



# The role of intraoperative epicardial echocardiography in pediatric cardiac surgery

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**Aim:** Our aim was to evaluate the findings and the role of intraoperative epicardial echocardiography (IEE) in the management of pediatric cardiac surgery patients.

**Methods:** Patients evaluated with IEE between December 2015 and December 2017 were analyzed retrospectively. Demographic data, preoperative transthoracic echocardiography (TTE), and IEE reports were evaluated.

**Results:** A total of 410 patients evaluated by IEE were included in the study. Of these, 52% were women, and 48% were men. The median age was 8.5 months (range: 1 month–7 years), and median body weight was 7.1 kg (range: 3.3–61 kg). The most common diagnoses were tetralogy of Fallot (TOF; n = 148), ventricular septal defect (VSD; n = 117), atrial septal defect (ASD; n = 57), and complete atrioventricular septal defect (AVSD; n = 48). There were minor residual lesions not requiring reestablishment of cardiopulmonary bypass (CPB) in 16.6% (n = 68), while major residual lesions requiring return to CPB were determined in 5.1% (n = 21). Major residual lesions were detected in 7 patients with TOF (4 severe right ventricular outflow tract obstructions, 2 pulmonary artery stenosis, 1 residual VSD shunt), 6 patients with VSD (hemodynamically significant residual shunts), and 5 patients with complete AVSD (3 left atrioventricular valve regurgitations, 1 right atrioventricular valve regurgitation, 1 left ventricular outflow tract obstruction). Transient bradycardia was observed in 5 patients.

**Conclusion:** Intraoperative epicardial echocardiography provides good guidance during congenital heart surgery. IEE helps to clarify the surgical planning and decreases morbidity and mortality due to unnecessary invasive procedures, especially for pathologies involving the pulmonary artery and its branches, as well as for apical ventricular septal defects.

## KEYWORDS

cardiac surgery, congenital heart disease, pediatric echocardiography

## 1 | INTRODUCTION

Residual cardiovascular lesions, either anatomical or functional, are major causes of morbidity and mortality following surgical repair. Intraoperative imaging modalities help postoperative intensive care

unit management of patients by delineating residual lesions, cardiac function, and hemodynamic changes during and immediately after surgical procedures. This, in turn, has resulted to an increase in the need for intraoperative echocardiography (transesophageal or epicardial), especially during congenital heart surgery.<sup>1,2</sup>

Intraoperative use is currently the most common indication of transesophageal echocardiography (TEE) in the pediatric age group. Numerous reports have documented the benefits of this approach, and the experience to date accounts for the incorporation of TEE into the standard care of patients undergoing surgery for congenital heart diseases (CHDs) in many centers worldwide.<sup>1,2</sup>

However, inappropriate probe size for newborns and infants, inappropriate anatomy of the jaw, macroglossia, and potential procedural complications (eg, esophageal trauma, arrhythmia) limit TEE application. Intraoperative epicardial echocardiography (IEE) might be a simple but effective alternative to TEE.<sup>3,4</sup>

In this study, we evaluate the IEE findings and potential effects of these findings on decision making about congenital heart surgery patients in a tertiary cardiac center. Our aim was to evaluate the indications, results, and complications of IEE in detail, and also to discuss the alterations in diagnosis and treatment strategy after IEE.

## 2 | METHODS

All IEE studies in the pediatric age group, performed between December 2015 and December 2017, were included in the study. In our pediatric heart center, TEE is the first option and is performed routinely for evaluation of patients during congenital heart surgery. IEE was performed when the TEE was in use in another operating room or in an interventional procedure. Of 1068 congenital heart surgeries performed during this time period, 410 patients who underwent IEE evaluation were analyzed retrospectively.

The age, gender, body weight, preoperative transthoracic echocardiography (TTE) findings, IEE reports, alterations in final decision after IEE evaluation, and complications related to IEE were recorded.

Residual lesions requiring reestablishment of cardiopulmonary bypass (CPB) were classified as major outcomes, while all other lesions were accepted as minor outcomes. Patients who developed ventricular dysfunction after CPB were excluded.

Echocardiographic evaluations were performed by two pediatric cardiologists using the GE Vivid S5 cardiac ultrasound system (General Electric VingMed Systems, Horten, Norway) with a 7S probe and echocardiographic gel, covered by a sterile plastic sheath. Warm saline solution was instilled within the chest cavity as needed by the surgeon (Figures 1 and 2). All echocardiographic evaluations were performed in accordance with the American Society of Echocardiography guidelines.<sup>5</sup>

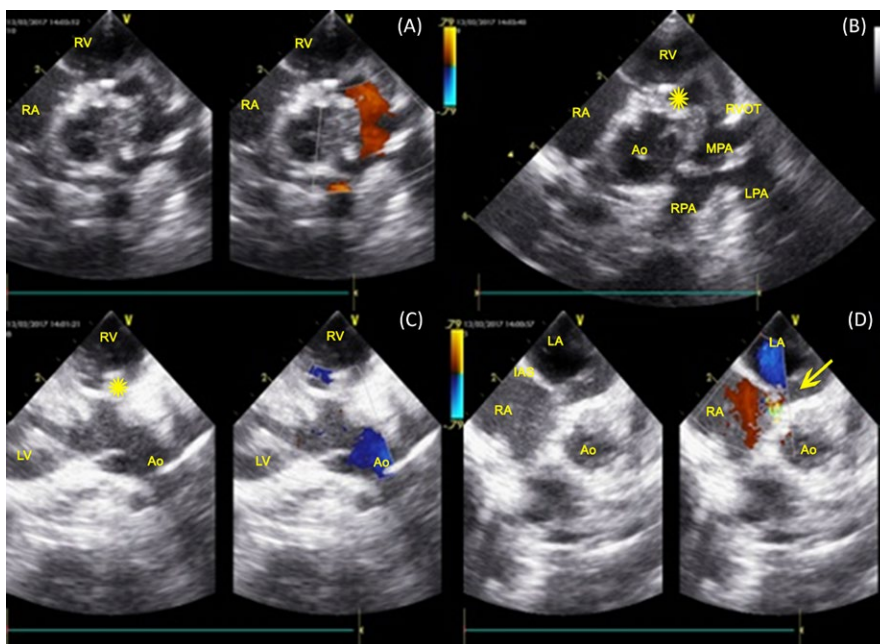
Postoperative TTE was performed routinely in all patients within 24 hours of the surgery, usually before extubation in the intensive care unit. Subsequent TTE studies were performed as needed by the patient.

Statistical analysis was performed using the SPSS version 17.0 package program (SPSS Inc., Chicago, IL, USA). The clinical and laboratory data are presented as median (range) values.

## 3 | RESULTS

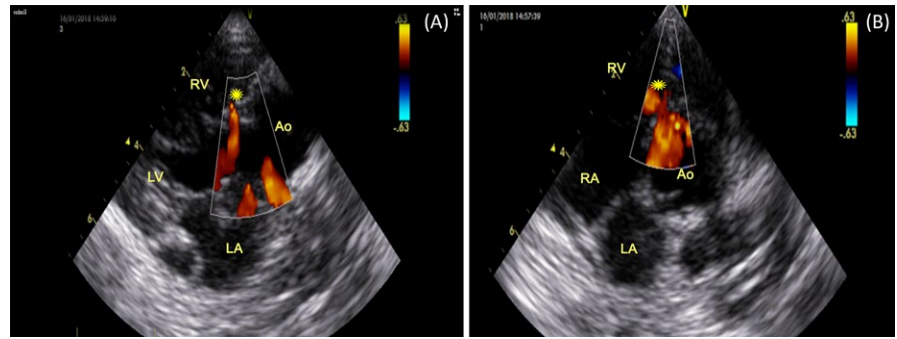
The demographic data and perioperative diagnoses of the 410 patients included in the study are demonstrated in Table 1.

Major residual lesions requiring reestablishment of CPB were present in 21 of the 410 (5.1%) patients. Major residual lesions were detected in 7 patients with tetralogy of Fallot (TOF; 4 severe right ventricular outflow tract obstructions, 2 pulmonary artery stenoses, 1 residual ventricular septal defect shunt), 6 patients with ventricular septal defect (VSD; hemodynamically significant residual shunt), 5 patients with complete atrioventricular septal defect (AVSD; 3 left atrioventricular valve regurgitations, 1 right atrioventricular valve



**FIGURE 1** Intraoperative epicardial echocardiogram of a patient with tetralogy of Fallot (10 mo old). A, modified short-axis view, color flow shows free pulmonary regurgitation; B, modified short-axis view; C, modified long-axis view; D, modified view of interatrial septum. Ao = aorta; IAS = interatrial septum; LA = left atrium; LPA = left pulmonary artery; LV = left ventricle, MPA = main pulmonary artery; RA = right atrium; RPA = right pulmonary artery; RV = right ventricle; RVOT = right ventricular outflow tract. Arrow shows interatrial communication, \* shows ventricular septal defect (VSD) patch

**FIGURE 2** Intraoperative epicardial echocardiogram of a patient with ventricular septal defect (15 mo old). A, modified short-axis view; B, modified long-axis view, color flow shows residual ventricular septal defect (VSD)



**TABLE 1** Patient characteristics

Patient characteristics	N	%
Total number of operations	1068	100
Intraoperative epicardial echocardiography	410	38.3
Transesophageal echocardiography	455	42.6
No intraoperative imaging	203	19.1
Sex (male/female)	197/213	48/52
Median age, in months (range)	8.5 (1–84)	
<6 mo	116	28.2
6–12 mo	198	48.2
>12 mo	96	23.6
Median body weight, in kg (range)	7.1 (3.3–61)	
Syndrome		
None	340	83.0
Down syndrome	57	14.0
Other	13	3.0
Diagnosis	n	%
Tetralogy of Fallot	148	36.0
Ventricular septal defect	117	28.5
Atrial septal defect	57	13.9
Complete atrioventricular septal defect	48	11.7
Mitral valve pathologies	11	2.6
Subaortic ridge	14	3.4
Anomalous pulmonary venous drainage	15	3.6
Partial	11	2.6
Total	4	1

regurgitation, 1 left ventricular outflow tract obstruction), 2 patients with subaortic ridge (1 left ventricular outflow tract obstruction, 1 anterior mitral leaflet rupture), and 1 patient with total anomalous pulmonary venous drainage (TAPVD; 1 obstruction of pulmonary vein anastomosis).

In total, 74 minor residual lesions were determined in 68 of the 410 (16.6%) patients. Insignificant hemodynamic lesions, namely residual small VSD (n = 22), recently developed tricuspid

regurgitation (n = 13), residual small atrial septal defect (ASD; n = 2), subaortic ridge without any obstructive gradient (n = 3), recently developed or increased mitral regurgitation (n = 14), and right ventricular outflow tract obstruction (RVOTO; n = 20), were considered as minor lesions. The etiologic pathologies for RVOTO were residual right ventricular outflow tract (RVOT) muscle mass (n = 7), pulmonary valve stenosis (n = 9), and left or right pulmonary artery branch stenosis (n = 4).

Postoperative echocardiography of patients with minor atrioventricular (AV) valve regurgitation revealed progression in 5 of them (increase in tricuspid regurgitation from mild to moderate in 3 patients, increase in mitral regurgitation from mild to moderate in 1 patient, and from moderate to severe in another). VSD patch dehiscence occurred in a patient with a minor residual defect on IEE on the first postoperative day.

In a patient with a mild degree of RVOTO on early postoperative echocardiography, a significant progression in RVOT gradient occurred.

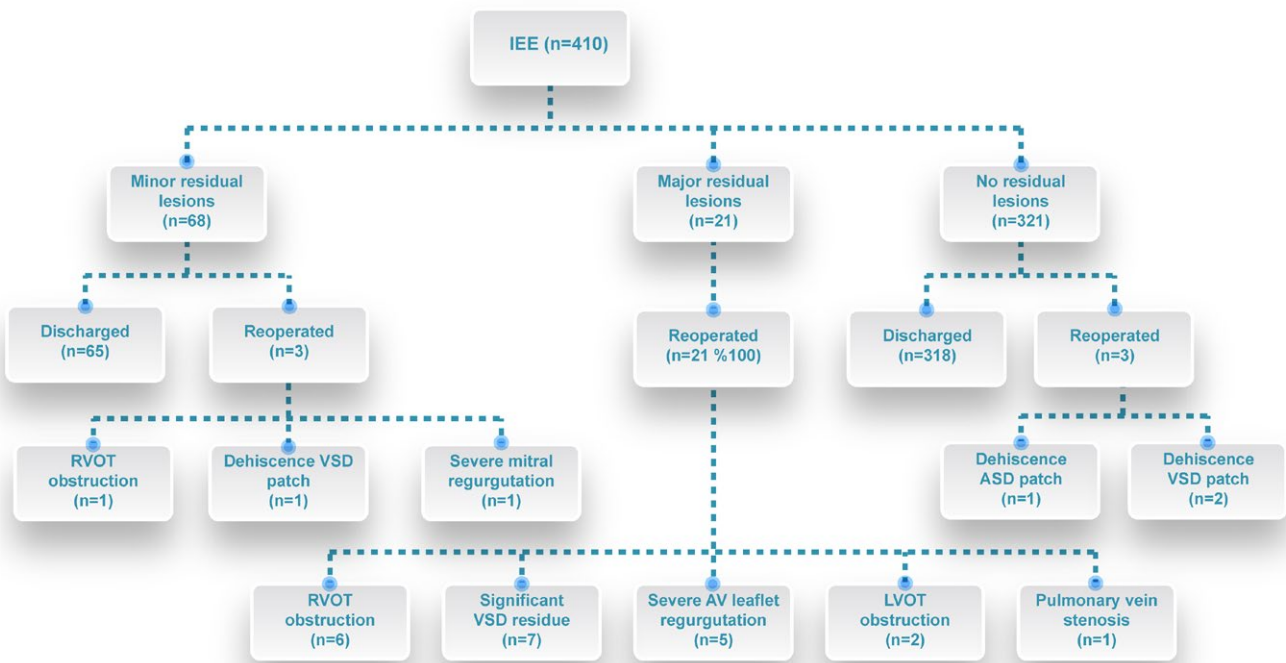
The patients with VSD patch dehiscence, significant residual RVOTO, and severe mitral regurgitation underwent a reoperation on the second, fourth, and sixth postoperative days, respectively.

There were no minor or major residual lesions detected in 321 of the 410 IEE patients (78%).

In 8 of the 321 (2.5%) patients without any lesions on IEE, postoperative TTE revealed a pathology. These were dehiscence of the ASD patch in 1 patient and of the VSD patch in 2 other patients, missed apical muscular VSDs not determined previously in 3 patients, and tricuspid regurgitation in 2 other patients. Patients with dehiscence of the ASD and VSD patches were reoperated on.

The detailed etiologies of the reoperations after IEE are summarized in Figure 3.

The operative findings of the surgeons were consistent with the echocardiography findings in 18 of the 21 (86%) immediate reoperations and in all late reoperations (n = 6). On the other hand, the findings in 3 of the 21 (14%) patients with major residual lesions on IEE were reported to be inconsistent with the intraoperative findings. These were hemodynamically significant residual VSD on IEE, which was found to be small on reoperation (patient 9); subaortic ridge, which could not be found during reoperation (patient 19); and inadequate data about the number and location of VSDs on IEE in another patient (patient 13).



**FIGURE 3** The etiologies of reoperation based on intraoperative epicardial echocardiographic (IEE) evaluation

No major complication occurred in relation to IEE, and only transient bradycardia was observed in 5 patients.

## 4 | DISCUSSION

In this study, the potential effects of IEE in the postoperative management of pediatric patients subjected to congenital heart surgery were evaluated.

Intraoperative epicardial echocardiography is technically feasible, with low complication rates. It is also quite useful for delineation of postoperative anatomy and aids in decision making for reoperations. It has already been established that intraoperative TEE has an undeniable role in optimal surgical management during pediatric cardiac surgery. It is useful for reevaluation of patients prior to the surgery, planning additional procedures as needed, and for determination of residual lesions immediately after the operation.<sup>6–8</sup> There are, unfortunately, limitations to the application of the TEE probe, especially in pediatrics. IEE might be an effective alternative to TEE,<sup>3,9,10</sup> particularly in the following cases: (1) where use of the TEE is impractical due to low body weight, micrognathia, macroglossia, or other such conditions; (2) where visualization with TEE is either difficult or insufficient (such as in the evaluation of the pulmonary artery bifurcation, branch pulmonary arteries, or apical muscular VSD); or (3) when the TEE probe is not available.<sup>3,9,10</sup>

In the study published by Muhiudeen et al, the results of 50 infants and children with congenital cardiac shunt lesions for whom TEE and IEE were used during the same procedure were compared. The intraoperative TEE and IEE findings before and after

cardiopulmonary bypass were correct and complete in 94% and 92% of patients, respectively.<sup>11</sup>

A recent study was reported by Dragulescu et al<sup>12</sup> about the visualization of branch pulmonary arteries, coronary arteries, pulmonary veins/baffles, and residual VSDs by IEE and TEE. It was concluded that IEE may detect residual intraoperative lesions that could not be visualized by TEE, particularly in the pulmonary arteries. The use of IEE might decrease the need for early reintervention in patients with pulmonary artery lesions.

Intraoperative epicardial echocardiography is an established diagnostic modality to assess the adequacy of the surgical repair. Advantages of IEE are timely and accurate decision making, especially in cases where significant residual lesions are present. As a result, the patient is reoperated on during the same procedure, avoiding excessive complications and cost.<sup>3,9,10</sup>

Ungerleider et al evaluated the efficiency of surgical repair using IEE in children with congenital heart disease. They found that the rates of reoperation and early death were significantly higher in those with unrepaired residual lesions detected by IEE. Accordingly, in the subset of patients in whom the residual lesions discovered on IEE were repaired, there was an uneventful postoperative period, with good long-term results.<sup>13</sup>

Kaushal et al evaluated the results of routine use of IEE to assess surgical repairs and found that IEE was inexpensive, accurate, valuable, and safe. They proposed that IEE should be mandatory for all corrective surgical procedures for congenital heart disease.<sup>14</sup>

Echocardiography, whether IEE or TEE, plays a key role in assessing the success of the operation and determining the need for cardiopulmonary bypass again. Manvi et al reported the overall



sensitivity and specificity of IEE in detecting significant residual lesions to be 86% and 100%, respectively. The positive predictive value and negative predictive value of IEE to detect significant residual lesions in the immediate post-CPB period was 100% and 97%, respectively. The percentages of false negativity and false positivity of IEE were 14% and 0%, respectively.<sup>10</sup>

Ayyildiz et al reported the significant difference between the TTE and TEE findings in 26 (6.1%) of 430 patients evaluated preoperatively. These findings were not enough to alter surgical management in 14 patients while 12 patients required a revision. Residual lesions were found in 19 patients (4.4%) by TEE.<sup>8</sup>

Jijeh et al evaluated 1036 surgical patients by either IEE or TEE and reported that 3.9% had major residual lesions requiring surgical revision.<sup>9</sup>

Manvi et al<sup>10</sup> reported a 15.1% rate of reentry to the CPB in light of IEE guidance. In the present study, 5.1% of patients were determined to have major residual lesions requiring surgical revision.

Intraoperative epicardial echocardiography and early postoperative TTE are performed at different times and often in different hemodynamic conditions. For example, VSD shunting and AV valve regurgitation often appear less severe on IEE in the operating room, where blood pressure is lower than in the intensive care unit. However, there are also studies reporting a high correlation between IEE and early postoperative TTE in major cardiac lesions.<sup>15</sup> In a study on comparative roles of IEE and early postoperative TTE by Sreeram et al,<sup>15</sup> it was detected that IEE correctly identified 6 of 7 patients with major residual lesions that needed revision. They likewise noted that residual outflow obstruction or AV valve regurgitation was usually underestimated.

The present study revealed that in 9.4% of patients with minor lesions (need for reoperation was 4.4%) and 2.5% of patients without a residual lesion (need for reoperation was 0.9%) on IEE, a difference was determined in TTE on the first postoperative day. In concordance with the reports in the literature, an increase in residual outflow tract obstruction and deterioration of AV valve regurgitation after the operation were also observed in our study.

As TEE is performed under general anesthesia and requires the probe in the esophagus, some complications may develop.<sup>16</sup> Although Randolph et al<sup>7</sup> reported a 1% rate of minor complications and no major complications in their study, Iwasaki et al<sup>16</sup> found 3 respiratory and 9 significant hemodynamic complications in a total of 773 patients.

Different complication rates were reported for IEE use in different studies. In the report by Muhiudeen et al, major complications that required termination of the procedure were observed in 3 (6%) of 49 patients. Manvi et al<sup>10</sup> reported no complications after IEE. Similarly, in the present study, no major complication was determined. The sole minor complication is transient bradycardia, which was seen in only 5 patients (1.2%).

#### 4.1 | Limitations

This study is limited by the retrospective, single-center nature of the data available for analysis. The other limitation was the inability to

compare the findings on IEE with those on TEE, which is the routine and generally accepted method for evaluation during the perioperative period.

## 5 | CONCLUSION

In the present study, the use of IEE allowed the detection of majority of the residual defects. IEE is an accurate, economical, and safe imaging modality that can be performed routinely in all patients undergoing corrective surgery and is especially useful for pathologies requiring evaluation of the pulmonary artery and branches, and apical ventricular septal defects. Widespread use of IEE may possibly avoid the complications and overcome the limitations of TEE in neonates and children.

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