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Utility of Intraoperative Transesophageal Echocardiography in the Assessment of Residual Cardiac Defects

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Abstract. To investigate the accuracy of immediate postbypass transesophageal echocardiography in the assessment of residual cardiac defects, we compared intraoperative transesophageal echocardiograms with intra/postoperative data in 86 patients, aged 4 days to 30.7 years (median = 1.4 years), at risk for a total of 174 postoperative lesions: right ($n = 55$) or left ($n = 26$) ventricular outflow tract obstruction, ventricular septal defect ($n = 65$), aortic ($n = 12$) or mitral regurgitation ($n = 8$), or mitral stenosis ($n = 8$). Accuracy of intraoperative transesophageal echocardiography was evaluated based on comparison with (1) immediate postbypass left ($n = 4$) or right ($n = 9$) ventricular outflow tract pressure gradients by pullback in the operating room, (2) direct surgical inspection of residual ventricular septal defects ($n = 3$), (3) pulmonary artery oxygen saturation ($n = 49$), (4) right ventricular outflow tract pullback gradient ($n = 24$), and (5) transthoracic echocardiogram ($n = 51$) performed within 40 days of surgery. The results indicate that intraoperative transesophageal echocardiography agreed with intra/postoperative data in 87% of patients at risk for right ventricular outflow tract obstruction, 96% at risk for left ventricular outflow tract obstruction, 97% at risk for ventricular septal defect, and 100% at risk for aortic regurgitation, mitral regurgitation, or mitral stenosis. Significant residual lesions led to immediate surgical revision in 11 cases: 3 ventricular septal defects, 6 right and 2 left ventricular outflow tract obstructions. Of these, intraoperative transesophageal echocardiography confirmed and quantified suspected residual lesions in 7 and identified unsuspected lesions in 4 cases. Immediate postbypass transesophageal echocardiography proved reliable for assessing residual ventricular septal defect, mitral stenosis, and mitral or aortic regurgitation. Although accurate for assessment of the left and right ventricular outflow tracts in most patients, transesophageal echocardiography may not reliably reflect the severity of obstruction in all cases.

Key words: Congenital heart disease — Operative transesophageal echocardiography — Residual cardiac defects

Advances in transducer technology and the continued miniaturization of transesophageal echocardiographic probes have led to a rapid increase in the use of intraoperative transesophageal echocardiography for monitoring and diagnosis during repair of congenital heart defects [1, 3, 12, 13, 16]. Intraoperative transesophageal echocardiography is now routinely employed to assess operative success [2] and has led to a decrease in the use of postoperative pulmonary artery catheters in many centers. Despite this increase, limited information is available correlating transesophageal echocardiographic assessment of postoperative hemodynamics with early and intermediate follow-up data. The purpose of this study was to compare intraoperative transesophageal echocardiographic assessment of cardiac defects immediately after cardiopulmonary bypass with operative and postoperative hemodynamic and echocardiographic data in a group of patients at risk for certain common postoperative lesions.

Methods

Patient Selection

Between January and September 1993, patients undergoing correction or palliation of congenital heart defects were considered for intraop-

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Table 1. Criteria for grading of lesions

	Insignificant	Potentially significant	Significant
RVOTO/ LVOTO	*Echo:* unobstructed by color Doppler and/or MIG ≤20 mmHg	*Echo:* MIG 20 mmHg to 40 mmHg	*Echo:* MIG >40 mmHg
	Hemodynamic: PSEG by pullback ≤20 mmHg	*Hemodynamic:* PSEG by pullback 20 mmHg to 40 mmHg	*Hemodynamic:* PSEG >40 mmHg
AR/MR	*Echo:* Absent or trivial regurgitant jet (width <2 mm) by color at the level of the valve leaflets	*Echo:* Regurgitant jet width 2–4 mm by color Doppler at the level of the valve leaflets	*Echo:* Regurgitant jet width >4 mm by color Doppler at the level of the valve leaflets
MS	*Echo:* Pulsed/CW Doppler mean gradient of ≤5 mmHg	*Echo:* Pulsed/CW Doppler mean gradient of 5–8 mmHg	*Echo:* Pulsed/CW Doppler mean gradient of >8 mmHg
VSD	*Echo:* Absent or trivial shunt based on systolic color Doppler jet (width ≤3 mm)[a]	*Echo:* Moderate shunt based on systolic color Doppler jet (width 3 to 4 mm)[a]	*Echo:* Large shunt based on systolic color Doppler jet (width >4mm)[a]
	Hemodynamic: PA saturation ≤80%[b]		*Hemodynamic:* PA saturation >80%[b]

[a] or qualitative assessment of shunt if multiple muscular or intramural VSDs.
[b] pulmonary artery oxygen saturation with inspired FIO2 ≤40% [7, 8]
AR, aortic regurgitation; CW, continuous wave; LVOTO, left ventricular outflow tract obstruction; MIG, maximal instantaneous gradient; MR, mitral regurgitation; MS, mitral stenosis; PSEG, peak systolic ejection gradient; RVOTO, right ventricular outflow tract obstruction; VSD, ventricular septal defect.

erative transesophageal echocardiograms based on cardiac lesion and planned repair. An attempt was made to perform transesophageal echocardiography on any patient at risk for postoperative right or left ventricular outflow tract obstruction, ventricular septal defect, aortic or mitral regurgitation, or mitral stenosis. A patient was classified as ''at risk'' for those lesions which, based on cardiac anatomy and planned repair, might be reasonably expected as a potential residual defect or complication of the procedure. While the majority of patients were evaluated by transesophageal echocardiography both before and after surgery, patients with only postoperative studies were included. In these patients, concern about adequacy of repair or hemodynamic instability prompted echocardiographic evaluation.

Transesophageal echocardiography was not performed on patients with known upper gastrointestinal tract pathology or on those weighing < 2.5 kg.

Echocardiographic Examination

Patients were anesthetized and intubated prior to placement of the transesophageal probe. Methodology for complete transesophageal echocardiographic evaluation of cardiac anatomy has been previously described [11]. Except for those undergoing emergent postoperative transesophageal echocardiography ($n = 5$), study patients underwent preoperative 2-dimensional imaging, pulsed and continuous wave Doppler, and color flow mapping prior to the onset of cardiopulmonary bypass. Postoperative examinations were performed subsequent to weaning from cardiopulmonary bypass.

Echocardiograms were performed by an experienced echocardiographer using a Hewlett-Packard Sonos 1000 or 1500 or an Acuson 128 phased array imaging system equipped with pulsed, continuous wave, and color Doppler capabilities. A pediatric single or biplane probe was used for patients ≤ 15 kg, an adult biplane probe for patients between 15 kg and 35 kg, and a multiplane probe for patients > 35 kg. Information regarding the sensitivity of single versus biplane transesophageal echocardiography has been reported previously [4].

Video link from the operating room allowed analysis of real time, slow speed, and frame-by-frame images by a staff echocardiographer at the time of surgery. Studies were recorded on 1/2-inch high-fidelity VCR tape for later review by a single observer.

Grading of Postoperative Lesions by Intraoperative Transesophageal Echocardiography

Postoperative lesions were graded for predicted hemodynamic significance as (1) absent or hemodynamically insignificant, (2) potentially significant, or (3) significant (see Table 1). Right and left ventricular outflow tract obstructions were evaluated, based on maximal instantaneous gradients obtained by pulsed and continuous wave Doppler interrogation. Ventricular septal defects were evaluated based on the size of the defect by color-flow mapping. For patients with ''intramural'' [9] or multiple muscular ventricular septal defects, a qualitative assessment of hemodynamic significance was made. Aortic and mitral regurgitation were evaluated based on the width of the regurgitant jet at the level of the valve leaflets by color-flow mapping. Mitral stenosis was evaluated based on mean transvalvar gradient obtained by pulsed and continuous wave Doppler interrogation. Attempts were made to perform color-flow mapping using settings that allowed maximum scan rate and minimal color aliasing.

Operative and Postoperative Evaluation

Data obtained in the operating room included peak-to-peak left ($n = 4$) or right ($n = 9$) ventricular outflow tract pull-back pressure gradients immediately after cardiopulmonary bypass and direct surgical inspection of residual ventricular septal defects after reinstitution of cardiopulmonary bypass ($n = 3$).

Postoperative hemodynamic data included (1) peak-to-peak right ventricular outflow tract pressure gradient recorded during pullback of the transventricular pulmonary artery monitoring catheter ($n = 24$, median = 24 hours, range = 16 to 117 hours after operation), and (2) pulmonary artery oxygen saturation ($n = 49$, median = 17 hours, range = 5 to 75 hours after operation) performed with an inspired

oxygen concentration of ≤ 40% [7, 15]. Pulmonary artery oxygen saturations of > 80% with echocardiographic evidence of left-to-right shunting at the atrial level were excluded from follow-up analysis ($n = 1$).

Follow-up transthoracic or transesophageal echocardiograms, performed within 40 days of surgery (median = 5 days, range = 1 to 40 days after operation), were available on 51 patients, 31 of whom also had operative or postoperative hemodynamic data. These studies were reviewed for right and left ventricular outflow tract obstruction, ventricular septal defect, aortic or mitral regurgitation, and mitral stenosis. Grading of postoperative lesions at follow-up was based on a combination of surgical, hemodynamic, and echocardiographic data (see Table 1).

For those patients in whom cardiopulmonary bypass was reinstituted to correct an identified postoperative defect, transesophageal assessment of lesions both before and after repeat bypass were included in subsequent analysis.

Results

Patient Population and Follow-up

Between January and September 1993, 114 of 167 patients undergoing transesophageal echocardiograhic evaluations during surgical correction or palliation of congenital heart defects were judged to be at risk for one or more of the postoperative lesions being studied. Follow-up was available on 86 of these 114 patients (75%), at risk for a total of 174 postoperative lesions: right ($n = 55$) or left ($n = 26$) ventricular outflow tract obstruction, ventricular septal defect ($n = 65$), aortic ($n = 12$) or mitral ($n = 8$) regurgitation, or mitral stenosis ($n = 8$). These 86 patients, aged 5 days to 30.7 years (median = 1.4 years), weighing 2.9 to 61.6 kg (median = 9.3 kg) make up the study population (Table 2).

Table 2. Patient diagnoses

Diagnosis	Additional diagnoses
VSD ($n = 21$)	subAS ($n = 7$)
	Obstructive RVOT muscle bundles ($n = 5$)
	Additional VSDs s/p device ($n = 3$)
	Additional VSDs ($n = 2$)
	Prolapsed aortic valve/AR ($n = 1$)
TOF/PA ($n = 11$)	s/p shunt ($n = 4$)
	s/p RV to PA conduit ($n = 2$)
TGA/VSD ($n = 10$)	Additional VSDs ($n = 2$)
	s/p ASO subAS ($n = 1$)
	s/p ASO supraPS ($n = 1$)
	s/p Rastelli subAS ($n = 1$)
	s/p Senning/baffle leak/supraPS ($n = 1$)
TOF ($n = 10$)	s/p shunt ($n = 3$)
	s/p repair—RV to PA conduit obstruction ($n = 1$)
	s/p repair—residual VSD ($n = 1$)
	Absent pulmonary valve ($n = 1$)
DORV ($n = 9$)	s/p PAB ($n = 2$)
	s/p shunt ($n = 1$)
	s/p repair—RV to PA conduit obstruction ($n = 1$)
CAVC ($n = 6$)	Additional VSDs ($n = 1$)
Transitional AVC ($n = 3$)	Severe MR ($n = 1$)
	LV to RA shunt ($n = 1$)
AS/AR ($n = 3$)	s/p balloon aortic valvuloplasty ($n = 2$)
SubAS ($n = 3$)	Shones ($n = 1$)
Single LV/restrictive BVF ($n = 3$)	
Truncus arteriosus ($n = 2$)	s/p repair—RV to PA conduit obstruction ($n = 1$)
TGA ($n = 1$)	s/p ASO supraAS/supraPS ($n = 1$)
Other ($n = 2$)	

AR, aortic regurgitation; AS, aortic stenosis; ASO, arterial switch operation; AVC, atrioventricular canal; BVF, bulboventricular foramen; DORV, double outlet right ventricle; LV, left ventricle; MR, mitral regurgitation; PA, pulmonary artery; PAtr, pulmonary atresia; PAB, pulmonary artery band; PS, pulmonary stenosis; RA, right atrium; RV, right ventricle; RVOT, right ventricular outflow tract; s/p, status post; TGA, transposition of the great arteries; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

Incomplete Studies and Complications

Insertion of the pediatric biplane probe beyond the posterior oropharynx was unsuccessful in 2 patients (a 3-kg patient with trisomy 21 and a 2.5-kg patient). Loose teeth were removed prior to probe insertion in 2 patients to avoid possible dislodgement and aspiration. In 4 studies, left atrial pressure appeared to increase with probe manipulation; 2 of these studies were terminated prematurely secondary to associated hypotension. One patient had inadequate imaging for accurate assessment of postoperative anatomy and was excluded from further analysis.

Right Ventricular Outflow Tract Obstruction

Of the patients at risk for postoperative right ventricular outflow tract obstruction ($n = 55$) intra/postoperative data confirmed the degree in all 38 patients thought to have insignificant obstruction by transesophageal echocardiography, in 6 of 11 with potentially significant obstruction, and in 4 of 5 thought to have significant obstruction by transesophageal echocardiogram. In 6 patients, the degree of right ventricular outflow tract obstruction was greater by transesophageal echocardiogram than by operative and postoperative measurements; 5 patients judged to have potentially significant obstruction and 1 judged to have significant obstruction had insignificant obstruction at follow-up. Intraoperative transesophageal echocardiography on the final patient demonstrated right ventricular outflow obstruction that varied in degree (30 to 90 mmHg) with the level of inotropic support. Predischarge transthoracic echocardio-

gram on this patient demonstrated a residual 50 mmHg maximal instantaneous outflow tract gradient.

Left Ventricular Outflow Tract Obstruction

Of the patients at risk for postoperative left ventricular outflow tract obstruction ($n = 26$), intra/postoperative data confirmed the degree in 15 of 16 with insignificant obstruction and in all 10 patients with potentially significant or significant obstruction by transesophageal echocardiography. The remaining patient, placed on an extracorporeal membrane oxygenator for poor cardiac function after surgery, had an insignificant left ventricular outflow tract gradient by transesophageal Doppler examination despite a narrowed subaortic region by 2-dimensional imaging. After recovery of cardiac function, follow-up echocardiographic evaluation demonstrated a 25 mmHg subaortic gradient.

Ventricular Septal Defect

Of the patients at risk for postoperative ventricular septal defect ($n = 65$), intra/postoperative data confirmed transesophageal echocardiography in all 58 patients judged to have an insignificant or no residual shunt, and in all 5 patients judged to have a significant residual shunt. Two patients were judged to have potentially significant shunts by transesophageal examination. In one patient, the postoperative pulmonary artery oxygen saturation was 90% and follow-up echocardiogram demonstrated a significant residual shunt. In the other, the pulmonary artery saturation was 72% and no significant left-to-right shunt was demonstrated by oximetry at a subsequent catheterization.

Aortic and Mitral Regurgitation

Of the patients at risk for aortic ($n = 12$) or mitral ($n = 8$) regurgitation, postoperative echocardiograms confirmed transesophageal findings in all 20 patients.

Mitral Stenosis

Of the patients at risk for mitral stenosis ($n = 8$), postoperative echocardiograms confirmed transesophageal findings in all 8 patients.

Reinstitution of Cardiopulmonary Bypass

Significant postoperative lesions led to reinstitution of cardiopulmonary bypass and surgical revision in 11 cases: outflow tract enlargement or placement of a right ventricle to pulmonary artery homograft for residual right ventricular outflow tract obstruction ($n = 5$), aortic valvotomy or enlargement of subaortic bulboventricular foramen for valvar or subvalvar obstruction ($n = 3$), or closure of postoperative ventricular septal defect ($n = 3$). Intraoperative transesophageal echocardiography confirmed and quantified suspected postoperative lesions in 7 and identified unsuspected lesions in 4 cases. Hemodynamic improvement was achieved in 10 of 11 cases. In the remaining case, suspected stenosis at the distal right ventricular outflow tract patch in a patient with tetralogy of Fallot was not significantly improved after patch augmentation.

Discussion

Previous studies have demonstrated the accuracy of intraoperative transesophageal echocardiography when compared with simultaneous epicardial echocardiography for the assessment of residual ventricular septal defect [8, 10, 17] or mitral regurgitation [6, 14] in the immediate postbypass period. Other investigators have reported reinstitution of cardiopulmonary bypass in order to address residual lesions identified by transesophageal examinations [2, 4, 12, 13, 14]. Despite the increasing use of transesophageal echocardiography during congenital cardiac surgery, a comparison of postbypass transesophageal assessment of residual lesions with traditional operative and postoperative follow-up monitoring is lacking for many lesions. Further validation of postbypass transesophageal echocardiography is warranted prior to the routine application of this technique toward intraoperative decision making.

In this study, we investigated the accuracy of transesophageal echocardiography for assessment of residual lesions in 86 patients at risk for postoperative right or left ventricular outflow tract obstruction, ventricular septal defect, mitral or aortic regurgitation, or mitral stenosis. Although accurate in the majority of patients, transesophageal echocardiography suggests a greater severity of right ventricular outflow tract obstruction in 13% of cases when compared with operative and postoperative gradients. Possible contributing factors include alterations in loading conditions, cardiac function, and hemoglobin levels; the effect of hypertrophied right ventricular muscle bundles; and, as was demonstrated in one case, variation in the level of postoperative inotropic support. In addition, there exists the inherent discrepancy in comparing maximal instantaneous gradients by pulsed or continuous wave Doppler with peak-to-peak systolic ejection gradients obtained by direct pressure pullback.

In contrast, transesophageal assessment of postoperative left ventricular outflow tract obstruction was accurate in 96% of cases. As might be expected, in the

setting of diminished ventricular function and low cardiac output immediately postbypass, Doppler echocardiography did not accurately predict the degree of residual left ventricular outflow obstruction in one patient.

The hemodynamic significance of postoperative ventricular septal defects was reliably predicted by transesophageal echocardiography in 97% of patients and transesophageal assessment correlated with follow-up in all patients at risk for mitral regurgitation, aortic regurgitation, and mitral stenosis.

The presence of a significant postoperative lesion led to the reinstitution of cardiopulmonary bypass in 11 of 114 (10%) patients at risk for the lesions under investigation. In 4 of these 11 cases, lesions were unsuspected based on immediate postbypass hemodynamics and most likely would not have been addressed at the time of surgery. In the remaining 7 patients, although lesions were suspected, transesophageal echocardiography confirmed, quantified, and/or allowed more rapid identification of a hemodynamically significant postoperative lesion.

Limitations

Transesophageal echocardiography was performed on a nonconsecutive patient population chosen for study based on their risk for postoperative lesions and includes some patients who underwent transesophageal examinations because a significant postoperative residual lesion was suspected. This study, therefore, was not designed to assess the incidence of postoperative lesions in all patients undergoing correction or palliation of congenital cardiac defects.

The echocardiographer performing the intraoperative study was aware of postbypass hemodynamics and surgical concerns regarding anatomy and operative technique. This knowledge may have influenced the speed and accuracy of transesophageal assessment of residual postoperative lesions. In addition, results of transesophageal studies were available for review at the time of postoperative echocardiography, potentially influencing performance and interpretation of the follow-up study.

Finally, although demonstrating the accuracy of intraoperative transesophageal echocardiography, this study did not address its impact on surgical decision making. Further studies are underway to address this question.

Conclusions

Intraoperative transesophageal echocardiography produces high quality images in patients with a wide range of congenital cardiac defects and can be used safely in the majority of small neonates. Postbypass transesophageal echocardiography is a highly reliable predictor of postoperative ventricular septal defect, aortic regurgitation, mitral stenosis, and mitral regurgitation. Although accurate for the assessment of right and left ventricular outflow tracts in most patients, transesophageal echocardiography may not accurately reflect the degree of obstruction in all cases.

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Current Concepts in Diagnosis and Management of Arrhythmias in Infants and Children

By B.J. Deal, G.S. Wolf, and H. Gelband; Futura Publishing, Inc., 1998

Doctor Deal gathers in this book the experience and opinions of many experts in pediatric arrhythmias. Contributors come from most of the prominent centers for management of cardiac arrhythmias in the United States. Their experience is presented in 14 chapters (427 pages and an index). The first chapter addresses many of the basic issues of evaluating children with arrhythmias. Chapter 2 explores diagnostic and therapeutic aspects of fetal arrhythmias in a logical and detailed fashion. Table 3, which lists antiarrhythmic medications for fetal supraventricular tachyarrhythmias, is very helpful. In addition to listing the medications and maternal doses, it provides valuable information such as drug half-life, therapeutic levels, toxic levels, percentage of placental transfer, advantages and disadvantages. Chapters 3–7 are dedicated to benign arrhythmias, sinus and atrioventricular conduction disorders, supraventricular and ventricular tachycardias. Chapter 8 reviews syncope, and Chapter 9 examines long QT syndrome. Chapter 10 is dedicated to pharmacologic therapy of arrhythmias, which includes an appendix listing 23 such agents along with their doses and various properties. Chapters 11–14 discuss various aspects in management of arrhythmias, such as emergency management, ablation therapy, and surgical management.

This textbook provides detailed, clear, and up-to-date information and guidance in the field of pediatric cardiac arrhythmias. It is a valuable reference for the Pediatric Cardiologist, and an important textbook for students in this field.

Ra-id Abdulla
Associate Editor