Multiplane Transesophageal Echocardiography: A Basic Oblique Plane Patient Imaging Sequence

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We have previously reported a standardized 10-step sequence of monoplane (transverse plane) transesophageal two-dimensional echocardiographic views and a standardized 7-step vertical plane examination, both suitable for expeditious intraoperative use by the beginning practitioner. A multiplane transesophageal examination involves transverse plane views, vertical plane views and the remaining "in-between" oblique plane views. This report describes a sequence of specific oblique views to be used as a framework for the completion of a multiplane transesophageal examination. Each of these steps is illustrated with a two-dimensional echocardiographic image, a matching diagram and a schematic representation of the corresponding axis of interrogation. This description of oblique plane imaging, therefore, completes the components of a multiplane transesophageal examination.

INTRODUCTION

Transesophageal echocardiography (TEE)\(^a\) has become widely applied to intraoperative and postoperative care of critically ill patients [1]. Initial clinical application of this technique was primarily restricted to the detection of new-onset left ventricular wall motion abnormalities as an indicator of myocardial ischemia using the transgastric transverse plane short-axis papillary muscle level view of the left ventricle [2, 3]. This view became the most common intraoperatively monitored cross-section. It is now widely accepted that the practitioner who wishes to use transesophageal echocardiography to monitor left ventricular regional wall motion also has an obligation to systematically evaluate the entire heart and great vessels during the course of the surgical procedure [1]. To this end, we have previously reported a standardized 10-step sequence of transverse plane transesophageal two-dimensional echocardiographic views and a standardized 7-step vertical plane examination, both suitable for expeditious intraoperative use [4, 5]. This report describes a sequence of specific oblique off-axis scans to be used as a framework for completion of a multiplane examination. Each of these off-axis images is presented with a matching diagram and a schematic illustration of the corresponding axis of interrogation. An absolute value of the approximate scanning angle is provided in each diagram which serves as a guide to the angle required. This description of oblique plane imaging completes the components of a multiplane examination, namely, transverse plane, vertical plane and oblique plane imaging (Figure 1).

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\(^b\) Abbreviations: TEE, transesophageal echocardiography.
EXTERIOR CONTROLS

The ultrasound transducer of a multiplane transesophageal imaging system can be rotated throughout a 180-degree arc. The manual controls, which adjust the angle of interrogation, consist of two control buttons. When one of these is pressed, the multiplane transducer array at the tip of the probe rotates in a counter-clockwise arc. When the other button is pressed, the transducer array rotates in the opposite direction. An icon on the screen of the imaging system console shows the scanning angle at any point in time. Thus, the heart and great vessels may be imaged from any angle within the 180-degree range. Zero-degree scans represent transverse plane scans: these are identical to those obtainable with a monoplane TEE probe (Figure 1). Ninety-degree scans represent vertical plane scans and are identical to those obtainable with the vertical plane transducer of a biplane TEE probe (Figure 1). One hundred and eighty-degree scans are mirror images of 0-degree scans and are inverted transverse plane scans. The remaining oblique plane scans (>0 to <90 degrees and >90 to <180 degrees) represent the final component of a multiplane examination and are the focus of this report (Figure 1).

In addition, the external handle of the assembly also contains two wheels that control motion of the transducer-containing tip. The large wheel controls anteroposterior motion (flexion/anteflexion) while the small wheel permits right and left lateral motion. The minimum possible degree of torque should be applied to the probe as repeated application of extremes of flexion or lateral motion can damage the fibers connecting the rotary control to the probe tip. However, the only view in which use of a rotary control is essential is during acquisition of the transgastric scans of the ascending aorta and left ventricular outflow tract (Step 7, described below).
The narrow top of the screen always represents posterior aspects of the scan, and the opposite broad section of the screen represents anterior aspects of the scan. The image orientation of the right and left segments of the screen depends on the angle of the scan. At 0 degrees, observer left corresponds with patient right; at 90 degrees, superiorly located structures are to the observer’s right and inferior structures to the left; at 180 degrees, a mirror image of scans at 0 degrees, patient right corresponds with observer right and vice versa. At >0 to <90 degrees and >90 to <180 degrees, image orientation depends on the obliquity of the scan. The orientation of scans close to 0 degrees is similar to that of 0-degree scans, while the orientation for scan angles close to 90 degrees resembles that of 90-degree scans. Finally, the orientation of scan angles close to 180 degrees matches that of 180-degree scans. These image orientation combinations are presented in Figure 2.

The following consists of a patient examination framework to be used as a guide for completion of a multiplane examination. Seven steps of an oblique plane patient examination sequence are described. It should be noted that oblique off-axis cross-sections are

![Image Orientation Diagram](image-url)

**Figure 2. Image orientation.** (a) Transverse plane (0 degrees) scan; (b) Scan close to 0 degrees; (c) vertical plane (90 degrees) scan; (d) Scan close to 90 degrees.
Table 1. Oblique scan examination sequence.

| Step | Description                                      |
|------|--------------------------------------------------|
| Step 1 | Distal aortic arch and descending thoracic-upper abdominal aorta. |
| Step 2 | Aortic valve - short-axis view.                  |
| Step 3 | Aortic valve - long-axis view.                   |
| Step 4 | Mitral valve - medial zone.                      |
| Step 5 | Right atrial appendage.                          |
| Step 6 | Right upper pulmonary vein.                     |
| Step 7 | Transgastric scans of the ascending aorta and left ventricular outflow tract. |

usually obtained in routine clinical practice during performance of an interrupted continuum of scanning from 0 degrees through 180 degrees, rather than as discrete steps. In addition, it should be noted that the absolute values of the scanning angles provided represent an approximation, and the operator should be aware of normal variation in the spatial orientation of the various anatomic structures. Magnetic resonance imaging studies have demonstrated that this range of normal variation can be considerable [6].

Two general principles related to manipulation of the multiplane transesophageal echocardiographic probe are helpful. First, it is useful to return to the familiar transverse plane imaging mode should the operator become disoriented. Second, the method enabling precise adjustment of the ultrasound transducer-containing tip to allow fine-tuning of the selected axis of interrogation depends on the scanning angle. When the scanning angle is close to transverse, it is best achieved by withdrawal/advancement of the probe and, when the scanning angle is near to vertical, by rotation of the probe.

The seven steps of an oblique plane patient examination sequence can be grouped into three stages: first, transesophageal and transgastric views of the distal aortic arch and descending thoracic-abdominal aorta; second, transesophageal views of the aortic and mitral valves, the right atrial appendage and right upper pulmonary vein; and third, transgastric scans of the ascending aorta and left ventricular outflow tract (Figure 3). As with our previously reported transverse and vertical plane examinations, the sequence starts at

![Figure 3. Oblique plane steps by group.](image-url)
the descending thoracic aorta, includes transesophageal scans of the heart, and terminates with a transgastric scan (Table 1). Our sequence is intended to be used as a guide and does not preclude the acquisition of additional views, as deemed clinically necessary.

**STEP 1. DISTAL AORTIC ARCH AND DESCENDING THORACIC-UPPER ABDOMINAL AORTA**

Oblique scanning of the aortic arch can be especially useful for imaging the branches of the arch when aneurism formation allows the outer rim of the aortic arch to "escape" from the ultrasound barrier imposed by the trachea. While transverse imaging alone is sufficient to make a diagnosis of aortic dissection (sensitivity, 99 percent and specificity, 98 percent), localization of dissection entry and exit sites also often requires oblique plane imaging. In addition, oblique scans can also furnish otherwise unobtainable images of the walls of the distal aortic arch, great vessels and descending thoracic/upper abdominal aorta (Figure 4). Finally, blood flow velocity profile in the aortic arch and descending aorta is frequently asymmetric and oblique plane imaging can allow placement of a Doppler beam along the centerline of eccentric flow, thus allowing accurate measurement of flow velocity (Figure 4).

Evaluation of the ascending aorta requires mention, particularly in the intraoperative setting. Transverse and vertical axis scans have limited use in the intraoperative assessment of the ascending aorta prior to cannulation. for the following reasons: 1) as demonstrated...
SHORT AXIS SCAN OF THE AORTIC VALVE

FEATURES:
- The aortic valve is tilted at an oblique angle with respect to neighboring structures.
- Because of this angulation, acquisition of a "true" short axis image of the valve can be greatly facilitated by transesophageal oblique angle scanning (approximately 45 degrees).
- Such "true" short axis measurements of the area of the orifice of the valve during systole can be used to quantify the severity of aortic stenosis.

Figure 5. Step 2, Short-axis scan of the aortic valve. LA = left atrium; RA = right atrium; AV = aortic valve; RVOT = right ventricular outflow tract; aortic valve; Asc Ao = ascending aorta; RV = right ventricle.

by Konstadt et al. [7], the cannulation site is usually out of range; and 2) the same authors have also demonstrated that, even when the site is within range, the axes of interrogation pass on either side of the cannulation site, rather than through it [7]. Similar oblique plane imaging data are unavailable. However, it is our experience that these same constraints also apply to oblique plane imaging. Despite this, pre-cannulation scanning can provide valuable information. For instance, the severity of plaque formation in the proximal ascending aorta, albeit below or not in the same plane as the cannulation site, can be taken to represent inferential evidence of plaque formation at the site. Parenthetically, it is our practice to perform epicardial imaging of the aorta in these instances. In addition, Konstadt et al.
LONG AXIS SCAN OF THE AORTIC VALVE

FEATURES:
• As would be expected, a transesophageal oblique angle scan inclined at 90 degrees to whatever angle provided a "true" short axis image of the aortic valve furnishes a long axis image of the valve (approximately 135 degrees).
• This scan can facilitate evaluation of aortic regurgitation in situations where the presence of a prosthesis or calcification of the valve impedes 0 degrees (transverse plane) or 90 degrees (vertical plane) imaging of the left ventricular outflow tract.

**Figure 6. Step 3, long-axis scan of the aortic valve. LA = left atrium; LV = left ventricle; AV = aortic valve; Asc Ao = ascending aorta; RV = right ventricle.**

have also demonstrated detection of dislodged debris during cannulation, even in instances where the actual cannulation site was outside the imaging sector [7].

**STEP 2. AORTIC VALVE—SHORT-AXIS VIEW**

Because the aortic valve is tilted at an angle with respect to neighboring structures, acquisition of a true short-axis image requires an oblique scanning angle of approximately 45 degrees (Figure 5). Measurement of the area of the valve orifice during systole in this plane can be used to quantify the severity of aortic stenosis, a technique that has been validated by Hoffman et al. [8].
STEP 3. AORTIC VALVE—LONG-AXIS NEW

A transesophageal oblique angle scan at 90 degrees to whatever angle provided a true short-axis image of the aortic valve (approximately 45 degrees) furnishes a long-axis view along the left ventricular outflow tract, through the aortic valve and into the ascending aorta (Figure 6). This 135-degree scan angle (45 degrees plus 90 degrees) can facilitate evaluation of aortic regurgitation when the presence of a prosthesis, valve sclerosis or calcification impedes transverse and vertical plane imaging of the left ventricular outflow tract. Minor manipulations of the probe in this scanning range may allow the operator to “sneak around” these obstructions. In the ideal image, the left ventricular outflow tract and the proximal portion of the ascending aorta should appear as a continuum, with cavities of relatively equal size (Figure 6). This may require exquisite fine-tuning of the scanning angle, most easily achieved by minor to-and-fro rotation of the probe [1].

STEP 4. MITRAL VALVE

Multiplane evaluation of the mitral valve allows a more in-depth analysis of anatomical structure than transverse and vertical plane scanning. Indeed, the evaluation can be so thorough as to include visualization of each individual scallop of the valve leaflets. Such detailed assessment is particularly important when valve repair is contemplated.

Anatomy

An alphanumeric zip code is used to identify the areas of the mitral valve (Figure 7). The letters P and A refer to the posterior and anterior leaflets. Each leaflet, in turn, is divided into three parts. The lateral zone of the leaflet is coded with the numeral 1, the middle zone with the numeral 2 and the medial zone with the numeral 3. The medial zone of the mitral valve (A3 and P3) cannot be reliably imaged by transverse or vertical plane imaging. In contrast, oblique plane imaging at 120 degrees furnishes consistent views of this region (Figure 8).

Step 4 technique

The operator needs to first position the TEE probe using transverse plane (0 degrees) imaging. The rationale is, as follows: oblique plane imaging of the medial zone of the

![Figure 7. Mitral valve zip codes. (a) Computer-aided design illustration of the mitral valve, as viewed from above (intraoperative direct observation through an incision in the left atrium); (b) Schematic representation of the mitral valve; (c) Alphanumeric coding of the various zip-code zones of the valve.](image-url)
MEDIAL ZONE OF THE MITRAL VALVE

FEATURES:
- The medial zone of the mitral valve (A3 and P3) cannot be reproducibly imaged by either transverse (0 degrees) or vertical plane (90 degrees) imaging. In contrast, oblique plane imaging at 120 degrees furnishes consistently reproducible views of this region.
- Start-up procedure: Acquire a standard transesophageal TRANSVERSE PLANE (0 degrees) 5-chamber view of the mitral valve before rotating the transducer to 120 degrees.
- Minimal rotation of the TEE probe medially (to patient right) furnishes the characteristic image.
- As illustrated below, the unique features of the image consist of an exceedingly short segment of posterior leaflet and a relatively long segment of anterior leaflet.

Figure 8. Step 4, Medial zone of the mitral valve. LA = left atrium; LV = left ventricle; AV = aortic valve; RVOT = right ventricular outflow tract; P3 medial zone of the posterior leaflet; A3 = medial zone of the anterior leaflet.

valve (A3 and P3) integrates the advancement and withdrawal features of 0-degree imaging with the fixed-position rotation features of a 90-degree examination. It is, therefore, necessary to define an “anchor-point” around which the arc of rotation should take place. A standard transverse plane (0 degrees) 5-chamber view provides a convenient “anchor-point” frame of reference for performance of the clockwise (to patient right) rotation of the probe that is necessary for interrogation of the medial zone. Thus, from a standard transverse plane 5-chamber view, set the transducer to a 120-degree scanning angle. Then rotate the TEE probe to the patient right until the image features an exceedingly short posterior
leaflet and a relatively long anterior leaflet. This image represents the medial zone of the valve, namely, A3 and P3 (zip code 3) (Figure 8).

Clinical approach to evaluation of all three zones: The mitral valve should be systematically assessed. Zone-by-zone, particularly following mitral valve repair, lest residual or new-onset abnormalities of leaflet coaptation be overlooked [9]. The three-zone evaluation involves both transverse and oblique plane imaging. The imaging technique is, as follows:

1. A standard transverse plane (0 degrees) 5-chamber view of the mitral valve is first obtained. This view images the mid-portion of the leaflets, namely, A2 and P2 (zip code 2) (Figure 9).

2. The lateral zone of the valve lies above and lateral to the mid-zone. Transverse plane (0 degrees) imaging is also utilized to view this region of the valve. Withdrawal and slight lateral rotation of the TEE probe to
patient left from the previous position provides an image featuring an exceedingly short posterior leaflet and a relatively long anterior leaflet. This image represents the lateral zone of the valve, namely, Al and P I (zip code 1) (Figure 9).

3. The medial zone of the valve lies below and medial to the mid-zone. Superficially, it would seem reasonable that a standard transverse plane 4-chamber view (in inferior to a 5-chamber view), with superimposed medial rotation of the probe, would furnish reproducible images of the medial zone of the valve. However, as noted by Sutherland et al. [10], the image obtained by this maneuver can present either mid or medial aspects of the valve. Consistently reproducible imaging of the medial zone requires the use of a multiplane TEE transducer, specifically performance of step 4, as described above. To restate, the image acquisition technique is, as follows: from a standard transverse plane (0 degrees) 5-chamber view, the transducer is set to a 120-degree scanning angle. The entire TEE probe is then rotated to patient right until the image features an exceedingly short segment of posterior leaflet and a relatively long segment of anterior leaflet. This image represents the medial zone of the valve, namely, A3 and P3 (zip code 3) (Figure 9).

Caveats

It should be noted that a 90-degree (vertical plane) scan angle was not incorporated into the beginning practitioner image acquisition technique just described. This advanced practitioner view of the mitral valve can be obtained by starting at the standard transverse plane 5-chamber view, setting the transducer to a 90-degree scanning angle and rotating the TEE probe slightly to and fro until the scan trisects the leaflets (Figure 10). This so-called “triple combination” image represents the junction between P3, A2 and P1 and has been previously been described in detail [15]. While 90-degree imaging can furnish additional information, findings obtained with this view of the valve can be difficult for the beginning practitioner to interpret. The rationale for this belief is as follows: first, as previously described, a triple combination 90-degree scan of the valve passes through posterior leaflet tissue (medial scallop), the midportion of the anterior leaflet, and again, through posterior leaflet tissue (lateral scallop) (Figure 10). This particular view of the valve is difficult to conceptualize and, thus, findings can be readily misinterpreted. Second, doming of the body of a leaflet into the left atrium, a normal variant that is often misconstrued to represent an abnormality, is a relatively common 90-degree scan finding (Figure 10) [11]. Such a finding can further confuse less experienced practitioners.

Clinical Presentation

Figure 11 demonstrates this zone-by-zone approach to evaluation of SAM (systolic anterior motion of the anterior leaflet) following mitral valve repair. The standard transverse plane (0 degrees) 5-chamber image presented in the upper panel shows the total occlusion of the left ventricular outflow tract in this plane of interrogation. In contrast, the oblique plane image (120 degrees) in the lower panel demonstrates a patent outflow channel. These findings emphasize the three-dimensional nature of the left ventricular outflow tract and the necessity for multiplanar evaluation in certain specific situations. Finally, figure 11 also presents an oblique plane continuous wave Doppler trace from the same patient. This transgastric measurement, unobtainable at either transverse or vertical angles of interrogation, allows the severity of the subaortic stenosis to be quantified.
Figure 10. Triple-combination mitral valve scan. This scan is termed a triple combination scan because the axis of the scan crosses three discrete zones of the valve. These zones consist of the medial and lateral scallops of the posterior leaflet (P3 and P1, respectively) and the interposed mid-zone of the anterior leaflet (A2). Top panels: (a) Diagram of the vertical or near-vertical axis of interrogation associated with acquisition of a triple-combination scan; (b) Computer-aided design illustration of the mitral valve, as viewed from above (intraoperative direct observation through an incision in the left atrium); (c) Axis of interrogation of a triple-combination scan superimposed on a diagram of the valve. Middle panels: (a) Line diagram of an image of a triple-combination scan; (b) Corresponding echocardiographic image; (c) Diagram of the valve highlighting the region being imaged. Bottom panels: Billowing of the anterior mitral leaflet. (a) Diagram illustrating a vertical plane (90 degrees) triple-combination axis of interrogation; (b) Computer-aided design illustration of a billowing anterior leaflet as viewed from above (direct observation through an incision in the left atrium). The billow of the mid-portion of the body of the anterior leaflet protrudes into the left atrium. The free edge has remained at a normal level; (c) Map of the anterior leaflet demonstrating the configuration of the billow. The surface elevations are presented topographically. The scale ranges from 0 (normal level) to 5 (highest elevation). The axis of interrogation of a triple-combination scan has been superimposed on the line diagram of the valve.
EVALUATION OF SAM

ZIP CODE 2 (mid-zone) - TRANSVERSE PLANE

ZIP CODE 3 (medial zone) - OBlique PLANE

TRANSGASTRIC CW DOPPLER - OBlique PLANE

Transgastric imaging allows placement of a Doppler beam of interrogation parallel to flow within the left ventricular outflow tract.

In this example, peak flow velocity exceeds 4 meters/second, definitive evidence of critical subaortic stenosis.

Figure 11. Post-repair SAM (systolic anterior motion of the anterior mitral leaflet following valve repair). (a) Transverse plane (0 degrees) scan demonstrating total obstruction of the left ventricular outflow tract in this plane of interrogation; (b) Oblique plane (120 degrees) scan revealing subtotal outflow tract obstruction in this plane; (c) Continuous wave Doppler spectral tracing of left ventricular outflow tract velocity, with a maximum flow velocity of 4.67 meters/second and a calculated peak instantaneous subvalvular gradient of 87 mm Hg. LA = left atrium; LV left ventricle; RA = right atrium; RV = right ventricle; Asc Ao = ascending aorta; LVOT = left ventricular outflow tract.

STEP 5. RIGHT ATRIAL APPENDAGE

Oblique scanning at 120 degrees allows visualization of the right atrial appendage and the junction between the right atrium and the superior vena cava (Figure 12). It should be
**STEP 5**

**RIGHT ATRIAL APPENDAGE**

**FEATURES:**
- This transesophageal oblique angle scan images the junction between the right atrial appendage and the superior vena cava. This region, a common site for localized tamponade following cardiac surgery, cannot be imaged from a transthoracic "window."
- To obtain this image, the scanning angle is maintained at 120 degrees. The entire TEE probe is then rotated to the right (patient right) through and beyond a view of the ascending aorta.
- It should be cautioned that the image quality of this scan is often sub-optimal.

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**Figure 12. Step 5, Right atrial appendage.** LA = left atrium; RA = right atrium; RAA = right atrial appendage; RV = right ventricle. Image.

noted that this area of the right atrium cannot be imaged via a transthoracic "window" [12]. The importance of this view is that it is a common site for localized tamponade following cardiac surgery [12]. Image acquisition is, as follows: first, the scanning angle is adjusted to 120 degrees. The entire probe is then rotated to patient right, through and beyond a view of the ascending aorta. The image quality of this scan is often suboptimal and acquisition of the precise axis of interrogation may require considerable fine-tuning of the scanning angle, as well as repeated minor supero-inferior adjustments in probe position, to obtain the appropriate image.
STEP 6.

RIGHT UPPER PULMONARY VEIN

FEATURES:

- Transverse (0 degrees) and vertical plane (90 degrees) imaging of the right upper pulmonary vein commonly fail to provide "Doppler-friendly" images of this structure.
- By "Doppler-friendly" is meant a vein orientation which allows placement of a Doppler beam of interrogation parallel to flow and positioning of the sampling site well within the vein.
- Oblique plane (120 degrees) imaging can often furnish an alternative view which fulfills these "Doppler-friendliness" criteria.
- Minimal rotation of the TEE probe to the right (patient right) of the right atrial appendage view places the axis of interrogation across the right upper pulmonary vein and the right pulmonary artery.
- Use color flow Doppler imaging to confirm findings. With the color intentionally overgained, the vein appears as a splash of red.

Figure 13. Step 6, Right upper pulmonary vein. LA = left atrium; RUTW = right upper pulmonary vein; RPA = right pulmonary artery; RA = right atrium.

STEP 6. RIGHT UPPER PULMONARY VEIN

Transverse and vertical plane imaging of the right upper pulmonary vein commonly fail to provide "Doppler-friendly" images of this structure. A "Doppler-friendly" view is one that allows the operator to place a Doppler beam of interrogation parallel to flow and to position the sampling site well within the vein. Oblique plane imaging often furnishes a view which fulfills these "Doppler-friendliness" criteria (Figures 13 and 14). Minimal rotation of the probe to the patient right of the right atrial appendage view places the axis of interrogation across the right upper pulmonary vein and the right pulmonary artery.
Figure 14. Step 6, continuation - right upper pulmonary vein. **Top panel:** Echocardiographic image. **Bottom panel:** Echocardiographic image with superimposition of a pulsed wave Doppler cursor well proximal to the entrance of the vein into the left atrium and the corresponding spectral Doppler tracing.

Color flow Doppler imaging can be used to confirm that the structure being imaged is indeed the pulmonary vein, as follows: using the color intentionally over-gained the vein appears as a splash of red.
STEP 7. TRANSGASTRIC SCANS OF THE ASCENDING AORTA AND LEFT VENTRICULAR OUTFLOW TRACT

A 105-degree scan allows imaging of the left ventricle along the vector of flow from the left ventricular outflow tract, through the aortic valve and into the ascending aorta (Figure 15) [13]. This view allows placement of a Doppler beam parallel to the flow within these structures, thus allowing a valid measurement of peak flow velocity ($V_{\text{max}}$).

**Technique**

The image acquisition technique, is as follows: first, a standard transverse plane (0 degrees) short-axis transgastric view of the left ventricle is obtained, to be used as a frame of reference. With the degree of flexion required to obtain this view maintained, the scanning angle is then changed to 105 degrees and the probe advanced toward the apex. Then, with the tip maximally anteflexed (large wheel), the probe is rotated slightly to patient right and slowly withdrawn until the characteristic image appears.

It should be noted that a similar view of the left ventricular outflow tract, aortic valve and ascending aorta can also be obtained using a “close to” 0-degree scanning angle (Figure 16). Again, the probe is advanced, maximally flexed and then slowly withdrawn until the left atrium and the mitral valve come into view. The axis of interrogation is then directed across the aortic valve and into the ascending aorta by slight rightward rotation of the probe. As with the 105-degree view, this view also allows placement of a Doppler beam across the left ventricular outflow tract, aortic valve and into the ascending aorta, allowing valid measurement of peak flow velocity ($V_{\text{max}}$) within any of these structures.

**Applications**

The peak pressure gradient across the aortic valve can be readily calculated from the ascending aorta $V_{\text{max}}$ by using a simplified form of the Bernoulli equation (pressure gradient = $4V_{\text{max}}^2$). In addition, a simplified form of the continuity equation (valve area = $\pi/V_{\text{max}}$) provides an estimate of aortic valve orifice area [14].

**ADVANTAGES OF MULTIPLANE IMAGING**

A number of advantages of multiplane imaging have been described [15, 16]:

1. Many oblique off-axis views can be obtained with single and biplane imaging systems by utilizing the external rotary controls to obtain the appropriate axis of interrogation [17-19]. The use of multiplane imaging TEE probes reduces the necessity to employ the external controls to obtain these off-axis images. This reduces the strain on the control fibers to the probe tip and may also reduce the risk of patient trauma [15].

2. A reduced learning curve has been reported with the use of multiplane imaging technology, as compared with single and biplane imaging for the following reasons [15]: a) multiplane systems are “user friendly” because complex maneuvers are not required to obtain off-angle scans; b) multiplane scanning allows viewing contiguous structures from a wide variety of angles, thus allowing easy orientation and appreciation of anatomy. By contrast, the use of biplane probes causes abrupt transitions between views, with the additional problem that compensation for offsetting is also required [16].
TRANSGASTRIC SCAN OF THE ASCENDING AORTA AND LEFT VENTRICULAR OUTFLOW TRACT

TRANSGASTRIC 105 DEGREES

FEATURES:
- A 105 degrees scan can furnish an image of the left ventricular outflow tract, the aortic valve, and the ascending aorta. This TRANSGASTRIC 105 view allows placement of a Doppler beam parallel to the flow within these structures, an orientation consistent with valid measurement of peak flow velocity ($V_{max}$).
- To obtain this image, first obtain a standard transverse plane (0 degrees) short axis view of the left ventricle. Set the scanning angle to 105 degrees and advance the TEE probe toward the apex. Then, with the tip maximally anteflexed (large wheel), rotate the entire TEE probe slightly to the right (patient right) and slowly withdraw it until the characteristic image appears.
- The peak pressure gradient across the aortic valve can be readily calculated from ascending aorta $V_{max}$ by using a simplified form of the Bernoulli equation ($\text{pressure gradient} = 4V_{max}^2$). Similarly, use of a simplified form of the continuity equation ($\text{valve area} = \pi/V_{max}$) provides an estimate of aortic valve area.

Figure 15. Step 6, continuation - right upper pulmonary vein. Top panel: Echocardiographic image. Bottom panel: Echocardiographic image with superimposition of a pulsed wave Doppler cursor well proximal to the entrance of the vein into the left atrium and the corresponding spectral Doppler tracing.

3. While there are no controlled studies relating to this issue, experience would suggest a significant increase in the amount of diagnostic data obtained with multiplane as compared with either single or biplane imaging, with new diagnoses having been reported in 5-10 percent of patients [15]. Multiplane imaging also allows better interpretation of suspicious lesions and true definition of the extent of pathologic lesions [15]. Therefore, the use of multiplane imaging usually leads to
It should be noted that a similar view of the left ventricular outflow tract, aortic valve, and ascending aorta can also be obtained using a 0 degrees or near 0 degrees scanning angle.

The TEE probe is advanced, maximally flexed, and then slowly withdrawn until the left atrium and the mitral valve come into view. The axis of interrogation is then directed across the aortic valve and into the ascending aorta by slight rightward (patient right) rotation of the probe.

Again, placement of a Doppler beam across the left ventricular outflow tract, aortic valve, and into the ascending aorta (parallel to flow) can allow for measurement of peak flow velocity ($V_{max}$) within the ascending aorta.

**Figure 16. Step 7, continuation.** LV = left ventricle; MV = mitral valve; AV = aortic valve; LA = left atrium.

greater diagnostic assurance in both the exclusion and the detection of abnormalities.

4. Multiplane imaging is more suited to take advantage of advanced applications of TEE such as 3-dimensional reconstruction techniques, a rapidly evolving field [20-24].

5. In contrast to single and biplane probes, multiplane probes usually come with two different transducer frequencies, 5.0 Mhz and 3.45 Mhz. The latter frequency is more suitable for two-dimensional visualization of more distant structures.

6. It has been stated that the chances of maintaining the transducer tip in stable contact with gastric mucosa is much greater with multiplane probes than with single or biplane probes because of a reduced need for manipulation of the entire probe to obtain the various scans [13].
In summary, this oblique plane imaging report represents the completion component of a three-part series on multiplane imaging in this journal, with the first and second parts having consisted of transverse plane [4] and vertical plane [5] reports, respectively.

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