Anesthesiology
76:165–172, 1992

Intraoperative Echocardiography for Evaluation of Congenital Heart Defects in Infants and Children

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To determine the accuracy, utility, and limitations of intraoperative transesophageal echocardiography (TEE) in infants and children, we performed prebypass and postbypass TEE in 90 children undergoing surgical repair of congenital heart lesions, comparing the results to those obtained using intraoperative epicardial echocardiography and pre- and postoperative precordial echocardiography. Patients ranged in age from 4 days to 21 yr (mean 4.1 yr) and in weight from 3 to 68 kg (mean 15.4 kg). Prebypass, we obtained high-quality, two-dimensional TEE images in 86 patients, with correction of the preoperative precordial diagnosis in 3 and confirmation of the preoperative diagnosis in the rest. Adequate epicardial images were obtained in 78 patients, with confirmation of the preoperative diagnosis in all. Shunt lesions that were well delineated prebypass by both TEE and epicardial imaging included interatrial, interventricular, and atrioventricular septal defect lesions. TEE failed to detect the exact size and location of lesions involving the right ventricular outflow tract, *i.e.*, doubly committed subarterial (supracristal) ventricular septal defects. Regurgitant lesions (n = 30) were identified and their severity evaluated in all patients by both TEE and epicardial imaging. Obstructive lesions (n = 33), excluding those involving the right ventricular outflow tract, were well defined by both echocardiographic approaches. Postbypass, we obtained high-quality, two-dimensional, color and Doppler TEE images in 86 patients and epicardial images in 78 patients. Compared with postoperative precordial imaging, TEE accurately showed the absence of hemodynamically significant shunt lesions in each of the 64 patients who had definitive shunt repairs, falsely overestimated the degree of postbypass valvular regurgitation 5 of the 30 patients with valvular regurgitation, and could not identify the degree of pulmonic insufficiency in 7 patients with tetralogy of Fallot. Results from epicardial echocardiography concurred with TEE results and accurately detected the presence or absence of all residual shunts and regurgitation, as well as the severity of residual defect. Mild residual obstruction was detected accurately by both TEE and epicardial imaging, except that TEE could not fully assess those involving the right ventricular outflow tract. We conclude that TEE provides accurate imaging of important morphologic and flow features of most pediatric congenital heart lesions and provides an accurate assessment of the surgical repair. It may improve diagnostic accuracy in some patients who have undergone precordial echocardiography and has the advantage of offering accuracy equal to that obtained using epicardial echocardiography. **(Key words: Anesthesia: pediatric. Monitoring techniques, transesophageal echocardiography: color Doppler; epicardial; two-dimensional; precordial; pulsed Doppler. Surgery, cardiac: congenital.)**

This article is accompanied by an editorial. Please see: Weintraub RG, Sahn DJ: Pediatric transesophageal echocardiography: Present and future. ANESTHESIOLOGY 76:159–160,1991.

TRANSESOPHAGEAL ECHOCARDIOGRAPHY (TEE) is currently used intraoperatively in adult patients for the evaluation of valvular repair[1,2] and prosthetic valve function,[3,4] as well as for monitoring myocardial ischemia[5–8,]†† and adequacy of preload[9,10,]‡‡. The benefit of immediate detection of inadequate cardiac surgical repairs in adults improves the efficacy of surgical corrections§§,¶¶ and subsequent reoperations can be avoided, thereby reducing morbidity, mortality, and cost. Until recently, intraoperative echocardiography for evaluation of surgical repairs in infants and smaller children has been limited to epicardial imaging[11] because there has been no transesophageal probe small enough for use in pediatric patients. The recent development of a small probe (6.9 mm compared to 9.9 mm) has generated preliminary studies[12–16,]*** indicating that this technique can be performed well and safely in pediatric patients. We recently published data[17] describing the utility of TEE in patients

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Received from the Departments of Anesthesia, Pediatrics, and Cardiovascular Surgery, and the Cardiovascular Research Institute, University of California, San Francisco, San Francisco, California. Accepted for publication August 28, 1991.

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†† Schiller NB, Cahalan MK, Lee E: Intraoperative assessment of left ventricular function and wall motion by transesophageal echocardiography. Echocardiography 6:79–85, 1989.

‡‡ Clements FM, Harpole D, Quill T, Jones RH, Aladj J, McCann R: Simultaneous measurements of cardiac volumes, areas and ejection fractions by transesophageal echocardiography and first pass radionuclide angiography (abstract). ANESTHESIOLOGY 69:A4, 1988.

§§Currie PJ, Stewart WJ, Salcedo EE, Agler DA, Lytle BM, Gill CC, Cosgrove DM: Comparison of intraoperative transesophageal and epicardial color flow Doppler in mitral valve repair (abstract). J Am Coll Cardiol 11:20A, 1988.

¶¶ Stewart JW, Currie PJ, Agler DA, Lytle BW, Lombardo HP, Cosgrove DM: Periprosthetic mitral and aortic regurgitation: Utility of pre- and intra-operative Doppler color flow mapping (abstract). J Am Coll Cardiol 11:20A, 1988.

***Ritter SB, Thys D: Pediatric transesophageal color flow imaging: Smaller probes for smaller hearts. Echocardiography 2:431–440, 1989.

with intracardiac shunt lesions. These patients were included in this report to present an all-inclusive study of patients with a spectrum of congenital heart defects (shunt, regurgitant, and obstructive defects).

In patients with congenital heart disease, the primary objectives of intraoperative TEE are to confirm preoperative diagnoses and, more importantly, to permit the direct evaluation of surgical repair. This allows for the immediate correction of severe residual defects and thus avoids the potential need for further surgery. Additionally, if TEE can be used reliably to detect residual defects following congenital heart surgery, this technique could be substituted for the epicardial technique now used. The present study evaluates the accuracy, utility, and limitations of intraoperative TEE in infants and children undergoing surgical repair of congenital heart lesions by comparing the intraoperative TEE diagnosis of lesions and evaluation of surgical repair with both pre- and postoperative precordial echocardiographic and intraoperative epicardial echocardiographic results.

Materials and Methods

We studied 90 consecutive patients undergoing surgical treatment of congenital cardiac defects, excluding those having a known airway or esophageal anomaly or disease (table 1). All patients were ASA physical status 3 and were studied with approval from the Committee on Human Research at the University of California, San Francisco.

Following induction of anesthesia with halothane, anesthesia was maintained with intravenous opioids (fentanyl or morphine) administered at the discretion of the attending anesthesiologist. Paralysis was maintained using vecuronium and pancuronium. Routine intraoperative monitoring included intraarterial pressure monitoring *via* an arterial catheter usually placed before tracheal intubation. TEE was used to monitor the short-axis view of the left ventricle to estimate function and preload throughout surgery.[5–8,†]

TABLE 1. Division of Lesions into Shunt, Regurgitant, and Obstructive

Shunt Lesions (n = 71)		Regurgitant Lesions (n = 30)		Obstructive Lesions (n = 33)	
ASD-P	3	AI	2	CT	1
ASD-S	8	AI/PI	1	Complex obstructions	9
ASD/VSD	9	AS/AI	2	DCRV	2
AVSD	11	MR	4	HLH	1
BHAS	1	MR/TR	10	PS	4
CT	1	PS/PI	2	SAS	4
SVASD	2	TOF (PI)	7	TOF	10
Senning	1	TR (Ebstein's)	2	Valvar AS	2
TOF	11				
Truncus	2				
VSD-DCSA	9				
VSD-Complex	7				
VSD-PM	6				

AI = aortic insufficiency; AS = aortic stenosis; ASD = atrial septal defect; ASD-P = atrial septal defect, primum; ASD-S = Atrial Septal Defect, secundum; AVSD = atrioventricular septal defect; BHAS = Blalock Hanlon atrial septostomy; CT = cor triatrum; DCRV = double-chambered right ventricle; DCSA = doubly committed subarterial; HLH = hypoplastic left heart; MR = mitral regurgitation; PI = pulmonic insufficiency; PM = perimembranous; PS = pulmonic stenosis; SAS = subaortic stenosis; SVASD = sinus venosus atrial septal defect; TOF = tetralogy of Fallot; TR = tricuspid regurgitation; VSD = ventricular septal defect.

Additional echocardiographic studies were performed using both TEE and epicardial imaging. Results of these studies were supplied to the surgeon intraoperatively as needed and recorded on S-VHS tape for later playback and analysis by research investigators. For transesophageal imaging in children weighing <20 kg (n = 77), a uniplane 5-MHz 26-element phased array probe of 6.9-mm maximum diameter (Aloka/Corometrics model UST 5233-5) was used. In 9 of the 13 children weighing >20 kg, a standard uniplane adult probe (9.9-mm diameter) was used, and in the remaining 4 patients, a bipolar matrix phased array probe (also 9.9-mm diameter) was acquired later in the study. For epicardial imaging, a 5-MHz precordial probe (Aloka/Corometrics model UST 5232-5) covered by a sterile sheath was used. All three probes interfaced with the Aloka/Corometrics model 870 echocardiographic system and provided two-dimensional, color Doppler, and pulsed Doppler capabilities. All studies were performed before cardiopulmonary bypass and after bypass before the removal of the venous or arterial cannulae. All images were obtained in real time and simultaneously interpreted by anesthesiologist (IAM) and the cardiology fellow (DAR) and the surgeons (KT and GSH). The echocardiographers (IAM and DAR) were aware of the preoperative diagnosis as printed on the operating room schedule but were blinded to the cardiac catheterization and preoperative precordial echocardiograms. This provided a mechanism for intervening with clinical management when necessary while retaining some level of objectivity during the echocardiographic exams.

Transesophageal Echocardiographic Studies

These studies began after induction of general anesthesia, administration of intravenous antibiotics, tracheal intubation, and thorough suctioning of gastric contents and were conducted by the anesthesiologist (IAM) and the cardiology fellow (DAR). The transesophageal probe (unlocked) was passed into the patient's esophagus, and, when necessary (n = 3), a laryngoscope was used to guide the probe's passage through the hypopharynx.

To provide a series of short-axis views encompassing the basal to transgastric levels, we manipulated the probe in three directions: advancing or withdrawing, anteflexing or retroflexing, and rotating it clockwise or counterclockwise relative to the midline sagittal plane. Beginning at the base of the heart, we obtained the first short-axis view and then anteflexed the probe slightly to view the aorta, pulmonic valve, and proximal pulmonary artery. Once in this position, the probe was advanced 0.5–1.5 cm to produce views of the proximal ascending aorta and proximal coronary arteries; subsequently, clockwise rotation imaged the left pulmonary veins and counterclockwise rotation, the right pulmonary veins, superior vena cava, and right atrial appendage. Advancing the probe an additional 0.5–1.5 cm produced views of the interatrial septum, tricuspid valve, and right ventricular inlet region; subsequent anteflexion displayed the right ventricular outflow tract. We then advanced the probe into the stomach to obtain transgastric horizontal-axis views of multiple cross-sections of the mitral valve and papillary muscles of the left ventricle and oblique views of the right ventricle. Withdrawing the probe to a midpoint between transgastric and basal short-axis placement produced a transesophageal four-chamber view of the interatrial and interventricular septa and the atrioventricular valves; subsequent probe anteflexion and counterclockwise rotation provided an image of the left ventricular outflow tract and mitral valve, an oblique view of the right ventricle, and a clear image of the membranous region of the interventricular septum. In children with very complex lesions, some transesophageal examinations required a considerable amount of time to image.

Epicardial Echocardiographic Studies

These studies began once the pericardium was opened and were completed in a 5-min period. They were performed by the surgeon (KT or GSH) in collaboration with an echocardiographer without flooding the pericardial sac with saline. The epicardial probe was manipulated using standard methods to obtain the standard long- and short-axis views, but it frequently required slight rotation, tilting, or repositioning from the standard positions to produce high-quality images. The initial epicardial view was a left ventricular long-axis view. Next the probe was manipulated through an arc oriented perpendicular to the long-axis plane, first left and superior and then right and posterior to the plane, and then was returned to the initial left ventricular long-axis view. Subsequent clockwise rotation 90° provided a left ventricular short-axis view from which the probe was swept through a plane paralleling the long axis to obtain a series of short-axis images ranging from cardiac apex to base. Subsequent positioning as near to the cardiac apex as the site of incision would permit, and superior to the base, provided an apical four-chamber view (often a foreshortened view because the transducer could not be positioned over the apex due to the median sternotomy). The probe was then swept (anteriorly and posteriorly) through an arc paralleling the interventricular septum to obtain views of septal defects.

Data Analysis

Diagnoses obtained from intraoperative prebypass transesophageal and epicardial imaging were compared with preoperative precordial echocardiographic diagnoses to determine which of the two intraoperative techniques more accurately and completely identified lesions. Prebypass echocardiograms also were compared to direct intraoperative inspection to evaluate their accuracy. The results of immediate postbypass TEE, including color Doppler and pulsed-wave Doppler analysis, were compared with those from postbypass epicardial echocardiography and postoperative precordial echocardiography to evaluate how TEE compared with epicardial imaging in detection of residual defects immediately following surgical repair and to determine how well both intraoperative techniques performed relative to postoperative imaging. Data from patients having more than one type of lesion were included in the analysis of each type. Results of all three echocardiographic techniques were compared using Fisher's exact test, and a value of $P < 0.05$ was used to identify significant differences.

Results

Patients ranged in age from 4 days to 21 years (mean, 4.1 yr) and in weight from 3 to 68 kg (mean 15.4 kg). Analyzable intraoperative TEE images were obtained in 86 of 90 patients: in 75 of 86 with the pediatric probe, in 5 of 86 with the uniplane adult probe, and in 6 of 86 with the biplane adult probe. Data from the remaining four patients were excluded from analysis because one developed severe bronchospasm after TEE probe placement, and three had poor-quality echocardiograms. Epicardial echocardiographic images were obtained in 78 of the 86 patients that had transesophageal echocardiograms. Analysis of data from the remaining patients was excluded by the induction of arrhythmias, with or without hypotension, during probe placement (n = 3) or by probe unavailability (n = 5). There were no other complications or interference in the anesthetic or surgical management.

Transesophageal versus Epicardial Echocardiography

Precordial echocardiographic diagnoses had identified intracardiac shunt lesions in 71 patients, regurgitant valve defects in 30, and obstructive lesions in 33. Both TEE and epicardial imaging confirmed, corrected, or missed some of these diagnoses, and each technique failed to display the morphology of specific lesions. Image quality generally was superior with the epicardial technique.

SHUNT LESIONS

Prebypass

TEE provided adequate intraoperative data for 68 of 71 shunt lesions, confirming the preoperative diagnosis in 65 and correcting it in 3, but failed to diagnose the defect correctly in the remaining 3 cases. Epicardial imaging provided information for 69 of 71 shunt lesions, confirming the preoperative diagnosis in 66 and correcting it in 3 (the same 3 as did TEE) and failing in the remaining 2 cases. Both techniques delineated interatrial, interventricular and atrioventricular septal defects well. TEE echocardiograms of these defects are demonstrated in figures 1 and 2.

The preoperative diagnoses corrected intraoperatively by both techniques were two patients with ostium secundum atrial septal defect and perimembranous ventricular septal defect (with persistent left superior vena cava connecting to a markedly dilated coronary sinus; fig. 3) that were preoperatively identified as atrioventricular septal defect; and one patient with pulmonary hypertension and multiple small muscular ventricular septal defects that were undetected preoperatively. The missed lesions were doubly committed subarterial ventricular septal defect (TEE only) and sinus venosus atrial septal defect (epicardial imaging only). TEE provided useful but only partial information on the doubly committed subarterial ventricular septal defects, successfully imaging fibrous continuity between the aortic and pulmonic valves (*i.e.*, the deficiency of the septal outlet) (in three of nine patients) and successfully imaging turbulent flow in the outflow tract of the right ventricle (in nine of nine patients) but failing to detect either the size or precise location of ventricular septal defect (in seven of nine patients). Biplane imaging provided better visualization of the lesion (in two of nine patients). Epicardial imaging could not completely

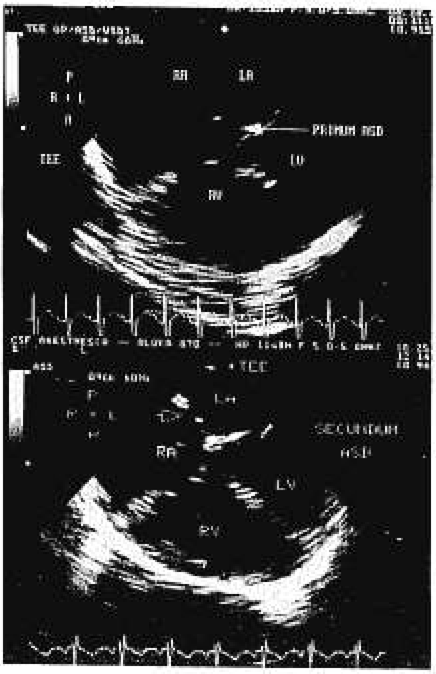

FIG. 1. Interatrial communication viewed from the transesophageal four-chamber view. Each is indicated by an arrow in the respective figure. *Top:* Ostium primum atrial septal defect (ASD). *Bottom:* Ostium secundum ASD. RA = right atrium; LA = left atrium; RV = right ventricle; LV = left ventricle.

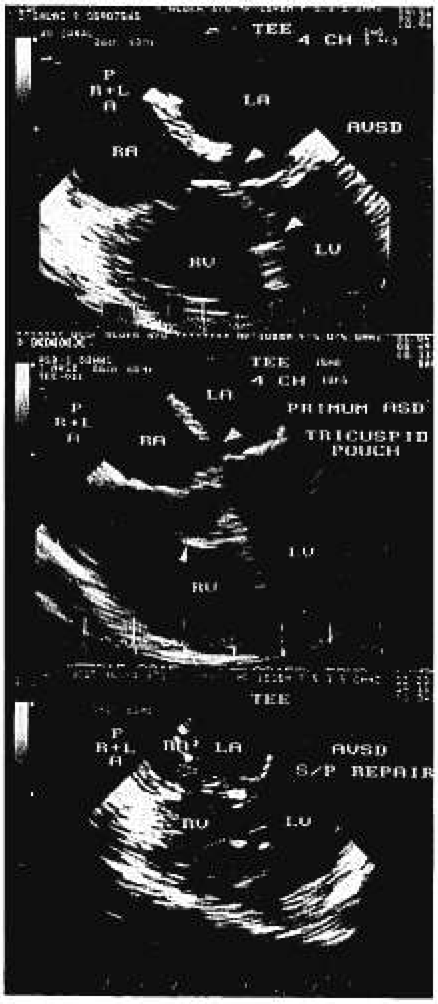

FIG. 2. Transesophageal echocardiographic view of a complete atrioventricular septal defect. Top TEE four-chamber view of a compete atrioventricular septal defect (AVSD). There is minimal bridging of the anterosuperior bridging leaflet, of which the chordal attachments to the ventricular septum is shown by the solid arrow. *Middle:* A divided atrioventricular valve, ostium primum atrial septal defect (top arrow), tricuspid pouch (bottom arrow), and a very small ventricular septal defect just inferior to the atrioventricular valve at the crest of the ventricular septum. *Bottom:* TEE four-chamber postbypass echocardiogram of a complete AVSD of the atrial (top arrow) and ventricular (bottom arrow) septal patch. RA = right atrium; LA = left atrium; RV = right ventricle; LV = left ventricle.

FIG. 3. *Top:* Transesophageal view of a secundum atrial septal defect (ASD) with a persistent left superior vena cava (LSCV; asterisk) draining to a coronary sinus (CS; open arrows). *Bottom:* Transesophageal four-chamber view of the dilated CS (solid arrow). RA = right atrium; LA = left atrium; RV = right ventricle; LV = left ventricle.

visualize sinus venosus atrial septal defect with partial anomalous pulmonary venous connection because the site of median sternotomy prevented viewing from the epicardium. TEE completely visualized this defect in one case but only partially in another, missing the anomalous pulmonary venous connection.

Overall, prebypass TEE provided adequate intraoperative information in 68/71 (96%) cases, and epicardial echocardiography in 69/71 (97%). This difference was not significant.

Postbypass

Definitive shunt repairs were performed in 64 patients and palliative procedures in the remaining 7 patients. Of the 64 undergoing corrective procedures, neither technique detected significant intraoperative residual defects in 51 patients (80%); small residual shunts were detected in 12 patients (19%); and a moderate-sized residual ventricular septal defect was detected in 1 (2%). No additional surgery was performed in any patient, including the latter case. Postoperative precordial echocardiography detected the presence of shunts in 5 patients that were not detected intraoperatively by either TEE or epicardial echocardiography. All of these leaks were deemed to be trivial and not significant. Trivial shunts were determined to be those with narrow-based jets that did not extend far into the receiving chamber. They were classified as insignificant because of the absence of clinical symptoms.

Regurgitant Lesions

Color Doppler flow-mapping classified the degree of valvular regurgitation as mild, moderate, or severe in the 30 patients with these lesions.

Prebypass

Both TEE and epicardial imaging identified in all patients the congenital cardiac anomaly causing the valvular regurgitation, and both provided diagnostic-quality two-dimensional and color Doppler flow echocardiograms of all four valves for assessment of the presence and severity of regurgitation.

Postbypass

Both TEE and epicardial imaging provided comparable estimates of the severity of residual regurgitation. When compared with postoperative precordial assessment, both techniques also overestimated immediate residual severity in five patients but were otherwise as accurate as postoperative assessment within 6 days of surgery. In all five cases regurgitation was classified intraoperatively as moderate but postoperatively as mild. Two of these patients had both mitral and tricuspid regurgitation; two had mitral regurgitation only; and one had aortic regurgitation associated with a doubly committed subarterial ventricular septal defect.

Epicardial echocardiography evaluated surgical repair well in all cases, whereas uniplane TEE in 28 patients could not adequately assess residual pulmonic insufficiency or stenosis because the right ventricular outflow tract often was difficult to image (fig. 4, top). Epicardial imaging clearly showed the entire right ventricular outflow tract (fig. 4, bottom). However, the use of the biplane TEE probe in two patients with tetralogy of Fallot provided good images of the right ventricular outflow tract and residual pulmonic insufficiency, permitting an evaluation of repair with two-dimensional and color Doppler flow echocardiography.

Obstructive Lesions

Prebypass

TEE confirmed the preoperative diagnosis in 29 of the 33 patients who had obstructive lesions and failed to confirm the diagnosis in the remaining 4 patients. Epicardial imaging and two-dimensional and color Doppler flow echocardiography confirmed the preoperative diagnosis in all patients, correcting none. Definitive surgery was performed in 29 of the 33 patients.

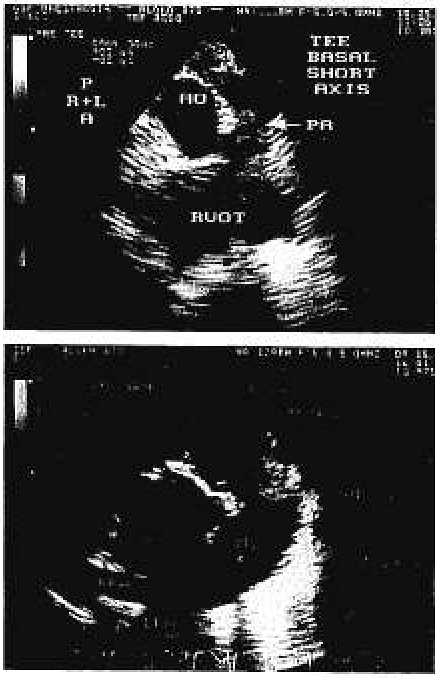

FIG. 4. *Top:* Transesophageal view of a patient with tetralogy of Fallot showing incompletely the subpulmonic stenosis (solid arrow) *Bottom:* Epicardial imaging of the same patient showing clearly the residual pulmonic stenosis and the right ventricular outflow patch (open arrow). RA = right atrium; LA = left atrium; RV = right ventricle; RA = right atrium.

Postbypass

TEE could not assess the surgical correction in four of nine patients who had tetralogy of Fallot because it failed to image the right ventricular outflow tract. Both TEE and epicardial imaging detected mild residual obstruction in all patients with double-chambered right ventricles (n = 2), subaortic stenosis (n = 2), and subpulmonic stenosis.

Discussion

This report describes the advantages, disadvantages, potentials and limitations of TEE in the assessment of surgical repair in a series of pediatric patients having a wide spectrum of congenital heart disease. Initially, intraoperative assessment of surgical repair involved epicardial echocardiography only.[11] More recently, we and others have described,[12–18,***] the role of TEE in a small series of patients and showed that TEE was useful and safe for intraoperative monitoring and evaluation of surgical repair. We now have performed an inclusive study of a wide variety of congenital heart defects including shunt, regurgitant, and obstructive lesions in patients as small as 3 kg.

We have also compared the intraoperative assessment of surgical repair by TEE to the postoperative assessment by precordial echocardiography to determine whether residual lesions detected intraoperatively are present postoperatively; *i.e.*, to determine if TEE is a useful clinical monitor in the operating room for patients undergoing surgical correction of congenital heart lesions. For TEE to have a purpose in the operating room we believe the technique should be able to determine whether the lesion has been repaired adequately and whether residual surgical problems exist. It should also be able to be used as a monitoring device.

Our findings have demonstrated that intraoperative TEE defines the anatomy of the usual spectrum of congenital heart diseases in infants and children and also provides an accurate assessment of the adequacy of surgical repair. A correct and complete prebypass intraoperative diagnosis, either confirmatory or new, was obtained in all of our cases, excluding those with doubly committed subarterial ventricular septal defects, tetralogy of Fallot, and anomalous pulmonary venous connections. Of significance in this study is the demonstration that intraoperative TEE plays an important role in the surgical management of congenital heart disease. For example, the finding of a persistent left superior vena cava to a markedly dilated coronary sinus in two cases was very important to the surgical approach, since the presence of a left superior vena cava alters the venous drainage crucial to repair of atrial septal defects and thus affects the placement of the venous cannulas. Also, during the early phase of the study, we detected a residual subaortic membrane that was present immediately postbypass. No further surgery was done at that time because it was early in the study and we were not certain of the validity of our findings. However, the residual membrane was confirmed on postoperative studies, and the patient required reoperation.

Subsequently, our practice has been to analyze carefully the postoperative TEE for residual shunt regurgitant and obstructive lesions. If residual septal defects are detected postbypass by color flow-mapping, then we confirm their presence by performing simultaneous right atrial and pulmonary artery blood gas analyses. If residual obstructive lesions are present then the surgeon performs estimates of pressure with a fluid-filled catheter. No hemodynamically significant residual shunt, regurgitant, or obstructive lesions were missed by this technique, although the incidence of these residual lesions was small. Other investigators[2–16,***] have found this technique accurate and useful in the evaluation of children with congenital cardiac anomalies, and Ritter[18] has reported a degree of accuracy with congenital anomalies similar to our own.

We have shown that intraoperative transesophageal imaging can be easily performed in patients weighing ≥3 kg. There was no incidence of gastrointestinal complications such as hematemesis or dysphagia in any of our patients. The relative safety of this technique has been also documented by several other studies.[18-21] *Post mortem* examination in the smallest patient (3 kg) showed a normal esophagus.

From the point of view of the anesthesiologist, TEE appears to have several advantages over epicardial imaging. It does not interrupt the surgical procedure and provides continuous on-line monitoring of ventricular function and volume. Because there is no direct contact with the heart, it avoids potential complications such as dysrhythmias or the contamination of the surgical field. Complete examinations were possible except for lesions involving the right ventricular outflow tract.

Epicardial echocardiography has the advantages of appearing to require no limitations on minimum patient size and no investment in specialized and expensive equipment. Image quality generally is superior to that obtained by the transesophageal technique. Some epicardial probes have continuous-wave Doppler capability that would allow for analysis of higher-flow velocities; this is not possible with the transesophageal equipment currently available. However, there are significant disadvantages of epicardial echocardiography; it interrupts surgery, permits only intermittent monitoring, and requires direct contact to the heart that may induce arrhythmias and hypotension. There were three cases in our series in which epicardial imaging was not completed due to this adverse reaction; however, these occurred early in the study. After more experience with handling the epicardial probe, significant arrhythmias were avoided.

The single-plane miniaturized pediatric transesophageal probe has notable limitations. The theoretical objections to the number of elements in this probe seem to be counterbalanced by its excellent penetration and near-field resolution that render images of adequate diagnostic quality. However, imaging of the right ventricular outflow tract can be difficult because of the distance of this structure from the probe. This deficiency was offset by the use of a biplane probe,††† which provides both an orthogonal and conventional view, resulting in accurate and complete right ventricular outflow tract imaging by the longitudinal plane in the few in whom a biplane probe was used. The finding that the longitudinal plane is valuable for imaging the right ventricular outflow tract and pulmonary arteries was corroborated by Ritter[18] and Elkadi *et al.*[22] The biplane probe can be used safely in larger children (≥ 20 kg) but lacks continuous-wave Doppler capabilities at this time. The absence of continuous-wave Doppler capability makes transesophageal echocardiographic assessment of higher-flow velocities impossible, and thus epicardial imaging becomes necessary in some patients.

TEE is now available for use in pediatric patients and will in the future become an integral part of management. Anesthesiologists involved in the care of patients with congenital heart disease will find that knowledge of the echocardiograms will aid in the understanding of the complex physiology and anatomy and hence in their clinical care.

††† Omoto R, Kyo S, Matsumura M, Shah P, Adachi H, Matsunaka T: Biplane color Doppler transesophageal echocardiography: Its impact on cardiovascular surgery and further technological progress in the probe, a matrix phased-array biplane probe. Echocardiography 6:423–430, 1989.

References

1. Goldman ME, Mora F, Guarino T, Fuster V, Mindich BP: Mitral valvuloplasty is superior to valve replacement for preservation of left ventricular function: An intraoperative two-dimensional echocardiographic study. J Am Coll Cardiol 10:568–575, 1987
2. Taams MA, Gussenhoven EJ, Cahalan MK, Roelandt J, van Herwerden LA, The HK, Bom N, de Jing N: Transesophageal Doppler color flow imaging in the detection of native and Bjork-Shiley mitral valve regurgitation. J Am Coll Cardiol 13:95–99, 1989
3. Nellesen U, Schnittger I, Appleton CP, Masuyama T, Bolger A, Fischell TA, Tye T, Popp RL: Transesophageal two-dimensional echocardiography and color Doppler flow imaging in patients with mechanical prosthesis in the mitral valve position. Circulation 78:848–855, 1988
4. Van der Brink, RBA, Visser CA, Basart DCG, Duren DR, de Jong AP, Dunning AJ: Comparison of transthoracic and transesophageal color Doppler flow imaging in patients with mechanical prosthesis in the mitral valve position. Am J Cardiol 63:1471–1474, 1989
5. Smith JS, Cahalan MK, Benefiel DJ, Byrd BF, Lurz FW, Shapiro WA, Roizen MF, Bouchard A, Schiller NB: Intraoperative detection of myocardial ischemia in high risk patients: Electrocardiography versus two-dimensional transesophageal echocardiography. Circulation 72:1015–1021, 1985
6. Beaupre PN, Cahalan MK, Lurz WF, Schiller NB, Hamilton WK: Intraoperative detection of changes in left ventricular segmental wall motion by transesophageal echocardiography. Am Heart J 107:1021–1023, 1984
7. Clements FM, de Brujin NP: Perioperative evaluation of regional wall motion by transesophageal two-dimensional echocardiography. Anesth Analg 66:249–261, 1987
8. Cahalan MK, Litt L, Botvinik EH, Schiller NB: Advances in noninvasive cardiovascular imaging: Implications for the anesthesiologist. ANESTHESIOLOGY 66:356–372, 1987
9. Debrujin NP, Clements FM: Transesophageal Echocardiography. Boston, Martinus Nijhoff, 1987
10. Abel MD, Nishimura RA, Calahan MJ, Rehder K, Ilstrup DM, Tajik AJ: Evaluation of intraoperative transesophageal two-dimensional echocardiography. ANESTHESIOLOGY 66:64–68, 1987
11. Ungerleider RM, Kisslo JA, Greeley WJ, Van Tright P, Sabiston DC: Intraoperative pre-bypass and post-bypass epicardial color flow imaging in the repair of atrioventricular septal defects. J Thorac Cardiovasc Surg 98:90–100, 1989

12. Cyran SE, Kimball TR, Meyer RA, Bailey WW, Lowe E, Balisteri WF, Kaplan S: Efficacy of intraoperative transesophageal echocardiography in children with congenital heart disease. Am J Cardiol 63:594–598, 1989

13. Stümper OFW, Elzenga NJ, Hess J, Sutherland GR. Transesophageal echocardiography in children with congenital heart disease: An initial experience. J Am Coll Cardiol 16:433–441, 1990

14. Ritter SB: Transesophageal echocardiography in children: A new peephole to the heart. J Am Coll Cardiol 16:447–450, 1990

15. Musewe NN, Smallhorn JF, Dyck J, Freedom RM: Transesophageal echocardiography in a pediatric population. Circulation 80(Suppl II-1–II-808)186:0739, 1989

16. Kyo S, Omoto R, Matsumura M, Shah P, Ito H: Intraoperative transesophageal Doppler echocardiography in pediatric congenital heart disease. Circulation 80(Suppl II-1–II-808)186: 0740, 1989

17. Muhiudeen I, Roberson D, Silverman N, Hass G, Turley K, Cahalan M: Intraoperative echocardiography in infants and children with congenital cardiac shunt lesions: Transesophageal versus epicardial echocardiography. J Am Coll Cardiol 16:1687–1695, 1990

18. Ritter SB: Transesophageal real-time echocardiography in infants and children with congenital heart disease. J Am Coll Cardiol 18:569–580, 1991

19. Geibel A, Kasper W, Behroz A, Przewolka U, Meinertz T, Just H: Risk of transesophageal echocardiography in awake patients with cardiac diseases. Am J Cardiol 62:337–339, 1988

20. Dennig K, Sedlmayr V, Seling B, Rudolph W: Bacteremia with transesophageal echocardiography. Circulation 80(Suppl II-1–II-808)473:1882, 1989

21. Daniel WG, Erbel R, Kasper W, Visser CA, Engberding R, Sutherland G, Grube E, Hanrath P, Maisch B, Dennig K, Schartl M, Kremer P, Angerman C, Iliceto S, Curtius J, Mugge A: Safety of transesophageal echocardiography: A multicenter survey of 10,419 examinations. Circulation 80:817–821, 1991

22. Elkadi T, Sahn D, Ritter S, Golebiovski P, Moises V, Chao K: Importance of color flow doppler (CFD) imaging of the right ventricular outflow tract and pulmonary arteries by transesophageal echocardiography (TEE) during surgery for CHD (abstract). Circulation 82(Suppl III):438–439, 1990