

## Original Article

# Routine intra-operative trans-oesophageal echocardiography yields better outcomes in surgical repair of CHD

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**Abstract** *Objectives:* Trans-oesophageal echocardiographic imaging is valuable in the pre- and post-operative evaluation of children and adults with CHD; however, the frequency by which trans-oesophageal echocardiography guides the intra-operative course of patients is unknown. *Methods:* We retrospectively reviewed 1748 intra-operative trans-oesophageal echocardiograms performed between 1 October, 2005 and 31 December, 2010, and found 99 cases (5.7%) that required return to bypass, based in part upon the intra-operative echocardiographic findings. *Results:* The diagnoses most commonly requiring further repair and subsequent imaging were mitral valve disease (20.9%), tricuspid valve disease (16.0%), atrioventricular canal defects (12.0%), and pulmonary valve disease (14.1%). The vast majority of those requiring immediate return to bypass benefited by avoiding subsequent operations and longer lengths of hospital stay. A total of 14 patients (0.8%) who received routine imaging required further surgical repair within 1 week, usually due to disease that developed over ensuing days. Patients who had second post-operative trans-oesophageal echocardiograms in the operating room rarely required re-operations, confirming the benefit of routine intra-operative imaging. *Conclusions:* This study represents a large single institutional review of intra-operative trans-oesophageal echocardiography, and confirms its applicability in the surgical repair of patients with CHD. Routine imaging accurately identifies patients requiring further intervention, does not confer additional risk of mortality or prolonged length of hospital stay, and prevents subsequent operations and associated sequelae in a substantial subset of patients. This study demonstrates the utility of echocardiography in intra-operative monitoring of surgical repair and highlights patients who are most likely to require return to bypass, as well as the co-morbidities of such manipulations.

**Keywords:** Residual abnormalities; cardiopulmonary bypass; pediatric imaging

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**T**RANS-OESOPHAGEAL ECHOCARDIOGRAPHY HAS become routine in the diagnosis and care of adults and children with CHD. It has been especially valuable in the operating room where it is used pre-operatively to delineate anatomy and structural details that may have remained ill-defined by transthoracic imaging, and used post-operatively

to evaluate surgical repair, assess residual lesions, and estimate cardiac function.<sup>1–3</sup> The need to return to bypass after initial surgical intervention is a serious decision that is influenced not only by the intra-operative trans-oesophageal imaging but also by direct visualisation and assessment by the surgeon and post-operative cardiovascular haemodynamics. Early identification of findings requiring further intervention prevents re-operation at a later date, further morbidity and mortality, and higher costs; however, the frequency of returning to bypass and the

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resulting outcomes in our institution are unknown. Therefore, we endeavoured to evaluate the importance of post-bypass trans-oesophageal echocardiography for assessing additional operative needs before separation from cardiopulmonary bypass and to evaluate where trans-oesophageal echocardiography provides the greatest positive yield.

## Materials and methods

We retrospectively reviewed from our database all trans-oesophageal echocardiograms performed on children and adults with CHD in the operating room between 1 October, 2005 – the first date of our current reporting system – and 31 December, 2010 at Lucile Packard Children's Hospital. All trans-oesophageal echocardiograms were performed by paediatric cardiologists using Siemens® Acuson C512, rev 12.0 (Siemens® Medical Solutions Inc., Mountain View, California, United States of America). We performed complete trans-oesophageal and trans-gastric conventional scans using 5–7 MHz probes. We identified all children requiring trans-oesophageal echocardiography, and excluded those performed in the cardiac catheterisation laboratory or ICUs and those without a clear indication. We categorised these patients based on primary lesion/initial diagnosis. To elucidate where trans-oesophageal echocardiograms led to further surgical repair, we further refined the review to those patients who required a second cardiopulmonary bypass run for residual or additional problems discovered by the first post-operative trans-oesophageal echocardiogram. We evaluated these patients based on primary lesion and findings on the initial echocardiogram that necessitated return to bypass. Finally, we identified all patients who left the operating room but needed to return within 1 week for additional surgical intervention. Details regarding surgical decisions and post-operative clinical management were obtained from the electronic health record. Each patient's date of birth and gender were also obtained from Stanford Translational Research Integrated Database Environment (STRIDE), a research and development project at Stanford University formed to create a standards-based informatics platform supporting clinical and translational research. The project described was supported by the National Center for Research Resources and the National Center for Advancing Translational Sciences, National Institutes of Health, through grant UL1 RR025744. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institute of Health.<sup>4</sup> The study was approved by the Stanford Institutional Review Board (protocol# 21195).

Statistical calculations were carried out using SAS Enterprise Guide version 4.2 (SAS Institute Inc.,

Cary, North Carolina, United States of America) and Microsoft Excel®. All values are expressed as mean  $\pm$  standard deviation. A Student's t-test was used to compare the ages and length of hospital stay for patients who did and did not require a second post-operative trans-oesophageal echocardiogram. Standard  $\chi^2$  analysis was used to compare gender, mortality, and trans-oesophageal echocardiography usage between surgeons. A  $\chi^2$   $r \times c$  table compared the percentage of trans-oesophageal echocardiograms performed each year. Finally, a Fisher exact test was used to compare the percentages of single and second post-operative cases returning to the operating room within 1 week. For all tests, a p-value  $<0.05$  was considered statistically significant.

## Results

We reviewed a total of 1748 intra-operative trans-oesophageal echocardiograms. Ages ranged from 1 day to 64.0 years (average  $4.6 \pm 7.8$  years) that fit our selection criteria. There were 766 females and 982 males. During the study period, all trans-oesophageal echocardiograms performed on a patient in a single operative setting were considered as one complete echocardiographic study.

There were 99 (5.66%) cases that required second post-operative trans-oesophageal echocardiograms (Table 1). The group was composed of 48 females and 51 males whose ages ranged from 1 day to 40.5 years ( $5.2 \pm 8.2$  years). When comparing these patients with those only requiring a single post-operative assessment, gender ( $p=0.42$ ) and age ( $p=0.47$ ) were not significantly different. In addition, there was no statistical difference in length of hospital stay or mortality within 90 days of admission between those with a second versus single post-operative assessment ( $20.2 \pm 29.6$  versus  $20.0$  days  $\pm 29.7$ ,  $p=0.46$ ;  $5.05$  versus  $3.26\%$ ,  $p=0.25$ ).

Of the total group of trans-oesophageal echocardiograms, those diagnoses that had the highest frequency of second post-operative studies relative to the number of operating room cases for that diagnosis included mitral valve disease (20.9%), tricuspid valve disease (16.0%), and atrioventricular valve stenosis or regurgitation (amongst atrioventricular canal defects) (12.0%) (Fig 1). In addition, 14.1% of pulmonary valve repairs required second studies.

Within the 99 operations requiring second post-operative trans-oesophageal echocardiograms (Fig 1), underlying diagnoses of tetralogy of Fallot (19 cases) and disease of the atrioventricular valves (22 cases) – tricuspid, mitral, and atrioventricular canal – accounted for the highest number of studies.

Reasons for return to bypass varied by case, but were based upon a combination of initial

Table 1. Pre-operative diagnoses requiring second post-operative trans-oesophageal echocardiographic evaluations (TEE).

Diagnoses	Total TEE	2nd evaluation	% of total
Aortic arch coarctation/interruption	65	2	3.1
Aortic insufficiency	28	2	7.1
Aortic stenosis, valvar, and supra-valvar	40	3	7.5
Aortic stenosis, subaortic	42	5	11.9
Atrioventricular canal	75	9	12.0
Cardiomyopathy	14	1	7.1
Complete transposition of great vessels	132	7	5.3
Corrected transposition of great vessels	63	6	9.5
Double-outlet right ventricle	70	5	7.1
Ebstein's anomaly	17	1	5.9
Hypoplastic left heart syndrome	127	3	2.4
Mitral insufficiency	29	7	24.1
Mitral stenosis	14	2	14.3
Partial anomalous pulmonary venous return	33	1	3.0
Pulmonary artery stenosis	27	5	18.5
Pulmonary atresia	37	4	10.8
Total anomalous pulmonary venous return	37	1	2.7
Tetralogy of Fallot	372	19	5.1
Tricuspid insufficiency	8	3	37.5
Truncus arteriosus	39	1	2.6
Ventricular septal defect	256	12	13.5
Other	223	0	0.0
Total	1748	99	

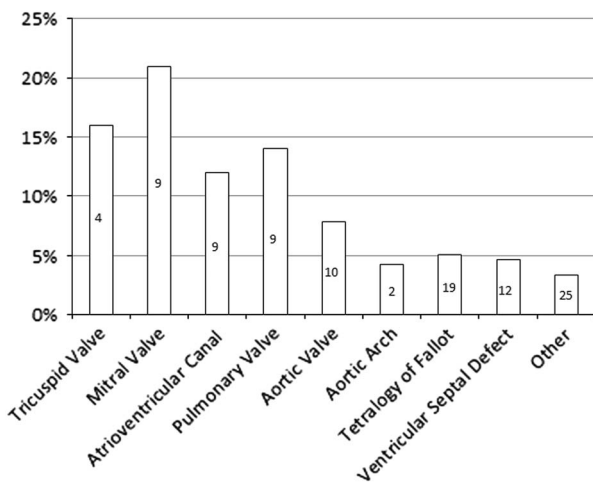


Figure 1. Percentage of total lesion-specific cases requiring second post-operative trans-oesophageal echocardiographic evaluations (raw numbers of cases within each column).

trans-oesophageal echocardiographic findings and surgical and haemodynamic concerns (Table 2). The most common reasons cited included residual ventricular septal defect (14%), residual tricuspid regurgitation (13%), residual mitral regurgitation

Table 2. Indications for second post-operative trans-oesophageal echocardiographic evaluations.

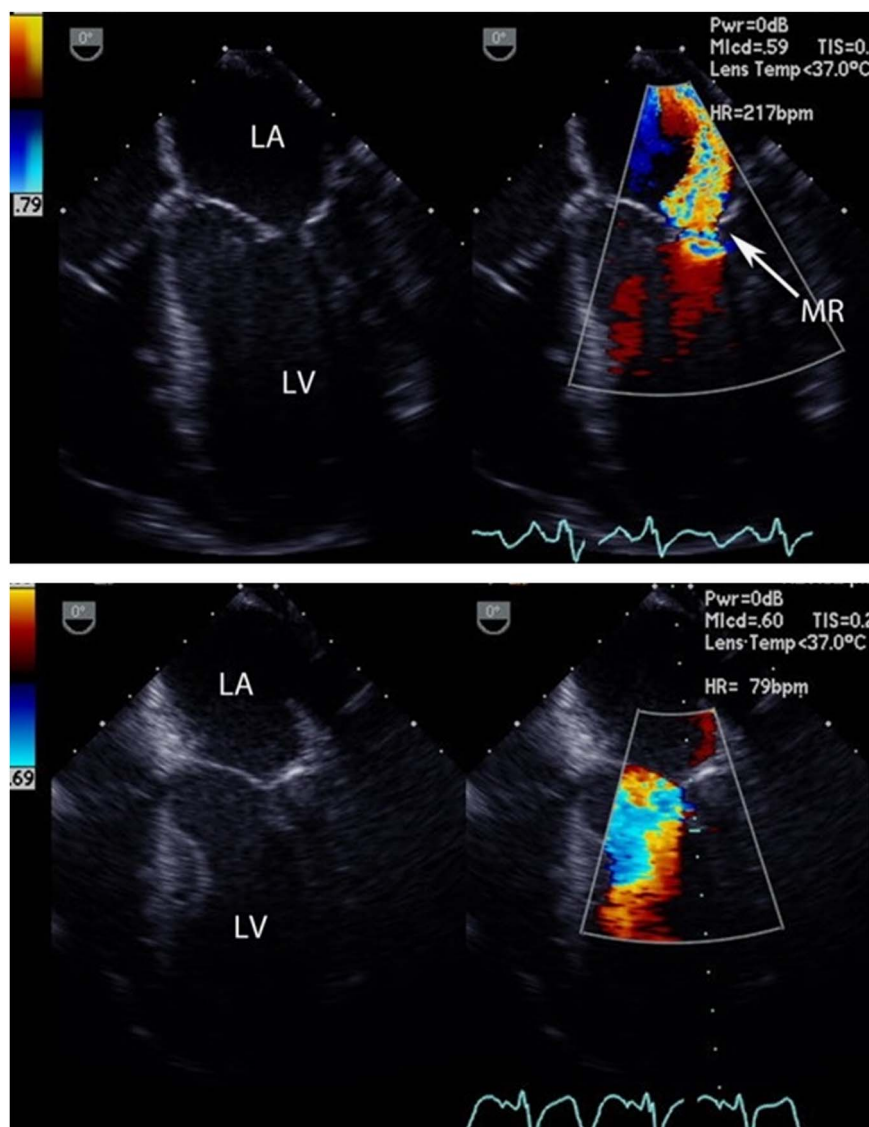
Reason	%
Additional shunt/window	2
Aortic insufficiency	4
Arterioplasty of pulmonary arteries	4
Aortic stenosis	2
Residual atrial septal defect	1
Baffle obstruction	1
Ventricular assist device cannula obstruction	1
Cardiac function	8
Intracardiac needle	1
Inferior vena caval obstruction	2
Left atrioventricular valve regurgitation	8
Left main coronary artery obstruction	1
Left ventricular outlet obstruction	4
Mitral regurgitation	12
Mitral stenosis	1
Mitral valve perivalvar leak	1
Pulmonary stenosis	6
Pulmonary vein obstruction	1
Pulmonary artery band replacement	1
Residual ventricular septal defect	14
Right ventricular outlet obstruction	11
Tricuspid regurgitation	13

(12%), right ventricular outlet obstruction (11%), and residual left atrioventricular valve regurgitation (8%). These included a 5.5-year-old boy with transposition of the great vessels who was found to have a cleft mitral valve with significant atrioventricular valve regurgitation after arterial switch operation (Fig 2), and a 21-month-old girl with complex infundibular muscular narrowing who underwent muscle resection, but was found to have a residual ventricular septal defect by color Doppler and left atrial contrast echocardiography (Fig 3).

There was no temporal difference in the frequency of return to bypass in any year.

All the patients who returned to the operating room within 1 week were further evaluated. In total, 14 patients (4 females and 10 males, ages 5 days to 32 years, average 7.02 ±8.75 years), or 0.8% of the total trans-oesophageal echocardiograms, returned to the operating room for surgical revision. Statistically, patients who had a second trans-oesophageal echocardiogram were slightly more likely than those with a single trans-oesophageal echocardiogram to return to the operating room at a later date for revision (0.7 versus 3.0%, p = 0.04).

Of the patients who returned to the operating room within 1 week, three had progressive atrioventricular valve or semilunar valve regurgitation and two had cyanosis suggesting baffle leak after atrial switch operations. In addition, there were two patients with progressive left ventricular systolic



**Figure 2.**

Post-operative trans-oesophageal echocardiogram in a 5.5-year-old boy with transposition of the great vessels, demonstrated moderate-to-severe residual mitral regurgitation (MR)(a). After return to bypass, a mitral valve cleft was discovered, and after repair was no longer insufficient (b). LA = left atrium; LV = left ventricle.

dysfunction associated with pulmonary artery banding, and two patients with Fontan palliation requiring fenestration closure or reduction. All these findings were changes from the initial post-operative evaluation.

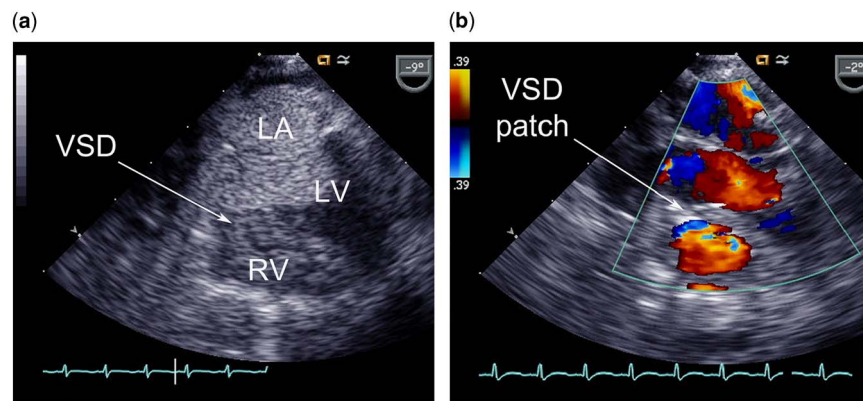
## Discussion

Intra-operative imaging in many centres has become a mainstay in the evaluation of surgical repair of patients with CHD. Previous studies have demonstrated the safety,<sup>5,6</sup> utility,<sup>7,8</sup> and cost-effectiveness<sup>9</sup> of its routine use. Except for patients weighing <2 kg and select patients with tracheal and oesophageal

anomalies,<sup>10</sup> routine intra-operative trans-oesophageal imaging in combination with surgical and haemodynamic evaluation provides immediate assessment of surgical results that can prompt further intervention.<sup>11</sup>

Our evaluation is the largest study to characterise patients who require further surgical intervention based on intra-operative trans-oesophageal echocardiographic findings. Although imaging aids the surgical repair of nearly all forms of CHD, we found that the evaluation of the atrioventricular valves benefits from it most frequently. Nearly 20% of all mitral and tricuspid valve repairs and 12% of all common atrioventricular canal repairs required





**Figure 3.**

*Twenty-one-month-old girl with complex infundibular muscular narrowing underwent muscle resection, found to have a residual ventricular septal defect (VSD) by left atrial contrast echocardiography (a) with left-to-right shunting. Further intra-cardiac repair with a ventricular septal patch alleviated the inter-ventricular shunt (b) by color Doppler. LA = left atrium; LV = left ventricle; RV = right ventricle.*

return to bypass after imaging-identified residual problems, with residual tricuspid, mitral, and left atrioventricular valve regurgitation being the most commonly cited reasons. Furthermore, even with attentive intra-operative assessment, atrioventricular valve regurgitation proved to be a finding that, in our study, caused 2/14 second operations within 1 week. Similar findings were described by Randolph et al.<sup>9</sup> Ultimately, the repairs may benefit from the use of more advanced imaging modalities such as three-dimensional echocardiography to evaluate the architecture and function post-operatively.<sup>12</sup>

Cases that involved relief of pulmonary valve stenosis frequently required additional post-operative imaging, and right ventricular outflow tract obstruction was the top reason for returning to bypass. As with atrioventricular valve regurgitation, trans-oesophageal echocardiography remains the most commonly used tool for assessment; however, stenotic lesions can also be evaluated with three-dimensional echocardiography<sup>13</sup> or can be directly measured.

The previous study by Guzeltas et al<sup>11</sup> found post-operative imaging to be very useful in patients with tetralogy of Fallot. Although this diagnosis did make up a large percentage of the total repeat trans-oesophageal echocardiograms (Table 1), we felt this was skewed by the multitude of complex tetralogy patients who underwent repair at our institution. In fact, only 5% of all tetralogy of Fallot patients who underwent repair during the study period required further imaging, which was relatively less than many of the other diagnoses.

Intraoperative trans-oesophageal echocardiography was extremely successful at identifying the vast majority of lesions needing acute revision. This is unquestionably beneficial for the patient's overall course. We also confirmed that additional imaging

after surgical revision is safe for patients and does not confer any increased risk of mortality or increased hospital length of stay.

For the 5% in whom trans-oesophageal echocardiographic imaging was not considered safe, because of low weight, airway compromise with probe insertion, or inherent tracheal and oesophageal abnormalities, assessment was unfortunately limited. Among those who could safely be evaluated, in ~5.7% of the cases, post-operative trans-oesophageal echocardiographic imaging provided information that led to bypass return immediately for further surgical correction. Routine intra-operative imaging provides better outcomes for patients with CHD. In our institution, trans-oesophageal echocardiograms are performed in over half of all congenital cases and 95% of all congenital cases requiring bypass.

As a retrospective review, this study is subject to inherent limitations. It represents a single institution's experience and may not reflect other institutions' reliance upon intra-operative imaging in decision making, spectrum of CHD, or surgical skill.

We did not evaluate patients who returned to bypass but did not have a second post-operative study while still not completely separated from cardiopulmonary bypass. It is assumed that the number of these patients is low, given that intra-operative imaging helped in the original decision to return to bypass, and would likely be requested to assess outcomes after further surgical intervention.

We did not investigate those patients who returned to bypass when that decision was not based on imaging. Again, it is assumed that this number would be small given our high frequency of trans-oesophageal echocardiographic usage in congenital cases.

It is difficult to speculate whether there were any intra-operative imaging clues that could have

prevented a second surgery later in the hospitalization. Ventricular dysfunction after banding (two patients) and excessive right-to-left shunting with Fontan fenestration (two patients) are both diagnoses that often require several post-operative days to be adequately assessed. Progressive valve regurgitation (three patients) also may develop with time and physiological changes during recovery. It is, therefore, not surprising that these patients needed to return to the operating room at a later date, and most likely their course could not have been predicted at the time of initial surgery.

In conclusion, routine trans-oesophageal echocardiographic imaging is helpful in the surgical repair of CHD in children and adults. This has been particularly valuable in patients with mitral, tricuspid, and common atrioventricular valve stenosis and regurgitation. The vast majority of patients with a second post-operative evaluation are unlikely to return to the operating room at a later date. In fact, from routine post-operative imaging and haemodynamic assessment, 99 patients benefited from immediate identification of surgical need, and 96 (5.5%) benefited from avoiding possible long-term complications associated with re-operations, redo-sternotomies, and potentially longer lengths of hospital stay. Those patients who do have to return to the operating room often have progressive disease that requires time and serial evaluations to be assessed. Overall, routine repeat imaging successfully identifies patients requiring further interventions, does not confer additional risk of mortality or prolong length of hospital stay, and can greatly influence the operative and post-operative course of a substantial number of patients.

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### Conflicts of Interest

None.

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