEE	TTE	TEE	TTE
Forward flow				
Systole				
Mean	21.3 ± 13.9	36.7 ± 15.0	5.7 ± 4.4	7.3 ± 3.4
Range	8.0 to 75.0	16.0 to 73.0	2.7 to 26.1	3.1 to 16.0
Diastole				
Mean	15.0 ± 9.5	23.9 ± 12.6	3.7 ± 1.7	4.7 ± 2.3
Range	4.0 to 43.0	10.0 to 60.0	1.4 to 7.2	1.7 to 8.4
SD ratio				
Mean	1.7 ± 1.1	1.7 ± 0.7	1.7 ± 1.1	1.9 ± 1.0
Range	0.7 to 6.5	0.9 to 3.0	0.6 to 5.2	0.7 to 3.5
Reverse flow				
A wave				
Mean	7.5 ± 5.2	15.5 ± 12.7*	1.5 ± 1.5	2.0 ± 1.8
Range	0.0 to 20.0	0.0 to 40.0	0.0 to 7.0	0.20 to 5.6
V wave				
Mean	3.1 ± 4.1	9.8 ± 9.7†	0.5 ± 0.6	1.0 ± 1.0
Range	0.0 to 14.0	0.0 to 30.0	0.0 to 2.1	0.0 to 2.9

*$p < 0.03$, †$p < 0.04$, values are expressed as mean values ± SD. TEE = transesophageal echocardiography; TTE = transthoracic echocardiography; Vel = velocity; Vel Int = flow velocity integral.

Interobserver variability. The interobserver variability for measuring time-velocity integrals, expressed as percent error, was 7.2% for systolic forward flow and 9.5% for diastolic flow. Interobserver correlation coefficients were also high (0.97 for systole and 0.94 for diastole).

Discussion

Previous studies (1–10) with other techniques have documented various ways of recording hepatic venous flow and its relation to right heart hemodynamics. However, hepatic venous flow has never been used to assess intraoperative right heart dynamics. The present study describes a method for assessing right heart dynamics during cardiac surgery by recording hepatic venous flow with transesophageal echocardiography.

Hepatic venous flow velocities. The present study verifies previous findings (1) that hepatic vein Doppler ultrasound recordings obtained with the transthoracic approach are adequate for analysis in only a minority of patients. In contrast, we obtained hepatic vein recordings of better quality and with good interobserver reproducibility in all patients using the transesophageal technique. The flow signal obtained was similar to that previously reported (1,13) but inverted because of the difference in probe location in relation to blood flow. A biphasic forward flow, with systolic peak flow velocities and flow velocity integrals greater than diastolic peak flow velocities and flow velocity integrals, was present in most patients. Reversed flow with atrial contraction has also been previously described (1,10,14). Reduced or even reversed velocity may occur normally at the end of ventricular systole at the time of the V wave in right atrial pressure (1,13). The systolic component of hepatic venous flow is known to be produced by right ventricular contraction with a decrease in right ventricular volume and descent of the tricuspid anulus toward the apex in combination with atrial relaxation. These events cause an increase in right atrial dimensions and passage of blood from the inferior and superior venae cavae into the right atrium. The diastolic component occurs with the opening of the tricuspid valve and is related to right ventricular filling, as well as to atrial contraction and relaxation (4,15). This pattern was observed in most of our patients studied with transesophageal echocardiography.

With the transesophageal technique, peak flow velocities and flow velocity integrals tended to be lower than with the transthoracic approach: this difference was not statistically significant except for peak flow velocity of atrial and ventricular end-systolic reversals. These findings may be due to better alignment of the ultrasound beam with blood flow when the transthoracic technique is used, a hypothesis supported by the similar systolic/diastolic ratios of peak flow velocity and velocity integral obtained with the two methods. The recording of our transesophageal studies during mechanical ventilation may also partially explain the differences observed. During inspiration with mechanical positive pressure ventilation, intrathoracic pressure increases causing a decrease in systemic venous return that may be expressed as a decrease in Doppler flow velocities as observed in our study (16,17). However, the great similarity in the patterns observed with the two approaches suggests that previous experience with transthoracic echocardiography can be applied to transesophageal echocardiography.

Abnormal hepatic venous flow recordings. Although the primary purpose of this report is to describe our method of recording, the flow velocity patterns seen in five of these patients are of interest. In two patients, both with previous cardiac surgery, the pattern was characterized by diastolic predominance on the day before and at the time of operation. It has been shown (4,15) that the diastolic component is often predominant in jugular venous flow velocity patterns after cardiac surgery. The findings in these two patients are probably on this basis.

Three other patients had a normal pattern before surgery that became abnormal after induction of anesthesia. In two of these the anesthetic agents administered included supplemental isoflurane, which is known to be associated with myocardial depression in the normal heart (18). The diastolic predominance of filling in these two patients may therefore be an expression of depressed right heart function, just as diastolic predominance of the pulmonary venous velocity curve is related to left ventricular systolic dysfunction (19). Both patients had previously had normal right and left ventricular systolic function and neither had significant tricuspid regurgitation by Doppler color flow mapping before or during surgery. One of them also had severe mitral regurgitation. It has been hypothesized that in patients with severe left ventricular volume overload a change in the pattern of venous return may be due to displacement of the atrial septum into the right atrium (as a result of high regurgitant volume and increased pressure in the left atrium during ventricular systole), restricting flow into the right side (4). However, this pattern was not observed in other patients with mitral regurgitation, suggesting that a more complex mechanism is responsible for the dominant diastolic flow. Variations in right heart filling may also be considered a potential cause of abnormal patterns of systemic venous return reflected by changes in Doppler flow velocity.

In one case the hepatic venous signal was recorded during a short period of ventricular fibrillation (Fig. 5). The apparently rather discrete flow velocity waves suggest atrial contraction and relaxation in the absence of organized ventricular activity. P waves are not defined on the ECG but there is a corresponding periodic atrial pressure wave in the right atrium. The passage of flow into the right atrium, together with the maintenance of atrial activity recorded during this episode of ventricular fibrillation, suggests that atrial contraction and relaxation play a significant role in the filling of the right atrium.

Limitations of the study. Our comparison of transthoracic and transesophageal results may be affected by the recording of transthoracic echocardiograms while the patients were awake and breathing normally and the recording of transesophageal studies while the patients were anesthetized and under mechanical ventilation. As previously mentioned, mechanical ventilation induces an inspiratory increase in intrathoracic pressure, causing decreased venous return to the heart and decreased right ventricular stroke volume (16,17).

Clinical implications. Hepatic venous flow recordings can be used to monitor right heart dynamics (1,4). The present study shows that such recordings can be obtained by the transesophageal technique without interfering with surgery, thereby permitting assessment of right heart hemodynamics during anesthesia and surgery. The close correlation between transesophageal and transthoracic methods may allow extrapolation from previous transthoracic experience. Further detailed insight into right heart dynamics may be obtained from hepatic venous flow tracings, especially when guided by closure and opening of the tricuspid valve and by monitoring tricuspid regurgitation, which is easily done with the transesophageal technique. For general anesthesia this method may aid in assessing the myocardial and cardiovascular impact of drugs.

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