Intraoperative Transesophageal Two-dimensional Echocardiography: A Basic Vertical Plane Patient Examination Sequence

Terence D. Rafferty and Guy Tousignant

Department of Anesthesiology, Yale University School of Medicine, New Haven, Connecticut

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We have previously reported a standardized stepwise transesophageal echocardiography transverse plane (monoplane) patient examination sequence suitable for intraoperative use. Biplane transesophageal echocardiography furnishes images of the heart and great vessels in both transverse and vertical planes. This report describes a seven-step vertical plane examination, the completion component of a comprehensive intraoperative biplane evaluation. Each step is illustrated by presentation of a two-dimensional echocardiographic image, a matching diagram and a schematic representation of the corresponding axis of interrogation. Examples of clinical presentations complete the report.

Transesophageal echocardiography has become increasingly applied to intraoperative management of critically ill patients. Early clinical application of this diagnostic technique in this setting was primarily restricted to detection of new-onset left ventricular regional wall motion abnormalities as indicators of myocardial ischemia [1]. It is now generally accepted that the practitioner who wishes to use transesophageal echocardiography to monitor intraoperative left ventricular regional wall motion also has an obligation to perform a systematic assessment of the entire heart and the great vessels during the course of the surgical procedure. We have previously reported a standardized 10-step sequence of monoplane (transverse plane) transesophageal two-dimensional echocardiographic views, which constitute a basic patient examination capable of being performed by a practitioner whose primary responsibility is the delivery of anesthesia care [2]. Biplane transesophageal echocardiography allows the heart and great vessels to be imaged in both a transverse plane and a vertical plane. Thus, vertical plane imaging represents the completion component of a biplane examination. This report describes a standardized seven-step vertical plane examination sequence suitable for intraoperative use. Each step is outlined by presentation of a standardized echocardiographic image, a matching diagram and a schematic representation of the corresponding axis of interrogation. Examples of clinical presentations complete the report.

TECHNOLOGY

A monoplane transesophageal echocardiography probe contains a single ultrasound transducer, fixed in position at the tip of the probe. The ultrasound transducer produces a fan-shaped ultrasound beam. This beam of interrogation emerges from the transducer at a right angle. With the probe hanging freely in space, the beam passes in a horizontal (transverse) plane. From this is derived various terms for a monoplane transesophageal echocardiography transducer. These synonymous terms include a single plane probe, a uni-plane probe, a horizontal plane probe, a transverse plane probe, a short axis probe and a 0 degrees imaging probe [3-10].

*To whom all correspondence should be addressed: Terence D. Rafferty, M.A., M.D., F.A.C.A., Department of Anesthesiology, Yale University School of Medicine, 333 Cedar Street, New Haven, CT 06510. Tel: (203) 785-2802; Fax: (203) 785-6664.*
A biplane transesophageal echocardiography probe contains two separate transducers, also fixed in position at the tip of the probe. These transducers are orientated at right angles to one another. This positioning of the transducers ensures a 90 degrees difference between the planes of interrogation of the beams of ultrasound that they emit (Figure 1). One of the two transducers of a biplane imaging system consists of a transverse (0 degrees) plane transducer, identical in every respect with the transducer of a monoplane probe. The second transducer of a biplane probe directs the ultrasound beam in a vertical (90 degrees) plane. This second transducer of a biplane system has been variously termed a vertical plane transducer, a longitudinal plane transducer, a sagittal plane transducer, a long axis transducer and a 90 degrees imaging transducer [3-10].

A further set of biplane imaging system terms in common usage require definition, namely, stacked transducers and matrix transducers. With most biplane imaging systems, the two transducers are stacked, one above the other, with the centers of the respective transducers set approximately 10 mm apart. Stacked transducers emit the two orthogonal ultrasound beams from two separate locations on the transesophageal echocardiography probe. With a stacked transducer system, slight advancement or withdrawal of the probe is required to ensure precise correspondence of the orthogonal images, particularly when the structure to be imaged is located in close proximity to the probe [11]. With more recent biplane systems, the two transducers are incorporated into a common unit, so-called, matrix transducers. This advance in technology allows acquisition of orthogonal images with an identical central axis, eliminating any need to readjust the position of the probe when switching from one transducer to the other [12].

**IMAGE ORIENTATION**

The optimal method by which transesophageal echocardiography images should be orientated on the screen of the imaging console is the subject of an, as yet, unresolved controversy [13, 14]. The following description corresponds to the image orientation most commonly employed by clinicians as a whole.

The echocardiographic image on the monitor screen is shaped like a fan (Figure 2). The narrow portion of the fan is closest to the posteriorly-located transesophageal echocardiography transducer. Accordingly, this section contains images of posteriorly located structures. The wide opposite portion of the fan represents anterior aspects of the image. This posterior-anterior orientation of vertical plane images is identical to that of transverse plane images. The orientation of the right and left sections of the monitor screen differs from that associated with transverse plane imaging. With transverse plane imaging, patient right corresponds to observer left, and vice versa. By contrast, with vertical plane images, superiorly located structures are presented to the observer's right, while inferior structures appear to the observer's left. This superior-inferior/observer right-left orientation of vertical plane images arises because of the nature of the scanning plane. By definition, a vertical scanning plane transects the heart in a superior-inferior (vertical) plane rather than in a side-to-side (transverse) plane.

**ANATOMIC RELATIONSHIPS**

Prior to considering the steps of a vertical plane patient examination sequence, several anatomic points require emphasis. Specifically, these consist of the normal orientation of the various cardiac chambers and the relative positions of the great vessels.

*Normal orientation of the cardiac chambers*

The normal orientation of the cardiac chambers is such that right heart structures, i.e., the right atrium, the tricuspid valve, the right ventricle, and the pulmonic valve, occupy the entirety of the anterior part of the heart. All but a portion of the left atrium, mitral
BIPLANE IMAGING

The probe of a biplane transesophageal echocardiography (TEE) imaging system contains 2 separate ultrasound transducers at the tip of the probe, stacked one above the other. The alignment of one of these transducers is identical to that of a standard single plane (transverse plane) imaging system, with the beam of interrogation being directed in a transverse (horizontal) plane relative to the tip of the probe. By contrast, the second transducer is oriented such that the interrogation beam is directed in a vertical (sagittal) plane, alternatively termed a longitudinal imaging plane.

The following should be noted:

1) The terms SINGLE PLANE, TRANSVERSE PLANE, HORIZONTAL PLANE, and INTERROGATION AT 0 DEGREES are synonymous.

2) The terms VERTICAL PLANE, SAGITTAL PLANE, LONGITUDINAL PLANE, and INTERROGATION AT 90 DEGREES are synonymous.

3) Biplane TEE imaging provides 2 planes of interrogation at right angles to one another.

Figure 1. Schematic representation of transverse and vertical planes of interrogation. Reproduced with permission from Ref. 1, Fig. 5-1.
IMAGE ORIENTATION

The optimal method by which TEE images should be oriented on the screen of the imaging console has been the subject of an, as yet, unresolved controversy. The description of vertical plane image orientation illustrated below corresponds with that most commonly employed by physicians as a whole.

FEATURES:

- As is also the case with transverse plane imaging, the narrow portion of the fan-shaped scan represents posterior aspects of the image, while the wide portion reflects anteriorly located structures.

- With transverse plane imaging, observer right corresponds with patient left, and vice versa. In contrast, with vertical plane imaging, structures located to the observer's right represent superior aspects of the scan, while structures appearing at the observer's left correspond with inferior locations.

Figure 2. Vertical plane image orientation.

valve, and left ventricle are located posteriorly. Accordingly, the “right heart” could more properly be termed the anterior heart. Equally, the “left heart” could best be described as the posterior heart. Figure 3, a diagram of the heart as viewed from an anterior position, illustrates these relationships.

Relative positions of the great vessels

The relative positions of the ascending aorta and the pulmonary artery do not relate to their site of origin because of the peculiar path of the left ventricular outflow tract. The left ventricular outflow tract arises posteriorly and travels anteriorly in a left-to-right direction. The end result of this tortuous path is that the ascending aorta emerges between the pulmonary artery and the superior vena cava. Figure 4, a diagram of the heart as viewed from a left lateral position, illustrates these relationships.
Figure 3. Schematic representation of the cardiac chambers as viewed from an anterior position. SVC = superior vena cava; RA = right atrium; RV = right ventricle; Ao = ascending aorta; PA = main pulmonary artery; LAA = left atrial appendage; LV = left ventricle.

Figure 4. Schematic representation of the left ventricular outflow tract as viewed from a lateral position. LVOT = left ventricular outflow tract; RVOT = right ventricular outflow tract; AV = aortic valve; MV = mitral valve.
AXES OF INTERROGATION

As with transverse plane imaging, vertical plane imaging involves scans of the distal aortic arch, the descending thoracic-upper abdominal aorta, the ascending aorta and the cardiac chambers. These scans can be conveniently grouped into three primary axes of interrogation, as follows: 1) scans of the distal aortic arch and descending thoracic-upper abdominal aorta; 2) cardiac scans via a transesophageal “window”; 3) cardiac scans via a transgastric “window”

Scans of the distal aortic arch and descending thoracic — upper abdominal aorta

When the transducer-containing tip of the transesophageal echocardiography probe lies immediately adjacent to the arch of the aorta, the vertical plane scan provides a short axis cross-section of this vessel. Accordingly, the corresponding echocardiographic image has a circular outline. In contrast, when the tip of the probe lies in proximity to the descending thoracic aorta or the upper abdominal aorta, the vertical plane scan transects the vessel along its long axis. Here, the corresponding echocardiographic image has a cylindrical shape. These axes of interrogation are illustrated in Figure 5.

Cardiac scans via a transesophageal “window”

A total of five cross-sections have been selected to represent the transesophageal vertical plane axes of interrogation of the heart. These axes of interrogation consist of a single primary parent scan and four secondary sibling scans (Figure 6). The parent vertical plane axis of interrogation provides a cross-section of the proximal portion of the ascending aorta. This axis of interrogation has been selected as the parent scan because of the distinctive, readily identifiable features of the corresponding two-dimensional echocardiographic image (vide infra). The four vertical plane sibling axes of interrogation are positioned to the right and left of the parent axis. These secondary sibling axes are obtained by rightward and then leftward rotation of the transesophageal echocardiography probe from the parent position. The four sibling axes of interrogation are composed of the following scans: 1) a cross-section to the right of the parent axis which transects the inflow tracts of the right atrium, i.e., the venae cavae. This cross-section is designated as sibling A axis of interrogation; 2) a series of cross-sections to the left of the parent axis. These cross-sections consist of a short axis view of the aortic valve, a scan that sections the outflow tract of the right ventricle, and, finally, a scan that allows acquisition of a long axis image of the mitral valve. These leftward cross-sections are designated as siblings B, C and D, respectively.

Cardiac scans via a transgastric “window”

A single transgastric scan of the left ventricle has been selected to illustrate vertical plane imaging from a transgastric “window.” The axis of interrogation of this particular scan transects the apex of the left ventricle and the mitral valve, thus, providing a long axis view of the chamber (Figure 7).

EXTERNAL ROTARY CONTROLS

The ultrasound transducer system is mounted on the distal tip of a conventional gastroscope. The external handle of the completed assembly contains two wheels, which 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. It should be emphasized that none of the transesophageal scans described below require manipulation of either of these control wheels. Each image is obtained by simply advancing, withdrawing or rotating the entire assembly and allowing it to passively follow the course of the esophagus. The only view in which use of a rotary control is employed is during acquisition of the transgastric scan of the left ventricle, the final step of the imaging sequence.
SCANS OF THE DISTAL AORTIC ARCH AND THE DESCENDING THORACIC/UPPER ABDOMINAL AORTA

FEATURES:

* When the tip of the TEE probe lies immediately adjacent to the arch of the aorta, the vertical plane scan provides a short axis cross-section of the vessel. Accordingly, the corresponding image has a circular outline.

* When the tip of the TEE probe lies in proximity to the descending thoracic aorta or the upper abdominal aorta, the vertical plane scan transects the vessel along its long axis. Therefore, the corresponding image has a cylindrical shape.

Figure 5. Axis of interrogation of the distal aortic arch and the descending thoracic-upper abdominal area.
TRANSESOPHAGEAL CARDIAC SCANS

FEATURES:
- A total of 5 cross-sections of the heart represent the transesophageal vertical plane cardiac axes of interrogation.
- The primary (parent) axis, illustrated in the upper left panel, provides a cross-section of the proximal segment of the ascending aorta.

Features:
- The 4 secondary (sibling) axes are positioned to the right (patient right) and to the left (patient left) of this parent axis. These axes are illustrated in the lower left panel. Sibling axes consist of the following:
  - **Rightward**
    - Sibling A – Right atrial inflow tracts (venae cavae)
  - **Leftward**
    - Sibling B – Short axis view of the aortic valve
    - Sibling C – Right ventricular outflow tract
    - Sibling D – Long axis view of the mitral valve

Figure 6. Transesophageal cardiac axes of interrogation. The primary (parent) axis consists of a cross-section through the ascending aorta (upper left panel). A total of four secondary (sibling) axes complete the interrogation (lower left panel). The arrows are to highlight that rotation of the transesophageal echocardiography probe represents the dominant maneuver in acquisition of these axes of interrogation.
TRANSGASTRIC CARDIAC SCANS

FEATURES:

A single transgastric scan of the left ventricle has been selected to illustrate vertical plane imaging from a transgastric "window." The axis of interrogation of this particular scan transects the apex of the left ventricle and the mitral valve, thus providing a long axis view of the chamber.

Figure 7. Transgastric axis of interrogation.

IMAGE ACQUISITION TECHNIQUE

The following consists of a stepwise approach to a vertical plane patient examination sequence. The complete vertical plane examination is divided into seven steps (Table 1). As with our previously reported transverse plane examination, the vertical plane examination starts at the descending thoracic aorta, includes transesophageal scans of the heart and terminates with a transgastric scan. This 7-step examination is intended to function as a guide for performance of a complete vertical plane study. It should be emphasized that the presentation format selected is not intended to preclude the acquisition of additional views of the heart or the great vessels as deemed clinically necessary.

Step 1. Distal aortic arch and descending thoracic — upper abdominal aorta

First, the descending thoracic aorta is located by transverse plane imaging. Its characteristic circular outline is followed inferiorly by advancing the transesophageal echocardiography probe until an image can no longer be obtained, marking the limits of evaluation of the upper portion of the abdominal aorta. The imaging system is then set to a vertical plane mode of interrogation. This activation of the vertical plane transducer will result in a change in the shape of the echocardiographic image of the upper abdominal and descending thoracic aorta from circular (transverse plane imaging) to cylindrical (vertical plane imaging). Gradual withdrawal of the probe allows for imaging of the entire length of the descending thoracic aorta, as well as a segment of the distal portion of the arch of the aorta (Figure 8). Between the upper abdomen and the aortic arch, the esophagus and the aorta gradually change their spatial relationship. At the diaphragm, the aorta lies posterior to the esophagus. In the mid-thorax, the aorta is lateral to the esophagus. Finally, the
aorta courses anterior to the esophagus at the level of the aortic arch. Therefore, from the level of the diaphragm, the transesophageal echocardiography probe should be rotated clockwise (to patient right) as it is withdrawn to follow the descending thoracic aorta superiorly.

As illustrated in Figure 8, the changeover from the descending thoracic aorta to the distal aortic arch is marked by a change in the shape of the echocardiographic image. The outline of the vertical plane image of the aorta becomes circular as soon as the axis of interrogation transects the distal aortic arch. The origin of the left subclavian artery and the left common carotid artery may be successfully visualized at this point, particularly when the aortic arch is aneurysmal. The arch of the aorta should be followed proximally by continued withdrawal of the probe until an image can no longer be obtained. This occurs because the air-filled, and, therefore, ultrasound-opaque trachea becomes interposed between the esophagus and the aorta.

Step 1 of the vertical plane examination is now complete. Before proceeding directly to step 2, the vertical plane mode of interrogation should be discontinued. Transverse plane imaging resumed to allow the operator to regain the midline of the mediastinum. This is accomplished by advancing the probe approximately 5 cm and, then, by rotating it clockwise (to patient right).

**Step 2. Proximal ascending aorta (parent transesophageal vertical plane cross-section)**

The operator needs to first position the transesophageal echocardiography probe using transverse plane imaging, the rationale for which is as follows: vertical plane imaging provides superior-to-inferior scans. Accordingly, the key feature of the technical maneuvers required to sequentially cross-section the heart consists primarily of rotation of the imaging probe. It is therefore necessary to define an “anchor-point” around which the arc of the rotation should take place. A standard transverse plane long axis view of the mitral valve forms a convenient “anchor-point” frame of reference for performance of the clockwise (to patient right) and, subsequently, anticlockwise (to patient left) rotations of the probe that are necessary for performance of vertical plane interrogation via the esophagus.

The start-up procedure is as follows: the operator should first acquire a standard transverse plane long axis view of the mitral valve. The imaging system is then set to a vertical plane mode of interrogation. Minimal rotation of the probe clockwise results in a vertical plane axis of interrogation which passes through the proximal portion of the ascending aorta, the parent image of the cardiac vertical scans via an esophageal “window.” The echocardiographic image associated with this transesophageal parent vertical plane axis of interrogation has distinctive morphologic features, making it a useful landmark. The scan passes through the aortic valve and into the ascending aorta. The cross-section of the aortic valve imparts a characteristic “sausage-shaped” appearance to the ascending aorta (Figure 9). This particular descriptive term for the appearance of the ascending aorta in this view was first coined by Omoto et al. [15]. The ascending aorta is
DISTAL AORTIC ARCH AND DESCENDING THORACIC/UPPER ABDOMINAL AORTA

FEATURES:

- The distal aortic arch appears as a concentric structure. The proximal portion cannot be visualized because the air-filled trachea acts as a barrier to ultrasound.

- As illustrated above, the descending thoracic aorta and the upper abdominal aorta appear as linear structures.

- The origin of major branches of the arch of the aorta, such as the subclavian artery, can sometimes be successfully imaged, particularly when the vasculature is aneurysmal.

Figure 8. Two-dimensional echocardiographic view of the distal aortic arch and the descending thoracic-upper abdominal aorta. Ao = aorta.
**PROXIMAL ASCENDING AORTA**

**FEATURES:**

- The key feature of the maneuvers involved in acquiring vertical plane cross-sections consist of rotation of the TEE probe. It is therefore necessary to define a fixed "anchor-point" around which to rotate the probe. A standard transesophageal TRANSVERSE plane long axis view of the mitral valve provides such a fulcrum.

- Start-up procedure: Acquire a standard transesophageal TRANSVERSE plane long axis view of the mitral valve before switching to the vertical plane system. Then set the imaging system to a vertical plane mode of interrogation.

- Minimal rotation of the probe to the right (patient right) furnishes a scan of the ascending aorta, the parent image of the transesophageal cardiac vertical plane scans.

- As illustrated below, the ascending aorta represents a readily-identifiable landmark structure with a characteristic appearance. Specifically, the ascending aorta presents with a unique sausage-like shape.

*Figure 9. Two-dimensional echocardiographic view of the proximal ascending aorta (parent transesophageal cardiac scan). AV = aortic valve; Asc Ao = ascending aorta; TV = tricuspid valve; LA = left atrium.*
RIGHT ATRIAL INFLOW TRACTS (VENAE CAVAE)

FEATURES:
- Rotation of the TEE probe to the right (patient right) allows for interrogation of the superior and inferior venae cavae.
- Completion of this Sibling A scan marks the limit of rightward rotation of the TEE probe, there being no more laterally located cardiac structures.

Figure 10. Two-dimensional echocardiographic view of the right atrial inflow tracts (sibling A transesophageal cardiac scan). IVC = inferior vena cava; RA = right atrium; SVC = superior vena cava; LA = left atrium.
SHORT AXIS VIEW OF THE AORTIC VALVE

**FEATURES:**
- Following completion of the previous step, the TEE probe is rotated to the left (patient left), through the parent ascending aorta scan, until a short axis view of the aortic valve is obtained.
- A true short axis view of the aortic valve corresponds with a 45 degree angle plane of interrogation. Accordingly, a vertical plane image (90 degrees) does not represent a true short axis scan of this valve. However, vertical plane imaging can provide a helpful quasi-valid short axis view in cases where multiplane imaging capabilities are unavailable.

*Figure 11. Two-dimensional echocardiographic short axis view of the aortic valve (sibling B transeophageal cardiac scan). AV = aortic valve; LA = left atrium; RVOT = right ventricular outflow tract; PV = pulmonic valve; MPA = main pulmonary artery.*
RIGHT VENTRICULAR OUTFLOW TRACT

SIBLING C TRANSESOPHAGEAL SCAN

FEATURES:
1. Further leftward (patient left) rotation of the TEE probe places the scanning axis across the right ventricular outflow tract.
2. An important aspect of this view is that it offers a consistently high quality image of the pulmonic valve.
3. It should be further noted that the left ventricular outflow tract lies posterior to the right ventricular outflow tract at this particular level.

Figure 12. Two-dimensional echocardiographic view of the right ventricular outflow tract (sibling C transesophageal cardiac scan). RVOT = right ventricular outflow tract; PV = pulmonic valve; LVOT = left ventricular outflow tract; AV = aortic valve; LA = left atrium.
LONG AXIS VIEW OF THE MITRAL VALVE

SIBLING D TRANSESOPHAGEAL SCAN

FEATURES:
- Further leftward (patient left) of the TEE probe provides the final transesophageal vertical plane scan.
- This laterally positioned scan furnishes a long axis view of the mitral valve and the left atrial appendage.
- It should be noted that minute to-and-fro rotation of the TEE probe can have a major impact on whether the scan passes primarily through the anterior or the posterior mitral leaflet. As illustrated below, a scan which primarily transects the posterior leaflet will furnish an image with an apparently elongated posterior leaflet.

Figure 13. Two-dimensional echocardiographic long axis view of the mitral valve (sibling D transesophageal cardiac scan). LA = left atrium; LAA = left atrial appendage; LV = left ventricle.
Figure 14a. Axes of interrogation within the sibling D transesophageal long axis view of the mitral valve. Upper panels (left-to-right): Diagram of the heart, as viewed from the left lateral position; Computer-aided design illustration of the mitral valve, as viewed from the left atrium; Diagram of the mitral valve. Lower panels: Sub-scan A, where the length of anterior leaflet cross-section exceeds the length of posterior leaflet cross-section. Succeeding sub-scans (Figure 14b) are obtained by rotation of the transesophageal probe.
Figure 14b. Continuation of axes of interrogation within the sibling D transesophageal long axis view of the mitral valve. Upper panels: Sub-scans B, where the length of the anterior leaflet cross-section equals the length of the posterior leaflet cross-section. Middle panels: Sub-scans C, where the cross-section passes through posterior leaflet tissue (medial scallop), the mid-portion of the anterior leaflet and, again, through posterior leaflet tissue (lateral scallop). Lower panels: Sub-scans D, where the length of the anterior leaflet cross-section is less than the length of the posterior leaflet cross-section.
TRANSGASTRIC LONG AXIS VIEW OF THE LEFT VENTRICLE

FEATURE:
- As with transesophageal vertical plane image acquisition, it is first necessary to define a standardized TRANSVERSE plane imaging-defined "anchor-point." A standard TRANSVERSE plane transgastric papillary muscle-level view of the left ventricle provides such a start-up point.
- The imaging system is then set to a vertical plane mode.
- The position of the TEE probe is "fine-tuned" by minimal to-and-fro rotation and up-and-down manipulation until the long axis view furnishes an image with the mitral valve in the center of the field, as illustrated below.
- A rounded left ventricular cavity implies that the scan has not passed through the true apex of the chamber.
- It should be noted that this scan images an appreciable segment of the inferior wall of the left ventricle, a useful feature in the detection of regional wall motion abnormalities in that particular region of the ventricle.

Figure 15. Two-dimensional echocardiographic transgastric long axis view of the left ventricle. LV = left ventricle; MV = mitral valve; LA = left atrium.
thus, readily identifiable, a feature that has led us to designate it as the parent transesophageal vertical plane scan.

It should be emphasized that this scan only images approximately 84 percent of the ascending aorta. Furthermore, the aortic cannulation site in cardiac surgery patients is inaccessible even when the site is within range by length estimates, presumably because the axis of the scan is off-line. Therefore, this scan has limited use in intraoperative pre-cannulation assessment of the aorta [16].

**Step 3. Right atrial inflow tracts — venae cavae (sibling A transesophageal vertical plane cross-section)**

Step 3 consists of a scan of the vena cavae and the right atrium, sibling A of the vertical plane scans via the esophagus (Figure 10). The parent image of step 2 is used as the starting point for the acquisition of this scan and the remaining three subsequent sibling scans. Rotation of the transesophageal probe clockwise (to patient right) places the axis of interrogation through the superior and inferior vena cavae and contiguous segments of the right atrium. The scan allows for comprehensive imaging of the membranous portion of the interatrial septum and the upper portion of the interatrial septum at its junction with the superior vena cava. This view assumes particular importance in the diagnosis of patent foramen ovale and sinus venosus atrial septal defects [17, 18]. The junction of the inferior vena cava and the right atrium is also particularly well seen in this cross-section. Redundant folds of tissue within the lower reaches of the right atrium, representing the ridge-like Eustachian valve of the inferior vena cava, are commonly seen in this view. This tissue should not be misconstrued as an abnormality. Completion of this component of the vertical plane patient examination sequence marks the limit of rightward rotation of the transesophageal echocardiography probe, there being no more laterally located cardiac structures that can be visualized by transesophageal ultrasound.

**Step 4. Short axis scan of the aortic valve (sibling B transesophageal vertical plane cross-section)**

Step 4 consists of a short axis view of the aortic valve. This step represents sibling B of the four sibling transesophageal vertical series. After completion of the previous step of the patient examination sequence, the transesophageal probe is rotated counterclockwise (to patient right), through the ascending aorta parent axis of interrogation, until a short axis scan of the aortic valve is obtained (Figure 11). A true short axis view of the aortic valve corresponds with an angle of interrogation of approximately 45 degrees [19-21]. While this vertical plane (90 degrees) scan does not furnish an exactly aligned, non-tangential short axis cross-section of the valve, it can represent an exceedingly helpful alternative in situations where multiplane imaging capabilities are not available [22].

A further refinement of this view has been described by Seward et al. [6]. These investigators have noted that rightward side-flexion of the tip of the transesophageal echocardiography probe (small external rotary control) in this position provides a view of the aortic valve comparable to the short axis view associated with using a multiplane transducer 45 degree scanning angle. Similarly, leftward side-flexion of the tip of the probe furnishes long axis views of the valve identical to those acquired using a multiplane transducer 135 degree scanning angle.

**Step 5. Right ventricular outflow tract (Sibling C transesophageal vertical plane cross-section)**

Step 5 consists of a scan of the right ventricular outflow tract. This step represents sibling C in the four sibling transesophageal vertical plane series (Figure 12). It is obtained by a further counterclockwise (to patient left) rotation of the transesophageal echocardiography
Step 6. Long-axis scan of the mitral valve (sibling D transesophageal vertical plane cross-section)

This step represents sibling D of the transesophageal vertical plane examination series, the last of the four sibling series. Further counterclockwise (to patient left) rotation of the transesophageal echocardiography probe from the previous scan position provides this final transesophageal vertical plane scan. As illustrated in Figure 13, this laterally positioned scan provides a long axis view of the mitral valve, the left atrium, the left atrial appendage and the left ventricle.

A specific technical feature of this scan requires elaboration. A disproportionately longer length of the anterior mitral leaflet, as compared with the posterior leaflet, is characteristic of transverse plane long axis images of the mitral valve. This difference in the relative lengths of the mitral leaflets with transverse plane imaging is so consistent that it makes the mitral valve a readily identifiable and useful landmark structure. The situation is entirely different with vertical plane imaging of the valve. Here, minute to-and-fro rotation of the transesophageal echocardiography probe can have a major impact on whether the scan passes primarily through the anterior leaflet or the posterior leaflet. A scan that passes primarily through the anterior leaflet will present an image where the anterior leaflet appears disproportionately longer than the posterior leaflet. In contrast, when the scan primarily transects posterior leaflet tissue, this leaflet will appear disproportionately longer than the anterior leaflet. Similarly, when equal amounts of anterior and posterior leaflet tissue are cross-sectioned, the leaflets will appear to be equidimensional.

A further, potentially confusing, cross-section also merits mention, as follows: when the scan passes through the medial scallop of the posterior leaflet, across the anterior leaflet, and emerges through the lateral scallop of the posterior leaflet, the echocardiographic image will show posterior leaflet tissue on either side of centrally located portion of the anterior leaflet [23]. This cross-section is readily obtainable when the posterior leaflet is excessively redundant. With flail or prolapse of the medial scallop of the posterior leaflet and a normal anterior leaflet, this scan can present an extremely confusing picture, with the potential for false positive diagnosis of anterior leaflet pathology. Schematic representations of these various combinations of sub-scans within the sibling D view are illustrated in Figures 14a and 14b.

Step 7. Transgastric long axis scan of the left ventricle

Step 7, the final step of this vertical plane patient examination sequence, consists of a transgastric long axis view of the left ventricle. As with vertical plane imaging via the esophagus, the acquisition of transgastric vertical plane images is facilitated by prior standardization of the position of the ultrasound transducer-containing tip of the imaging probe by using transverse plane imaging to provide the frame of reference. For this final step, fulfillment of this prerequisite can be accomplished by using a standard transgastric short axis mid-chamber level view of the left ventricle as the required “anchor-point.” Acquisition of this transverse plane short axis image of the left ventricle is achieved with
anterior flexion of the ultrasound transducer-containing tip of the probe. This flexion is maintained during subsequent maneuvers. The probe is next advanced further into the stomach to position the tip as close to the apex of the left ventricle as possible, while still maintaining image clarity. The imaging console vertical plane mode is then set.

The resulting image is that of a long axis cross-section of the left ventricle (Figure 15). This vertical plane axis of interrogation is “fine-tuned” by minimal and up and down and to-and-fro manipulation of the transesophageal probe until the scan furnishes an image with the mitral valve in the center of the field and a ventricular cavity that does not appear rounded. A rounded cavity implies that the axis of interrogation has not passed through the true apex of the left ventricle. This scan furnishes images of the inferobasal and apical segments of the left ventricle, regions not readily accessible by transverse plane imaging [24]. This feature of transgastric vertical plane imaging has been successfully applied to detect new-onset regional wall abnormalities of those particular regions of the ventricle [19]. A side-by-side representation of transgastric transverse and vertical plane views of the left ventricle during diastole and systole is presented in Figure 16.

![Diagram of the left ventricle showing diastolic and systolic views](image_url)

**Figure 16.** Two-dimensional echocardiographic transgastric transverse and vertical plane views of the left ventricle. Left panels: transverse plane images; Right panels: vertical plane images. LV = left ventricle.
VEGETATION WITHIN THE ASCENDING AORTA

The transverse plane (left panel) and vertical plane (right panel) images demonstrate the presence of a vegetation within the ascending aorta.

Figure 17. Two-dimensional echocardiographic view of a vegetation within the ascending aorta. Left panel: transverse plane image; Right panel: vertical plane image. RPA = right pulmonary artery; LA = left atrium.

SINUS VENOSUS ATRIAL SEPTAL DEFECT

The vertical plane two-dimensional echocardiographic (left panel) and color flow Doppler (right panel) images demonstrate a sinus venosus atrial septal defect with right-to-left shunting. The site of this defect could not be conclusively established by transverse plane imaging.

Figure 18. Two-dimensional echocardiographic and color flow Doppler vertical plane image of a sinus venosus atrial septal defect. The color flow Doppler image (right panel) is presented in black and white, rather than in color. This emphasizes that recognition of the presence of an abnormal pattern of flow is as important as evaluation of the specific color assignment. ASD = atrial septal defect; LA = left atrium; RA = right atrium; SVC = superior vena cava.
**TRICUSPID REGURGITATION**

The transverse plane (left panel) and vertical plane (right panel) color flow Doppler images demonstrate tricuspid regurgitation. In this particular example, the true maximal dimensions of the regurgitant jet were not apparent with vertical plane imaging.

![Color flow Doppler images of tricuspid regurgitation. Left panel: transverse plane image; Right panel: vertical plane image. Images are presented in black and white, rather than in color. This emphasizes that recognition of the presence of an abnormal pattern of flow is as important as evaluation of the specific color assignment.](image)

**DeVEGA TRICUSPID ANNULOPLASTY**

Performance of this valve repair procedure involves placement of a running suture through the native valve annulus along the margins of the anterior and septal leaflets. The suture is then drawn taut and anchored by pledgeted material. The transverse plane (left panel) and vertical plane (right panel) images demonstrate the two-dimensional echocardiographic appearances of these anchoring pledgets (arrows).

![Two-dimensional echocardiographic view of a De Vega tricuspid annuloplasty procedure. Left panel: transverse plane image; Right panel: vertical plane image. RA = right atrium; LA = left atrium; RV = right ventricle.](image)
Figures A through H illustrate how a combination of transesophageal transverse plane and vertical plane views of the heart and great vessels allows imaging of a pulmonary artery flow-directed catheter as it passes from the superior vena cava into the right atrium, through the right ventricle and pulmonic valve, and, finally, successively through the main pulmonary artery and into the right pulmonary artery. In this particular viewing sequence, the air-filled balloon at the tip of the catheter was deflated prior to acquisition of each image in order to minimize reverberation artifacts which would interfere with image quality.

A. SUPERIOR VENA CAVA (VERTICAL PLANE IMAGE)

B. PROXIMAL RIGHT ATRIUM (TRANSVERSE PLANE IMAGE)

Figure 21a. Passage of a pulmonary artery flow-directed catheter. LA = left atrium; RA = right atrium; SVC = superior vena cava; RV = right ventricle.
Figure 21b. Passage of a pulmonary artery flow-directed catheter. LA = left atrium; RA = right atrium; RV = right ventricle; LV = left ventricle; LVOT = left ventricular outflow tract; AV = aortic valve; RVOT = right ventricular outflow tract; PA = main pulmonary artery.
Figure 21c. Passage of a pulmonary flow-directed catheter. LA = left atrium; AV = aortic valve; RVOT = right ventricular outflow tract; PA = main pulmonary artery; RPA = right pulmonary artery; SVC = superior vena cava; Ao = ascending aorta
CLINICAL PRESENTATIONS

A variety of two-dimensional echocardiographic and color flow Doppler clinical presentations referable to steps of this vertical plane patient examination sequence are illustrated in Figures 17-20. Color flow Doppler images are presented in black and white rather than color. This emphasizes that recognition of the presence of an abnormal pattern of flow is as important as evaluation of the specific color assignment. Figure 17 demonstrates two-dimensional echocardiographic transverse and vertical plane images of a vegetation within the ascending aorta. The site of origin of this vegetation was the sewing ring of an aortic valve prosthesis. At aortotomy, the ascending aorta was found to be filled with gelatinous, infected material. Figure 18 represents vertical plane two-dimensional echocardiographic and color flow Doppler images of a large sinus venous atrial septal defect. Vertical plane imaging plays a major role in the diagnosis of this specific lesion. Definition of the site of this type of defect usually cannot be consistently diagnosed with a transverse plane axis of interrogation, and, indeed, transverse plane imaging was not contributory in this particular patient. Figure 19 demonstrates transverse and vertical plane color flow Doppler images of tricuspid regurgitation. In this particular example, the true maximal dimensions of the regurgitant jet could only be appreciated with transverse plane imaging. Figure 20 demonstrates two-dimensional echocardiographic transverse and vertical plane images acquired from a patient who had undergone a DeVega tricuspid annuloplasty. Performance of this valve repair procedure involves placement of a running suture through the native tricuspid valve annulus along the margins of the anterior and septal leaflets. The suture is then drawn taut and anchored by pledgets. The transverse and vertical plane scans image these pledges.

Figures 21a to 21c show how a combination of transesophageal transverse and vertical plane views of the heart and great vessels allow for imaging of a flow-directed pulmonary artery catheter during its passage from the central venous circulation to its final destination, the right pulmonary artery. A vertical plane scan first demonstrates the catheter within the superior vena cava (Step 3 of the vertical plane examination sequence). Switching the imaging system to a transverse plane imaging mode then shows the progress of the catheter through the right atrium and into the body of the right ventricle. Vertical plane imaging then shows the catheter passing through the right ventricular outflow tract, the pulmonic valve and into the main pulmonary artery (Step 5 of the vertical plane examination sequence). The final position of the catheter in the right pulmonary artery is assessed by transverse plane imaging using a basal short axis view of the great vessels.

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