Regurgitant Jet Size by Transesophageal Compared With Transthoracic Doppler Color Flow Imaging

Mikel D. Smith, MD; Michael R. Harrison, MD; Rita Pinton, MD; Hossam Kandil, MD; Oi Ling Kwan, BS; and Anthony N. DeMaria, MD

Combined echocardiography and Doppler color flow mapping from transthoracic imaging windows has become the standard method for the noninvasive assessment of valvular regurgitation. This study compared regurgitant jet areas by Doppler color flow imaging derived from the newer transesophageal approach with measurements obtained from conventional transthoracic apical views. Maximal regurgitant jet area determinations and an overall visual estimate of lesion severity were obtained from 42 patients who underwent color flow examination by both techniques. Seventy-three regurgitant lesions were visualized by transesophageal flow imaging: 34 mitral, 22 aortic, and 17 tricuspid jets. Transthoracic studies in the same patients revealed fewer regurgitant lesions for each valve: 20 mitral, 16 aortic, and 12 tricuspid ($p=0.0009$). A comparison of maximal jet areas determined by transesophageal and transthoracic studies showed a good overall correlation ($r=0.85, \text{SEE}=2.8 \text{cm}^2$) and a systematic overestimation by the transesophageal technique (TEE=0.96 TTX+2.7). For the subgroup with mitral insufficiency, valve lesions visualized by both techniques were larger by the transesophageal approach ($n=18, 6.0 \text{ versus } 3.6 \text{ cm}^2$, $p=0.008$). Semiquantitative visual grading of individual valve lesions by two independent observers revealed a higher grade of regurgitation with more jets classified as mild (38 versus 25), moderate (18 versus 13), and severe (17 versus 10) by esophageal imaging than by transthoracic imaging. Thus, transesophageal color flow mapping techniques yield a higher prevalence of valvular regurgitation than do transthoracic techniques in the same patients. Jet area and the overall estimate of regurgitant lesion severity were also greater by transesophageal color Doppler imaging compared with standard transthoracic imaging. As a result, currently used standards for predicting severity of regurgitation by Doppler color flow mapping must be reexamined when the esophageal window is used. (Circulation 1991;83:79–86)

Doppler color flow echocardiography has assumed a prominent role in the noninvasive evaluation of patients with a variety of cardiac disorders. This technique has been used to identify shunts,\textsuperscript{1,2} to assess direction of stenotic jets,\textsuperscript{1} and to evaluate flow through prosthetic devices.\textsuperscript{3} Color flow imaging has achieved its most frequent application, however, in the evaluation of valvular regurgitation.\textsuperscript{4} Although this methodology is susceptible to a variety of technical and physiological variables, the size of the flow disturbance as depicted by Doppler color flow mapping has been shown to correlate with the severity grade of the lesion as assessed by cineangiography.\textsuperscript{5–8}

The recent development of transesophageal probes has provided a new window for high-resolution ultrasonic imaging of cardiac structures and dynamic blood flow. This technique has proven useful in evaluating prosthetic valves,\textsuperscript{9,10} atrial septal defects,\textsuperscript{11} descending thoracic aortic dissection,\textsuperscript{12,13} and atrial thrombi and vegetations.\textsuperscript{14,15} In addition, transesophageal echocardiography has permitted ultrasonic visualization in patients in whom the transthoracic approach yielded poor-quality images.\textsuperscript{15,16} Transesophageal echocardiography with Doppler color flow imaging has contributed particularly to the intraoperative assessment and management of valvular heart disease during valve repair or replacement.\textsuperscript{17,18}
Despite the increasing application of transesophageal echocardiography, few data exist on the presence and size of flow disturbances visualized from this approach compared with the transthoracic window. In making the transition to transesophageal echocardiography, it has generally been assumed that the same reference standards used for transthoracic imaging can be applied to these images. However, the greater proximity to flow, reduced attenuation, and higher frequency sound signals inherent in the transesophageal technique have the potential to alter the size of flow disturbance in this presentation. Therefore, the purpose of this study was to compare Doppler color flow regurgitant jet areas in patients undergoing both transesophageal and transthoracic Doppler echocardiography.

Methods

Patient Population

The patient population consisted of all patients having clinically indicated and technically adequate transthoracic and transesophageal color flow studies during a 10-month period. During this time, 42 patients underwent Doppler color flow examinations performed from both windows with the same instrument (Hewlett-Packard 77020AC or Aloka SSD 860). Twenty-five esophageal studies were electively performed before valve replacement, (14), valve repair, (7), left atrial myxoma removal, (2), or coronary artery bypass (2). For the 17 awake patients studied in the noninvasive laboratory, transesophageal imaging was performed to exclude intracardiac mass, (10), to evaluate the left atrium before mitral balloon valvuloplasty, (4), or to assess prosthetic mitral valve function (3). All regurgitant valve lesions noted by Doppler color flow were believed to be chronic in nature and to result from a variety of causes including rheumatic, ischemic, and degenerative etiologies.

Doppler Color Flow Imaging

Transesophageal echocardiography was performed with 5.0-MHz probes, whereas transthoracic color flow echocardiography was performed with either 2.5- or 3.5-MHz transducers. As part of the general examination, images were recorded in multiple planes from the standard parasternal, apical, and subcostal windows by transthoracic echocardiography and from the basal and transgastric short-axis, four-chamber, and five-chamber planes by transesophageal echocardiography. However, for the purposes of quantification, only transthoracic and transesophageal four- or five-chamber planes were compared because the orientation of the beam to the regurgitant jet in these views is identical for esophageal and thoracic windows and is closely parallel to the direction of the disturbed flow. For each study, transducer position and instrument settings for depth, sector arc, gain, velocity scale, velocity map, and other variables were individualized to yield optimal images. Transesophageal imaging was performed according to a previously described protocol. In our laboratory, intravenous glycopyrrolate (0.2 mg), midazolam (1–5 mg), and topical xylocaine spray were used in awake patients before introduction of the esophageal probe. No additional anesthesia was given for examinations performed during operative studies.

The left atrium, left ventricular outflow tract, and right atrium were carefully examined by both esophageal and thoracic approaches for the presence of mitral, aortic, or tricuspid regurgitation, respectively. The presence of valve leakage was then substantiated by pulsed-wave sampling in the region of disturbed flow. Doppler color flow images were recorded on 0.5-in. VHS videotape for offline review and quantification. In those patients in whom regurgitation was identified, the jet was measured by planing the outer border of the largest clearly definable flow disturbance by use of a digitizing pad and a graphic video overlay with a commercially available microprocessor system (Microsonics, Inc., Indianapolis, Ind.). The maximal jet area that was traced included central varianced and aliased signals and the immediately contiguous nonturbulent velocities that were moving in the same direction as the jet. For aortic insufficiency jets, only those frames containing abnormal flows that could be clearly distinguished from normal mitral inflow were traced. Jet areas were taken in frames from three separate cardiac cycles for transesophageal and transthoracic studies and were expressed as mean values for the three measurements in square centimeters. In addition, each regurgitant jet was visually assessed by severity grade (none, mild, moderate, or severe) based on the perceived width and penetration of the jet into the left atrium.

Interobserver Variability

Observer variability may account for some differences in measurements of Doppler color flow jet area. To evaluate the effect of observer variability on the maximal jet area measurements in our study, videotapes from 10 randomly selected cases were chosen for examination by two observers. The presence and size of disturbed flow determined by two observers from transesophageal and transthoracic approaches were compared by use of linear regression analysis.

Statistical Methods

Jet areas for each lesion were reported as mean values for three measurements in square centimeters. Student’s t test for paired data was used to compare regurgitant jet areas obtained by the transthoracic and transesophageal approaches. Correlations for the two imaging techniques were obtained by use of simple linear regression analysis.

Results

Visualization of Regurgitant Jets

All studies were carefully assessed for the presence of valvular regurgitation. A total of 75 regurgitant
mitral, aortic, or tricuspid jets were observed by either transthoracic or transesophageal windows. The number of regurgitant jets seen for mitral, aortic, and tricuspid valves are shown in Table 1. Of the 126 total valves evaluated, 48 were observed to have regurgitation by conventional transthoracic imaging (20 mitral, 16 aortic, and 12 tricuspid), whereas 73 regurgitant jets were identified by transesophageal imaging (34 mitral, 22 aortic, and 17 tricuspid). Thus, 25 more regurgitant jets were imaged by the transesophageal method than by the transthoracic method. The presence of a regurgitant jet was imaged by both techniques for 44 valve lesions.

**Comparison of Jet Areas**

Maximal areas for transesophageal jets ranged from 0.2 to 29.4 cm² (mean, 4.5±5.2 cm²). The same lesions, measured from the transesophageal window, ranged from 1.4 to 31.9 cm² (mean, 6.2±4.2 cm²). The comparative values for mitral, aortic, and tricuspid valve regurgitant jet sizes are shown in Figure 2. Transesophageal jet areas were significantly larger than areas obtained from the transthoracic technique (p<0.0001) with an overall mean difference of 2.6 cm². Transesophageal regurgitant jet areas were larger for each valve lesion, with p=0.008 for 18 mitral jets, p=0.002 for 15 aortic areas, and p=0.009 for 11 tricuspid lesions (Figure 2). Only four of 44 (9%) jets appeared larger by the transthoracic technique.

There was a good overall correlation between transthoracic and transesophageal color flow jet areas with r=0.85 and SEE=2.8 cm² (Figure 3). However, there was a systematic overestimation of jet area by the esophageal window compared with the thoracic examination, as demonstrated by the positive y intercept.

**Visual Assessment of Regurgitation**

The results of visual grading of lesion severity, comparing 75 transthoracic and transesophageal images, are shown in Figure 4. More jets were graded higher by transesophageal color flow for each category of mild (38 versus 25), moderate (18 versus 13), and severe (17 versus 10) degrees of regurgitation. In 31 cases, the transesophageal jet was graded larger by one category compared with standard color flow imaging. However, in 10 instances, the transesophageal estimate of regurgitation was greater by two categories.

**Interobserver Variability**

Review of videotapes by two separate observers revealed 15 regurgitant jets in these 10 patients by transesophageal scanning. There was complete agreement regarding the presence of lesions, and the correlation of jet areas was excellent at r=0.93 and SEE=2.4 cm², and p<0.001. Nine transthoracic regurgitant jets were identified by both observers in these patients, and the correlation between jet areas was excellent at r=0.98, SEE=0.72 cm², and p<0.0001.

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**TABLE 1. Visualization of Regurgitant Jets by Doppler Color Flow Imaging**

<table>
<thead>
<tr>
<th>Valve</th>
<th>Transesophageal</th>
<th>Transthoracic</th>
<th>Both</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral</td>
<td>34</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Aortic</td>
<td>22</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>Tricuspid</td>
<td>17</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>73</td>
<td>48</td>
<td>44</td>
</tr>
</tbody>
</table>

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**FIGURE 1. Still-frame images of a mitral regurgitant jet obtained from the four-chamber views by the transthoracic (panel A) and transesophageal (panel B) techniques in the same patient. Although the depth scales are different, the blue jet in panel A measured 1.8 cm², whereas the red and green area in panel B measured 5.2 cm² by planimetry. LA, left atrium; LV, left ventricle; RV, right ventricle.
Simultaneous Studies

Previous data from our laboratory and others have shown that the size of the regurgitant jet area by color flow imaging may be influenced by loading conditions. Thus, to assess the influence of differences in heart rate and blood pressure, we separately analyzed the group of patients in whom sequential transthoracic and transesophageal Doppler echocardiography was performed. Twelve such patients accounted for 22 regurgitant jet lesions in this study (10 mitral, eight aortic, and four tricuspid). Transesophageal regurgitant jet areas were larger than transthoracic areas by a mean of 2.7 cm² (p<0.001) and were related by the regression equation TEE=0.78 TTX+3.2. Thus, in a cohort of patients with nearly simultaneous standard and esophageal examinations in whom there was no evidence of a change in loading conditions, the transesophageal studies demonstrated significantly larger jets.

Intraoperative Loading Conditions

Similarly, to determine whether alterations in loading conditions after induction of anesthesia and intubation in the operating suite influenced the differences observed in jet areas, we evaluated heart rates and blood pressures obtained from anesthesia records at the time of transesophageal imaging and compared them with preoperative records. Data were available from 19 patients who accounted for 35 regurgitant jet areas in the operative group (10 aortic, 15 mitral, and 10 tricuspid). Preoperative and intraoperative (postinduction) heart rates and blood pressures were not significantly different by Student's t test (preoperative mean heart rates, 79.6 beats/min; blood pressure, 118.6/69.2 mm Hg; intraoperative heart rate, 78.4 beats/min; blood pressure, 119.1/64.4 mm Hg; p=0.53 and 0.86, respectively). Transesophageal jet areas were larger than corresponding lesions imaged during transthoracic examinations (p<0.0001, TEE=0.89 TTX+3.6) with a mean difference in area of 3.3 cm² for this operative group. Thus, although heart rate and blood pressure differences were present in individual cases, there was no consistent alteration in these parameters for the group, yet the jet areas were consistently larger in this cohort.

Qualitative Grading of Color Flow Regurgitant Jets

<table>
<thead>
<tr>
<th>Transesophageal</th>
<th>Transthoracic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe</td>
<td>10</td>
</tr>
<tr>
<td>Moderate</td>
<td>13</td>
</tr>
<tr>
<td>Mild</td>
<td>25</td>
</tr>
<tr>
<td>None</td>
<td>27</td>
</tr>
</tbody>
</table>

Figure 4. Nomogram of semiquantitative grading of regurgitation into none, mild, moderate, and severe categories. Transesophageal assessment was higher by one category in 31 cases and by two grades in 10 cases. In five lesions, the transthoracic estimate of severity was greater than the transesophageal grade. Connecting lines and small digits represent the number of discordant grades between the techniques.
Discussion

The advent of Doppler color flow imaging has given the clinician the potential for the noninvasive quantification of valvular regurgitation from measurements of the area of disturbed flow. However, a variety of physiological and technical factors have been recognized to determine the size of a jet in patients with regurgitation.\textsuperscript{25} From a physiological standpoint, jet area has been shown to be related not only to the regurgitant volume but also to transvalvular pressure gradient, orifice size, and compliance of the receiving chamber. In the Doppler color flow mapping assessment of mitral regurgitation, jet area has been demonstrated to be dependent on gain, pulse repetition frequency, and even the type of instrumentation used.\textsuperscript{25} Despite these theoretical limitations, measurements derived from the area of disturbed flow have correlated with the angiographic grade of regurgitation.\textsuperscript{5-7,21} Therefore, based on the ease of application and visual impact, evaluation of valv regurgitation by analysis of jet area in Doppler color flow imaging has become commonplace in clinical practice.

The recent development of transesophageal echocardiographic probes has enabled cardiac imaging by ultrasound from a new window. Transesophageal echocardiography has provided a method to overcome obstacles to the transmission of ultrasound through the thorax and has proven to be of great value in visualizing posteriorly located cardiac structures.\textsuperscript{13-16} In making the transition from transthoracic to transesophageal echocardiography, it has often been assumed that the presentation of a particular regur gitant flow disturbance will be similar by both methods. It is also assumed that the general (overall) visual estimation of valvular regurgitation will use the same methodology for both methods. The data from the present study demonstrate that these assumptions are inaccurate and that regurgitant jet areas depicted by transesophageal Doppler color flow imaging are larger than those portrayed by transthoracic imaging. As demonstrated in Figure 4, the semiquantitative visual assessment of regurgitant grade was one level higher in 31 cases and two levels higher in 10 cases. Because jets appear larger during transesophageal examination, inexperienced observers may possibly overestimate the severity of regurgitation.

Transesophageal Compared With Transthoracic Doppler Studies

In light of the recent development of transesophageal probes, it is not surprising that few data are currently available comparing transesophageal with conventional Doppler or color flow images.\textsuperscript{9,10} Schluter et al\textsuperscript{26} provided early information comparing transesophageal with transthoracic quantification of mitral regurgitation by use of standard pulsed-wave Doppler mapping of the left atrium. Their study demonstrated a higher sensitivity for pulsed-wave Doppler recordings from the transesophageal approach (100%) compared with those Doppler recordings from conventional transthoracic parasternal and apical windows (58%).

Nellessen et al\textsuperscript{9} noted that transesophageal echocardiography provides enhanced two-dimensional resolution in patients with malfunctioning valve prostheses. Color flow mapping in their study resulted in a higher grade of regurgitation by transesophageal compared with transthoracic imaging. Using criteria similar to ours, they found that transesophageal grading for mitral, aortic, and tricuspid insufficiency corresponded well with the angiographic assessment of lesion severity. More recent data comparing transesophageal and transthoracic images in patients with mechanical mitral prostheses have been provided by van den Brink et al.\textsuperscript{10} Their study revealed the presence of "closure and leakage backflow" in 100% of patients by transesophageal Doppler but in only 21% of patients with transthoracic continuous-wave and color flow examination.

Our results in three patients with mitral and in two with aortic prosthetic valves are consistent with these early studies. We again showed that the transesophageal color flow technique is more sensitive for detecting regurgitation and that the jet areas imaged are larger from this window than by the transthoracic method. Thus, transthoracic Doppler color flow imaging appears inadequate for evaluating prosthetic mitral valve regurgitation because the artificial device may inhibit the transmission of the ultrasound beam and result in flow masking. Similar findings were observed in our patients with heavily thickened or calcified valves such as mitral stenosis. Of greater significance, these data demonstrate that the enhanced transmission of high-frequency sonic energy from the transesophageal approach may influence the presentation of the flow disturbance by Doppler even in patients with noncalcified native valves. Our data indicate that jets imaged from the transesophageal window are larger than those imaged from the transthoracic window. This increase in size may lead to overestimation of lesion severity by means of visual assessment.

Technical Considerations

Several technical factors, inherent in the performance of color flow imaging, may have affected our results and deserve mention. Theoretically, signals from the transducers used in the transthoracic studies (2.5 MHz) should attenuate less than those from the 5.0-MHz transesophageal probes and, therefore, result in comparatively larger color flow jets. However, this factor may be offset by shallower depths and fewer tissue interfaces from the transesophageal window. Studies were performed at a mean depth scale of 11.6 cm (range, 6-15 cm) by the transesophageal approach compared with a mean of 16.8 cm (range, 12-22 cm) for the transthoracic method ($p<0.0001$). The mitral valves were located at a mean depth of 5.6 cm with regurgitant jets emanating toward the transducer by esophageal studies. The mitral valve was imaged at a mean depth of 8.6 cm.
from the transducer with jets at greater distance (away) into the left atrium by transthoracic studies. For aortic regurgitation, the valve plane was at 5.9 cm by transesophageal and at 8.2 cm depth by the transthoracic approach, with jet directions away and toward the transducer, respectively. In theory, regurgitant jets from calcified aortic valves or aortic prostheses may be better visualized from the transthoracic apical window because the jet is interposed between the transducer and valve and eliminates the problem of flow masking. Although there were too few patients with aortic prostheses in our series to substantiate this, the aortic valve plane is imaged at shorter distances in transesophageal views and, therefore, may offset this potential limitation.

In some cases, flow masking by prosthetic valves or calcification within the native valve or annulus may have limited visualization of the entire regurgitant jet.27 For two of the 10 regurgitant jets that differed by two grades, flow masking may have prevented complete visualization of mitral insufficiency due to the interposition of strong tissue reflectors between the transducer and left atrium by transthoracic conventional color flow scan planes. When the group of seven patients with either mitral prosthesis or mitral stenosis was evaluated separately, the mean jet area by the transthoracic method was 1.47 cm² and was significantly larger for the transesophageal studies (4.6 cm², p<0.001). This corroborates data from other studies comparing the sensitivity of transesophageal and standard windows in the evaluation of prosthetic valves by color flow imaging.9,10

The fan-shaped, two-dimensional color flow sector may occasionally limit the ability of transesophageal scanning to examine regurgitant flow and chamber size. From the esophageal approach, the narrowest part of the scan plane is located near the left atrium often making it impossible to encompass the entire chamber within the color sector. The number of tomographic scan planes obtainable from manipulation of the transesophageal probe is limited when compared with the standard technique because of the constraints of the esophageal walls. This may occasionally lead to an inability to detect the largest regurgitant jet and may account for the higher grades of regurgitation seen by transthoracic imaging in five patients in this study (Figure 4). The development of commercially available biplane transesophageal transducers may eliminate these imaging difficulties by offering additional scan planes for jet visualization in orthogonal views.28

Interobserver variability may account for some differences in Doppler color flow jet area measurements.22 However, the correlation for the cases measured by two observers was excellent. In addition, the largest percent difference in jet area between observers was 10%, and transesophageal measurements by the second observer were again larger in all cases. Thus, observer variability does not account for the overestimation of transthoracic color flow jet sizes.

Because artifacts were introduced by cross-talk between transducers, the transthoracic and transesophageal examinations in this study could not be acquired simultaneously. Therefore, differences in hemodynamic variables including heart rate could account for some differences in jet size. However, for the subset of ambulatory patients who were studied sequentially, there was a consistently larger jet area during transesophageal study compared with the same jets from standard scan planes. This subgroup was studied under nearly identical conditions and with minimal time separating the two echocardiographic studies. Thus, significant variability in loading conditions probably did not exist during these examinations.

To evaluate whether differing conditions were present at the time of intraoperative study, heart rates and blood pressures after induction of anesthesia were examined. Although individual differences were occasionally present, there was no consistent increase or decrease in these vital signs to suggest a major alteration in hemodynamics. Of clinical relevance, intraoperative images are always obtained after general anesthesia and tracheal intubation as was done in our study. In this setting, a number of factors including loading conditions, limited scan planes, and lack of signal attenuation may all contribute to differences in transesophageal Doppler color flow images. For this reason, we believe it is imperative that a baseline transesophageal study be performed before sternotomy, to be used as a baseline with which to compare postoperative results, especially with valve repair surgery.

Color flow machine settings such as gain, width, and frame rate were not identical in transthoracic and transesophageal studies. Standardization of these parameters is impractical in the clinical setting because the frequency and attenuation of the signal differ radically. Therefore, our data were acquired using the color flow control techniques established to provide optimal images.5 Similarly, the narrowest sector arc and shallowest depth that allowed the color sector to encompass the entire flow disturbance were used.

An independent reference standard to identify and quantify regurgitation was not available for most lesions detected by color flow imaging in these patients. Thus, a "true" sensitivity or specificity for transesophageal and transthoracic flow mapping was not calculated in this study. Neither could the relative accuracy of quantitative assessment of regurgitation by transthoracic and transesophageal approaches be determined because simultaneous hemodynamic and angiographic data were not available for all these patients. Indeed, for the patient population examined in this clinical study, a large number of the jets seen by color flow were small and may represent physiological flow reversal or "closing volume."29
Clinical Implications

The transesophageal window for color flow imaging provides evidence of regurgitant flow more frequently than does the conventional transthoracic window. Doppler regurgitant jet areas by transesophageal echocardiography are larger than those by transthoracic jets using comparable scan planes, and hence, semiquantitative grading of regurgitant valve lesions may differ between the two techniques. Thus, for the intraoperative use of esophageal echocardiography to evaluate the severity of valve leakage, a preoperative transesophageal study before sternotomy is indicated to provide a baseline for jet size and grade. When heavily calcified or prosthetic valves are being examined, the transesophageal approach appears to offer a better assessment of regurgitation, especially for the mitral valve. Previously accepted transthoracic color flow methods for predicting severity of regurgitation compared with angiography must be reexamined using the esophageal window.

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References


KEY WORDS • echocardiography, Doppler • echocardiography, transesophageal • valvular regurgitation
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