OTTO

The Practice of Clinical Echocardiography

Second Edition

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The Practice of Clinical Echocardiography

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Second Edition

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VI

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The Role of Echocardiography in the Diagnosis and Management of Heart Disease in Pregnancy;
Echocardiographic Findings in Acute and Chronic Pulmonary Disease

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X

XI

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Preface

Echocardiography increasingly has become a key component in the routine evaluation of patients with suspected or known cardiovascular disease. As this technique has evolved and matured, the role of the echocardiographer has shifted from simply providing a description of images to providing an integrated assessment of echocardiographic data in conjunction with the other clinical data from each patient. In effect, echocardiography has become a specialized type of cardiology consultation.

The information now requested by the referring physician includes not only the qualitative and quantitative interpretation of the echocardiographic images and Doppler flow data but also a discussion of how this information might affect clinical decision making. Specific examples include decisions regarding medical or surgical therapy (e.g., treatment of endocarditis, surgery for aortic dissection), optimal timing of intervention in patients with chronic cardiac diseases (e.g., valvular regurgitation, mitral stenosis), prognostic implications (e.g., heart disease in pregnancy, heart failure patients), and the possible need for and frequency of periodic diagnostic evaluation (e.g., congenital heart disease, the postoperative patient).

This book reflects our role as *clinicians* with specialized expertise in echocardiography and is of value to cardiology fellows pursuing advanced training in echocardiography, cardiologists in clinical practice, researchers using echocardiographic techniques, and other individuals using echocardiographic approaches in the clinical setting (including anesthesiologists, radiologists, emergency medicine physicians, and obstetricians), as well as to cardiac sonographers, cardiovascular technologists, and nursing professionals.

Each chapter provides an advanced level of discussion, written by an expert in the field, building upon the basic material in the *Textbook of Clinical Echocardiography* (C. M. Otto, 2nd Edition, WB Saunders, Philadelphia, 2000). The emphasis is on optimal data acquisition, results of recent studies, quantitative approaches to data analysis, potential technical limitations, and areas of active research, in addition to a detailed discussion of the impact of echocardiographic data on patient management. Tables, line drawings, echocardiographic images, and Doppler tracings are used to summarize and illustrate key points. In this Second Edition, the text has been revised to reflect recent advances, illustrations and tables have been updated, and new references have been added to each chapter.

The book is organized into sections based on major diagnostic categories. In this new edition, an introductory section on *transesophageal echocardiography* has been added. Chapters include basic principles of transesophageal imaging, monitoring of ventricular function in the operating room, and a discussion of echocardiographic evaluation of aortic dissection and trauma. Other detailed information on the role of transesophageal echocardiography is integrated into subsequent chapters, which are organized by disease categories. The next section focuses on *the left ventricle*, with chapters spanning the spectrum from emerging new techniques (e.g., myocardial contrast echocardiography, automated edge detection, tissue characterization, three-dimensional echocardiography) to critical appraisals of quantitative techniques (e.g., left ventricular geometry and systolic function, evaluation of regional function, and assessment of diastolic function).

The section on *ischemic heart disease* includes chapters on the role of echocardiography in the emergency room and coronary care unit, stress echocardiography (exercise and nonexercise), and the basic principles, instrumentation, and clinical applications of intravascular ultrasound in patients with coronary artery disease. The critical role that echocardiography now plays in management of patients with *valvular heart disease* is evident in a section of chapters on technical aspects of echocardiographic evaluation, optimal timing of surgery and periodic evaluation of patients with valvular regurgitation, management of patients undergoing balloon mitral commissurotomy, clinical decision making in patients with endocarditis, evaluation of disease severity, progression in valvular aortic stenosis, and evaluation of prosthetic valves.

The following clinically oriented sections bring together data from both the echocardiographic and general cardiology literature to discuss the role of echocardiography in patients with *cardiomyopathies* (heart failure, hypertrophic cardiomyopathy, restrictive cardiomyopathy, and the post-transplant patient) *and pericardial disease, pregnant patients with cardiac disease*, and a wide range of *other vascular and systemic diseases* that lead to cardiac dysfunction (hypertension, aortic dissection, pulmonary disease, systemic immune-mediated diseases, renal disease, aging, systemic embolic events, and cardiac arrhythmias).

In recognition of the increasing number of adult patients presenting with *congenital heart disease*, either as a new diagnosis or following prior surgical procedures, three chapters are devoted to this topic. In addition, a new section has been added on the *echocardiography laboratory* to address issues that increasingly affect our clinical practice, including education and training of echocardiographers, quality improvement in the echocardiography laboratory, and the transition to a digital laboratory.

It is hoped that this book will provide the needed background to support and supplement clinical experience and expertise. Of course, competency in the acquisition and interpretation of echocardiographic and Doppler data depends on appropriate clinical education and training as detailed in accreditation requirements for both physicians and technologists, and as recommended by professional societies including the American Society of Echocardiography, the American College of Cardiology, and the American Heart Association. I strongly support these educational requirements and training recommendations;

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readers of this book are urged to review the relevant documents.

In addition, there continue to be advances both in the the technical aspects of image and flow data acquisition and in our understanding of the clinical implications of specific echocardiographic findings. This book represents our knowledge base at one point in time; readers should consult the current literature for the most up-to-date information. Although an extensive list of carefully selected references is provided with each chapter, the echocardiographic literature is so robust that it is impractical to include all relevant references; the reader can use an online medical literature search if an all-inclusive listing is desired.

Catherine M. Otto MD

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Section 1 - Transesophageal Echocardiography

1

Chapter 1 - Indications, Procedure, Image Planes, and Doppler Flows

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Transesophageal echocardiography (TEE) has become a valuable diagnostic imaging modality for the dynamic assessment of cardiac anatomy and function. Since the initial description of esophageal echocardiography in 1976,[1] the potential role and utility of TEE in the evaluation of diseases of the heart and great vessels have expanded to involve all aspects of cardiac disease. The close proximity of the esophagus to the heart and great vessels provided the echocardiographer with an easily accessible window with the potential for excellent visualization of cardiac structures, avoiding the intervening lung and chest wall tissues that limit transthoracic imaging. The potential of TEE to provide a valuable imaging tool became widely recognized in the 1980s with advancements in TEE probe technology, including the availability of single-plane phased array transducers and the addition of color flow and continuous wave Doppler imaging technology. TEE does not supplant transthoracic echocardiography

(TTE), however; it is a complementary imaging modality with its own strengths and weaknesses. The

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introduction of biplane TEE transducers in the late 1980s and multiplane transducers in the 1990s has resulted in a further expansion of potential diagnostic applications.

Perhaps the best evidence of TEE's diagnostic utility and value in patient management is the widespread use of this technology. TEE is found in the inpatient and outpatient ambulatory setting, in the operating room, in the intensive care unit, and in the emergency department. Currently, TEE accounts for approximately 5% to 10% of all echocardiography studies performed. The indications and utility of TEE will likely expand in the future with new technologic advancements such as three-dimensional echocardiography.

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Performance of Transesophageal Echocardiography

Transesophageal echocardiography is a semi-invasive procedure that should be performed only by a properly trained physician who understands the indications for and potential complications of the procedure. Both technical and cognitive skills are required for the competent performance and interpretation of TEE studies (Table 1-1) , and guidelines on training have been published.[2] The physician should be assisted by an experienced sonographer whose tasks are to ensure that optimal images are obtained by adjusting the controls of the echocardiographic system and to ensure safety by monitoring the responses of the patient during the procedure. Although family members or friends are usually not allowed in the room when the procedure is being performed, there are situations in which their presence can be helpful. The presence of a parent can have a calming effect when one is dealing with an apprehensive teenager. A friend or a relative who speaks the same language can relieve much of the anxiety when dealing with an anxious patient who is not fluent in English.

Transesophageal echocardiography should be performed in a spacious room that can comfortably accommodate a stretcher. The room should be equipped with an oxygen outlet and suction facilities. A pulse oximeter should be available, to be used mainly in cyanotic patients and patients with severe lung disease. The TEE probe should be carefully examined prior to each use. In addition to visual inspection, it is important to palpate the probe, particularly the flexion portion, to ensure that there is no unusual wear and tear of the probe.[3] Stretching of the steering cables may result in increased flexibility and mobility of the probe tip with buckling of the probe tip within the esophagus.[4] This phenomenon is associated with a poor TEE image and resistance to probe withdrawal. The probe should be advanced into the stomach and straightened by retroflexion of the extreme antiflexed probe tip. We have also detected perforation of the TEE probe sheath by a ruptured steering cable and recommend inspection of the casing for any protruding wires prior to probe insertion.[3] The flexion controls need to be tested on a regular basis. Anterior flexion should exceed 90 degrees, and right and left flexion should approach 90 degrees.

TABLE 1-1 -- Cognitive and Technical Skills Required for the Performance of Transesophageal Echocardiography (TEE)

Cognitive Skills
Knowledge of appropriate indications, contraindications, and risks of TEE
Understanding of differential diagnostic considerations in each clinical case
Knowledge of physical principles of echocardiographic image formation and blood flow velocity measurement
Familiarity with the operation of the ultrasonographic instrument, including the function of all controls affecting the quality of the data displayed
Knowledge of normal cardiovascular anatomy, as visualized tomographically
Knowledge of alterations in cardiovascular anatomy resulting from acquired and congenital heart diseases
Knowledge of normal cardiovascular hemodynamics and fluid dynamics
Knowledge of alterations in cardiovascular hemodynamics and blood flow resulting from acquired and congenital heart diseases
Understanding of component techniques for general echocardiography and TEE, including when to use these methods to investigate specific clinical questions
Ability to distinguish adequate from inadequate echocardiographic data and to distinguish an adequate from an inadequate TEE examination
Knowledge of other cardiovascular diagnostic methods for correlation with TEE findings
Ability to communicate examination results to patient, other health care professionals, and medical record
Technical Skills
Proficiency in performing a complete standard echocardiographic examination, using all echocardiographic modalities relevant to the case
Proficiency in safely passing the TEE transducer into the esophagus and

stomach and in adjusting probe position to obtain the necessary tomographic images and Doppler data
Proficiency in correctly operating the ultrasonographic instrument, including all controls affecting the quality of the data displayed
Proficiency in recognizing abnormalities of cardiac structure and function as detected from the transesophageal and transgastric windows, in distinguishing normal from abnormal findings, and in recognizing artifacts
Proficiency in performing qualitative and quantitative analysis of the echocardiographic data

From Pearlman AS, Gardin JM, Martin RP, et al: J Am Soc Echocardiogr 1992;5:187–194.

Preparation of Patient

Patients should be contacted at least 12 hours before the procedure and instructed to fast for at least 4 hours before the procedure. They are informed that they should be accompanied, because they will not be able to drive or return to work for several hours owing to the lingering effect of sedation. On the day of the study, the procedure is explained in greater detail, and informed consent is obtained. Patients are told to expect mild abdominal discomfort and gagging following the insertion of the probe and are reassured that these responses are transient. A 20-gauge intravenous cannula is then inserted for administration of medications and contrast agents, if necessary. Lidocaine hydrochloride spray is routinely used for topical anesthesia, which should cover the posterior pharynx and the tongue. We usually use diazepam 2 to 10 mg intravenously

for sedation.[5] Midazolam at 0.05 mg/kg, with a total dose between 1 and 5 mg, can also be used.

Sedation is used in about 85% of our patients and should be more sparingly used in elderly patients, because they tend to be more stoic and the effect of sedation is more likely prolonged. On the other hand, sedation is essential in young anxious patients and when the study is expected to be protracted. We aim for light sedation so that at the end of the procedure the patients are awake and can leave with an escort. Heavy sedation is needed in situations in which blunting the hemodynamic responses to the procedure is desirable. One obvious example is a patient undergoing TEE for suspected aortic dissection.[6]

It has not been our practice to use anticholinergic agents such as glycopyrrolate to decrease salivation. In the rare circumstances in which there is excessive salivation, it is usually adequate to simply instruct the patient to let the saliva dribble onto the towel placed under the chin, or the saliva can be removed by intermittent suction. Bacteremia is not a significant risk in TEE, and we do not use antibiotic prophylaxis to prevent endocarditis even in patients with prosthetic heart valves.[7] [8]

Esophageal Intubation

We perform the TEE study with the patient in the left decubitus position. The physician, the sonographer, and the echocardiographic system are all positioned on the left-hand side of the patient.[5] Artificial teeth or dentures are routinely removed. The flexion controls should be unlocked to allow for maximum flexibility of the probe when it is being inserted. The patient's head should be in a flexed position. The tip of the probe is kept relatively straight and gently advanced to the back of the throat. It should be maintained in a central position, because deviation to either side increases the likelihood that it may become lodged in the piriform fossa. The operator can facilitate this process by inserting one or two fingers into the patient's oropharynx to direct the path of the probe. Gentle pressure is exerted and the patient is instructed to swallow. The swallowing mechanism helps guide the probe into the esophagus. In older patients, cervical spondylosis with prominent protrusion into the posterior pharynx can create difficulty with passage of the probe.[5] Manually depressing the back of the tongue provides more room, allowing the TEE probe to assume a less acute angle and facilitating the intubation of the esophagus. If significant resistance is encountered when the probe is advanced, it is prudent to withdraw the probe and then initiate a new attempt. Esophageal intubation is more difficult with the multiplane probe than with the smaller monoplane and biplane probes.[9] [10] The latter can be used, if available, when esophageal intubation cannot be achieved with a multiplane probe. In experienced hands, the rate of failure of esophageal intubation should be less than 2%.[5] [9] [11]

A bite guard should always be used, except in edentulous patients. Our practice is to put it between the patient's teeth after the TEE probe has been successfully passed into the esophagus. Patients with a very sensitive pharynx may close their mouths involuntarily during esophageal intubation. In these patients, it is safer to insert the bite guard before the insertion of the TEE probe. The patient should be instructed to keep the guard between the teeth throughout the procedure, and regular checks should be made to ensure that it is in the proper position to prevent damage to the probe or injury to the patient.

Even when the probe is inserted without difficulties, it is not uncommon for the patient to develop nausea with or without mild retrosternal or abdominal discomfort. We find it useful to pause for 10 to 15 seconds to allow these symptoms to subside before proceeding with echocardiographic imaging. Our practice is to start with images acquired from the esophagus before advancing the probe into the stomach for the gastric views. The gastroesophageal sphincter is usually reached when the probe is advanced 40 cm from the teeth. Gentle pressure is all that is required to advance the probe through the gastroesophageal sphincter. The patient may again experience nausea and mild discomfort, and it may be advisable to pause momentarily for these symptoms to subside. Imaging of the proximal descending thoracic aorta and aortic arch is generally reserved for the end of the study, because the probe needs to be positioned in the upper esophagus and the patient is generally more aware of the probe at this position and tends to have more discomfort and gagging.

Inadvertent passage of the probe into the trachea can occur, particularly in deeply sedated patients. The development of stridor and incessant cough should alert the operator of this possibility. Furthermore, it would be difficult to advance the probe beyond 30 cm from the teeth and the image quality is usually poor.[5]

In patients on mechanical ventilation, esophageal intubation is more difficult. We usually introduce the probe with the patient lying supine, because the airway is protected and aspiration is unlikely. The probe is positioned behind the endotracheal tube and gently advanced. It is helpful to have the patient's mandible pulled forward when the probe is being advanced. If there is undue resistance at about 25 to 30 cm from the teeth, slight deflation of the cuff of the endotracheal tube can be considered to ease the passage of the probe. We do not usually remove the gastric tube, which can be used as a guide to help in the proper positioning and passage of the TEE probe. In a minority of intubated patients, successful esophageal intubation may be achieved only with direct laryngoscopy.

Image Format

There is no general agreement on how the imaging planes should be displayed. Our preference is to orient the images such that the right-sided structures are on the left side of the screen and the left-sided on the right. The apex of the imaging plane with the electronic artifact is at the top of the screen. Thus, in the longitudinal views, superior structures are to the right of the screen and the inferior to the left.[12]

TABLE 1-2 -- Standard Imaging Planes with Multiplane Transesophageal Echocardiography (TEE) at the University of Ottawa Heart Institute

Imaging View	Standard Imaging Plane	Angle of Imaging Array (degrees)	Main Cardiac Structures
Basal	Aortic valve	0–60	Aortic valve, coronary arteries, left atrial appendage, pulmonary veins
	Atrial septum	90–120	Fossa ovalis, superior vena cava, inferior vena cava
	Pulmonary bifurcation	0–30	Pulmonic valve, main and right pulmonary arteries, proximal left pulmonary artery
Four-chamber	Left ventricle	0–180	Left ventricle (regional and global function), right ventricle, tricuspid valve
	Mitral valve	0–180	Anterior and posterior mitral leaflets, papillary muscles, chords
	Left ventricular outflow tract	120–160	Aortic valve, ascending aorta, left and right ventricular outflow tracts, pulmonic valve, main pulmonary artery
Transgastric	Left ventricle	0–150	Left ventricle, right ventricle, tricuspid valve
	Mitral valve	0–150	Anterior and posterior mitral leaflets, papillary muscles,

			chords
	Coronary sinus	0	Coronary sinus, tricuspid valve
Aortic	Descending thoracic aorta	0	Entire descending thoracic aorta
	Aortic arch	90	Aortic arch, arch vessels, left pulmonary artery

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Standard Imaging Planes

Advances in TEE transducer technology have culminated in the development of the multiplane probe capable of two-dimensional and color flow imaging in multiple planes. The imaging plane can be steered electronically from 0 to 180 degrees by means of a pressure-sensitive switch, providing views unattainable by monoplane and biplane probes. The following discussion focuses only on standard imaging views routinely performed at the University of Ottawa Heart Institute using multiplane TEE (Table 1-2) . These views are considered "standard" because they have important clinical relevance and can be obtained in most patients with specific imaging planes.

Four basic maneuvers are used to obtain specific tomographic views with TEE.[13] The first relates to the positioning of the probe by advancement or withdrawal of the probe. Although this is a simple maneuver, it is the most crucial, and the imaging views can be conveniently categorized according to the location of the TEE probe within the esophagus or stomach (Fig. 1-1) . The second maneuver involves rotation of the probe from side to side. This is particularly useful when using longitudinal imaging planes, which provide a better demonstration of the continuity between vertically aligned structures such as the superior vena cava and the arch vessels.[12] [13] Steering the imaging plane using the pressure-sensitive switch is the third maneuver to obtain different tomographic views. The ability to image cardiac structures from 0 to 180 degrees not only enhances understanding of cardiac anatomy but also provides a ready means for three-dimensional reconstruction. [14] [15] The fourth maneuver involves manipulation of the anterior-posterior and right-left flexion control knobs. The availability of a steerable imaging plane has drastically reduced the need to use the flexion knobs, but there are situations in which these knobs play a crucial role in obtaining proper tomographic views.[10] [13]

The versatility of multiplane TEE provides an almost infinite number of