Transesophageal and Doppler Echocardiography in the Diagnosis and Management of Infective Endocarditis
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The evaluation of infective endocarditis (IE), a complex and diagnostically difficult disease, has benefited dramatically from the developments in noninvasive cardiology, particularly in echocardiography. In the preantibiotic era, the disease progressed inexorably until death, with the diagnosis often confirmed at autopsy. With the development of modern antibiotic therapy and cardiothoracic surgery, the potential for lifesaving therapeutic interventions has increased the value of making an early diagnosis for improved outcome. Patients with IE now present earlier in their illness when classic Oslerian clinical stigmata may be absent (eg, Roth spots). The rampant abuse of intravenous drugs has increased the prevalence of both bona fide and suspected cases of IE. Two-dimensional transthoracic echocardiography (TTE) has improved diagnostic acumen in IE by demonstrating both valvular and myocardial pathology; moreover, through the use of Doppler echocardiography, noninvasive hemodynamic assessment of cardiac function is readily available. In addition to diagnosing vegetative IE and identifying valvular abnormalities predisposing to IE, the TTE has also become very useful for defining the need for surgery and guiding the eventual cardiac repairs. Transesophageal echocardiography (TEE) is the latest technologic advance in the noninvasive evaluation of the patient with IE, with a potential to further add to our diagnostic and prognostic armamentarium.

Technical Aspects of TEE

Transesophageal echocardiography is a technique which was developed to improve visualization of cardiac structures by taking advantage of the close anatomic relationship of the esophagus to the heart (Fig 1). By incorporating an echocardiographic transducer into an endoscope, one can image the heart from the esophagus and avoid the technical problems of TTE, created by having to image through the thoracic wall and lung. In TEE, the transducer rests on the anterior esophageal wall adjacent to the left atrium, which then provides an excellent fluid-filled ultrasound window (Fig 2); TEE was first attempted in the late 1970s by appending an M-mode echocardiographic transducer onto the end of an endoscope.†

FIGURE 1. Anatomic specimen demonstrating close relationship of heart, great vessels, and esophagus. With exception of area adjacent to and obscured by left bronchus (LB), esophagus provides excellent window for examination of cardiac structures. LA, Left atrium; LV, left ventricle; LPA, left pulmonary artery; and Ao, aorta; Ao, (reproduced with permission from Hewlett-Packard).

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IE = infective endocarditis; TEE = transesophageal echocardiography; TTE = two-dimensional transthoracic echocardiography

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The technology has now advanced, with progressive miniaturization of the electronic equipment with one or, more recently, two imaging transducers placed on the end of one probe. The probes use high-resolution phased-array ultrasound and are only 1 to 1.5 cm in width.

Performing TEE is similar to performing upper gastrointestinal endoscopy. The posterior pharynx is anesthetized and the patient sedated (depending on the patient’s level of cooperation and anxiety). We have frequently used diphenhydramine for sedation, because of this agent’s minimal respiratory depression and moderate sedative and antisecretory effects. In the absence of continuous oxygen monitoring facilities by pulsed oximetry, heavy sedation should probably be avoided in performing TEE. The TEE probe is advanced past the oropharynx to a depth of 25 to 40 cm. Manipulation and angulation of the transducer allow the operator to make a series of tomographic cuts through the cardiac structures. By rotating and angling the probe at various levels through the esophagus and the stomach, it is possible to visualize the major cardiac structures, as well as substantial parts of the ascending and descending thoracic aorta. The use of new biplane probes has increased the number of angles from which the various cardiac structures can be visualized. The imaging planes are nearly orthogonal and thus generate short-axis and long-axis views. The TEE procedure lasts about 10 to 15 minutes and is usually well tolerated. In our laboratory, over 90 percent of the patients are successfully examined by TEE. Although the risks of respiratory arrest, aspiration pneumonia, or bradycardia are present, we have not had a major complication in over 300 TEE procedures; other laboratories have reported similar low complication rates. The risk of TEE-associated bacteremias has not been well delineated to date. One study documented a rate of periprocedural bacteremia of 17 percent in patients undergoing TEE, with known valvular pathogens being isolated from the bacteremic patients. Other studies have not confirmed such high rates of periprocedural bacteremias in TEE, however, because of the severe consequences of IE in recipients of prosthetic valves and those with significant underlying valvular lesions, we currently use prophylactic antibiotic regimens as recommended by the American Heart Association for upper airway procedures when performing TEE in such patients.

In Figures 3 and 4, a comparison of several anatomic
sections with corresponding TEE views is demonstrated. In addition, there are several excellent technical reviews of TEE describing the various views and the appearance of cardiac structures in both standard and biplane orientation.2,7,8 Compared to standard TTE, the differences in quality and detail of the images with TEE are notable. Structures of 1 to 2 mm in size can be readily visualized by TEE.9 Valvular morphology and valve structures, chordae, and attachments are better defined by TEE than TTE. Prosthetic valves, which often heavily shadow other structures and are themselves difficult to image, are more clearly seen using the TEE technique. For example, prosthetic mitral valves frequently generate artifacts on TTE which obscure significant parts of the left atrium and valve annulus; however, with TEE, the left atrium is easily visualized without interference by the intervening prosthetic valve. Left atrial thrombi, vegetations on the atrial surface of the mitral valve, and the atrial appendage can then be studied by TEE. Additionally, images of the aortic root and annulus and the ascending aorta are also far superior with TEE, allowing one to detect mycotic aneurysms, valve ring abscesses, and abnormalities of the proximal coronary arteries not usually well defined in adults by TTE. It has only been in the last year that biplane probes have been commercially available, and they have thus not been widely used clinically; the benefit of the biplane probe over single-plane transducers in TEE requires further elucidation.

**Doppler Echocardiography**

Doppler echocardiography uses sound waves to identify and quantify flow through intracardiac and extracardiac vascular structures. By using pulse wave or gated Doppler flow, the direction and location of blood flow in an area of the heart can be identified. Using continuous Doppler echocardiography, peak velocities through valves can be measured; similarly, using several relatively simple mathematical formulae, a variety of hemodynamic measurements can be made; for example, the mitral valve area, as well as gradients across the aortic or pulmonic valves, can be calculated. Right ventricular systolic pressure can be estimated and used to assess the degree of pulmonary hypertension. Blood flow can be displayed as a color map, with flow toward the transducer represented in red and flow away from the transducer in blue; this enables one to estimate the severity of valvular regurgitation, identify intracardiac shunts, and localize the origin of regurgitant jets to a transvalvular or paravalvular region. Doppler echocardiography is an integral part of TTE or TEE. In evaluating prosthetic mitral valve dysfunction and mitral regurgitation, the Doppler TEE is far superior to standard TTE approaches (Fig 5).

**Diagnostic Use of TEE in IE**

Various studies have confirmed TTE as having a diagnostic sensitivity for identifying valvular vegetations of only about 60 percent in bona fide cases of IE.9,10 Although the data are still relatively limited, the sensitivity of TEE for documenting vegetative IE
is over 90 percent,\textsuperscript{6,12} with a high degree of specificity. A major indication for performing TEE in patients with IE is a technically suboptimal TTE, for example, in patients with underlying pulmonary disease, those on ventilators, obese patients, or those with chest wall deformities, TEE yields substantially better images than TTE. In addition, TEE is superior to TTE at delineating small valve vegetations (<5 cm). There are extensive data in the literature confirming that patients with aortic or mitral valve IE (or both) and a TTE positive for valve vegetations have a worse prognosis than their vegetation-negative counterparts (ie, embolic events, development of congestive heart failure, or frank valve disruption\textsuperscript{9,12,13}). Patients with left-sided IE and vegetations larger than 1 cm by TTE have a significantly worse clinical outcome than those with smaller lesions.\textsuperscript{9,13} Further studies are necessary to characterize whether this same relationship exists between the presence or size of vegetations (or both) as defined by TEE and the clinical outcome in IE.

We have shown that among patients with community-acquired \textit{Staphylococcus aureus} bacteremia, about 20 percent of those without stigmata of IE will have findings on TTE that recategorizes them to either definite or probable IE.\textsuperscript{14} Because of the ability of TEE to better visualize smaller vegetations than TTE, we are currently evaluating TEE as a screening tool to identify occult vegetative IE among patients with community-acquired \textit{S. aureus} bacteremia.

We have recently studied 49 patients with suspected IE prospectively by both TTE and TEE. Of the 22 patients with clinically defined IE, the sensitivity of TTE and TEE for valvular vegetations was 64 and 82 percent, respectively.\textsuperscript{15} In virtually all of the cases with clear-cut valvular vegetations by TTE, TEE confirmed this finding. Importantly, in 17 of the 49 patients, TTE identified valves which were abnormal, but not definitely diagnostic of vegetations (eg, valve thickening); in 13 of these 17 “nondiagnostic” TTE studies, TEE clearly showed these valves either to be normal or to have vegetations. Thus, TEE appears to be very useful at adjudicating equivocal valve abnormalities noted on TTE.

There are a number of other potential advantages of TEE over TTE, as shown in the following tabulation:

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<th>Advantages of TEE over TTE</th>
<th>Disadvantages of TEE</th>
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<td>Somewhat invasive</td>
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<td>Superiority of visualizing:</td>
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<td>Valve ring abscesses</td>
<td>Potential risk of bacteremic seeding of abnormal valves</td>
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In aortic valve IE, it is not uncommon to have secondary infectious involvement of the anterior leaflet of the mitral valve via “jet lesion” effect of the regurgitant aortic flow; TEE appears to be superior to TTE in evaluating this latter lesion (Fig 6). Also, TEE is probably better at defining mural IE lesions than TTE;\textsuperscript{15} this is particularly important in the evaluation of febrile bacteremic patients with known intracardiac shunts (eg, ventricular septal defects), intracardiac catheters (eg, Swan-Ganz catheters), or pacemakers. Transesophageal echocardiography is also superior to TTE in detecting chordal tears, flail leaflets, and valve disruption in IE. Moreover, TEE appears to be much better than TTE for evaluating vegetations on prosthetic valves.

One of the most feared complications of both native and prosthetic valve IE is perianular extension of...
infected abscesses in patients with both native and prosthetic valves. Our studies showed that aortic valve IE and active use of intravenous drugs were the two most important independent risk factors for development of perianular extension of native valve IE. We are currently recommending serial evaluation of such patients with TEE to detect such perianular complications early in the clinical course of IE.

Lastly, we have begun to identify an increasing number of pulmonic valve vegetations in suspect IE cases by TEE, but not TTE. This has raised the question of whether patients with the right-sided IE syndrome, but with negative TTE for tricuspid valve vegetations, in fact, have occult pulmonic valve IE. Current studies are continuing to clarify this point further.

**Use of TEE in the Surgical Management of IE**

Making decisions with regard to valve surgery in IE is highly dependent on the ability to assess both valve function and appearance before surgery. For example, in multivalvular IE, the ability to perform valvuloplasty, rather than replacing the involved valve, has both immediate surgical implications (shorter bypass time) and long-term prognostic implications (lack of a cardiac prosthesis with the attendant anti-coagulation and infectious complications); however, leaving a dysfunctional valve may render the patient with IE hemodynamically unstable and unable to come off bypass. Transesophageal echocardiography is particularly useful in documenting multivalvular IE and, when combined with Doppler techniques, can identify dysfunctional valves before surgery. Also, knowing before surgery that IE involves both aortic and mitral valves alerts the surgeon to carefully inspect the trigonal region between the valves for potential myocardial abscess or fistulous connections between the aorta and left atrium. In addition, identification of an aortic root or valve ring abscess by TEE before surgery increases the urgency for surgical repair and also defines the need for more major reconstruction of the aorta (ie, with prosthetic valve plus graft) rather than utilizing simple valve replacement.

The development of congestive heart failure in IE is an ominous sign, associated with a markedly increased mortality. Clarifying the cause of heart failure in the face of IE, particularly in patients with prosthetic valves, is not always straightforward. The management strategies for treatment of congestive heart failure secondary to ongoing sepsis, myocardial dysfunction, fistulous communications, or prosthetic valve dysfunction are each quite different. Rapid noninvasive assessment of cardiac hemodynamics is essential before surgery, even if surgery is considered imminent. Echocardiography has decreased the overall need for cardiac catheterization prior to valve surgery, as well as guided such invasive studies by defining the specific questions to be answered (eg, presence or absence of coronary artery disease). Transesophageal echocardiography with Doppler interrogation of patients with prosthetic valve IE and congestive heart failure is critical in making surgical decisions, both in deciding on surgery and in defining the type of surgical repair; for example, identification of a regurgitant lesion as transvalvular or paravalvular or as due to fistulous intracardiac communications guides optimal surgical repairs. Finally, intraoperative TEE evaluation of patients with IE is being used with increasing frequency after valve surgery to assess the adequacy of repairs. Thus, the surgeon can be sure that all intracardiac shunts have been identified and closed and that the surgical repair has not created additional defects (for example, destabilization of the mitral valve apparatus during aortic root reconstruction, or distortion of the tricuspid valve during ventricular septal defect repair). It should be emphasized that although valvular regurgitation can be detected by TEE with remarkable clarity, the quantitation of regurgitation by TEE has not been scientifically validated as a tool for guiding surgical decision-making.

**Future Directions**

The full potential of TEE in IE remains to be fully defined, and there are a number of questions to be
resolved by further studies. For example, are biplane transducers significantly better than single-plane instruments in the evaluation of suspected IE? Does a TEE negative for valvular vegetations in clinically bona fide IE identify a subset of patients appropriate for short-course or oral antibiotic treatment? Will TEE be useful to follow the adequacy and completeness of antibiotic therapy of IE by evaluating echocardiographic resolution of valvular vegetations? Will TEE-based tissue characterization enable one to distinguish infected from uninfected (marasmic) valve vegetations? Transesophageal echocardiography has certainly given us a clearer window with which to examine the heart both structurally and functionally. Moreover, this technique appears to have provided clinicians with a powerful tool for delineating important diagnostic and prognostic aspects of IE. 28-28

REFERENCES