Assessment of Transesophageal Pulsed Doppler Echocardiography in the Detection of Mitral Regurgitation

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SUMMARY The value of transesophageal pulsed Doppler echocardiography (PDE) was studied in six patients with competent mitral valve and in 12 patients with angiographically proved mild to moderately severe mitral regurgitation. The results were compared with those from the standard transthoracic method of investigation. The advantages of the esophagoscopic over the transthoracic approach in the detection of mitral regurgitation are (1) absence of anatomic obstacles between the ultrasound transducer and the heart; (2) nearly parallel alignment of the ultrasound beam with the blood flow direction; (3) the use of high pulse repetition frequencies; and (4) detection of localized regurgitant jets by left atrial scanning. This results in a superior recording quality and greater sensitivity. Based on a specific systolic flow pattern in the time-interval histogram, mitral regurgitation was detected in all patients by the transesophageal technique (100% sensitivity), but in only 58% by the precordial approach. Thus, transesophageal pulsed Doppler echocardiography can accurately detect the presence of mitral regurgitation, particularly in cases of mild or moderate severity.

STANDARD M-mode and two-dimensional echocardiography are useful in the noninvasive diagnosis of various cardiac malfunctions. In certain cases of mitral regurgitation, both techniques can be applied to establish the cause; yet they fail to yield specific results if the lesion is not accompanied by structural abnormalities. By its ability to record flow velocity patterns, though, the recently developed technique of range-gated pulsed Doppler echocardiography (PDE)

Methods

The basic concepts of range-gated PDE have been reported in detail elsewhere. They are briefly reviewed here to emphasize the advantages of an esophageal position of the ultrasound transducer.

Theoretically, the magnitude of the Doppler frequency shift depends on the blood flow velocity and on the angle between the ultrasound beam and the blood flow velocity vector. To get a high sensitivity for velocity measurements, the ultrasound beam should be aligned as parallel as possible to the blood flow direction.

PDE permits determination of the investigation site (i.e., sample volume) within the cardiac region of interest. This advantage over continuous Doppler systems, however, has a serious drawback: the fundamental limitation of a constant range-velocity product. Since each reflected pulse must reach the receiver before the next pulse is emitted (to avoid range ambiguities), the pulse repetition frequency (PRF) sets an upper limit to the maximum travel distance. Furthermore, due to the pulsed nature of the system, the Doppler signal cannot be obtained as a continuous wave form. It is constituted from samples at the rate of the PRF and thus obeys the laws of information theory; specifically, the sampling (Nyquist) theorem, which demands that the highest signal frequency be less than half the PRF. Therefore, not only does the PRF limit the maximum depth range to be investigated, but it also determines the highest measurable Doppler frequency shift, and thus the highest measurable blood flow velocity in that range. The higher the PRF is set,
the higher the maximum detectable flow velocity, but the less will be the maximum distance of the sample volume from the transducer.

PDE was performed using a commercially available Echo-Doppler unit (Advanced Technology Laboratories, model 500 A) that emits 3-MHz ultrasound pulses at three different PRFs, corresponding to range settings of 5, 12 and 17 cm. It incorporates a range-gating unit in conjunction with an M-mode recording system that facilitates the orientation of the Doppler sample volume within the cardiac chambers. Doppler frequency shifts are represented as tonal quality changes of an audio signal, in which laminar flow is heard as a fairly smooth “musical” sound (narrow band of frequencies) and turbulent flow as harsh and scratchy (broad frequency bandwidth). In addition to the aural presentation, the device gives a permanent record of the Doppler frequency shifts in a time-interval histogram (TIH). Frequencies are depicted as deflections from a zero-flow baseline, with flow toward the transducer as positive and flow away from the transducer as negative. The distance of each dot away from the baseline reflects the magnitude of the instantaneous frequency shift, which is directly proportional to the instantaneous blood flow velocity. Laminar flow generates a narrow cluster of dots in the TIH, while turbulent flow results in a widely dispersed dot pattern.

Patient Selection

The study group consisted of 12 patients (three female and nine male), ages 19–69 years (mean 46 years), with angiographically proved mitral insufficiency. The severity of mitral regurgitation was judged angiographically according to Grossman as grade I (mild — rapid clearance of contrast agent with each beat, incomplete opacification of the left atrium), grade II (moderate — slower clearance of contrast agent, opacification of the entire left atrium not as strongly as that of the left ventricle), or grade III (moderately severe — left atrium completely opacified with the same density as in the left ventricle). None of our patients had grade IV (severe) mitral regurgitation. The etiology of the incompetent mitral valve was rheumatic in seven cases. One patient had mitral valve prolapse and mild mitral regurgitation; one had coronary artery disease; one cardiomyopathy; one suffered incompetence resulting from mitral commissurotomy; and one case was of undetermined origin. Six subjects (two female and four male), ages 19–55 years (mean 31 years), in whom mitral regurgitation had been ruled out by either standard noninvasive procedures or by angiography, served as the control group.

Doppler Studies

After giving informed consent, all 18 subjects underwent transthoracic as well as transesophageal PDE examination. In the precordial study a 3.0-MHz transducer was used, and mitral regurgitation was sought from the left sternal border with the sample volume positioned in the left atrium posterior to the anterior mitral leaflet or posterior to the aortic root. The transducer was also placed in the apical position, with the sample volume in the left atrium posterior to the anterior mitral leaflet, while searching for systolic regurgitant flow.

For the transesophageal investigation, we used a commercially available gastroscope with an outer diameter of 7 or 9 mm to permit easy swallowing. A 3.5-MHz transducer of continuously adjustable depth (5 mm to 17 cm) was attached to the tip of the gastroscope and embedded in soft plastic material to avoid damage to the esophagus. Rotation of the gastroscope and transducer angulation in two perpendicular directions could be achieved by external control (fig. 1). Diverticules or varices of the esophagus were ruled out by x-ray examination.

Patients fasted for about 8 hours before the investigation. They were given 0.50 mg of atropine sulfate subcutaneously 1 hour before the actual examination to prevent bradycardia and hypersalivation. The gastroscope was introduced in a blind manner with the patient supine.

After insertion of the gastroscope to about 40 cm from the patient’s teeth, the transducer position was identified by the M-mode echo of the aortic root posterior to the left atrium. By counterclockwise rotation

FIGURE 1. The transducer-gastroscope system. (top) The ultrasonic transducer fixed at the end of a commercially available gastroscope. Transducer orientation can be manipulated by the control unit at the proximal end of the gastroscope. (bottom) Photomontage of transducer angulation in two orthogonal planes.
Mitral regurgitation was diagnosed on the basis of a systolic high-frequency noise in the audio signal and, mainly, on a marked systolic flow pattern in the TIH. Systolic turbulence was not considered diagnostic of regurgitation. Only a clearly visible systolic deflection profile with as little dot dispersion as possible (indicative of regurgitant flow as opposed to turbulence in the mitral valve area) was considered proof of mitral regurgitation.

**Results**

In the transesophageal examination, all subjects in the control group exhibited typical TIH profiles as shown in figure 3. Because of the esophageal position of the ultrasound transducer, the M-mode recording in the upper third of the figure is an upside-down version of the conventional transthoracic M-mode pattern. Nearest to the transducer (top of fig. 3), the echo of the left atrial posterior wall is shown, followed by the typical biphasic echo trace of the anterior (aortic) mitral leaflet. Farthest from the transducer is the broad echo of the left ventricular anterior wall. The site of the sample volume in the left atrium close to the mitral valve is indicated by the straight horizontal line.

The TIH is registered below the ECG tracing. Most obvious is the biphasic diastolic flow, which corresponds exactly with the motion of the anterior leaflet in the M-mode recording. The fact that this diastolic flow profile is negative signifies blood flow through the sample volume directed away from the transducer, as is expected with normal left ventricular filling from the left atrium. Furthermore, there is no significant systolic flow apparent, indicative of a competent mitral valve.

Figure 4 demonstrates transesophageal Doppler recordings from patients with grades I and III mitral insufficiency. In both cases, the sample volume was placed in the same location as in the previous case, i.e., in the left atrium close to the mitral valve orifice.

The TIH tracing of figure 4A shows a biphasic diastolic flow away from the transducer, corresponding to the motion pattern of the aortic mitral leaflet. However, as a definite sign of mitral regurgitation, pathologic blood flow in the opposite direction is recorded in
diastolic echo profile. Most prominent TIH activatation of positive systolic flow is with slight early systolic turbulences. Systole, with slight early systolic turbulences. Although this is a case of mild mitral regurgitation, the positive systolic deflection is nearly as pronounced as it is in figure 4B, which is an example of moderately severe mitral incompetence in a patient with mitral stenosis as well. The motion of the stenotic mitral leaflet is restricted, as indicated by the monophasic diastolic echo pattern and the corresponding diastolic TIH profile. Most prominent in the TIH is the positive systolic flow pattern with hardly any turbulence, indicative of pathologic reflux through the mitral valve. Compared with these transesophageal findings, standard transthoracic Doppler recordings turned out to be formally inferior, as shown in figure 5. This recording is from the same patient as in figure 4B, with the transducer placed at the left sternal border. Despite the severity of mitral regurgitation (grade III), only systolic turbulence was observed, and a distinct systolic flow profile could not be registered.

Transesophageal PDE yielded a higher sensitivity than transthoracic PDE in the detection of mitral insufficiency (table 1). Of the 12 patients with angiographically proved mitral regurgitation, seven cases were confirmed by transthoracic PDE, yielding a sensitivity.
of 58%. Transesophageal PDE, on the other hand, detected mitral insufficiency in all patients, for a sensitivity of 100%. If we restrict our attention to mild-to-moderate cases of mitral regurgitation, the discrepancy between transesophageal and transthoracic PDE becomes more pronounced. Five of nine cases were detected by the precordial approach (55% sensitivity), compared with 100% sensitivity of the transesophageal technique.

Discussion

Continuous-wave Doppler flowmetry from the esophagus was introduced in 1971 by Side and Gosling for velocity measurements in the thoracic aorta. Similar investigations with pulsed Doppler velocity meters have been repeatedly by Wells et al., who studied blood flow in the descending aorta and pulmonary artery in six conscious humans. The idea of using an esophageal ultrasound transducer has also been taken up for transesophageal M-mode studies, and recently Hisanaga et al. presented an esophageal probe for PDE, which has not been used in an extensive study of cardiac diseases. Hisanaga et al. also manufactured a mechanical sector-scanning system for transesophageal cross-sectional images of the heart. All authors used more or less rigid gastroscope-like systems that offered little or no means to selectively manipulate the orientation of the ultrasound transducer.

We have systematically evaluated transesophageal PDE in the detection of mitral regurgitation and compared the results with standard external Doppler technic. For our study, a highly flexible transduccergastroscopy system was used that supplied the investigator with several degrees of freedom for transducer orientation, such as rotation and angulation in two perpendicular planes.

The disadvantages of the precordial approaches to investigations of the mitral valve area are obvious. Transducer placement at the left sternal border results in the ultrasound beam and the blood flow through the mitral valve to be nearly at right angles to each other, yielding poor sensitivity for velocity measurement. The apical approach, due to the relatively large distance between transducer and mitral valve, is only workable with a low PRF, limiting the registration of high regurgitant flow velocities. The transesophageal technique circumvents these restrictions. One may obtain high-quality echo Doppler registrations even from patients who are obese or have emphysema or barrel-chested diseases. The incident ultrasonic beam can be aligned nearly parallel with the axis of blood flow through the mitral valve by proper manipulation of the esophageal transducer. Eccentric jets of mitral regurgitation can easily be detected by scanning the sample volume all over the left atrium, which is only possible from the esophagus, since there are no anatomic obstacles between the esophagus and the heart. And finally, due to the small distance between the mitral valve area and the esophagus high PRFs can be used and, consequently, high-velocity regurgitation is readily registered.

Several investigators have based their diagnoses of mitral regurgitation by PDE on the presence of a typical systolic noise in the audio signal and on systolic turbulences in the TIH output. However, the interpretation of an audio signal is a rather subjective criterion that cannot be documented with the present system. Furthermore, the TIH is derived from a zero-crossing detector, an electronic device extremely sensitive to gain and threshold calibration. Consequently, one must interpret turbulences very carefully. Particularly in the presence of a weak Doppler signal with a low signal-to-noise ratio that necessitates high gain and low threshold settings, the electronic noise of the Doppler instrument itself may create a widely dispersed dot pattern in the TIH.

We have therefore, on principle, based our diagnosis of mitral regurgitation on a distinct and clearly visible systolic flow profile in the TIH (fig. 4), and did not rely on systolic turbulence. Consequently, the sensitivity of the transesophageal technique turned out to be significantly higher (100%) than that of the transthoracic method of investigation (58% sensitivity).

Although the transesophageal technique causes some discomfort to the patient and some skill is required to introduce the gastroscope into the esophagus, the high diagnostic success rate and the superior recording quality over several consecutive heart cycles compensate for the disadvantages. The increased sensitivity of this technique compared with transthoracic PDE, particularly in the detection of mild-to-moderate mitral regurgitation, which may sometimes be difficult to diagnose with clinical means alone, completely justifies the transesophageal application of PDE. It also promises to be of high diagnostic value in the functional assessment of prosthetic mitral valves, which cannot be investigated from the apical transducer position, because of the different acoustic properties of the prosthetic valve material.

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