Clinical Applications of Transesophageal Echocardiography

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Standard transthoracic ultrasound examination of the heart has provided increasingly better images since it was clinically introduced approximately 25 years ago. Although two-dimensional echocardiography is an established tool in clinical cardiology, the image qualities of conventional transthoracic approaches can sometimes be unsatisfactory for various reasons, such as patient obesity, chronic obstructive pulmonary disease, and chest wall changes with age. In these patients, transesophageal echocardiography can provide important diagnostic information because chest wall interference and intrathoracic attenuation are eliminated. Furthermore, the close vicinity of the heart and thoracic aorta to the echocardiographic sensor allows the use of higher-frequency, near-focused transducers, which produce better resolution and an improved signal-to-noise ratio. In addition, some structures that are poorly visualized by standard precordial echocardiography are better observed by the transesophageal approach, including wide areas of both atrial chambers, prosthetic valves, the left coronary arteries, and the thoracic aorta. Recently, color Doppler flow imaging with a transesophageal approach has increased available clinical diagnostic information and therefore expanded the diagnostic capabilities of cardiac ultrasound.

In this brief review, we discuss the diagnostic possibilities and clinical advantages of transesophageal echocardiography based on its clinical application in more than 1,700 awake patients in our echocardiographic laboratory.

Historical Background

Although transesophageal M-mode echocardiography1–6 and transesophageal two-dimensional echocardiography7–9 were introduced in the late 1970s, acceptance of its use in awake patients has been slow, mainly due to methodological disadvantages for clinical application. In 1976, Frazin and associates1 attached a single-crystal M-mode ultrasound transducer to the tip of a cable and studied the feasibility of obtaining accurate measurements of the aortic root and mitral valve motion in awake patients. However, they failed to visualize the left ventricle due to limited positioning of the transesophageal probe. Because of limited possibilities for positioning the transducer, this device was not used much. In 1977, we attached a 3-MHz, 6-mm transducer to the tip of a gastro-camera and obtained left ventricular images,2,4 which we used to evaluate the left ventricular anterolateral wall motion in awake patients with coronary artery disease.4,6 In 1980, Matsumoto and coworkers also succeeded in recording left ventricular images and measured its diameters and wall thicknesses and derived parameters of left ventricular systolic function in intubated, anesthetized patients.5 In addition to developing this technical advance, transesophageal echocardiography was used to monitor intraoperative cardiac performance in patients undergoing coronary artery bypass surgery and valve replacement.5 With the development of mechanical sector scan7–9 and phased-array technology, as well as miniaturization of transducers and introduction of soft, flexible tubing, clinical applications of this technique in both intraoperative monitoring and outpatient settings were examined extensively in Europe,10–14 mainly for imaging intra-atrial structures. US and Japanese investigators used the transesophageal approach mainly for intraoperative monitoring of left ventricular wall motion and overall left ventricular function.5,6,15–18

Examination Technique

For performing transesophageal echocardiography, we recently used a biplane phased-array transducer (5 MHz; 32 elements in each) mounted at the tip of a flexible shaft (9-mm diameter, 100-cm length; Figure 1) and interfaced with a commercial echocardiograph (Model SSD-870, Aloka Co. Ltd., Japan). With the specially devised probe, two-dimensional color Doppler flow images of both transverse and longitudinal scan planes can be obtained separately with one introduction of the transesophageal probe. In awake patients, the pharyngeal region is anesthetized locally with 2% viscous xylocaine and 10%...
Baseline Scan

The transducer is advanced into the esophagus approximately 25 cm from the incisors. This position places the transducer posterior to the left atrium, and tomograms of both atria can be obtained (Figure 2B). By tilting left-laterally or slightly withdrawing the transducer, the aortic valve, left atrial appendage, ostium of the left upper pulmonary vein or ascending aorta, and main pulmonary artery are easily visualized. A sagittal scan plane with the longitudinal scan transducer can provide a precise picture of the upper portion of the ascending aorta, where there is usually a blind region because of interference of the air-filled trachea with the single-transverse scan probe (Figure 2A).

Four- or Two-Chamber Scans

With further advancement of the transducer from the position of the basal scan, four- or two-chamber scans of the heart are obtained (Figure 2C). These tomographic scans image the mitral and tricuspid valves and both ventricular long-axis views; therefore, color flow assessment for mitral regurgitation and the evaluation of ventricular wall motion can be performed from this transducer position. With sagittal scanning at this position using the biplane probe, a right anterior oblique view of the left ventricle can be obtained (Figure 2C), which increases diagnostic power for left ventricular regional wall motion abnormalities.

Short-Axis Scans of Both Ventricles

By further advancing the transducer into the stomach and anteflexing the tip, left ventricular (Figure 2D) and right ventricular (Figure 2E) short-axis views can be imaged (transgastric view). This transducer position is most often used intraoperatively to monitor wall motion of both ventricles. Right ventricular free wall function can readily be examined with this scan plane, which is usually difficult with conventional transthoracic echocardiography.

Scans of Thoracic Aorta

Visualization of the aortic arch and descending aorta is one of the most prominent applications of transesophageal echocardiography. Throughout the vertical extent of the esophagus, most of the thoracic aorta can be systematically imaged with transesophageal echocardiography. Thus, as described above, the proximal ascending aorta is optimally visualized with the single-transverse scan probe, but the trachea prevents imaging of the upper half of the ascending aorta; however, with this transducer position, the biplane probe provides a new window to the aorta for diagnosing ascending aortic lesions (Figure 2). With horizontal scanning, a transverse section of the arch is demonstrated with the ascending aorta to the left of the screen (Figure 2G) at approximately 25 cm from the incisors. With the biplane scan probe, horizontal and longitudinal planes of the descending aorta (Figure 2F) can readily demonstrate the extent

Cardiac Examination and Image Orientation

Because the transesophageal probe is relatively fixed along the esophagus, transesophageal echocardiography has limited scan planes. A diagram of common scan planes and resultant two-dimensional echograms at each plane are shown in Figure 2. Two distinct tomographic examinations—the heart and the thoracic aorta—are performed during transesophageal echocardiography.

Xylocaine spray. The procedure for inserting the transducer is similar to that for inserting a gastroscope—with the patient lying in the left decubitus position. Proper training of the cardiologist in endoscopic procedures is necessary for successful introduction of the transducer into the esophagus. With the tip of the transducer at the esophageal orifice, the patient is requested to swallow, and the transducer is then advanced firmly but without force to approximately 30 cm from the mouth. At this level, serial tomographic views of the heart are obtained by slightly tilting and rotating the transducer tip with the remote controls of the transducer cable. To obtain left or right ventricular cross-sectional views, the transducer should be introduced slightly deeper, 35–40 cm from the incisors, with upward tilting of the tip. It is sometimes necessary to advance the transducer into the stomach and to anteflex it to obtain short-axis views of the heart.

Figure 1. Photograph of transesophageal two-dimensional echocardiographic probes. Single or double phased-array transducers are mounted at tip of a flexible shaft calibrated to 100 cm. Tip of each transducer is 12 mm in diameter, and shafts are 9 mm in diameter. Tip portion has approximately 90° of forward, reverse, and lateral mobility. Single-plane probe (5 MHz, 46 elements) incorporates a horizontal phased-array transducer, and double-phased probe (5 MHz, 32 elements in each) permits imaging in horizontal and longitudinal cross-section scans.
of aneurysmal lesions or atheromatous changes in the vessel wall.

**Clinical Applications**

Clinical settings in which transesophageal echocardiography is often advantageous for diagnosing cardiovascular lesions include suspected aortic aneurysm and examination of the aortic root; evaluation of intracardiac thrombi, particularly in the left atrial appendage; diagnosis and quantitative evaluation of atrial septal defect and assessment of atrial shunting after percutaneous mitral valvuloplasty; detailed anatomical assessment of endocarditis and its complications; evaluation of mitral regurgitation; dysfunction of mitral valve prostheses; and monitoring of cardiac function and intraoperative detection of intracardiac air. Furthermore, transesophageal echocardiography can be used to obtain images of proximal portions of the coronary arteries, coronary flow, and pulmonary venous flow signals.

The procedure can also be useful in obtaining better images when transthoracic approaches yield suboptimal results, such as those in postoperative patients with difficult echo windows.

**Examination of Thoracic Aorta**

Transthoracic echocardiography has been used extensively for detecting aortic lesions from suprasternal, left parasternal, or subcostal approaches. However, standard surface approaches have significant limitations due to inconsistent quality of imaging of the ascending aorta and aortic arch. Because of the morphological position of the esophagus, most of the thoracic aorta can be readily imaged by transesophageal echocardiography in multiple scanning planes. Its use in defining the extent of aortic dissection is shown in Figure 3. The proximal portion of the ascending aorta and the descending thoracic aorta are satisfactorily visualized with a single-transverse plane probe; however, the distal portion of the ascending aorta and aortic arch are suboptimally imaged because
of the interposition of the bronchus. In many cases, a biplane probe (i.e., a transducer with a longitudinal sector scan) yields direct imaging of most parts of the ascending aorta (Figures 2A and 3), and arch vessels can sometimes be visualized on the longitudinal scan plane. Therefore, use of a biplane probe should increase diagnostic ability to precisely define lesions of the ascending aorta.

Recently, Erbel and the European Cooperative Study Group reported a multicenter study showing the diagnostic accuracy of a single probe in 164 consecutive patients with suspected aortic dissection. Transesophageal echocardiography had high sensitivity (99%) and specificity (98%) in making the diagnosis of aortic dissection and provided a dynamic assessment of the intimal flap and the presence of luminal thrombus. Combined use of color Doppler flow imaging can readily and directly demonstrate the systolic flow in the true lumen and the flow across the intimal rupture (entry) from the true lumen into the false lumen (Figure 4).

Transesophageal echocardiography should be performed whenever possible in patients with suspected acute aortic dissection before aortography because acute aortic dissection is a medical emergency requiring prompt diagnosis and often immediate surgery. The procedure provides an optimal screening bedside test without the use of an intravenous contrast agent, an important factor because these patients may have compromised renal perfusion. Some sedation is helpful in performing the transesophageal approach in the acute phase. No major complication has been reported during the procedure, even in the acute phase of aortic dissection. In some patients, surgery on the acute dissection can be carried out immediately after transesophageal echocardiographic examination without additional computed tomography or aortography. If the patient is more than 45 years old and coronary risk factors are present or if DeBakey type I dissection is diagnosed echocardiographically, aortography and coronary arteriography should be performed to delineate the

Figure 3. Transesophageal echocardiographic scans of thoracic aorta of a patient with DeBakey type III aortic dissection. Referring to figures in a clockwise direction, longitudinal and horizontal scan planes by biplane probe revealed no lesions in ascending aorta or aortic arch. Dissecting aneurysm with mural thrombus (TH) in false lumen (FL) was visualized in proximal part of descending aorta, and true lumen (TL) was also visualized. Rupture of intimal flap (ENTRY) was clearly demonstrated at 35 cm from incisors. Tear size of intimal flap was approximately 9×5 mm, which was measured from biplane cross-sectional echograms. AO, aorta; RPA, right pulmonary artery; AV, aortic valve; FE, spontaneous echo contrast.
apparatus. They can lead to catastrophic embolic events. Therefore, in these patients, the detection of a left atrial thrombus may be helpful in reinforcing the need for anticoagulant treatment or in determining the timing of corrective surgery. Precordial two-dimensional echocardiography has been the diagnostic technique of choice for the assessment of intra-atrial masses, yet there are several limitations to this approach, particularly in the echocardiographic demonstration of the left atrial appendage. Transesophageal echocardiography provides optimal imaging of this particular structure because this approach is not limited by the chest wall, lung tissue interference, or thoracic attenuation, and a high-frequency transducer can be used routinely. Figure 5 shows a representative patient with mural thrombus in the left atrial appendage and remarkable swirling of blood (spontaneous echo contrast) in the left atrial cavity.

Daniel and coworkers32 evaluated the incidence of spontaneous echo contrast, indicating disorganized velocities or even slow blood flow velocities in the left atrial cavity, in the left atrium in 122 patients with mitral stenosis or after mitral valve replacement using transesophageal echocardiography. They reported that patients with spontaneous echo contrast had a significantly greater incidence of both left atrial thrombi and a history of arterial embolic episodes than did patients without spontaneous echo contrast. Therefore, spontaneous echo contrast in the left atrium detected by transesophageal echocardiography might be useful in identifying increased thromboembolic risk. However, Daniel et al32 also reported that there were embolic episodes in four patients with mitral stenosis who did not have spontaneous echo contrast; therefore, the probability is that we cannot use the nondetection of spontaneous echo contrast in the left atrium to make a determination to not anticoagulate. We recently reported the relation between blood flow velocity in the left atrial appendage and thromboembolic risk in 28 patients with chronic atrial fibrillation.33,34 In patients with lone atrial fibrillation and a history of cerebral thromboembolism, a small mural thrombus in the left atrial appendage was observed in 22%, and only one patient had spontaneous echo contrast in the left atrium. However, mean flow velocity (averaged flow of a saw-tooth velocity pattern) in the left atrial appendage was significantly lower in the patient with lone atrial fibrillation and history of thromboembolic episodes (11±4 cm/sec) than that in patients with lone atrial fibrillation and no history of thromboembolic episodes (29±9 cm/sec), indicating severe blood stagnation in the appendage in the group with a history of thromboembolism. Thus, measurements of the flow velocity signal in the left atrial appendage with transesophageal echocardiography may be useful in identifying increased thromboembolic risk in patients with atrial fibrillation.

Diagnosis and Quantitative Evaluation of Atrial Septal Defect

Diagnosis of atrial septal defect is possible by transthoracic two-dimensional echocardiography.
with various thoracic transducer positions. However, the ultrasonic beam does not usually penetrate the interatrial septum perpendicularly, and echo dropout often gives false-positive results for secundum atrial septal defect. Furthermore, the accurate diagnosis of sinus venosus defect or partial anomalous pulmonary venous connection is quite difficult with transthoracic echocardiography. Transesophageal echocardiographic imaging of the atrial septum is particularly advantageous because the esophageal transducer faces this structure nearly perpendicularly at a short distance. Changing the transducer position by advancement or slight rotation allows all parts of the atrial septum to be readily imaged and scanned for septal defects. We reported on the quantitative evaluation of atrial septal defects by transesophageal Doppler echocardiography. The size of the defect in the atrial septum from the transesophageal approach correlated well with direct measurement during cardiac surgery, and a high linear correlation was obtained between shunt flow volume across the defect and that obtained by the Fick method.

The biplane transducer may offer even more accurate views of the defect. Figure 6 shows transesophageal two-dimensional color flow imaging of a sinus venosus atrial septal defect with partial anomalous pulmonary venous connection. The direct connection of the right upper pulmonary vein to the right atrium is clearly visualized, and pulmonary venous blood (red flow signal) flows into the right atrium (Figure 6, lower panel). Recently, Yoshida et al reported the assessment of left-to-right atrial shunting after percutaneous mitral valvuloplasty by transesophageal color Doppler echocardiography. On the first day after valvuloplasty, transesophageal color Doppler echocardiography demonstrated atrial shunts in 13 of 15 patients (87%) without a significant oxygen step.
The mean diameter of the interatrial septal defect detected by transesophageal two-dimensional echocardiography was $1.8 \pm 1.0$ mm. Six months after valvuloplasty, however, the shunt flow remained in only three patients (20%) and was associated with a significant decrease in the diameter of the atrial defect.

The transesophageal approach is a “semi-invasive” method; we do not recommend this technique as a routine examination in the assessment of atrial septal defect, but we suggest that it is indicated in patients with inadequate or nondiagnostic results by the transthoracic approach.

**Diagnosis of Infective Endocarditis**

The clinical importance of echocardiography for diagnosing infective endocarditis has been established. Two-dimensional color flow imaging demonstrates valvular destruction as well as valvular incompetence and is capable of imaging vegetations, which are the most important findings for echocardiographically diagnosing infective endocarditis. However, transthoracic approach is of limited diagnostic value in approximately 30% of patients due to chest wall interference and intrathoracic attenuation of ultrasound. Transesophageal echocardiography is superior to the transthoracic approach in evaluating the detailed anatomy of the mitral or aortic apparatus because of the use of a higher-frequency, near-focused transducer and scanning in the near field without interference from the chest wall. Erbel et al reported the clinical value of transesophageal echocardiography compared with transthoracic echocardiography for detecting vegetations in 96 consecutive patients with suspected infective endocarditis and 70 control patients with valvular heart disease without infective endocarditis. Their prospective study demonstrated that for transthoracic and transesophageal approaches, measured sensitivity was 63% and 100%, specificity was 98% and 98%, positive predictive accuracy was 92% and 95%, and negative predictive accuracy was 91% and 100%, respectively. An important factor contributing to the superiority of transesophageal echocardiography over the transthoracic approach was the size of vegetations. Only six of 24 vegetations (25%) measuring 5 mm or less but nine of 13 6–10-mm vegetations (69%) and 14 of 14 11-mm or larger vegetations detected by transesophageal echocardiography were observed with transthoracic echocardiography. Figure 7 shows transesophageal echocardiographic images of the mitral valve during systole obtained from a patient with infective endocarditis and splenic embolism. In this patient, transthoracic echocardiography demonstrated abnormal mass echoes (vegetation) attached to the anterior mitral leaflet in the left ventricular outflow tract during diastole. However, detailed anatomical changes of the mitral valve could not be evaluated satisfactorily with transthoracic echocardiography because of obesity. The transesophageal echocardiographic image clearly demonstrated a perforation of the anterior leaflet of the mitral valve (Figure 7, left panel, black arrow), and vegetations attached to the edge of the perforation were passing through the perforated lesion of the leaflet during the cardiac cycle. Transesophageal color flow imaging revealed severe mitral regurgitation through the perforation of the leaflet with a suction signal on the left ventricular aspect (Figure 7, right panel, black arrow).
Transesophageal echocardiography is superior to the transthoracic approach, both in detecting vegetations and in demonstrating aortic and mitral valve lesions in patients with suspected infective endocarditis, because of better image quality.

**Evaluation of Mitral Valve Prostheses**

Transthoracic Doppler color flow imaging provides images of mitral regurgitation, and its potential value in the assessment of prosthetic cardiac valves has been well established. However, accurate diagnosis of prosthesis malfunction may be difficult with precordial approaches because of attenuation of the ultrasound signal due to the distance involved or the material of most prostheses. These problems can be avoided to a large extent with transesophageal echocardiography because the transesophageal probe is closer to the mitral valve and the ultrasound beams are reflected from the left atrial blood without attenuation from the mitral prostheses, thus facilitating detection of vivid regurgitant flow. Recently, Nellessen and associates reported the potential value of transesophageal echocardiography in the assessment of biological mitral prosthesis malfunction. The pathological morphology of the mitral prosthesis was additionally or more clearly visualized by transesophageal echocardiography compared with images obtained by the transthoracic approach. In 12 of 13 patients, the degree of mitral regurgitation evaluated by transesophageal echocardiography corresponded well to that found on left ventriculography; however, the degree of regurgitation obtained by precordial color Doppler was underestimated in eight of 13 patients.

Figure 8 shows representative transesophageal echocardiographic images obtained from a patient with biological mitral prosthesis malfunction (Carpentier-Edwards valve). In this patient, transthoracic approaches failed to image prosthetic valve motion and provide accurate assessment of mitral regurgitation due to an attenuation of the ultrasound beam by the material of prosthetic valve. Transesophageal echocardiography clearly demonstrated prolapsed leaflets of the prosthetic mitral valve (arrow), and biplane color Doppler flow images revealed holosystolic, broad, and multicolored regurgitant jets directed eccentrically in the left atrium, indicating severe mitral regurgitation.

**Perioperative Monitoring**

With the introduction of the use of transesophageal echocardiography during surgery, continuous echocardiographic monitoring is possible during an entire surgical procedure without obstructing the surgeon. The intraoperative uses of this approach can be divided into three major categories: monitoring of cardiac function, detailed intraoperative diagnosis, and detection of intracardiac air embolism. Global and regional left ventricular wall motion can be analyzed by this approach. Global function is usually best monitored from the short-axis view of the left ventricle at the chordal level with the transgastric approach. Anterolateral, apical, and inferior wall motion can be evaluated more precisely with the longitudinal scan plane (Figure 2C).

Smith and coworkers reported that this approach was reliable for the detection of acute regional myocardial ischemia and was more sensitive than...
electrocardiography or pulmonary artery wedge pressure values. They prospectively studied 50 high-risk patients. Twenty-four of the 50 patients developed new segmental wall motion abnormalities intraoperatively, whereas only six developed ST segment changes (all limb leads plus V3). ST segment changes were always accompanied by regional wall motion abnormalities. Of three patients who had perioperative myocardial infarction, only one had intraoperative ST segment elevation; all patients had persistent new wall motion abnormalities.

During anesthesia, left ventricular volume is an important determinant of cardiac output as a preload. However, during surgery, the ventricular volume is difficult to measure directly; thus, preload is often derived indirectly by monitoring the pulmonary artery wedge pressure. Unfortunately, the relation between left ventricular volume and pulmonary wedge pressure is poor. Moreover, in the presence of changes in left ventricular compliance, that relation is unpredictable. Transesophageal two-dimensional echocardiography offers a practical solution to intraoperative preload assessment17 because it directly images the left ventricular short-axis dimension. More accurate evaluation of the left ventricular volume might be accomplished by using the biplane transducer, with the short-axis view by using the transverse scan plane, and with the long-axis view by using the longitudinal scan plane probe.

Air embolism is a major risk in patients undergoing neurosurgical procedures and implantation of hip prostheses.85 Ulrich et al reported that in 12 of 13 patients, transesophageal two-dimensional echocardiography revealed considerable air bubbles in the right atrium and right ventricle during the implantation of the femoral shaft prosthesis, and mild pulmonary emboli detectable in eight patients were associated with the end-expiratory CO2 partial pressure decrease.85 Paradoxical embolization is thought to occur through a patent foramen ovale.57 Mügge et al82 demonstrated a clear image of right-to-left shunt flow through a patent foramen ovale with transesophageal color Doppler echocardiography, and they suggested that this diagnostic potential might be important in patients with unexplained arterial embolism.

Topol et al68 reported on 82 patients and detected intracardiac air bubbles after cardiopulmonary bypass in 41%; they found this to be more frequent after cardiectomy (75%) than after routine coronary bypass surgery (10%). Neurological events were not associated with the presence of intracardiac air or with its apparent quantity. It is extremely common to find mobile intracardiac bubbles during open heart surgery, and their frequent occurrence suggests that it is common for some air to gain access to the central circulation during open heart surgery. Transesophageal echocardiography readily demonstrates intracardiac air; however, quantitative assessment of air volume is impossible by this approach, and most patients with intracardiac air demonstrated by this method have no neurological events. Thus, we suggest that monitoring for intracardiac air may not be a major indication for intraoperative application of this approach.

Intraoperative assessment of the competence of reconstructed atrioventricular valves is also an important application of transesophageal echocardiography. The value of transthoracic echocardiography for evaluating atrioventricular valve competence after conservative valve repair has also been established; however, there are considerable limitations in performing this approach in a sterile field during surgery. Drexler et al52 reported advantages with the use of transesophageal echocardiography for the intraoperative assessment of reconstructed valves: An individual familiar with echocardiographic investigations can perform the examination without concern for sterile conditions because one is working out of the sterile field when performing echocardiography. Therefore, time for the echo procedure can be shortened, and better-quality cross-sectional echo planes may be obtained. Once the transesophageal echo probe is inserted into the esophagus at the beginning of surgery, no additional disturbance of the anesthesiological or surgical procedure is necessary.

Dahm et al51 performed intraoperative transesophageal echocardiography for the evaluation of reconstructed atrioventricular valves in 18 mitral valves, 11 tricuspid valves, and double atrioventricular valve reconstructions. After termination of cardiopulmonary bypass, the result of the reconstruction was tested in the beating heart by transesophageal contrast echocardiography. In six patients, transesophageal echocardiography revealed mild regurgitation, and no additional surgery was done. In three patients with mitral repair, contrast echocardiography showed severe regurgitation that had not been detected by examination during open cardiac arrest. In these patients, systolic dislocation of the leaflets was clearly observed, and definitive valve replacement was performed during the same operation.

Transesophageal color flow image may be more convenient for the intraoperative assessment of reconstructed valve incompetence, but additional studies are necessary to establish quantitative evaluation of the grade of mitral regurgitation by transesophageal color flow imaging.

**Imaging of Coronary Arteries**

The imaging of a coronary artery by conventional precordial echocardiography has been reported, but the image quality is generally too poor to allow an evaluation of anatomical details in adult patients. High-resolution images of the proximal coronary artery can be obtained by the higher-frequency (5 MHz) transesophageal probe,73 with an imaging quality superior to transthoracic recordings. The main trunk of the left coronary artery from the left coronary sinus and its bifurcation into the LAD and circumflex coronary artery can frequently be visualized. Recently, Yoshida et al75 reported that adequate images of the full length of the left main...
coronary artery and identification of the bifurcation of the LAD and circumflex coronary artery were obtained in 60 of 67 patients (90%) by transesophageal echocardiography. They also demonstrated quantitative evaluation of left main coronary artery narrowing (>50%) in 10 of 11 patients (sensitivity, 91%) and insignificant narrowing or no abnormalities of the coronary lumen in the other 49 patients (specificity, 100%). The blood flow signal in the left main coronary artery was detected in 57 of 67 patients (85%) by the transesophageal color Doppler flow image. In their report, the positive and negative predictive accuracies for left main coronary artery disease was 100% and 98%, respectively.

The right coronary artery is seen to originate from the right aortic sinus, usually at a tomographic level different from that of the left coronary artery, and detection of its image is much more difficult than that of the left coronary artery. A flow velocity signal, particularly in the LAD, is often detectable by positioning the sample volume in the lumen; adjustment of the angle between the ultrasound beam and the flow direction is necessary to record a proper flow velocity by monitoring color Doppler flow images (Figure 9). The diastolic component of the flow signal can usually be obtained satisfactorily when the image of the LAD is clearly demonstrated. However, the flow signal during systole is often not necessarily stable enough for analysis because of displacement of the sample volume by the abrupt systolic movement of the heart. Yamagishi et al reported that transesophageal echocardiography provided images of the LAD in 77% of all patients examined, and a stable flow signal from the proximal LAD could be recorded in all patients in whom the image of the left coronary artery was well visualized; however, the detection rate of the right coronary (26%) was much lower than that of the left coronary artery, and precise analysis of the right coronary flow pattern was not possible due to numerous noise signals. Further study will be necessary to demonstrate the clinical value of transesophageal echocardiographic assessment of coronary arterial morphology and pathophysiology.

**Figure 9. Transesophageal color Doppler echocardiogram of proximal left coronary artery and pulsed Doppler–derived flow velocity signal in left anterior descending coronary artery (LAD).** LAD flow velocity pattern is characterized by a small systolic component followed by rapid onset of diastolic components with much higher velocity, with slight reduction in velocity during atrial contraction. LMT, left main trunk of coronary artery.

**Intraoperative Monitoring of Congenital Heart Disease in Pediatric Patients**

As described in “Perioperative Monitoring,” intraoperative use of transesophageal echocardiography with color flow imaging has gained rapid and wide acceptance. However, there was a considerable limitation of the available commercial transesophageal probe, namely, the probe was too large to use in pediatric cardiac patients. Thus, until quite recently, transesophageal echocardiography seemed to be an
inadequate tool for evaluating the palliative or corrective repair of complex congenital heart disease in pediatric patients with a body weight of less than 15 kg. Recently, Kyo and coworkers developed a pediatric probe with a diameter of 6.8 mm; they used it intraoperatively in five pediatric patients with complex congenital heart diseases including tetralogy of Fallot, ventricular septal defect and pulmonary stenosis, single ventricle, and pulmonary atresia. They successfully examined both ventricular functions, adequacy of valve replacement, signs of any residual shunts, and adequacy of pulmonary debanding. They also reported an experience of successful use of the pediatric transesophageal probe in a 3.9-kg (3-month-old) patient with an endocardial cushion defect and patent ductus arteriosus, and showed clinical applicability of the pediatric probe in patients weighing less than 10 kg (minimum body weight, 3.9 kg) without technological difficulties and clinical complications. Further study is recommended to clarify the clinical usefulness and safety of application of transesophageal echocardiography in pediatric patients with complex congenital heart disease.

Risk of Transesophageal Echocardiography

The risk and potential complications associated with transesophageal approach in cardiac patients should be always considered. However, as far as we know, reports of critical complications directly caused by transesophageal echocardiography are almost nonexistent. Schlueter et al. reported no major side effects during transesophageal echocardiography in 300 consecutive cardiac patients. Erbel et al. described only a 1% incidence of noncrirical complications, namely, one patient with an attack of bronchial asthma and another patient with transient atrioventricular block, during transesophageal approaches in patients with dissecting aneurysm, including acute dissections. Geibel et al. studied the risk of transesophageal echocardiography in 54 consecutive awake patients with various heart diseases and evaluated the severity of the side effects, such as arrhythmia, blood pressure elevation, or heart rate change, during transesophageal approach. They reported that few hemodynamic changes and ventricular arrhythmias occurred during transesophageal echocardiography, even in patients with congestive heart failure, and there was no evidence for the occurrence of malignant arrhythmias. They also reported that in their previous experience in more than 1,400 patients examined by transesophageal echocardiography, there was a very low overall incidence of complications (<1%), such as asymptomatic nonsustained ventricular tachycardia, pathological bradycardia, or transient myocardial ischemia, requiring cessation of the procedure. These data agree with our previous uncontrolled experiences in more than 1,700 awake patients with cardiovascular diseases who have undergone transesophageal echocardiography during a 14-year period. In these patients, we have also observed a very low incidence of side effects, although four patients with significant coronary artery stenoses had anginal attacks, one patient with single ventricle had a severe arterial hypoxicemic episode, and three patients had transient ventricular tachycardia that required interrupting the procedure. Several patients had marked elevation of systolic blood pressure immediately after insertion of the transesophageal probe; however, blood pressure usually decreased to a level slightly higher than the rest value during continuation of the procedure.

During intraoperative use of transesophageal echocardiography, attention should be paid to the possibility of traumatic esophageal bleeding because large doses of heparin are usually administered during surgery.

To avoid the complications of transesophageal echocardiography in patients with cardiovascular diseases, cardiac rhythm and blood pressure should be monitored, and the operator should not force a difficult entry. The transesophageal approach should be avoided in cardiac patients with suspected esophageal disease, such as liver cirrhosis and esophageal diverticulum.

Future Directions

Instrumentation and applications of transesophageal echocardiography are changing rapidly. Currently, the biplane probe and the probe with a small caliber shaft for pediatric examination are available, and its potential clinical advantages for assessing cardiovascular disorders will soon undergo examination. Other innovations include high-frequency transducers for tissue characterization, high-resolution transducers with a smaller-caliber shaft for adult patients, a variable multifrequency transducer, transducers for wide-angle imaging, and addition of continuous wave Doppler. The introduction of a smaller probe may eliminate the need for sedation, making this semi-invasive approach even more noninvasive.

Conclusions

The available data indicate that ultrasound as an imaging medium has been further advanced by the introduction of transesophageal echocardiography, and this unique high-resolution imaging approach has opened a new window to the heart. A possible disadvantage is that the procedure may be unpleasant in awake patients; however, this disadvantage may be largely overcome by minimizing the transducer size. Transesophageal echocardiography is now considered an established procedure for diagnosing and evaluating a variety of cardiovascular disorders. Based on our experience of this approach during a 14-year period, we believe that transesophageal echocardiography can be done without major complications when the procedure is performed by a physician familiar with echocardiography, endoscopy, and the spectrum of cardiac pathophysiology.
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