Clinical Investigation

Evaluation of Biplane Color Doppler Transesophageal Echocardiography in 200 Consecutive Patients

Ryozo Omoto, MD; Shunei Kyo, MD; Makoto Matsumura, MD; Pratima M. Shah, MD; Hideo Adachi, MD; Yuji Yokote, MD; and Yuji Kondo, BS

Background. We developed the first biplane transesophageal echocardiography (TEE) probe with two orthogonal transducers, allowing synchronous side-by-side displays of the heart on a monitor TV, and compared its diagnostic value with that of conventional single-plane TEE using commercially available Doppler equipment in 200 consecutive patients intraoperatively, perioperatively, or on an outpatient basis.

Methods and Results. Insertion was easy, except in one patient with a mediastinal tumor, and no complications were encountered. Both transverse and longitudinal scans allowed correct identification of true and false lumina in all 30 aortic dissection examinations, but longitudinal scanning was slightly superior in detecting types I and III entry sites. Three entries that were not detected by transverse scanning (two of DeBakey type I and one of type III) were visualized by longitudinal scanning. Among 37 cases of mitral regurgitation (MR), longitudinal scans were significantly superior (p<0.05) in revealing multiple jets (nine compared with two with transverse scanning). Although both planes yielded almost identical mean values for the maximum jet areas, a difference of over 50% in jet area size on the two planes was observed in 19 cases. The measured jet areas showed significant correlation with the angiographic MR grading, especially for the larger of the biplane measurements (p<0.01), and different grades showed little overlap. Longitudinal images increased the acoustic window of the heart and aorta from the esophagus. Moreover, longitudinal scanning provided good visualization of both ventricular outflow tracts, the ascending aorta, main pulmonary artery, and superior vena cava.

Conclusions. This modality greatly facilitates a three-dimensional comprehension of cardiovascular lesions and flow dynamics, especially in aortic dissection and MR, and its safety was demonstrated. Our data demonstrate the usefulness of this new technique in comparison with conventional single-plane TEE. (Circulation 1992;85:1237–1247)

Key Words • echocardiography, transesophageal • echocardiography, Doppler

Color Doppler transesophageal echocardiography (TEE) has rapidly become an important noninvasive imaging tool for real-time on-line continuous imaging and monitoring.1–3 There are many centers where TEE is used routinely in outpatient clinics4–5 as well as during surgery and in early postoperative periods.6,7 It has various applications, for example, evaluation of the adequacy of valvuloplasty,8,9 management of dissecting aortic aneurysms,10–12 and monitoring of left ventricular wall motion to detect early evidence of myocardial ischemia.13–16 In the present state of the art, however, the major limitation is that only the transverse image can be obtained, with virtually no visualization in the longitudinal or oblique planes. Intraoperative epicardial echocardiography can provide important information; however, some of the drawbacks are that the technique requires placement of a transducer in a sterile surgical field, thus introducing risk of infection; it is not an on-line continuous monitor; and it requires interruption of surgery. To overcome this shortcoming, in close collaboration with the biomedical engineering department of Aloka, Inc., we developed a biplane TEE probe with two orthogonal transducers that can provide synchronous biplane images of the heart for a side-by-side TV monitor display.17 This article evaluates the clinical applicability of biplane images of the heart and aorta from the esophagus and describes the important advantages of this modality in providing new diagnostic information unavailable with conventional single-plane TEE probes.

Methods

Patients

The study consisted of 200 consecutive patients examined in the Department of Surgery, Saitama Medical School, from September 16, 1988, to September 8, 1989. Of the 200 patients, 105 were examined during surgery, in the intensive care unit, or both, and 95 were studied in the outpatient clinic. Informed consent was obtained from all patients in accordance with the regulations of our institution. Dyspnea was recognized in one patient

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follow-up in the outpatient clinic. In the surgical group of 105 patients, biplane TEE examination was performed during surgery and/or in the immediate postoperative period in the intensive care unit. When the patients in the intensive care unit were examined, they were medicated with 10 mg morphine or diazepam, and the upper airway was anesthetized with 8% lidocaine spray. In outpatients, the upper airway and pharynx were anesthetized with 5 ml of 2% viscous lidocaine and topical spray of 8% lidocaine. Blood pressure was checked frequently with an automated instrument. Continuous ECG monitoring was also performed. The insertion of the probe and examination were carried out by three cardiac surgeons and one cardiac anesthesiologist, all familiar with the insertion technique of the conventional single-plane probe.

Biplane Transesophageal Probe and Instrumentation

The probe (Aloka UST-5228-4, Tokyo, Japan) is 13.5 mm in diameter and 100 cm long (Figure 1). The transverse and the longitudinal transducers are mounted end-to-end, 1.5 mm apart, with the transverse transducer at the tip and the longitudinal transducer immediately proximal to it on the same shaft. The diameter is only 0.5 mm larger than the conventional single-plane probe we used (Aloka UST-5233-5), but the rigid tip is 29.5 mm long, compared with the 13-mm-long tip of the conventional probe. The flexible tip can be controlled by the manual control on the gastroscope like the conventional TEE probe. Each transducer has 32 elements, each of which is 0.18 mm wide. Each has a separate cable within the same shaft. Either transverse or longitudinal scanning can be performed as desired, and simultaneous biplane images can be reproduced from the built-in cine-memory mode. The electrical safety of the probes was confirmed in a phantom model experiment and in animal experiments before clinical use. The leakage of current was found to be less than 50 μA. The isolation resistance was more than 5 MΩ. Thermal stability was also checked. In patients with normal circulation, there was a 0.7°C increase from baseline temperature at the surface of the probe. During the entire cardiopulmonary bypass pro-

**TABLE 1. Population Undergoing Biplane Transesophageal Echocardiographic Examination**

<table>
<thead>
<tr>
<th>Type of disease</th>
<th>n</th>
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<tbody>
<tr>
<td>Ischemic heart disease</td>
<td>33</td>
</tr>
<tr>
<td>Valvular heart disease</td>
<td>66</td>
</tr>
<tr>
<td>Aortic valve lesion</td>
<td>13</td>
</tr>
<tr>
<td>Mitral valve lesion</td>
<td>34</td>
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<tr>
<td>Multivalvular lesion</td>
<td>19</td>
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<tr>
<td>Congenital heart disease</td>
<td>16</td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>8</td>
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<tr>
<td>Ventricular septal defect</td>
<td>2</td>
</tr>
<tr>
<td>Ruptured Valsalva sinus aneurysm</td>
<td>2</td>
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<tr>
<td>Others</td>
<td>4</td>
</tr>
<tr>
<td>Aortic aneurysm</td>
<td>68</td>
</tr>
<tr>
<td>Dissecting</td>
<td></td>
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<tr>
<td>DeBakey type I</td>
<td>14</td>
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<tr>
<td>DeBakey type II</td>
<td>2</td>
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<tr>
<td>DeBakey type III</td>
<td>32</td>
</tr>
<tr>
<td>Nondissecting</td>
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<tr>
<td>Thoracic</td>
<td>13</td>
</tr>
<tr>
<td>Abdominal</td>
<td>3</td>
</tr>
<tr>
<td>Normal (suspected of dissecting aneurysm)</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>17</td>
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<tr>
<td>Left ventricular myxoma</td>
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<tr>
<td>Constrictive pericarditis</td>
<td>3</td>
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<td>Mediastinal tumor</td>
<td>3</td>
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<tr>
<td>Lung cancer</td>
<td>6</td>
</tr>
<tr>
<td>Others</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>200</td>
</tr>
</tbody>
</table>

*These four patients were referred on an initial diagnosis of acute dissecting aneurysm.

with mediastinal tumor causing a major tracheal shift, and the examination was discontinued. Of the other 199 patients, 131 were men and 68 were women (mean age, 54 years; range, 17–78 years) (Table 1). The nonsurgical group (95 patients) consisted of 32 patients with DeBakey type III aneurysm treated conservatively, eight patients examined to rule out the possibility of dissecting aneurysm, and 55 patients for postoperative examination.
procedure, the power to the transducers was turned off to ensure safety.

The color Doppler flow mapping system was used with commercially available equipment (Aloka SSD-870). The phased array sector scanning of each transducer is 5-MHz frequency, with maximum velocity ranges of 32, 47, 64, and 96 cm/sec and pulse repetition frequencies of 4, 6, 8, and 12 kHz. The scanning angle is either 80° or 30°, with diagnostic depths of 4, 6, 9, 12, 15, 18, and 22 cm and frame rates of 10, 15, 20, and 30 frames per second. For measurement of maximum jet area in mitral regurgitation (MR), the settings used are

**FIGURE 2.** Longitudinal image of normal aorta and main pulmonary artery. Panel a: Ascending aorta. Panel a': Schematic of the findings in panel a. Panel b: Main pulmonary artery (PA). Panel b': Schematic of the findings in panel b. Ao, aorta; RPA, right pulmonary artery; LA, left atrium; LV, left ventricle; RV, right ventricle; RVOT, right ventricular outflow tract; L, longitudinal.

**FIGURE 3.** Biplane images of descending aorta and aortic arch. Panel a: Descending aorta (Ao) with transverse (T) and longitudinal (L) scanning. Note that with transverse scanning, the descending aorta appears in cross section, whereas with longitudinal scanning, an angiogram-like image is obtained. Panel a': Schematic of panel a. Panel b: Aortic arch (Ao) with transverse (T) and longitudinal (L) scanning. Note that with transverse scanning, the arch appears sausage-shaped, whereas with longitudinal scanning, cross section of the aortic arch of aorta is obtained. Panel b': Schematic of panel b.
uniformly a scanning angle of 80°, diagnostic depth of 9 cm, and frame rate of 15 frames per second. The position of the probe is finely adjusted to obtain maximum visualization of the jet with the 80° visual field. In each scan, the maximum MR jet size on the monitor is measured automatically with built-in software and a joystick to outline the area, and the mean of data from five consecutive heartbeats is calculated without arbitrary attempts to guess area of jet flow outside the scan angle or to add the areas of different scans. In cases of eccentric jets, the angulation of the scan is finely adjusted to obtain the best visualization of the jet, and when necessary, the wall echo is subtracted and color flow mapping of the jet is performed. The format of color flow imaging is similar to that of the conventional color flow technology; flow toward the transducer is displayed in red and flow away from the transducer in blue. The brightness of the color is in direct proportion to the velocity of the blood flow. Turbulence of blood flow is displayed with a mixture of green and red or blue (16 levels). When the blood velocity exceeds the velocity range, the color flow imaging is displayed in the opposite color, showing the aliasing phenomenon. A mosaic pattern usually appears when the flow velocity is very high or disturbed. The system can store 64 frame images in its cine-memory mode. It also allows storage of two sets of 30 images by built-in vertical split mode. In sequential and ECG synchronized freeze mode, two series of approximately two seconds' worth of images are stored (at a frame rate of 15 per second) and separately synchronized with the R wave of the ECG. The stored images can be replayed simultaneously on the same TV screen.

Results

In 199 of 200 patients, the probe could be inserted without any difficulty. One patient with a mediastinal tumor with tracheal shift developed increasing dyspnea; hence, the examination was discontinued. To date, we have observed no complications with the procedure. We have used this probe safely for a continuous maximum duration of 12 hours for monitoring in the intensive care unit. Because each transducer has exactly the same number of elements as the conventional single-plane

**Figure 4.** Biplane images from transgastric scan of a normal left ventricle in diastole. Panel a: Simultaneous biplane images. Transverse scan (T) shows approximately equal protrusion of anterior and posterior papillary muscles. This indicates that a correct short-axis view at the papillary muscle level has been obtained. Longitudinal scan (L) of the same site provided long-axis view of the left ventricle passing through or close to the apex. Panel a': Exactly the same as the longitudinal scan (L) shown in panel a' but on a full-width monitor screen. This permits display of a wider extent of the longitudinal scan than shown when both scans are displayed simultaneously. Simultaneous display requires slight limitation of width of images on display, although they are recorded entirely in the memory. In this case, the chordae tendineae are strongly echogenic. Echoes from mitral leaflets are indistinct, probably because of artifacts. LV, left ventricle; LA, left atrium; PPM, posterior papillary muscle; APM, anterior papillary muscle; chord, chordae tendineae.

**Figure 5.** Biplane images of the distal aortic arch in a patient with DeBakey's type III aneurysm showing retrograde extension to aortic arch. Entry is located immediately beneath left subclavian artery. Panel a': Diagram of panel a. T, transverse; L, longitudinal; TL, true lumen; FL, false lumen.
TEE probe (Aloka UST-5233-5), image quality and resolution were identical.

Observation of Normal Anatomy with the Biplane Probe

Anatomical observations in normal aorta and main pulmonary artery. We examined 28 normal aortas and main pulmonary arteries of 16 patients with primary valve pathology and 12 patients with ischemic heart disease. The following observations were made. 1) Ascending aorta: A few more centimeters of the ascending aorta from the aortic root were visualized by longitudinal scanning, thus providing an increase in the echo window of the ascending aorta. A wider anatomic area from the left ventricular outflow tract to the ascending aorta was displayed by longitudinal scanning (Figure 2, panels a and a'). 2) Pulmonary artery: The longitudinal scan provides a panoramic view on a single screen extending from the right ventricular outflow tract as far as the main pulmonary artery (Figure 2, panels b and b'). 3) Descending thoracic aorta: The images obtained by transverse scanning resembled CT images and those by longitudinal scanning resembled angiography findings (Figure 3, panels a and a'). 4) The aortic arch: With the transverse transducer, the aortic arch is visualized as a sausage-shaped structure, whereas with longitudinal scanning, a cross section of the arch was obtained (Figure 3, panels b and b').

Observations of the normal cardiac anatomy. When 68 patients with aortic pathology were examined to rule out concomitant cardiac lesions, 32 showed essentially normal cardiac anatomy. The following advantages over the transverse mode were provided by longitudinal scanning. 1) Transgastric longitudinal scan of the left ventricle depicted the anterior and posterior walls in a long-axis view. In transgastric scanning, the longitudinal scan performed at the site where the transverse scan indicated equal protrusions of the anterior and posterior papillary muscles yielded the image of a view through, or very close to, the ventricular apex (Figure 4). Such images were obtained in all but six of the 32 cases. The reason why visualization was not achieved in those six cases was probably poor penetration of the ultrasound beam as a result of insufficient contact of the transducers with the gastric wall. 2) In all 32 cases, 3–5 cm of the superior vena cava was visualized with the right atrium.

Aortic aneurysm. Examination of 20 cases of suspected nondissecting thoracic aortic aneurysm revealed a normal aorta in four patients and true aneurysm in 16 (thoracic, 13; abdominal, 3). These results were confirmed by angiography. Of our 48 aortic dissection cases, 30 were analyzed in detail, their entry sites being

![Figure 6. Biplane images of ascending aorta in a patient with DeBakey's Type I aneurysm. Panel A: Two-dimensional biplane images. In this particular case, the entry, located 2 cm proximal to the innominate artery, was visualized only by the longitudinal plane. Panel B: Color images of exactly the same as the biplane images shown in panel A. Panels C and D: Diagrams of panels A and B. Panels E and F: Schematics representing the differences between echo-blind areas of transverse and longitudinal scanning. Red area indicates the transverse scan plane (panel E) and blue indicates the longitudinal (panel F). Echo-blind area of the latter is smaller than that of the former. Arrow pointing toward true lumen (TL) indicates blood flow in diastole, and that pointing toward false lumen (FL) indicates flow in systole. T, transverse; L, longitudinal.](http://circ.ahajournals.org/doi/abs/10.1161/01.CIR.112.7.1241)
TABLE 2. Identification of Entry Site in Aortic Dissection

<table>
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<tr>
<th></th>
<th>Transverse</th>
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<th>Longitudinal</th>
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<th>p</th>
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<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>DeBakey type I</td>
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<td>67</td>
<td>8/9</td>
<td>89</td>
<td>NS</td>
</tr>
<tr>
<td>DeBakey type II</td>
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<td>100</td>
<td>1/1</td>
<td>100</td>
<td>NS</td>
</tr>
<tr>
<td>DeBakey type III</td>
<td>19/20</td>
<td>95</td>
<td>20/20</td>
<td>100</td>
<td>NS</td>
</tr>
<tr>
<td>Total</td>
<td>26/30</td>
<td>87</td>
<td>29/30</td>
<td>97</td>
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</tr>
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</table>

Probability value by Student’s paired t test. 
p<0.05 was considered significant.

confirmed surgically and/or by angiography. Both scan planes enabled correct identification of true and false lumina in all aortic dissection cases. Their effectiveness in localizing the 30 entry points was roughly equal, but three that were not detected by transverse scanning (two of DeBakey type I in the aorta 1–2 cm proximal to the innominate artery and one of DeBakey type III immediately beneath the left subclavian artery) were visualized by longitudinal scanning; one (DeBakey type I, in the arch between the innominate and left common carotid arteries) was not found on either imaging plane (Table 2 and Figures 5 and 6). Although the longitudinal scan showed slightly greater diagnostic effectiveness, the difference was not statistically significant; nevertheless, the added information yielded by the biplane scanning technique provided a more complete understanding of the entire lesion.

Mitral regurgitation. Among the 66 cases of valvular heart disease examined, 37 cases of MR confirmed by left ventriculography were further analyzed. The detection and quantification of MR jets were compared in the two planes. The only significant difference to emerge was the superior ability of the longitudinal plane to identify multiple jets (Figure 7). Multiple jets were seen in transverse scanning in two of 37 patients. In nine patients, however, more than one jet was seen only by longitudinal scanning (p<0.05). The maximum MR jet areas measured in the transverse and longitudinal planes in 37 patients were analyzed. Although the mean jet areas for each plane were nearly identical (3.0±3.2 and 3.2±2.9 cm²), in 19 patients, jet areas in the transverse and longitudinal planes differed by more than 50% (Figure 8). Color flow jet areas of MR measured in two planes were compared with the angiographic grading of regurgitation. Jet areas in square centimeters were depicted for the transverse, the longitudinal, and both planes. Correlation between jet area and angiographic grade was recognized when the area of the largest jet on either plane was used for classification. Using both planes, however, permitted distinc-
scanning permitted precise evaluation of global cardiac function in a patient with apical aneurysm.

**Congenital heart disease.** Sixteen patients with adult congenital heart disease were examined with the biplane probe. Atrial septal defects were visualized in both planes (Figure 13), which allowed measurement of the size of the defect. Close correlation was obtained with the size recognized at surgery in eight patients. Moreover, the single case of sinus venosus atrial septal defect was correctly diagnosed before surgery with the longitudinal scan, which revealed the location of the defect between the left atrium and superior vena cava immediately beneath the right pulmonary artery.

**Discussion**

Although there were some earlier efforts to use phased array in biplane TEE, to the best of our knowledge, successful simultaneous delineation of the images obtained with biplane scanning has not been reported. In both the above reports, the biplane scanning used was not with color flow mapping or with side-by-side biplane imaging. Thus, our preliminary report at the International Symposium on Transesophageal Echocardiography in Mainz, FRG, in 1988 was the first to clearly document and define the color Doppler TEE biplane images of the major cardiovascular structures. Because the number of elements (32) in each transducer of the biplane probe is exactly the same as in the conventional single-plane probe, the image resolution was identical with both kinds of TEE probes. The tip of the biplane probe is only slightly longer than some commercially available single-plane probes; hence, no difficulty was encountered in its manipulation. We have also established the safety of the probe by examining 199 patients without any complication. The definite advantage of the new method is the availability of new acoustic windows to the heart and aorta provided by the longitudinal transducer and three-dimensional understanding of lesions by observing side-by-side biplane images.

Examination of the aortic dissections shows that longitudinal scanning has provided additional information regarding the site of entry, the site of reentry, the shape and size of the false lumen, and evidence of thrombus formation. Also, the additional windows of the biplane probe make it possible to visualize the portion of the ascending aorta and arch at the site of origin of one or more arch vessels. The addition of a longitudinal plane perpendicular to the single transverse plane of the conventional transesophageal probe permits three-dimensional understanding of the condition of aortic dissection. The experience in this series shows that either plane can identify true and false lumina of all cases in all three types of dissection. In identifying and localizing the entry site, biplane TEE was of confirmatory value in that both planes were equally demonstrative for types II and III. In the identification of entry sites in type I dissection, the two planes may prove to be complementary. Three tears in the arch near the origins of the innominate and left common carotid arteries were overlooked altogether on the transverse plane, but two of them were recognized on the longitudinal plane. In this area, where the vascular structures are obscured by air in the interposed

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**Figure 9.** Plots show mitral regurgitant jet area on biplane transesophageal echocardiography and vs. angiographic grading in 37 patients. Top and middle panels: Maximum jet areas measured in the transverse and longitudinal transesophageal planes are compared with the angiographic grading of each patient by cardiac catheterization. Bottom panel: The larger of the jet areas measured in the two planes is compared with the angiographic grading. Mean ± SD is shown for each comparison. Combination of data from both planes resulted in greater distinction of cases according to angiographic grade. MR, mitral regurgitation; probability values are by Fisher's t test.
The advantages of biplane views could add significantly to the clinical usefulness of TEE (Figure 6).

Examination of the mitral valve on two planes also provides more information regarding the condition of the valve. The advantages of the biplane transesophageal Doppler probe are as follows: 1) Detection of additional regurgitant jets and determination of the direction and site of regurgitant jets in MR. 2) Because a difference of more than 50% in the size of the jet area on the two planes was recognized in 19 of 37 cases, biplane scanning provides a more reliable and accurate assessment of the valvular condition. 3) Accurate definition of the site and degree of the prolapsed leaflet in mitral valve prolapse, thus providing a guide to surgical management. Confirmation of the accuracy of longitudinal scan evaluation of the exact site of prolapse in all cases treated surgically underlines the fact that the anatomy of the mitral valve is such that it is more amenable to visualization on the longitudinal plane. Although the transverse scan may yield important information concerning mitral leaflet lesions in the vicinity of the anterolateral commissure, it can be difficult to demonstrate what part of the leaflet is prolapsing in mitral leaflets in areas close to the posteromedial commissure. Rotation of the longitudinal scan probe can obtain a scan crossing the closure line with a good relative alignment, however, permitting accurate evaluation of all areas of the mitral leaflets, including the vicinity of the postero-

**Figure 10.** Biplane images in two cases of severe mitral regurgitation caused by mitral valve prolapse involving the posterior mitral leaflet (PML). Panel a: Prolapse of the anterior scallop of PML. Panel a': Diagram of panel a. Panel b: Prolapse of the posterior scallop of PML. Panel b': Diagram of panel b. LA, left atrium; LV, left ventricle; Ao, aorta; RV, right ventricle; RA, right atrium; AML, anterior mitral leaflet; T, transverse; L, longitudinal.

**Figure 11.** Schematic indicates how slight rotation (1, 2, 3) of longitudinal scan probe can obtain images accurately demonstrating the condition of mitral valve prolapse. LA, left atrium; LV, left ventricle; AML, anterior mitral leaflet; PML, posterior mitral leaflet.
nary artery, superior vena cava and right atrium, and transgastric long-axis view of the left ventricle. There was no difficulty in obtaining the transgastric biplane images of the left ventricle except in four of 33 cases of ischemic heart disease in which the longitudinal scanning of the left ventricle was unsatisfactory. In congenital heart disease, the new acoustic window provided to the heart and aorta allows, for example, accurate measurement of the size of an atrial septal defect, making this biplane technique of use for performing transcatheter closure of atrial septal defect.20

In the recent past, several reports from various heart centers have demonstrated the usefulness of biplane TEE in various cardiac diseases in addition to MR and dissecting aneurysms,21–26 including its applications in the detection of left main coronary artery stenosis.27

One of the drawbacks of the biplane technology is that it is not in true real time. The images from each transducer must be stored in the cine-memory and then replayed shortly afterward. Also, because there is a 1.0-cm distance from center to center of the two transducers, slight repositioning is required to image the same portion of the heart, and good contact with the esophageal wall is necessary. On occasion, some difficulty may be experienced in obtaining the same degree of contact with transducers. One other drawback is that the present instrument is too large for pediatric use. Although the quality of each of the biplane transducer images does not have the high resolution of certain 48- or 64-element high-image-quality single-plane transducers, the biplane image provides a three-dimensional understanding, and it is likely that future technological improvements will make possible even higher-resolution biplane images. To resolve these problems, further advances in related technologies are being studied.28,29

In conclusion, the clinical application of the new technology of color Doppler biplane TEE in 199 consecutive patients was described. An attempt was made to delineate biplane images in normal and diseased heart and aorta. The technology is definitely superior to previous technology in that it not only provides the images obtained by the conventional single-plane transducer but also provides longitudinal images, thereby increasing the acoustic window of the heart and aorta from the esophagus. Furthermore, it is possible to reproduce the biplane images and display them simultaneously side by side by means of the cine-memory loop. Hence, three-dimensional understanding of cardiac structure and flow dynamics in cases of MR and aortic dissection was possible with biplane scanning. The color biplane TEE probe is versatile; it can be used for transverse scanning or longitudinal scanning alone or for biplane scanning with side-by-side simultaneously reproduced biplane images.

**Acknowledgments**

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**Figure 13.** Biplanar images in two cases of atrial septal defect (ASD). Panel a: Biplane images of central type of ASD. Panel b: Biplane images of sinus venous ASD. Note that with longitudinal scanning, the ASD appears between the right atrium and superior vena cava. Panel a': Diagram of panel a. Panel b': Diagram of panel b. Arrow indicates direction of shunt flow. L, longitudinal; T, transverse; LA, left atrium; RA, right atrium; Ao, aorta; RPA, right pulmonary artery; SVC, superior vena cava; IVC, inferior vena cava; PV, pulmonary vein.

**References**

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