Flow reversal in the descending aorta: A guide to intraoperative assessment of aortic regurgitation with transesophageal echocardiography

This study assessed the value of biplane transesophageal echocardiographic assessment of diastolic flow reversal in the descending aorta as an alternative to Doppler color flow imaging in determining severity of aortic regurgitation. In 45 patients undergoing cardiac operations, the severity of aortic regurgitation was assessed by semiquantitative grading of the width of the Doppler color flow regurgitant jet relative to the left ventricular outflow tract, and the presence of diastolic flow reversal was assessed with pulsed-wave Doppler measurements at three sites in the descending aorta. In four patients, the diastolic flow reversal method was the only available form of assessment because of inadequate visualization of the left ventricular outflow tract beneath a mitral valve prosthesis. Diastolic flow reversal in the descending aorta was not observed in patients without aortic regurgitation and was always present in patients with severe aortic regurgitation. Aortic valve replacement successfully eliminated descending aortic flow reversal in all 19 patients in whom it was present before valve replacement. Identification of diastolic flow reversal at multiple sites in the descending aorta with biplane transesophageal echocardiography helps to confirm the presence of severe aortic regurgitation and can serve as an alternative method of assessment when visualization of the left ventricular outflow tract is impaired. (J THORAC CARDIOVASC SURG 1994;108:576-82)


Intraoperative transesophageal echocardiographic assessment of severity of mitral regurgitation has become an important contributing factor to the success of mitral valve repair.1,6 With growing interest in aortic valve repair,7-8 detection and grading of severity of aortic regurgitation may be useful to guide patient selection and identify immediate surgical outcome. Furthermore, regurgitant flow through the aortic valve may cause left ventricular distention, impair myocardial preservation during cardiopulmonary bypass, and flood the operative field during open mitral valve procedures.9 Alternative bypass techniques may thus be required. Preoperative assessment of the severity of aortic regurgitation may occasionally be unclear and need confirmation. This may be particularly true in the emergency presentation of a patient with aortic dissection. Different operative procedures may need to be considered if intraoperative findings reveal a change in valvular competence since preoperative assessment.

With transthoracic Doppler color flow echocardiography, the severity of aortic regurgitation has been reliably estimated by the width of the jet in the left ventricular outflow tract during diastole.10,11 Despite less optimal alignment of the Doppler ultrasonic beam and left ventricular outflow tract from the esophageal transducer position, comparable results to transthoracic imaging have been obtained with transesophageal echocardiography.12,13 In some patients, however, flow masking and

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acoustic shadowing by heavily calcified or prosthetic mitral or aortic valves may prevent visualization of the aortic regurgitant color jet during transesophageal echocardiography. Pulsed-wave Doppler measurements of diastolic flow reversal in the aortic arch from the suprasternal notch and in the abdominal aorta have also been used to predict severity of aortic regurgitation but have not been adapted to transesophageal echocardiography.

The recent introduction of the biplane transesophageal transducer may facilitate intraoperative assessment of aortic regurgitation. Biplane imaging allows pulsed-wave Doppler measurements of flow patterns in the descending aorta to be obtained and also allows a more complete description of the spatial distribution of the regurgitant jet in the left ventricular outflow tract than imaging in the transverse plane alone. The aim of this study was to assess the value of biplane transesophageal echocardiographic assessment of diastolic flow reversal in the descending aorta as an alternative to Doppler color flow imaging of the left ventricular outflow tract in determining the severity of aortic regurgitation.

Methods

Patient selection. After approval by the Brigham and Women's Hospital Human Research Committee, consecutive adult patients requiring a cardiac operation were prospectively studied until approximately equal numbers in each group of a four-point severity scale of preoperative aortic regurgitation (on the basis of routine preoperative aortography or transthoracic echocardiography) were achieved.

Echocardiographic and Doppler techniques. Patients were studied intraoperatively, during stable hemodynamic conditions, after induction of general anesthesia, and before sternotomy. Transesophageal echocardiography was performed with an ATL UM7 system (Advanced Technology Laboratories, Bothell, Wash.) with a 5.0 MHz biplane phased-array transducer.

Color flow mapping of the left ventricular outflow tract was obtained from the transverse five-chamber view and the longitudinal mid-esophageal long-axis view of the left ventricular outflow tract, each oriented to maximize width and color disturbance in the left ventricular outflow tract. Two-dimensional imaging gain was adjusted so that cardiac chambers contained no signal. Color gain was adjusted so that no color was evident outside the cardiac chambers. Screen depth varied from 10 to 12.5 cm, color sector angle 30 degrees, pulse repetition frequency 4 kHz, frame rate 15 sec⁻¹, and power and color velocity-variance map remained unchanged throughout the study.

Pulsed-wave Doppler spectra were obtained from the descending aorta imaged in the longitudinal plane just beyond the aortic arch. A 2 mm sample volume was placed in the center of the descending aorta at the periphery of the 90-degree imaging sector arc, first proximally (position 1) and then distally (position 2) (Fig. 1). Flow velocity measurements were corrected on-line for the Doppler angle between the ultrasonic beam and long axis of the descending aorta. The transesophageal echocardiography transducer was then advanced 5 cm, and Doppler measurements were repeated (position 3). Doppler filters remained at 200 Hz, scan depth at 5 cm, and pulsed-wave gain was adjusted so that acceptable displays were obtained.

Color Doppler and pulsed-wave Doppler measurements were repeated 10 to 20 minutes after cardiopulmonary bypass when hemodynamic stability had been achieved. All images were recorded on 0.5-inch VHS videotape for later analysis.

Echocardiographic and Doppler measurements. The videotape recordings of Doppler color flow in the left ventricular outflow tract were inspected and assessed semiquantitatively by two independent observers, unaware of Doppler measurements in the descending aorta. Severity of aortic regurgitation was categorized into four grades, according to an estimation of the largest width of the aortic regurgitation color jet disturbance in relation to the width of the left ventricular outflow tract just beneath the aortic valve: none, mild (aortic regurgitation jet width less than one third of left ventricular outflow tract width), moderate (between one third and two thirds), and severe (greater than two thirds). The higher of the color grades for transverse and longitudinal views was termed maximum color grade. Presence of an impinging jet (one that appeared to contact either the interventricular septum or mitral valve) was noted.

Doppler spectra from the descending aorta were assessed for the presence or absence of diastolic flow reversal by two independent observers blinded to results of color measurements. Diastolic flow was considered to be normal when flow was predominantly antegrade or when only an early small retrograde flow was observed. Abnormal flow reversal was regarded as present when retrograde holo-diastolic flow was seen (Fig. 2). Hemodynamic variables. Hemodynamic stability during echocardiographic measurement periods was verified by measurement of heart rate and an estimate of aortic transvalvular pressure gradient (the mean radial artery pressure-pulmonary artery wedge pressure difference) at end-expiration and at the beginning and end of each measurement period.

Statistical analysis. Spearman rank correlation coefficients (r) and percentages of patients with identical gradings were used to assess the relation between aortic regurgitation grades determined in different planes and between different observers. The significance of the relationship between the presence of diastolic flow reversal and maximum color grade was determined with a Mantel-Haenszel χ² test for ordered categories within contingency tables (SAS, SAS Institute Inc., Cary, N.C.). Paired t tests were used to analyze the hemodynamic variables before and after the echocardiographic study. All continuous data are presented as mean ± standard deviation. A p value less than 0.05 was considered significant.

Results

Demographic and clinical information are detailed in Table I. Doppler measurements in the descending aorta and color flow mapping of the left ventricular outflow tract were easily performed in all patients before cardiopulmonary bypass. After bypass, adequate color flow mapping of the left ventricular outflow tract could not be obtained in four patients because of shadowing beneath mitral prostheses. Descending aortic Doppler measurements were easily obtained in all patients after bypass.
Fig. 1. Pulsed-wave Doppler measurements of flow velocity patterns in the descending aorta. A, Longitudinal echocardiogram of the proximal descending aorta showing the pulsed-wave Doppler (PWD) sample volume directed distally in the center of the vessel. (See text for details.) B, Typical pulsed-wave Doppler spectrum showing antegrade flow without diastolic flow reversal in a patient without aortic regurgitation. ECG R, R wave of the electrocardiogram; TEE, transesophageal echocardiography.

**Doppler color flow imaging.** Good correlation was evident between color grades determined in transverse and longitudinal planes. Evaluations were identical in 39 of 45 patients (87%; $r = 0.91, p < 0.001$). Evaluation in the longitudinal plane compared with the transverse plane was higher by one grade in two patients, higher by two grades in one patient, and lower by one grade in three patients. In 20 of 34 patients (59%) with aortic regurgitation by color grading, an impinging jet was found in at least one plane (19 in the transverse and 17 in the longitudinal plane). All evaluations that were not identical in both planes had impinging jets. Maximum color grade determined by two independent observers was identical in 36 of 45 patients (80% interobserver agreement, $r = 0.91, p < 0.001$) and never differed by more than one grade. Differences in nine patients were resolved by consensus.

**Diastolic flow reversal in the descending aorta.** Two patients (one with mild and one with severe aortic regurgitation) had pulsed-wave Doppler spectral recordings before bypass that were uninterpretable and were therefore excluded from analysis. Diastolic flow reversal was seen in at least one of the three sites in the descending aorta in 20 of 43 patients (17 cases at position 1, 18 cases at position 2, and 16 cases at position 3). Diastolic flow reversal was evident in at least one position in all patients with severe aortic regurgitation, 7 of 13 patients with moderate aortic regurgitation, and 5 of 11 patients with mild aortic regurgitation; it was absent in all patients without aortic regurgitation (Fig. 3). The presence of flow reversal was significantly related to the grade of aortic regurgitation ($p < 0.001$, Mantel-Haenszel $\chi^2$ test). Reversal was observed at all three aortic sites in 6 of 8 patients with severe aortic regurgitation but in only 2 of
11 patients with mild and 5 of 13 with moderate aortic regurgitation \((p < 0.001,\) Mantel-Haenszel \(\chi^2\) test). In patients with mild and moderate aortic regurgitation, no apparent differences in hemodynamic variables, previous valve operations, impinging color flow jets, rhythm, or presence of aortic stenosis were found between patients with and without flow reversal.

Twenty of 31 patients who underwent aortic valve operations had flow reversal in the descending aorta before cardiopulmonary bypass. In all 19 patients who underwent aortic valve replacement, prebypass flow reversal was no longer present after cardiopulmonary bypass. However, in the one patient who underwent aortic valve repair, flow reversal remained after cardiopulmonary bypass. In this patient moderate aortic regurgitation was evident by maximum color grade. Trans-thoracic echocardiography performed after the operation confirmed the presence of moderate residual aortic regurgitation.

Two independent observers agreed on the presence or absence of flow reversal in all 43 patients.

**Hemodynamic variables.** No significant differences in hemodynamic variables were noted between the beginning and end of the echocardiographic and Doppler measurement periods before cardiopulmonary bypass. The mean radial artery pressure–pulmonary artery wedge pressure difference was 61.9 ± 12.7 mm Hg at the beginning of the measurements and 60.4 ± 12.1 mm Hg at the

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**Fig. 2.** Pulsed-wave Doppler spectrum from the descending aorta of a patient with aortic regurgitation and diastolic flow reversal. ECG, Electrocardiogram.
Table 1. Demographic and clinical data

<table>
<thead>
<tr>
<th>Max color grade</th>
<th>No.</th>
<th>M/F</th>
<th>Age (yr)*</th>
<th>Previous AV operation (No.)</th>
<th>Aortic stenosis (No.)</th>
<th>Atrial fibrillation (No.)</th>
<th>Valve procedure performed (No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>11</td>
<td>8:3</td>
<td>71.9 ± 5.7</td>
<td>Nil</td>
<td>2</td>
<td>1</td>
<td>1 AVR</td>
</tr>
<tr>
<td>Mild</td>
<td>12</td>
<td>4:8</td>
<td>72.9 ± 5.7</td>
<td>1 AVR</td>
<td>9</td>
<td>5</td>
<td>8 AVR</td>
</tr>
<tr>
<td>Moderate</td>
<td>13</td>
<td>9:4</td>
<td>65.0 ± 11.8</td>
<td>1 AV repair</td>
<td>7</td>
<td>1</td>
<td>8 AVR, 1 AV repair</td>
</tr>
<tr>
<td>Severe</td>
<td>9</td>
<td>8:1</td>
<td>57.1 ± 11.8</td>
<td>5 AVR, 1 AV repair</td>
<td>3</td>
<td>1</td>
<td>9 AVR</td>
</tr>
<tr>
<td>Total</td>
<td>45</td>
<td>29:16</td>
<td>67.2 ± 10.7</td>
<td>6 AVR, 2 AV repair</td>
<td>21</td>
<td>8</td>
<td>26 AVR, 1 AV repair, 4 AVR/MVR, 1 MVR, 1 MV repair</td>
</tr>
</tbody>
</table>

No., Number of patients; AV, aortic valve; AVR, aortic valve replacement (17/30 St. Jude Medical prostheses, 13/30 bioprostheses); MVR, mitral valve replacement (4/5 St. Jude Medical prostheses, 1/5 bioprosthesis); MV, mitral valve; max color grade refers to severity of intraoperative aortic regurgitation.

*Mean ± standard deviation.

end, and heart rate was 67 ± 12 beats·min⁻¹ before and 66 ± 14 beats·min⁻¹ after the measurements.

Discussion

Assessment of flow reversal in the descending aorta and semiquantitative Doppler color flow grading of the left ventricular outflow tract are both easily performed during a routine transesophageal echocardiographic examination and so are ideally suited to the accurate assessment of aortic regurgitation in real time in the operating room. In four patients, the diastolic flow reversal method in the descending aorta was the only available form of assessment of aortic regurgitation, because of inadequate visualization of the left ventricular outflow tract beneath mitral valve prostheses. Pulsed-wave Doppler measurements of flow in the descending aorta were easily obtained regardless of the cardiac disease and were interpretable in nearly all patients. No diastolic flow reversal occurred in the descending aorta in patients without intraoperative aortic regurgitation. On the other hand, all patients with severe aortic regurgitation had diastolic flow reversal. In all but two patients with severe aortic regurgitation, diastolic flow reversal was noted at all three measurement sites in the descending aorta. Hence it appears that the demonstration of flow reversal at multiple sites increases the likelihood that severe aortic regurgitation is present.

This study is unique in that our intraoperative measurements were validated by being repeated after cardiopulmonary bypass. Aortic valve replacement eliminated diastolic flow reversal in the descending aorta in all patients. In one patient, diastolic flow reversal persisted because of the presence of moderate aortic regurgitation after aortic valve repair.

Longitudinal imaging of Doppler color flow in the left ventricular outflow tract was useful in confirming the assessment made from the transverse five-chamber view in most patients and in finding a larger amount of color disturbance than transverse imaging in a small number of patients with impinging jets. If an impinging jet is visualized on transverse imaging, longitudinal imaging should be used and may provide a higher assignment of the severity of aortic regurgitation.

Limitations. Pulsed-wave Doppler measurements of blood flow in the descending aorta from the transesophageal approach may be limited by the large Doppler interrogation angle caused by the relation of esophagus and descending aorta and the possibility of nonuniform descending aortic blood flow. Doppler color flow mapping is known to be influenced by hydraulic, instrumental, and human factors. By maintaining constant machine settings and confirming hemodynamic stability before and after our measurements, we minimized the effect of these confounding variables in our study.

Although the absence of flow reversal excluded severe aortic regurgitation, some of the patients with mild and moderate aortic regurgitation did have flow reversal. These results differ from data from Takenaka and colleagues. Using a subcostal transducer approach, they found flow reversal in the abdominal aorta in patients with
severe aortic regurgitation and no flow reversal in patients with mild and moderate aortic regurgitation. The far more distal site of sampling in the aorta used with their technique compared with that used in the present study may explain these differences. It is possible that more distal sampling of blood flow in the descending aorta with the transesophageal echocardiography approach would have been less likely to identify flow reversal with mild and moderate aortic regurgitation and would still have detected severe aortic regurgitation. On the other hand, Tak-enaka and coworkers were unable to obtain adequate Doppler flow velocity recordings in 19% of their patients, whereas we were able to obtain adequate spectra in over 95% (43/45) of our patients.

Clinical implications and conclusions. Considering the prevalence of echocardiographically detected aortic regurgitation and its implications for surgical and anesthetic management, a reliable noninvasive intraoperative measure of severity would be valuable. Assessment of flow reversal in the descending aorta and semiquantitative grading of the width of the Doppler color flow jet in the left ventricular outflow tract are convenient intraoperative indicators of severity of aortic regurgitation. Longitudinal Doppler color flow imaging confirms the severity of regurgitation evident in the transverse plane and provides a better assessment in a small number of patients when an impinging jet is evident in the transverse plane. Identification of diastolic flow reversal at multiple sites in the descending aorta with the biplane transducer helps to confirm the presence of severe aortic regurgitation and can serve as an alternative method of assessment when visualization of the left ventricular outflow tract is impaired.

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