Usefulness and Limitations of Transesophageal Echocardiography in The Assessment of Proximal Coronary Artery Stenosis

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To assess the usefulness of transesophageal echocardiography in the evaluation of proximal coronary artery stenosis, 111 consecutive patients (mean age 61 years) who had intraoperative transesophageal echocardiography and coronary angiography within 1 week of surgery were studied. Transesophageal echocardiography visualized the entire length of the left main artery (0.2 to 2.2 cm, mean 0.93), 0.2 to 2.2 cm of the proximal left anterior descending artery and 0.1 to 3.4 cm of the proximal left circumflex artery in 103 patients (93%) and 0.1 to 4.6 cm of the proximal right coronary artery in 55 patients (49%).

In the coronary artery segments visualized by echocardiography and compared with the corresponding angiographic segments, transesophageal echocardiography correctly identified 23 (96%) of 24 left main stenoses, 11 (78%) of 14 stenoses involving the left anterior descending artery, 6 (75%) of 8 left circumflex stenoses and all 7 stenoses (100%) of the right coronary artery. In all seven patients with ostial stenosis (left main artery in five and right coronary artery in two), the condition was correctly diagnosed by this technique. The sensitivity and specificity of transesophageal echocardiography in the overall evaluation of proximal coronary artery stenosis as customarily defined by angiography were 96% and 99% for the left main artery, 48% and 99% for the left anterior descending artery, 67% and 100% for the left circumflex artery and 37% and 100% for the right coronary artery, respectively.

The distance of the stenotic lesion from the origin of the vessel by transesophageal echocardiography also correlated well with that measured by angiography (r = 0.63 to 0.99). Color flow mapping was found to be less useful because significant narrowing of the flow channel was seen in only 40 of 53 stenoses visualized by two-dimensional echocardiography.

Several recent published reports (1–7) have reported encouraging but preliminary results of the use of transesophageal echocardiography in direct evaluation of the coronary arteries. Transesophageal echocardiography offers several advantages that may potentially overcome the technical problems associated with the transthoracic approach, including closer proximity of the transducer to the proximal coronary arteries and avoidance of anterior chest wall structures that cause degradation of the ultrasonic signal. This allows the routine use of higher frequency transducers and thus better spatial resolution and more detailed image quality. In addition, it facilitates the concomitant pulsed wave and color Doppler evaluation of coronary blood flow. The purpose of this study was to assess the usefulness of transesophageal echocardiography in the assessment of proximal coronary artery stenosis.

Methods

Study group. The study group consisted of 111 consecutive patients examined at our medical center who underwent intraoperative transesophageal echocardiography and coronary angiography within 1 week before surgery was performed. The only exclusions were one patient whose angiographic films were lost, one with an aortic dissection flap extending into the left main coronary artery and two with congenital coronary artery anomalies (one with no left main coronary artery but separate origins of the left circumflex and left anterior descending arteries from the left coronary sinus, and the other with an anomalous origin of the left circumflex artery from the right coronary sinus). None of these patients had significant proximal coronary artery stenosis by angiography. Of the 111 patients included in this study, 69 were male and 42 were female. The age range was 32 to 84 years (mean 61).
A

Figure 1. A, Transesophageal echocardiographic identification of proximal left-sided coronary arteries. The aortic short-axis view demonstrates the left main coronary artery (LMCA) originating from the aorta (AO) at approximately the 1 o'clock position and coursing to the left and somewhat anteriorly before its bifurcation into the left anterior descending (LAD) and left circumflex (LCX) branches. There is no evidence of lumen narrowing. B, Transesophageal echocardiographic identification of the proximal right coronary artery. The aortic short-axis view demonstrates the right coronary artery (RCA) originating from the aorta at about the 6 or 7 o'clock position. There is no evidence of lumen narrowing. LA = left atrium.

B

the transducer was slightly withdrawn and tilted to the left to visualize the left main coronary ostium. The left main coronary artery, which was seen to originate at the 1 or 2 o'clock position on the aortic circumference, was followed to its point of bifurcation, thus assuring that the entire length of this vessel was identified (Fig. 1A). An attempt was then made to examine as much of the proximal left anterior descending and left circumflex arteries as possible. The transducer was next tilted to the right to delineate the orifice and as much of the proximal segment of the right coronary artery as possible (Fig. 1B). The entire examination was recorded on 0.5 in. (1.27 cm) VHS videotape and analyzed on a commercially available off-line videotape-video disk system (Nova Microsystem, Inc.). No side effects relating to transesophageal echocardiography were noted in any patient.

Echocardiographic Analysis

Coronary artery segment length. The left main coronary artery was measured from its origin at the aortic root to the level of its bifurcation. For the left anterior descending and left circumflex arteries, the maximal length was measured from the point of origin of these vessels at the bifurcation to the most distal portion of the segment. The length of the right coronary artery was measured from its origin on the aortic circumference to the maximal point of the visualized proximal segment.

Maximal coronary artery width. Multiple measurements of the internal diameter of the left main and right coronary
arteries were obtained. The largest diameter for each artery determined the maximal lumen width.

**Determination and localization of proximal coronary artery stenosis.** If an area of localized echo density was seen to impinge on the lumen of the coronary artery, multiple measurements were taken in this region. The smallest diameter was compared with the width of the vessel just proximal to the narrowing and expressed as a percent, except in ostial lesions in which the width of the vessel immediately distal to the narrowing was taken. An area of stenosis was considered significant if it was \( \geq 50\% \) (8). In all cases of stenosis, a segment of the coronary artery distal to the narrowing was identified, thus excluding the possibility of an artefactual narrowing due to bending of the coronary artery, cardiac motion or plane obliquity. In addition, the echo densities (plaque) protruding into the coronary lumen were disregarded if not consistently visualized during multiple repeat scanning of the coronary arteries with different transducer angulations. Localization of each stenosis was determined by measuring its distance from the origin of the coronary artery involved to the point of the start of the lesion. For the left main and right coronary arteries, the distance from the origin of the vessel to the lesion was measured. For the left anterior descending and left circumflex coronary arteries, the point of origin of these vessels at the bifurcation of the left main coronary artery to the point of the start of the lesion was measured.

All measurements were performed by two independent observers who did not know the patients' clinical status or echocardiographic findings. Subsequently, one of the two observers repeated all measurements in a blinded manner 2 months later. Distances were determined utilizing digital calipers with the aid of frame by frame analysis. All measurements were taken from the coronary segments imaged during the study performed before coronary bypass surgery. Segments visualized during cardioplegic infusion or after bypass surgery were not considered.

**Doppler color flow analysis.** This analysis was performed in all patients. The Doppler color gain was optimized as described by Miyatake et al. (9). The Nyquist limit was kept in the range of 0.41 to 0.72 m/s and in >80% of the patients between 0.41 and 0.55 m/s. Doppler color imaging was initiated to help identify the lumen of the coronary artery and follow the artery's course. It also helped differentiate the left anterior descending artery from the accompanying anterior interventricular vein and the left circumflex artery from the adjacent great cardiac vein where blood flow is of much lower velocity and hence no color signals are usually visualized. In our experience, color flow signals are visualized in the veins mainly during cardioplegia and even then they may be differentiated from arterial flow by their opposite flow direction as in the case of the anterior interventricular vein (Fig. 2). Narrowing of the color flow channel to >50% of the width immediately before narrowing was taken as an indication of significant stenosis, except for the ostial lesions in which the width of the flow channel narrowing was compared with the width of the channel in the immediate distal vessel.

**Angiographic Analysis**

All coronary angiograms were reviewed by an experienced independent angiographer who did not know the patients' clinical status or echocardiographic findings. In all patients, the maximal length and width of the left main coronary artery and the maximal width of the proximal right coronary artery were measured. All measurements were performed with electronic digital calipers (Digit Cal II) (10). The magnification factor was determined by measuring the coronary artery catheter in the same view as that used for the coronary artery measurements. The magnification factor was derived by dividing the measured width of the catheter by the actual diameter of the catheter provided by the manufacturer. All distances were measured in angiographic projections with minimal if any foreshortening of the area of interest. As with the echocardiographic criteria, any angiographic obstruction of >50% in the proximal portion was considered a significant stenosis (10). Stenotic coronary arteries were measured in the projection in which the stenosis was judged to be the most severe. Proximal coronary artery stenosis was defined as an area of narrowing in the left main coronary artery, the proximal one-third of the right coronary artery or the proximal segments of the left anterior descending (up to the first septal perforator) or circumflex (up to the obtuse marginal) vessels (11). Because the length of the proximal portions of the left anterior descending, left circumflex and right coronary arteries by echocardiography

![Figure 3. Comparison of transesophageal echocardiography (TEE) and angiography (ANGIO) in the assessment of the length of the left main coronary artery in 103 patients. The number of points on the graph appears less than the total number of observations because of overlapping values.](image-url)
Coronary segment length and width. The transesophageal technique provided complete visualization of the left main coronary artery from its origin to its bifurcation in 103 (93%) of the 111 patients. This artery could not be imaged in seven patients and was incompletely visualized in one (coronary angiography demonstrated a normal coronary artery in four of these eight patients, distal stenosis in four and proximal stenosis in one). The results were analyzed by taking into consideration only the corresponding angiographic segments of the coronary arteries. For instance, if only 1.5 cm of the left anterior descending artery was visualized during transesophageal echocardiography, a corresponding comparison was made with the proximal 1.5 cm as determined angiographically. Therefore, it was assumed that the lengths of the segments visualized by intraoperative transesophageal echocardiography were practically identical to the length determined angiographically.

Statistical analysis. The echocardiographic results were compared with those of the corresponding angiographic study. All statistical data were analyzed using a Macintosh II computer and the Stat View II statistical analysis software program. Results were expressed as mean values ± SEE. A p value < 0.05 was considered statistically significant. The correlations between transesophageal echocardiography and angiographic measurements were assessed with linear regression analysis. The accuracy of transesophageal echocardiography in the detection of stenosis in the angiographic segments corresponding to the echocardiographically visualized segments as well as the sensitivity and specificity of this technique in the assessment of proximal coronary artery stenosis as traditionally defined by angiography were determined according to:

\[\text{Sensitivity} = \frac{\text{True positives}}{\text{True positives} + \text{False negatives}}\]
\[\text{Specificity} = \frac{\text{True negatives}}{\text{True negatives} + \text{False positives}}\]

Results

Figure 4. Comparison of transesophageal echocardiography (TEE) and angiography (ANGIO) in the assessment of the width of the left main coronary artery (n = 103) (A) and right coronary artery (n = 55) (B). The number of points on the graphs appears less than the total number of observations because of overlapping values.

Figure 5. Transesophageal echocardiographic identification of left main coronary artery stenosis. The aortic (AO) short-axis view demonstrates an eccentric highly reflective echo density (arrow), producing marked narrowing of the left main coronary artery (LMCA) lumen. Other abbreviations as in Figure I.
steno$sis$ in none). In the 103 patients with complete visualization of this artery, it varied in length from 0.2 to 2.2 cm (mean 0.93 ± 0.06) and in maximal lumen width from 0.2 to 0.7 cm (mean 0.45 ± 0.01). Varying lengths of the proximal left anterior descending (0.2 to 2.2 cm, mean 0.82 ± 0.08) and left circumflex (0.1 to 3.4 cm, mean 0.67 ± 0.09) coronary arteries were also visualized in these patients. The right coronary artery was visualized in only 55 patients (49%). Its length varied from 0.1 to 4.6 cm (mean 0.7 to 0.2) and maximal width from 0.2 to 0.8 cm (mean 0.4 ± 0.01).

No significant interobserver variations were noted for the length (r = 0.89, SEE = 0.054) and width (r = 0.88, SEE = 0.010) of the left main artery, the width of the right coronary artery (r = 0.86, SEE = 0.017) and the length of the left anterior descending (r = 0.95, SEE = 0.061), left circumflex (r = 0.98, SEE = 0.054) and right (r = 0.96, SEE = 0.122) coronary arteries. Also, no significant intraobserver variations were found for the lengths of these vessels (r = 0.99 to 0.96, SEE = 0.045 to 0.128) and for the width of the left main and right coronary vessels (r = 0.97, SEE = 0.010 and r = 0.93, SEE = 0.017, respectively).

The length and maximal width of the left main coronary artery as well as the maximal width of the right coronary artery as assessed by echocardiography correlated well...
Figure 7. Transesophageal echocardiographic identification of proximal left anterior descending coronary artery stenosis. The aortic (AO) short-axis view demonstrates two prominent echo densities (arrowheads), one at the origin and the other slightly beyond, producing marked narrowing of the left anterior descending coronary artery (LAD). Both the left main coronary artery (LMCA) and proximal circumflex vessel are free of echo densities. LA = left atrium.

with the angiographic measurements (r = 0.94, 0.87 and 0.77, respectively) (Fig. 3 and 4).

Coronary artery stenosis. Comparison of the echocardiographically visualized coronary arteries with the corresponding angiographic segments indicated that a correct diagnosis of significant stenosis was made in 47 (88%) of 53 lesions. This included 23 (96%) of 24 patients with left main stenosis and all 7 with ostial stenosis (5 left main, 2 right coronary artery). Eleven (78%) of 14 lesions in the left anterior descending vessel, 6 (75%) of 8 in the left circumflex artery and all lesions (100%) in the right coronary artery were also correctly identified by this technique (Fig. 5 to 9). The sensitivity and specificity of transesophageal two-dimensional echocardiography in the detection of stenosis in the visualized segments were, respectively, 96% and 99% for the left main artery, 79% and 99% for the left anterior descending artery, 75% and 100% for the left circumflex artery and 100% for the right coronary artery (Table 1). However, if all angiographically identified proximal lesions were taken into consideration irrespective of whether these coronary segments were visualized echocardiographically, the overall sensitivity and specificity of transesophageal two-dimensional echocardiography were, respectively, 96% and 99% for the left main artery, 48% and 99% for left anterior descending artery, 67% and 100% for left circumflex artery and 37% and 100% for right coronary artery stenosis (Table 2). The distance of the stenotic lesion from the origin of the vessel by transesophageal echocardiography also correlated with that measured by angiography (for the left circumflex artery r = 0.63, for other vessels r = 0.91 to 0.99) (Fig. 10).

There was no disagreement regarding the presence or absence of significant stenosis in any patient between the two independent observers or on reanalysis of the data by the same observer 2 months later.

Doppler color flow mapping. A Doppler color flow mapping finding of narrowing of the flow channel was less useful than two-dimensional echocardiography in detecting proximal coronary artery stenosis because flow signals were not present in 13 (24%) of 53 stenoses visualized by two-dimensional echocardiography. However, when present, flow channel narrowing served to enhance the level of confidence with which the diagnosis of a stenosis was made, especially in patients with ostial stenosis. The sensitivity and specificity of color flow channel narrowing in the detection of proximal coronary artery stenosis taking into account only the coronary artery segments visualized by two-dimensional echocardiography were, respectively, 92% and 100% for the left main artery, 64% and 86% for the left anterior descending artery, 75% and 84% for the left circumflex artery and 43% and 81% for the right coronary artery (Table 3). The overall sensitivity and specificity of the color flow channel narrowing in the identification of all angiographically seen proximal lesions were, respectively, 92% and 100% for the left main artery, 48% and 84% for the left anterior descending artery, 67% and 83% for the left circumflex artery and 37% and 75% for the right coronary artery (Table 4).

Figure 8. Transesophageal echocardiographic identification of proximal left circumflex coronary artery (LCX) stenosis. The aortic (AO) short-axis view demonstrates a prominent eccentric echo density (arrow), producing marked narrowing of the left circumflex coronary artery approximately 1 cm from its origin. The left circumflex artery is identified by its posterior course in contrast to the left main coronary artery (LMCA), which courses somewhat anteriorly. The left main and proximal left anterior descending (LAD) coronary arteries do not show significant narrowing. LA = left atrium; RVOT = right ventricular outflow tract.
Figure 9. Transesophageal echocardiographic identification of proximal right coronary artery (RCA) stenosis. The aortic (AO) short-axis view demonstrates two highly reflective echo densities (arrowheads), producing marked narrowing of the proximal lumen of the right coronary artery. One echo density is located at the origin of the vessel and the other slightly beyond. Abbreviations as in Figures 1 and 8.

Discussion

Previous studies (Table 5). There have been several preliminary reports documenting the feasibility of visualizing proximal coronary arteries by transesophageal two-dimensional echocardiography. Also, attempts have been made to identify left main coronary artery stenosis with this technique (2, 7, 12-15) and the detection rate has varied from 65% in a series of 23 patients (2) to 100% in a small group of 4 patients (15). One study (2) claimed a high detection rate of 64% for left circumflex vessel stenosis, but because the left main coronary bifurcation appeared to have been identified in only a small number of patients, the accuracy of that study is questionable. In another small series (15), transesophageal echocardiography failed to detect left circumflex stenosis but identified left anterior descending stenosis in five (71%) of seven patients.

A more recent study (14) detected left coronary artery ostial stenosis in four patients studied with a combination of two-dimensional echocardiography and conventional and Doppler color flow imaging. In another study (16), the finding of mosaic "disordered" flow by Doppler color imaging resulted in the detection in five patients of left main stenosis that was not diagnosed by two-dimensional echocardiography. However, several investigators (16) have questioned the accuracy of Doppler color flow imaging in the identification of disturbed flow. To date, no study has examined the detection of proximal right coronary artery stenosis by transesophageal echocardiography.

Present findings. The present study comprises a relatively large number of consecutive patients, many of whom had proximal coronary artery stenosis. In >90% of patients with and without stenosis, the left main coronary artery could be completely visualized to its bifurcation and the proximal left anterior descending and left circumflex vessels were also visualized at least for a short distance. The proximal right coronary artery was also visualized in approximately 50% of the patients studied.

Table 2. Detection of Proximal Coronary Artery Stenosis

<table>
<thead>
<tr>
<th>LMCA</th>
<th>LAD</th>
<th>LCx</th>
<th>RCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEE/Ang</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td>+</td>
<td>23</td>
<td>11</td>
<td>6</td>
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<tr>
<td>-</td>
<td>1</td>
<td>78</td>
<td>12</td>
</tr>
<tr>
<td>Sensitivity (%)</td>
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<td>48</td>
<td>67</td>
</tr>
<tr>
<td>Specificity (%)</td>
<td>99</td>
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</table>

Abbreviations as in Table 1.

finding of mosaic "disordered" flow by Doppler color imaging resulted in the detection in five patients of left main stenosis that was not diagnosed by two-dimensional echocardiography. However, several investigators (16) have questioned the accuracy of Doppler color flow imaging in the identification of disturbed flow. To date, no study has examined the detection of proximal right coronary artery stenosis by transesophageal echocardiography.

Figure 10. Comparison of transesophageal echocardiography (TEE) and angiography (ANGIO) in the localization of proximal coronary artery stenosis of the left main artery (LM), left anterior descending coronary artery (LAD), left circumflex coronary artery (LCX) and right coronary artery (RCA). The number of points on the graphs appears less than the total number of observations (n = 47) because of overlapping values.
We found transesophageal echocardiography highly sensitive and specific in the diagnosis of significant left main coronary artery lesions in a relatively large number of patients. In particular, transesophageal echocardiography made a correct diagnosis in all seven patients with ostial stenosis involving both the left main and the right coronary artery. Also, in the coronary artery segments visualized by echocardiography, all lesions involving the right coronary artery and most of the lesions involving the left anterior descending and left circumflex vessels were identified by this technique. Thus, transesophageal echocardiography reliably detected almost all lesions in the coronary arteries whenever the segments containing these lesions were visualized completely, including a short segment beyond the lesion.

Limitations. A major limitation was the inability of transesophageal echocardiography to visualize long segments of these vessels so that the overall sensitivity of identifying stenoses in the proximal coronary arteries as customarily defined by angiography was not high, except for the left main coronary artery. The reasons for failure to detect every stenotic lesion in the visualized segments are not clear but may be related to the presence of calcification in the plaque, causing acoustic shadowing (2). Also, the echocardiographic planes may not exactly correspond to the angiographic views, resulting in discrepancies regarding the severity of stenosis, especially in eccentric lesions. In addition, the lumen size of the proximal coronary arteries is relatively small, making it difficult to obtain accurate measurements by echocardiography, which has limited resolution capability in axial and lateral planes. There are also potential errors in the calculation of the magnification factor, which may lead to imprecise angiographic measurements of lumen widths (10).

Table 3. Detection of Coronary Artery Stenosis by Doppler Color Flow Imaging

<table>
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<tr>
<th>Flow channel narrowing</th>
<th>CD/Ang</th>
<th>Flow channel narrowing</th>
<th>CD/Ang</th>
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<th>CD/Ang</th>
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<th>CD/Ang</th>
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<tr>
<td>LMCA</td>
<td>+</td>
<td>LAD</td>
<td>+</td>
<td>LCx</td>
<td>+</td>
<td>RCA</td>
<td>+</td>
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<tr>
<td>No flow channel narrowing</td>
<td>0 0 0 0</td>
<td>79 79 0 0</td>
<td>79 79 0 0</td>
<td>39 39 0 0</td>
<td>2 2 5 5</td>
<td>12 12 2 2</td>
<td>4 4 9 9</td>
</tr>
<tr>
<td>Color signals not seen</td>
<td>2 0</td>
<td>5 12</td>
<td>2 15</td>
<td>4 9</td>
<td>2 0</td>
<td>12 13</td>
<td>3 16</td>
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<tr>
<td>Sensitivity (%)</td>
<td>92</td>
<td>64</td>
<td>75</td>
<td>43</td>
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<td>86</td>
<td>84</td>
<td>81</td>
<td>100</td>
<td>84</td>
<td>83</td>
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CD = transesophageal Doppler color echocardiography; other abbreviations as in Table 1.

Abbreviations as in Tables 1 and 3.

Table 5. Reported Studies on the Evaluation of Proximal Coronary Artery Stenosis by Transesophageal Echocardiography

<table>
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<th>First Author (ref. no.)</th>
<th>LMC (%)</th>
<th>LAD (%)</th>
<th>LCx (%)</th>
<th>RCA (%)</th>
<th>LMCA 50%</th>
<th>Proximal LAD 50%</th>
<th>Proximal LCx 50%</th>
<th>Proximal RCA 50%</th>
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<td>Zwicky (4) (50 pts)</td>
<td>100</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Awake</td>
</tr>
<tr>
<td>Yamagishi (3) (39 pts)</td>
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<td>77</td>
<td>54</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Postoperative</td>
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<tr>
<td>Pearce (5) (138 pts)</td>
<td>79</td>
<td>62</td>
<td>57</td>
<td>50</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Consecutive pts; awake; no complications</td>
</tr>
<tr>
<td>Yoshida (13) (38 pts)</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Consecutive pts; awake; no complications</td>
</tr>
<tr>
<td>Yamagishi (12) (52 pts)</td>
<td>90</td>
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<td>12 diagnosed by 2D echo, 4 by color Doppler</td>
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<td>100% (4/4)</td>
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<td>52</td>
<td>88</td>
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<td>Taams (2) (83 pts)</td>
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<td>14</td>
<td>68</td>
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<tr>
<td>Present study (111 pts)</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>49</td>
<td>96% (23/24)</td>
<td>82% (11/14)</td>
<td>80% (6/8)</td>
<td>100% (7/7)</td>
<td>Consecutive pts; intraoperative; no complications</td>
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*Numbers in parentheses denote our reference number. pts = patients; 2D echo = two-dimensional transesophageal echocardiography; other abbreviations as in Table 1.
Narrowing of the flow channel by Doppler color flow imaging was also found useful in detecting significant stenosis, but color flow signals were not visualized in the coronary arteries in a significant number of patients, probably because of the nonparallel orientation of the vessel in relation to the transesophageal ultrasonic beam. That all patients were examined intraoperatively rather than in the awake state represents another limitation of our study. Biplane transesophageal examination was not performed in any patient, but our recent experience suggests that this technique does not add significantly to the standard method in the assessment of coronary arteries.

Conclusions. In a relatively large number of patients, transesophageal echocardiography identified left main coronary artery stenosis with a high degree of accuracy. It also correctly identified ostial lesions involving the left and right coronary arteries. The technique was less useful in the detection of stenotic lesions in the proximal portions of the left anterior descending, left circumflex and right coronary arteries.

References