Intraoperative Two-Dimensional Echocardiography and Color Flow Doppler Imaging: A Basic Transesophageal Single Plane Patient Examination Sequence

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Recent advances in technology have allowed application of transesophageal echocardiography to intraoperative care of critically ill patients. Early clinical application primarily involved evaluation of left ventricular regional wall motion. However, valid intraoperative use of transesophageal echocardiography should also encompass systematic assessment of the entire heart as well as the great vessels. This report describes a 10-step sequence of single plane, 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. A 5-step color flow Doppler examination sequence is also presented. These views complement the two-dimensional echocardiographic steps. Representations of methods for grading Doppler-defined valvular regurgitation complete the report.

Transesophageal echocardiographic monitoring has been widely applied to intraoperative care of critically ill patients. The transgastric transverse plane short axis papillary muscle level view of the left ventricle allows for simultaneous evaluation of regional wall motion in areas supplied by each of the coronary arteries. As a result, this view is, by far, the most commonly intraoperatively monitored cross-section. However, such a view clearly only represents one aspect of potentially available diagnostic information from a transesophageal transverse plane examination. Valid use of intraoperative transesophageal echocardiographic monitoring should also involve systematic evaluation of the entire heart as well as the great vessels. A suggested representative intraoperative diagnostic study must be capable of being performed expeditiously by a practitioner whose primary responsibility is the delivery of anesthesia care, lest clinical care be compromised. This report describes a 10-step sequence of single plane, two-dimensional echocardiographic views which constitute such a basic patient examination (Table 1). Each step is outlined by presentation of a standardized echocardiographic image and a matching diagram, together with a schematic representation of the corresponding axis of interrogation. This mode of presentation is designed to aid the beginner perform and interpret a basic intraoperative diagnostic study.

Two-dimensional echocardiographic examinations are normally supplemented by color flow Doppler imaging of the aortic, mitral and tricuspid valves, as well as interrogation of the interatrial and interventricular septa (Table 2). A 5-step sequence of views of these structures is also presented. These views complement the 10 steps of the basic two-dimensional echocardiographic examination. Finally, representations of a variety of methods for grading valvular regurgitation complete the report.

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Table 1. Listing of the two-dimensional echocardiographic patient examination sequence.

| Step | Description |
|------|-------------|
| 1    | Transverse and descending thoracic aorta |
| 2    | Basal short axis view of the great vessels |
| 3    | Basal short axis view of aortic valve level |
| 4    | Long axis view of the left ventricular outflow tract |
| 5    | Long axis view of the mitral valve and left ventricle |
| 6    | Basal short axis view of the left atrial appendage |
| 7    | Saline-contrast imaging of the interatrial septum |
| 8    | Long axis view of the right ventricle at the level of the anterior mitral leaflet |
| 9    | Long axis view of the right ventricle at the level of the coronary sinus |
| 10   | Transgastric short axis mid-chamber view of the ventricles |

Table 2. Listing of the transesophageal color flow Doppler patient examination sequence.

| Step | Description |
|------|-------------|
| 1    | Aortic valve |
| 2    | Mitral valve |
| 3    | Interatrial septum |
| 4    | Tricuspid valve |
| 5    | Interventricular septum |

**IMAGE ORIENTATION**

The echocardiographic image on the monitor screen is shaped like a fan (Figure 1). The narrow portion of the fan is closest to the transducer. This segment represents posterior aspects of the image. The wide portion of the fan represents anterior aspects of the image. Finally, patient left corresponds to observer right, and *vice versa*.

**PRACTICAL LANDMARKS**

1. The descending thoracic aorta, aortic valve, and mitral valve have characteristic morphological features which make them readily identifiable and, thus, useful landmark structures. These features are as follows: a) The descending thoracic aorta is transected horizontally, and, thus, appears as a concentric structure situated in the posterior aspect of the image being bounded anteriorly by ultrasound-opaque lung parenchyma; b) The orientation of the aortic valve leaflets is such that the three commissures form an inverted Y-shape. This appearance has been likened to that of a "Mercedes-Benz" emblem; c) The mitral valve presents as a two-leaflet structure, with the more medial anterior leaflet being disproportionately longer than the posterior leaflet.

2. A further guide to orientation is that each of the cardiac valves lie at slightly different levels, the order being, from above down, as follows: pulmonary, aortic, mitral, and tricuspid. This feature provides orientation as to the supero-inferior level of interrogation and allows anticipation of anatomic relationships as follows: Since the pulmonary valve is situated above the aortic valve, the operator should expect to find the right ventricular 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 two views of the tricuspid valve subsequently presented (*vide infra*) lies at level of the mitral valve, the lower coronary sinus level view is inferior to this structure.

3. The presence of mitral valve leaflets in a transgastric cross-section indicates an image at the level of the base of the left ventricle, whereas papillary muscle outlines represent a mid-chamber level.
AXES OF INTERROGATION

FEATURES:
The three primary axes of interrogation consist of basal short axis (uppermost), long axis (middle) and transgastric short axis (lower).

IMAGE ORIENTATION

FEATURES:
The transducer scanning sector is fan-shaped, and appears as such on the monitor screen. The narrow portion of the fan lies closest to the transducer. Accordingly, this segment represents posterior aspects of the image. The wide portion of the fan represents anterior aspects of the image. Finally, patient left corresponds to observer right and vice versa.

Figure 1. Primary axes of interrogation and image orientation.
**FEATURES:**

1. The transverse aorta appears as a linear structure. The proximal portion cannot be visualized because the air-filled trachea acts as a barrier to ultrasound.
2. As illustrated above, the descending aorta appears as a concentric structure.
3. Irregularities of the intima represent plaque formation.

*Figure 2.* Two-dimensional echocardiographic view of the transverse and descending thoracic aorta.
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 1). The distal transverse aortic arch, the entirety of the descending thoracic aorta, and the upper portion of the abdominal aorta are also accessible to transverse plane imaging (Figure 2).

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 essential is during acquisition of 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, a motion requiring counterclockwise rotation of the large external control wheel. It is important to minimize the degree of torque applied during this maneuver. The equipment is not durable and repeated application of extremes of anteflexion will result in stretching of the fibers connecting the rotary control to the endoscope tip.

IMAGE ACQUISITION TECHNIQUE

The patient examination sequence consists of scans of the descending and transverse thoracic aorta, followed by basal short axis, long axis and transgastric short axis scans (Table 1). Following insertion to approximately 40 cm, the transesophageal echocardiography transducer assembly is rotated in a counter-clockwise direction (to the left) to visualize the descending thoracic aorta (Figure 2). This structure can be readily localized at virtually any level throughout the entire length of the posterior mediastinum. The transducer is advanced inferiorly until the image can no longer be obtained, marking the limits of transgastric evaluation of the upper abdominal aorta. It should be emphasized that the endoscope can be safely advanced only as long as it does not meet resistance. If resistance is encountered, the endoscope should be withdrawn and redirected. Gradual withdrawal of the transducer allows for evaluation of the entire length of the descending thoracic aorta and a portion of the arch of the aorta. The arch of the aorta is marked by a change in the shape of the image from circular to longitudinal. The aortic arch is followed proximally (continued withdrawal of the transducer) until, again, the image can no longer be obtained because the air-filled and, thus, ultrasound-opaque trachea lies between the esophagus and the aorta (Figure 2). The interposition of this structure precludes meaningful imaging of mid-line structures at this level. The transducer is therefore re-advanced inferiorly until the descending aorta is again visualized, thus escaping the ultrasound barrier imposed by the trachea. Step 1 of the examination is now complete.

Step 2, a view of great vessels as they junction with the heart, is a centrally located image. The transducer must be rotated clockwise (to the right) away from the descending aorta as a preliminary maneuver in order to place it facing the midline of the mediastinum. Following reorientation by imaging of such landmark structures of the aorta or mitral valve, the transducer position is adjusted to place the aortic valve in the center of the field. The transducer is then slowly withdrawn superiorly until the characteristic outlines of the aortic arch, superior vena cava, main pulmonary artery, and right pulmonary
are obtained (Figure 3). This view represents a basal short axis scan. The pulmonary 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 via single plane transesophageal echocardiography, at least in adult patients.

The aortic valve lies inferior to the aortic arch. Thus, Step 3, a basal short axis scan of this valve, necessitates that the transducer be advanced inferiorly (Figure 4). The coronary arteries originate above the aortic valve cusps, and both coronary artery ostia and portions of the left anterior descending and circumflex branches may also be visualized. Step 4 lies at a slightly lower level and delineates the left ventricular outflow tract. The superior and inferior boundaries of the left ventricular outflow tract consist of the anterior mitral leaflet and the interventricular septum, respectively. Accordingly, the transducer must be advanced inferiorly and rotated slightly counterclockwise (to the left) to outline these structures, giving a 5-chamber view of the heart (Figure 5). Step 5 consists of interrogation of the mitral valve, thus necessitating slight rotation of the transducer to place both leaflets of this valve in the center of the field (Figure 6). As with the left ventricular outflow tract, this view also represents a long axis plane of interrogation. The transducer is moved superiorly and inferior to visualize the structure at both a 5-chamber level (uppermost) and a 4-chamber level (lowermost).

Left atrial appendage pathology and disturbances in pulmonary vein flow are often linked to mitral valve abnormalities. Because of this association, Step 6 consists of imaging the left atrial appendage and left upper pulmonary vein, with the latter representing an important target for pulsed-Doppler studies. These structures are contiguous and can be visualized within the same cross-section (Figure 7). Both are superior and lateral to the mitral valve. Acquisition of this image requires withdrawal and slight counterclockwise (to the left) rotation of the transducer. This view is superior to the mitral valve view and represents a basal short axis plane of interrogation.

Step 7 involves interrogation of the interatrial septum. The transducer is repositioned to re-establish orientation by using the aortic and/or mitral valves as landmarks. The interatrial septum is visible at two levels. A comprehensive assessment involves both a cephalad basal short axis scan at aortic valve level and a more caudal long axis view at mitral leaflet level. Particular attention should be paid to interrogation of the membranous mid-portion of the septum, the site of flow-patent foramen ovale. A complete two-dimensional echocardiographic evaluation should also involve a saline-contrast study of the integrity of the interatrial septum, i.e., a two-dimensional echocardiographic analysis in conjunction with a intravenous administration of hand-agitated saline (Figure 8). Ballottlement of saline causes microbubble formation within the solution. These microbubbles are ultrasound-opaque and, accordingly, function as a contrast medium. The peripheral or central venous saline injection is timed to achieve right atrial opacification synchronous with sudden release of positive airway pressure. The appearance of microbubbles in the left side of the heart is definitive evidence of a right-to-left shunt. This technique is particularly applicable to an intraoperative setting. In this situation, the operator invariably has venous access and, with general anesthesia and controlled ventilation, the capacity to readily manipulate the pressure gradient between the atria by varying airway pressure.

Steps 8 and 9 represent long axis views of the tricuspid valve and right ventricle at two levels. Step 8, the uppermost view, represents a 4-chamber image with the transducer rotated clockwise (to the right) to partially exclude the left atrium and left ventricle and position the right ventricle in the center of the field (Figure 9). Thus, only the medial portion of the anterior mitral leaflet is visible in the image. The cross-section is below the level of the aortic valve. This imaging plane usually allows visualization of the junction
STEP 2

BASAL SHORT AXIS VIEW OF THE GREAT VESSELS

FEATURES:
1. The cross-section is such that the aorta and superior vena cava are concentric. The normal disproportion between the aorta and superior vena cava dimensions should also be noted.
2. The aorta lies anterior to the bifurcation of the main pulmonary artery.
3. The superior vena cava lies directly anterior to the right pulmonary artery.
4. The left pulmonary artery cannot usually be imaged beyond its origin.

Figure 3. Two-dimensional echocardiographic basal short axis view of the great vessels. SVC = superior vena cava; Ao = ascending aorta; RPA = right pulmonary artery; MPA = main pulmonary artery.
STEP 3

BASAL SHORT AXIS VIEW AT AORTIC VALVE LEVEL

FEATURES:
1. As illustrated below, the right atrial area is normally less than that of the left atrium at the level of this cross-section.
2. Note that the aortic valve and right ventricular outflow tract lie at the same level, the pulmonic valve being superior to both structures.

Figure 4. Two-dimensional echocardiographic basal short axis view at the level of the aortic valve. AV = aortic valve; RCC = right coronary cusp; LCC = left coronary cusp; NCC = non-coronary cusp; RA = right atrium; LA = left atrium; RVOT = right ventricular outflow tract.
LEFT VENTRICULAR OUTFLOW TRACT

FEATURES:
1. Landmark structures include the aortic valve, with its characteristic “Mercedes-Benz” emblem morphology, and the anterior leaflet of the mitral valve.

Figure 5. Two-dimensional echocardiographic long axis view of the left ventricular outflow tract. AV = aortic valve; LVOT = left ventricular outflow tract; IVS = interventricular septum; LA = left atrium; RV = right ventricle; LV = left ventricle.
LONG AXI S VIEW
OF THE MITRAL VALVE AND LEFT VENTRICLE

FEATURES:
1. As illustrated below, the anterior mitral
   leaflet is normally disproportionately longer
   than the posterior leaflet.
2. The true apex of the left ventricle may not
   be visualized.

Figure 6. Two-dimensional echocardiographic long axis view of the mitral valve and left ven-
tricle. RA = right atrium; TV = tricuspid valve; RV = right ventricle; LA = left atrium; AML =
anterior mitral leaflet; PML = posterior mitral leaflet; LV = left ventricle.
**STEP 6**

**BASAL SHORT AXIS VIEW OF THE LEFT UPPER PULMONARY VEIN**

**FEATURES:**
1. The left upper pulmonary vein lies posterior to the left atrial appendage and anterior to the descending thoracic aorta.

**Figure 7.** Two-dimensional echocardiographic basal short axis view of the left atrial appendage and left upper pulmonary vein. LA = left atrium; LAA = left atrial appendage; LUPV = left upper pulmonary vein; Ao = descending thoracic aorta.
STEP 7

SALINE-CONTRAST IMAGING OF THE INTERATRIAL SEPTUM

FEATURES:
1. The microbubbles represent intravenously administered agitated saline.
2. In the illustration below, a right to left shunt is evidenced by the presence of saline in the left atrium.

The interrogation should include several views of the interatrial septum.

Figure 8. Saline-contrast two-dimensional echocardiographic imaging of the interatrial septum. RA = right atrium; LA = left atrium; RV = right ventricle; AV = aortic valve.
LONG AXIS VIEW OF THE RIGHT VENTRICLE AT THE LEVEL OF THE ANTERIOR MITRAL LEAFLET

FEATURES:
1. As illustrated below, the normal tricuspid valve is usually not visualized in its entirety.

Figure 9. Two-dimensional echocardiographic long axis view of the 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.
between the right ventricular free wall and the interventricular septum. Step 9, the lower of the two views, is obtained by minimal advancement of the endoscope (Figure 10). This plane of interrogation is below the level of the mitral valve, which, accordingly, is not represented in the image. Rather, the cross-section transects the coronary sinus as it empties into the base of the right atrium just above the tricuspid valve. It should be remembered that the coronary sinus runs across the heart below and parallel to the plane of the mitral valve annulus.

Step 10 consists of a transgastric rather than a transesophageal view (Figures 11, 12). This cross-section furnishes a short axis image of the left ventricle at mid-chamber level. This left ventricular cross-section represents the papillary muscle-level view most commonly employed for the assessment of regional wall motion. Since the left ventricle should be in the center of the field in this view, the transducer assembly should be rotated in an counterclockwise (to the left) direction following completion of Step 9, the appropriate degree of rotation is confirmed by visualization of the mitral valve. The transducer is then advanced into the stomach. The papillary muscle level image is obtained by gentle anteflexion of the transducer. It should be emphasized that extreme anteflexion of the transducer will align the beam of interrogation across the mitral valve leaflets rather than across the papillary muscles. Acquisition of an adequate transgastric image can be greatly facilitated by increasing the gain settings to levels above those required for transesophageal imaging.

**CLINICAL PRESENTATIONS**

A variety of clinical abnormalities referable to each step of the patient examination sequence are presented in Figures 13–16. Figure 13 illustrates the transesophageal two-dimensional echocardiographic appearances of a pleural effusion, represented by the "orange-slice" cavity anterior to the descending thoracic aorta. The presence of this latter structure in the image identifies the effusion as being a left-sided entity. Drainage of this fluid and subsequent re-expansion of the underlying lung resulted in a marked improvement in the alveolar-arterial oxygen tension gradient of the patient. In this case, the imaging technique provided an immediately available end-point for assessment of the efficacy of these therapeutic manoeuvres. Figure 14 consists of 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, to the extent that the chamber wall is "tented" inwards, resulting in clinically significant impairment of venous return. Figure 15 represents 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 sub-valvular apparatus is also involved in the disease process, in that the chordae tendineae are also markedly deformed and partially fused. Of significance in a cardiac surgery setting is the finding that the valve anulus is free of calcification. Finally, Figure 16 consists of an long axis image of a mass within the right atrium. The mass, freely mobile within the cavity, was subsequently identified as a thrombus.

Figures 17–19 represent the intraoperative use of transesophageal echocardiography for imaging of commonly utilized intravascular catheters and cannulae, specifically, a pulmonary artery flow-directed catheter, an intra-aortic balloon pump, and a right atrial venous drainage cannula, respectively. The materials from which these prostheses are constructed are ultrasound-opaque. This allows for definition of their location within the vascular system by noting both the ultrasound reverberations which occur as the interrogation beam strikes their surface, as well as the distal areas of ultrasound "dropout"
STEP 9

LONG AXIS VIEW OF THE RIGHT VENTRICLE AT THE LEVEL OF THE CORONARY SINUS

FEATURES:
1. The orifice of the coronary sinus lies proximal to the septal leaflet of the tricuspid valve.

Figure 10. Two-dimensional echocardiographic long axis view of the right ventricle at the level of the coronary sinus. RA = right atrium; RV = right ventricle; LA = left atrium; LV = left ventricle.
TRANSGASTRIC SHORT AXIS VIEW

FEATURES:
1. This standard view represents a mid-papillary muscle level cross-section.
2. Asymmetry of the papillary muscles usually indicates an improper oblique section.

Figure 11. Two-dimensional echocardiographic transgastric short axis view of the right and left ventricle. RV = right ventricle; LV = left ventricle.
EVALUATION OF LEFT VENTRICULAR REGIONAL WALL MOTION

**FEATURES:**
1. The transgastric short axis image is divided into four segments.
2. The motion of each of the segments is graded as follows; 0 = normal; 1 = hypokinetic; 2 = dyskinetic; 3 = akinetic.

Figure 12. Evaluation of left ventricular regional wall motion. RV = right ventricle; LV = left ventricle.

PLEURAL EFFUSION

**FEATURES:**
1. The descending thoracic aorta is visible in the posterior aspect of the image. The presence of this landmark structure defines the pleural effusion as being left-sided.

Figure 13. Two-dimensional echocardiographic view of a pleural effusion. Ao = descending thoracic aorta.
PERICARDIAL EFFUSION

FEATURES:
1. The long axis view (left panel) illustrates extrinsic compression of the right atrium by the effusion.
2. The transgastric short axis view (right panel) demonstrates a posterior separation of the pericardium from the heart.

Figure 14. Two-dimensional echocardiographic long and short axis views of a pericardial effusion. RA = right atrium; LA = left atrium; AV = aortic valve; RV = right ventricle; LV = left ventricle.

RHEUMATIC MITRAL ENDOCARDITIS

FEATURES:
1. The anterior and posterior leaflets are thickened and deformed. An area of calcification (arrow) can be seen on the posterior leaflet.

Figure 15. Two-dimensional echocardiographic long axis view of chronic rheumatic mitral valve endocarditis. RA = right atrium; RV = right ventricle; LA = left atrium; LV = left ventricle.
RIGHT ATRIAL THROMBUS

FEATURES:
1. The mass, freely mobile within the right atrial cavity, was subsequently identified histologically as a thrombus.

Figure 16. Two-dimensional echocardiographic long axis view of a right atrial thrombus. RA = right atrium; RV = right ventricle.

SWAN-GANZ® CATHETER

FEATURES:
1. The catheter (arrows) is visible in the right atrium and the right ventricle.

Figure 17. Two-dimensional echocardiographic long axis view of a pulmonary artery catheter. RA = right atrium; RV = right ventricle; LA = left atrium; LV = left ventricle.
INTRA-AORTIC BALLOON PUMP

FEATURES:
1. The intra-aortic balloon pump occupies the center of the lumen of the descending thoracic aorta.
2. The thickening and irregularity of the intima of the anterior wall of the aorta represents plaque formation.

Figure 18. Two-dimensional echocardiographic view of an Intra-aortic balloon pump in the descending thoracic aorta. IABP = intra-aortic balloon pump.

RIGHT ATRIAL CANNULA “DROPOUT”

FEATURES:
1. Ultrasonic waves cannot penetrate the prosthesis, thus precluding distal imaging. This is evidenced by the above illustrated wedge-shaped area of ultrasound “dropout” in the right atrium.

Figure 19. Two-dimensional echocardiographic long axis view of a right atrial two-stage single venous cannula. RA = right atrium; RV = right ventricle; LV = left ventricle; LA = left atrium; LV = left ventricle.
caused by the imposition of a barrier to further passage of the beam of interrogation. Figure 17 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 the cavities of the right atrium and the right ventricle, represented by arrows, denote the outline of a pulmonary catheter. To be noted in Figure 18, an image of an intra-aortic balloon pump within the descending thoracic aorta, is the central density delineating the base of the rigid tip of the device. The densities located in immediate proximity to this central density represent the junction of the balloon material with this tip. Acquisition of this particular image was facilitated by discontinuation of counterpulsation, thus minimizing reverberation artifacts caused by motion of the device as the balloon cyclically inflated and deflated throughout the cardiac cycle. In Figure 19, the presence of a single two-stage venous drainage cannula within the right atrium is evidenced by the large wedge-shaped area of ultrasound "dropout." In this case, the finding that the prosthetic material precluded imaging of structures lying anterior to the cannula represented the diagnostic feature of the image. The absence of decompression of the right heart suggests that venous drainage had not yet been initiated, and, indeed, this image was obtained prior to institution of cardiopulmonary bypass.

COLOR FLOW DOPPLER IMAGING PRINCIPLES

Color coding

Color flow Doppler systems assign specific colors to the direction of flow. Blue represents flow away from the transducer. Flow towards the transducer is coded in red. When the velocity of flow exceeds the measurement capacity of the instrument, the color coding reverses, i.e., blue appears as red and vice versa. This phenomenon, whereby the direction of flow has apparently reversed, is termed aliasing. Turbulent flow, on the other hand, is multidirectional. Accordingly, the associated images exhibit a multicolored mosaic pattern.

Each image in the following color flow Doppler patient examination sequence 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.

Gain settings

Adjustment of color gain settings is a crucial step in obtaining quality images. The gain control should be manipulated to increase the gain upward until static "noise" appears and then decreased to just below this threshold. Gain control plays an important role in acquiring accurate measurements. Excessively low color gain minimizes the extent of abnormal flow patterns and excessively high gain obscures the image.

COLOR FLOW DOPPLER PATIENT EXAMINATION SEQUENCE

For clarity, the following 5-step color flow Doppler patient examination sequence is presented separately from the two-dimensional echocardiographic sequence just described. In clinical practice, the color flow Doppler data are obtained at the appropriate stages of the two-dimensional-echocardiographic sequence, specifically, at Steps 4, 5, 7, 8, and 9.

Evaluation of aortic valve integrity, the first step of the color flow Doppler sequence, involves interrogation of the left ventricular outflow tract, the receiving chamber for aortic regurgitation (Figure 20). This view corresponds with Step 4 of the two-dimensional echocardiographic examination. The presence of an abnormal flow pattern should be con-
confirmed by color M-mode imaging (Figure 21). Color M-mode imaging can be particularly useful when diastolic and systolic flows are not readily distinguishable. In these instances, the diastolic timing of a regurgitant flow can be readily identified by referring to the corresponding electrocardiogram. It should be cautioned that mild aortic regurgitation represents a common incidental finding in the elderly, with a prevalence of 89% by the right decade.

The mitral valve is examined in the imaging plane described in Step 5 of the two-dimensional echocardiographic patient examination sequence. An example of a regurgitant native mitral valve is presented in Figure 22. Again, as with the aortic valve, mild mitral regurgitation can be a normal finding, in that "normal" mitral regurgitation can be found in every age group, with an overall prevalence of 20-43%, depending on the series. Finally, Figure 23 illustrates "physiologic" regurgitation of a mechanical prosthetic mitral valve. This regurgitation is a built-in feature of these prostheses, the intent being to prevent clot formation on the exposed surfaces.

Step 7 of the two-dimensional echocardiographic sequence involves evaluation of the interatrial septum. This view also allows for color flow Doppler evaluation of the integrity of this structure, as illustrated in Figure 24. The transducer is then repositioned by moving it inferiorly to assess tricuspid valve function at the two levels described in Steps 8 and 9 of the two-dimensional echocardiographic examination (Figure 25). Again, it should be cautioned that mild and even moderate tricuspid regurgitation represents a common finding in the general population, with a prevalence of 34–52%, depending on the study. This finding is almost invariable in highly trained athletes.

The final stage of the color flow Doppler patient examination sequence involves interrogation of the interventricular septum, both in a long axis plane (Figure 26) as well as via the transgastric imaging plane described in Step 10 of the two-dimensional echocardiographic examination.

GRADING OF VALVULAR REGURGITATION

The grading of valvular regurgitation involves several principles. First, the Doppler technique provides measurements of velocity rather than volume. Accordingly, color flow Doppler estimates only approximate regurgitation severity. Second, measurements are based on the maximal demonstrable regurgitant jet, and multiple planes should be scanned to avoid underestimates. Third, since most measurements can vary considerably over consecutive beats, analyses should involve a minimum of five cardiac cycles. Finally, data should always be interpreted in the context of concurrent hemodynamic loading conditions.

Reported methods for evaluating the severity of valvular regurgitation are based on measurement of the dimensions of the regurgitant jet, specifically, measurement of the jet width, length, and area, either alone or in combination. Each of the following grading systems express the evaluations on a 4-point grading scale, i.e., none, mild, moderate or severe. More complex systems are available. However, these have been omitted from this presentation.

Aortic valve

Evaluation of aortic regurgitation is based on two measurements, specifically, the width of the jet at the point of origin (proximal width) and the width of the left ventricular outflow tract. The severity of regurgitation is given by presenting the proximal width of the regurgitant jet as a percentage of the corresponding width of the left ventricular outflow tract. Estimates are expressed on a 4-point scale as follows: 0 = none; < 25% = mild; 25–65% = moderate; > 65% = severe. A schematic representation of this method is
Aortic regurgitation is represented by the discrete bright, speckled area of backflow into the left ventricular outflow tract (arrow).

**FEATURES:**

*Figure 20. Color flow Doppler view of aortic regurgitation.* Ao = ascending aorta; AV = aortic valve; LVOT = left ventricular outflow tract; AML = anterior mitral leaflet; IVS = interventricular septum; AR = aortic regurgitation; LA = left atrium; LV = left ventricle.
COLOR M-MODE CONFIRMATION

Color M-mode imaging can be particularly useful when diastolic and systolic flows are not readily distinguishable. In these instances, the diastolic timing of the abnormal flow can be confirmed by referring to the corresponding ECG.

**COLOR M-MODE CONFIRMATION**

**COLOR M-MODE IMAGE**

**FEATURES:**
Upper panel: severe aortic regurgitation;
Middle panel: corresponding image following aortic valve replacement (porcine valve);
Lowest panel: ECG referable to middle panel.

**COLOR M-MODE IMAGE**

**FEATURES:**
Upper panel: severe aortic regurgitation;
Middle panel: corresponding image following aortic valve replacement (porcine valve);
Lowest panel: ECG referable to middle panel.

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**Figure 21.** Color M-mode interrogation of the left ventricular outflow tract - measurement technique and corresponding image. AV = aortic valve; AML = anterior mitral leaflet; IVS = interventricular septum; ECG = electrocardiogram.
STEP 2

MITRAL VALVE

FEATURES:
The regurgitant jet within the left atrium (arrow) illustrates moderate mitral regurgitation.

Figure 22. Color flow Doppler view of mitral regurgitation. RA = right atrium; TV = tricuspid valve; RV = right ventricle; LA = left atrium; MR = mitral regurgitation; MV = mitral valve; LV = left ventricle.
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Mechanical prosthetic valves feature "physiologic" regurgitant jets intended to prevent clot formation. In contrast, the presence of regurgitation in a biologic prosthesis ("porcine valve") is considered to represent an abnormality.

Figure 23. Two-dimensional echocardiographic and color flow Doppler view of a mechanical mitral valve prosthesis. AV = aortic valve; LA = left atrium; MV = mitral valve; LV = left ventricle.
**STEP 3**

**INTERATRIAL SEPTUM**

Figure 24. Color flow Doppler view of a patent foramen ovale. RA = right atrium; RV = right ventricle; IAS = interatrial septum; LA = left atrium; Ao = ascending aorta.

FEATURES:
The elongated jet extending across the right atrium (arrow) represents left-to-right shunt flow through a patent foramen ovale.
**STEP 4**

**TRICUSPID VALVE**

*FEATURES:*
The regurgitant jet within the right atrium illustrates severe tricuspid regurgitation.

Figure 25. Color flow Doppler view of tricuspid regurgitation. RA = right atrium; RV = right ventricle; PV = pulmonary valve; PA = pulmonary artery; TR = tricuspid regurgitation.
INTERVENTRICAL SEPTUM

FEATURES:
The bright speckled area within the right ventricle (arrow) represents a left-to-right shunt through a ventricular septal defect.

Figure 26. Color flow Doppler view of a ventricular septal defect. RA = right atrium; RV = right ventricle; LA = left atrium; LV = left ventricle; TV = tricuspid valve; VSD = ventricular septal defect; AML = anterior mitral leaflet.
AORTIC REGURGITATION

**FEATURES:**

1. Evaluation of the severity of aortic regurgitation is based on two measurements, specifically, the width of the jet at the point of origin (proximal width) and the width of the left ventricular outflow tract.

2. The proximal width is presented as a percentage of the left ventricular outflow tract measurement, as follows: 
   
   \[ \text{Proximal width (%) } = \frac{\text{PROXIMAL WIDTH}}{\text{LVOT WIDTH}} \times 100 \]

**FEATURES:**

1. Estimates are expressed on a 4-point scale, as follows: 
   
   0=none; <25% = mild; 25–65% = moderate; >65% = severe.

2. The regurgitant jet expands within the left ventricular outflow tract. Accordingly, jet width measurements determined beyond the point of origin may overestimate regurgitation severity.

Figure 27. Grading of aortic regurgitation. AV = aortic valve; ALM = anterior mitral leaflet; IVS = interventricular septum; LVOT = left ventricular outflow tract.
MITRAL REGURGITATION

**JET AREA**

**FEATURES:**
1. The severity of regurgitation is assessed by measuring the cross-sectional area of the jet.
2. The magnitude of the measurement represents the degree of regurgitation. Estimates are expressed on a 4-point scale, as follows: 0 = none; <2.5 cm² = mild; 2.5-5.0 cm² = moderate; >5.0 cm² = severe.

**JET AREA AS A FUNCTION OF ATRIAL DIMENSIONS**

**FEATURES:**
1. Regurgitation severity is determined by expressing the area of the jet in relationship to atrial dimensions.
2. The percentage of the atrium occupied by the jet represents the degree of regurgitation. Estimates are expressed on a 4-point scale, as follows: 0 = none; <33% LA = mild; 33-66% LA = moderate; >66% LA = severe.

**JET LENGTH**

**FEATURES:**
1. The severity of regurgitation is assessed by measuring the length of the jet.
2. The magnitude of the measurement represents the degree of regurgitation. Estimates are expressed on a 4-point scale, as follows: 0 = none; <2 cm = mild; 2-4 cm = moderate; >4 cm = severe.

**JET LENGTH AS A FUNCTION OF ATRIAL DIMENSIONS**

**FEATURES:**
1. Regurgitation severity is determined by expressing the jet longitudinal length from the plane of the valve (arrow) in relationship to atrial dimensions.
2. The depth of penetration into the atrium represents the degree of regurgitation. Estimates are expressed on a 4-point scale, as follows: 0 = none; <33% LA = mild; 33-66% LA = moderate; >66% LA = severe.

Figure 28. Grading of mitral regurgitation. LA = left atrium; LV = left ventricle.
TRICUSPID REGURGITATION

**JET AREA**

**FEATURES:**
1. The severity of regurgitation is assessed by measuring the area of the jet.
2. The magnitude of the measurement represents the degree of regurgitation. Estimates are expressed on a 4-point scale, as follows: 0 = none; < 2 cm² = mild; 2–4 cm² = moderate; > 4 cm² = severe.

**JET AREA AS A FUNCTION OF ATRIAL DIMENSIONS**

**FEATURES:**
1. Regurgitation severity is determined by expressing the area of the jet in relationship to atrial dimensions.
2. The percentage of the atrium occupied by the jet represents the degree of regurgitation. Estimates are expressed on a 4-point scale, as follows: 0 = none; < 33% RA = mild; 33–66% RA = moderate; > 66% RA = severe.

**JET LENGTH**

**FEATURES:**
1. The severity of regurgitation severity is assessed by measuring the length of the jet.
2. The magnitude of the measurement represents the degree of regurgitation. Estimates are expressed on a 4-point scale, as follows: 0 = none; < 2 cm = mild; 2–4 cm = moderate; > 2 cm = severe.

**JET LENGTH AS A FUNCTION OF ATRIAL DIMENSIONS**

**FEATURES:**
1. Regurgitation severity is determined by expressing the jet longitudinal length from the plane of the valve (arrow) in relationship to atrial dimensions.
2. The depth of penetration into the atrium represents the degree of regurgitation. Estimates are expressed on a 4-point scale, as follows: 0 = none; < 33% RA = mild; 33–66% RA = moderate; > 66% RA = severe.

Figure 29. Grading of tricuspid regurgitation. RA = right atrium; RV = right ventricle.
presented in Figure 27. It must be emphasized that regurgitant jets expand beyond the confines of their origin. Accordingly, width measurements determined beyond the point of origin, i.e., measurements that do not represent the proximal width, will tend to overestimate regurgitation severity.

**Mitral valve**

The severity of mitral regurgitation can be quantified by a variety of methods. Broadly speaking, techniques can be divided into two categories. These consist of measurement of either the area or the length of the regurgitant jet. The area and length measurements can be expressed either in absolute terms (direct planimetry of the actual cross-sectional area or length) or as a function of left atrial dimensions (area or length as a percentage of corresponding atrial dimensions). The magnitude of the measurement represents the degree of regurgitation.

The details of the absolute area grading system are as follows: the severity of regurgitation is assessed by measuring the cross-sectional area of the regurgitant jet. Estimates are expressed as 0 = none, < 2.5 cm² = mild, 2.5-5.0 cm² = moderate, and > 5.0 cm² = severe. The format for describing regurgitant jet area as a function of left atrial (LA) dimensions involves evaluation of the percentage of the atrium that is occupied by the jet. Estimates are expressed as 0 = none, < 33% LA = mild, 33–66% LA = moderate, and > 66% LA = severe. This system is illustrated in Figure 28.

Length measurements are completed in an analogous fashion. The absolute length of the jet relates to regurgitation severity, with estimates expressed as 0 = none, < 2 cm = mild, 2–4 cm = moderate, > 4 cm = severe. For describing jet length as a function of left atrial dimensions, the depth of penetration of the jet into the left atrial cavity represents regurgitation severity (Figure 28). This depth of left atrial penetration is expressed as 0 = none, < 33% LA = mild, 33–66% LA = moderate, and > 66% LA = severe.

**Tricuspid valve**

The techniques involved in grading tricuspid regurgitation are similar to those employed for quantification of mitral regurgitation. Again, estimates represent measurements of regurgitant jet area and length, expressed either in absolute terms or as a function of corresponding atrial dimensions (Figure 29). The numerical "cut-off" values between the various grades are also identical to those of mitral regurgitation, with the exception that absolute area grading system "cut-off" values reported in the literature are skewed downwards with respect to the corresponding mitral area values (see Figure 28). Specifically, mild tricuspid regurgitation is defined as a regurgitant jet < 2 cm² whereas mild mitral regurgitation is given as a regurgitant jet < 2.5 cm². Similarly, moderate tricuspid regurgitation has been reported as a regurgitant jet between 2–4 cm², the corresponding mitral valve value being 2.5–5 cm². The values for severe regurgitation, by exclusion, consist of >4 cm² for tricuspid regurgitation and >5 cm² for mitral regurgitation.

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