Transesophageal Echocardiographic Imaging Workshop: A Basic Transverse Plane Examination Sequence

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This workshop describes a 10-step sequence of transverse plane two-dimensional transesophageal echocardiographic views of the heart and great vessels that constitutes a basic standardized examination capable of being performed by a beginning practitioner.

INTRODUCTION

Valid use of transesophageal echocardiography (TEE) should involve routine systematic evaluation of the heart and great vessels. A standard TEE evaluation consists of a sequence of two-dimensional echocardiographic views, supplemented by color flow Doppler, spectral Doppler and M-mode studies. In clinical practice, the sequence of standardized two-dimensional echocardiographic images is the framework of the TEE evaluation. The supplementary data are obtained within the context of these two-dimensional echocardiographic images. A previously reported transverse plane two-dimensional echocardiographic imaging sequence [1, 2], capable of being performed by a beginning practitioner, the basis of a complete study, will be described in this workshop. Standardization of the images is based on the criteria of Schluter et al. [3, 4] and Seward et al. [5]. Each step of the 10-step sequence is outlined by presenting a standardized image and a matching diagram.

DEFINITIONS

The terms “transverse plane imaging,” “horizontal plane imaging” and “single plane imaging” are synonymous. A transverse plane transesophageal probe contains a single ultrasound transducer at its tip. This transducer produces a fan-shaped ultrasound beam that is orientated at right angles to the plane of the probe tip. When the probe is hanging freely, the spatial orientation of the beam is, thus, horizontal (i.e., in a transverse plane).

As stated, the beam of interrogation that the ultrasound transducer emits is always in a horizontal plane relative to the transducer during transverse plane imaging. However, the heart is an asymmetric structure. Furthermore, the esophagus turns and angulates during its passage through the posterior mediastinum.

Accordingly, the angle at which the beam strikes the heart or great vessels varies. Finally, the angulation of the beam of interrogation relative to the structure being examined.

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b Abbreviations: TEE, transesophageal echocardiography.
can also be varied by antero-posterior or side-to-side flexion of the transducer-containing tip of the transesophageal probe. Thus, the cross-sections obtained can represent long-axis or short-axis images, depending on the orientation of the tip of the probe relative to the structure being examined.

**PRACTICAL LANDMARKS**

A knowledge of the anterior-to-posterior and superior-to-inferior reference points is required to avoid disorientation on the part of the beginner. The following is a description of practical guides to orientation:

1. **Right heart structures** (right atrium, tricuspid valve, right ventricle and pulmonic valve) occupy virtually the entirety of the anterior heart. All but a portion of the left atrium, mitral valve and left ventricle are located posteriorly. Accordingly, the “right heart” could be termed the “anterior heart” and, equally, the “left heart” could best be described as the “posterior heart.” This can be used as a guide to antero-posterior orientation. It should also be noted that the great vessels are not orientated accordingly. Because the left ventricular outflow tract arises posteriorly and traverses anteriorly in a left-to-right direction, the ascending aorta emerges between the pulmonary artery and the superior vena cava. These relationships are illustrated in Figure 1.

2. Each of the heart valves lies at slightly different levels. From above down, these consist of the pulmonic, aortic, mitral and tricuspid valves (Figure 2). This feature provides supero-inferior orientation and allows anticipation of anatomic relationships. Since the pulmonic valve is situated above the aortic valve, one should expect to find the right ventric-
Figure 2. Diagrammatic representation of the heart illustrating the relative levels of the pulmonic, aortic, mitral and tricuspid valves. The aortic and mitral valves lie at a similar level, with the aortic valve being slightly uppermost. SVC = Superior Vena Cava; RA = right atrium; RV = right ventricle; IVC = Inferior Vena Cava; PA = main pulmonary artery; LA = left atrium; LV = left ventricle.

ular outflow tract in aortic valve cross-sections. Similarly, optimal imaging of the tricuspid valve is usually inconsistent with simultaneous imaging of the aortic valve. Finally, while the upper of the two views of the tricuspid valve subsequently presented (see below) lies at the level of the mitral valve, the lower coronary sinus view is inferior to it.

3. The descending thoracic aorta, aortic valve, and mitral valve have characteristic features which make them readily identifiable: a) The descending thoracic aorta lies within the posterior mediastinum. It appears as a concentric structure situated in the posterior aspect of the image, bounded anteriorly by air-filled, and thus, ultrasound-opaque lung parenchyma; b) The orientation of the three aortic valve leaflets is such that the commissures form an inverted Y-shape when the valve is transected horizontally during diastole. This characteristic appearance has been likened to that of a Mercedes-Benz emblem; c) The mitral valve is a two-leaflet structure. The more medial anterior leaflet is disproportionately longer than the posterior mural leaflet.

4. The presence of mitral valve leaflets in a transgastric short-axis cross-section indicates an image at the level of the base of the left ventricle, whereas the presence of papillary muscle outlines represent a mid-chamber level scan.

EXTERNAL ROTARY CONTROLS

The ultrasound transducer is mounted on the distal tip of a conventional gastroscope. The external handle of the assembly contains two wheels that control motion of the transducer-containing tip. The large wheel controls anteroposterior motion (flexion/anteflexion), while the small wheel controls right and left lateral motion. It should be emphasized that the
transesophageal scans described below do not require manipulation 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 that requires use of a rotary control is the transgastric short-axis mid-chamber view of the left ventricle (Step 10). In this scan, the appropriate cross-section is obtained by flexion of the tip of the endoscope, requiring counterclockwise rotation of the large external control wheel. It is important to minimize the degree of torque applied during this maneuver, as repeated application of extremes of anteflexion results in stretching of the fibers connecting the control to the endoscope tip.

**IMAGE ORIENTATION**

The following description of image orientation is that most commonly employed. The echocardiographic image on the monitor screen is shaped like a fan. The narrow, uppermost portion of the fan is closest to the transducer, and this segment represents posterior aspects of the image. The wide, lowermost portion of the fan represents anterior aspects of the image. Finally, patient left corresponds to observer right, and vice versa. These image orientation features are illustrated in Figure 3.

**AXES OF INTERROGATION**

The scans of the ascending aorta and the cardiac chambers can be grouped into three primary axes of interrogation. From above down, these consist of basal short-axis, long-axis and transgastric short-axis cross-sections (Figure 4). The distal transverse aortic arch,
Griffin et al.: Transesophageal echocardiography workshop

**Figure 4. Cardiac axes of interrogation.** These consist of basal short-axis, long-axis and transgastric short-axis cross-sections.

The entirety of the descending thoracic aorta, and the upper portion of the abdominal aorta are also accessible to transverse plane imaging.

**IMAGE ACQUISITION TECHNIQUE**

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

Following insertion of the transesophageal echocardiography probe to approximately 40 cm, the probe is rotated counterclockwise (to patient left) to visualize the descending thoracic aorta (Figure 5). This vessel can be localized at virtually any level. The probe is then advanced inferiorly until an image can no longer be obtained, marking the limits of evaluation of the upper abdominal aorta. It should be emphasized that the probe can be safely advanced only as long as it does not meet resistance. If resistance is encountered, the probe is withdrawn and redirected.

| Table 1. TEE examination sequence. |
|-----------------------------------|
| Step 1. Distal aortic arch and descending thoracic/upper abdominal aorta. |
| Step 2. Basal short-axis scan of the great vessels. |
| Step 3. Basal short-axis scan of the aortic valve. |
| Step 4. Long-axis scan of the left ventricular outflow tract. |
| Step 5. Long-axis scan of the mitral valve and left ventricle. |
| Step 6. Basal short-axis scan of the left atrial appendage. |
| Step 7. Imaging of the interatrial septum. |
| Step 8. Long-axis scan of the right ventricle at the level of the anterior mitral leaflet. |
| Step 9. Long-axis scan of the right ventricle at the level of the coronary sinus. |
| Step 10. Transgastric short-axis mid-chamber scan of the right and left ventricle. |
Figure 5. Distal aortic arch and descending thoracic/upper abdominal aorta.

Figure 6. Basal short-axis scan of the great vessels. SVC = superior vena cava; Ao = ascending aorta; RPA = right pulmonary artery; MPA = main pulmonary artery; LPA = left pulmonary artery.
Gradual withdrawal of the probe allows for evaluation of the entire descending thoracic aorta and a segment of the distal arch of the aorta. The changeover from the descending thoracic aorta to the arch of the aorta is marked by a change in shape of the image from circular to longitudinal. The arch of the aorta is followed proximally (continued withdrawal of the probe) until an image can no longer be obtained. This occurs because, at this point, the air-filled and ultrasound-opaque trachea is interposed between the esophagus and the aorta. Step 1 of the patient examination is now complete. Before proceeding to Step 2, additional manipulation of the probe is required. The probe is re-advanced until the descending thoracic aorta is again imaged in order to “escape” from the trachea.

**Step 2. Basal short-axis scan of the great vessels**

Step 2, a view of the great vessels as they join with the heart, is a midline image. Accordingly the probe is rotated clockwise (to the right) away from the descending thoracic aorta to point it midline in the mediastinum. Orientation is accomplished by identifying landmark structures such as the aortic or mitral valve. The aortic valve is then placed in the center of the field, and the probe is gradually withdrawn superiorly until the characteristic outlines of the superior vena cava, ascending aorta, main pulmonary artery and right pulmonary artery are obtained (Figure 6). This view is a basal short-axis scan. The pulmonic valve is also situated at the level of this cross-section. However, poor image quality is the rule rather than the exception in this view, and the valve leaflets cannot usually be defined in adult patients.

**Step 3. Basal short-axis scan at aortic valve level**

Step 3 consists of a basal short scan of the aortic valve (Figure 7). Since the aortic valve lies inferior to the ascending aorta, the probe must be advanced inferiorly. The coronary arteries originate above the level of the aortic valve leaflets, and both coronary ostia and portions of the left anterior descending and circumflex branches may be visualized at this level.

**Step 4. Long-axis scan of the left ventricular outflow tract**

Step 4 lies at a slightly lower level and is a view of the left ventricular outflow tract (Figure 8). The left ventricular outflow tract is defined as that portion of the left ventricle
bounded by the aortic valve, the anterior mitral leaflet, the interventricular septum and the cavity of the body of the left ventricle. The probe must be advanced inferiorly and rotated slightly counterclockwise (to the left) to outline these structures. This view corresponds to a 5-chamber view of the heart (Figure 8).

Step 5. Long-axis scan of the mitral valve and the left ventricle

Step 5 involves in-depth interrogation of the mitral valve. The probe is rotated slightly counterclockwise (to the left) to place both leaflets of the valve in the center of the field (Figure 9). As with the left ventricular outflow tract view, this mitral valve view represents a long-axis plane of interrogation. The entire probe is moved back and forth to visualize
Figure 10. Basal short-axis scan of the left atrial appendage and the left upper pulmonary vein. LA = left atrium; LAA = left atrial appendage; LUPV = left upper pulmonary vein; Ao = descending thoracic aorta.

the mitral valve at both a 5-chamber level (uppermost) and at a 4-chamber level (lowermost).

It must be emphasized that the long-axis image of the left ventricle furnished by this scan may not represent a cross-section through the true apex of the ventricle. This is suggested by an image in which the cavity of the left ventricle appears rounded.

Step 6. Basal short-axis scan of the left atrial appendage and the left upper pulmonary vein

Transesophageal two-dimensional echocardiography and color flow Doppler/pulsed-wave Doppler imaging can define left atrial appendage and pulmonary
The left upper pulmonary vein is an important target for pulsed-Doppler studies. Both the left atrial appendage and the left upper pulmonary vein can be imaged within the same cross-section (Figure 10). This area of the heart is superior and lateral to the mitral valve, necessitating slight withdrawal and counterclockwise rotation of the probe. The view represents a basal short-axis scan.

Figure 12. Long-axis scan of the tricuspid valve and right ventricle at the level of the anterior mitral leaflet. RA = right atrium; TV = tricuspid valve; RV = right ventricle; LA = left atrium; AML = anterior mitral leaflet; LV = left ventricle.

Figure 13. Long-axis scan of the tricuspid valve and right ventricle at the level of the coronary sinus. RA = right atrium; RV = right ventricle; LA = left atrium; LV = left ventricle.
Step 7. Imaging of the interatrial septum

Step 7 consists of an interrogation of the interatrial septum (Figure 11). Re-orientation following the previous step is accomplished by using the aortic or mitral valve as a landmark. The interatrial septum can be imaged at two levels: a cephalad basal short-axis scan at aortic valve level and a caudal scan at mitral leaflet level. Particular attention should be paid to the membranous mid-portion of the septum, the site of a patent foramen ovale. A two-dimensional echocardiographic evaluation of this region should also include a saline-contrast study. This consists of imaging with simultaneous intravenous administration of hand-agitated saline. Forceful ballottment of a crystalloid causes formation of ultrasound-opaque microbubbles. The appearance of bubbles on the left side of the heart is definitive evidence of a right-to-left shunt. The sensitivity of the technique can be increased by timing the administration of the saline so that right atrial opacification occurs synchronous with sudden release of a Valsalva maneuver. This modification is designed to make right atrial pressure exceed left atrial pressure in order to unmask a subtle right-to-left shunt.

Steps 8 and 9. Long-axis scans of the tricuspid valve and the right ventricle

Steps 8 and 9 consist of long-axis views of the tricuspid valve and the right ventricle at two different levels. Step 8 represents a 4-chamber image with the probe rotated clockwise (to the right) to position the right ventricle in the center of the field (Figure 12). The rotation of the probe excludes the lateral aspects of the left atrium, mitral valve and left ventricle from the field. The cross-section is below the level of the aortic valve. This view usually allows simultaneous imaging of the lateral border of the tricuspid annulus and the junction between the right ventricular free wall and the interventricular septum. This has application in the analysis of right ventricular systolic function.
Figure 15. Left-sided pleural effusion. Ao = descending thoracic aorta.

Step 9 is obtained by minimal advancement of the probe. This plane of interrogation is below the level of the mitral valve, which, accordingly, is not visualized (Figure 13). The cross-section transects the coronary sinus as it drains into the base of the right atrium, bearing in mind that the coronary sinus runs across the heart below and parallel to the plane of the mitral valve.

Step 10. Transgastric short-axis scan of the ventricles at the level of the papillary muscles

Step 10, the final view of the sequence, consists of a transgastric cross-section. This scan furnishes short-axis images of both ventricles (Figure 14). The scan of the left ventricle most commonly employed for evaluation of regional wall motion is a mid-chamber...

Figure 16. Pericardial effusion. Left panel: transesophageal long-axis view. Right panel: transgastric short-axis view. RA = right atrium; RV = right ventricle; LA = left atrium; LV = left ventricle; AV = aortic valve.
Figure 17. Chronic rheumatic endocarditis of the mitral valve. Long-axis image demonstrating thickened and deformed leaflets, calcification on the posterior leaflet (arrow) and deformed, partly fused chordae. RA = right atrium; RV = right ventricle; LA = left atrium; LV = left ventricle.

A number of technical considerations require elaboration. First, consistent acquisition of an adequate image requires repeated performance of the maneuvers in order to develop a "feel" for the technique. Second, the presence of asymmetry of the papillary muscles indicates an improper oblique cross-section. Third, acquisition of an adequate

Figure 18. Right atrial thrombus. Transesophageal long-axis view. RA = right atrium, RV = right ventricle.
Figure 19. Pulmonary artery catheter visible in the right atrium and right ventricle (arrows). Long-axis view. RA = right atrium; RV = right ventricle; LA = left atrium-, LV = left ventricle.

The image is facilitated by increasing the gain setting above that required for transesophageal imaging. Finally, the presence of mitral leaflets rather than papillary muscles in the image indicates that the probe has not been advanced sufficiently into the stomach or that undue anteflexion has been applied to the tip of the probe, thus aligning the interrogation beam across the mitral leaflets.

Figure 20. Transverse plane imaging of an intra-aortic balloon pump within the descending thoracic aorta.
CLINICAL PRESENTATIONS

A variety of clinical abnormalities referable to each step of the patient examination sequence is presented. Figure 15 illustrates the TEE appearances of a pleural effusion, an "orange-slice" cavity anterior to the descending thoracic aorta. The presence of this latter structure in the image identifies the effusion as being left-sided. Drainage of this fluid and subsequent re-expansion of the underlying lung resulted in a marked improvement in the alveolararterial oxygen tension gradient. In this case, imaging provided an immediately available end-point for assessment of the efficacy of drainage. Figure 16 represents a long- and short-axis view of a pericardial effusion in a patient with cardiac tamponade. In the short-axis image (right panel), a clear separation between the epicardium and pericardium is evident posteriorly. The long-axis image (left panel) demonstrates anterior extrinsic compression of the right atrium, with "tenting" inwards of the chamber wall. Figure 17 demonstrates the echocardiographic appearances of chronic rheumatic endocarditis of the mitral valve. The anterior and posterior leaflets are thickened and deformed. An area of calcification can be seen on the posterior leaflet. The chordae tendinae are also markedly deformed and partially fused. Figure 18 consists of an long-axis image of a mass within the right atrium. The mass, which was freely mobile within the cavity, was subsequently identified as a thrombus.

Figures 19 and 20 demonstrate the use of transesophageal echocardiography for imaging of intravascular devices, specifically, a pulmonary artery flow-directed catheter and an intra-aortic balloon pump. The materials from which these devices are constructed are ultrasound-opaque. This allows their localization by both the ultrasound reverberations that occur as the interrogation beam strikes their surface and, also, the distal areas of ultrasound "dropout" caused by the imposition of a barrier to further passage of the beam. Figure 19 consists of a long-axis view of the right atrium, the tricuspid valve and right ventricle at the level of the anterior mitral leaflet. The "echo-densities" within the cavities of the right atrium and the right ventricle, represented by arrows, denote the outline of the pulmonary artery catheter. Figure 20 demonstrates an intra-aortic balloon pump within the descending thoracic aorta. The central density delineates the base of the rigid tip of the device and the lateral densities located in immediate proximity to this central density represent the junction of the balloon material with this tip. Acquisition of this image was facilitated by temporary discontinuation of counterpulsation, thus minimizing reverberation artifacts caused by motion of the device.

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