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ORIGINAL ARTICLE

Impact and Cost Effectiveness of Routine Intraoperative Transthoracic and Transesophageal Echocardiography on Surgical Decision Making in Pediatric Cardiac Surgery

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ABSTRACT

Introduction: Congenital heart diseases (CHD) present with wide spectrum of lesions leading to diagnostic dilemmas and it is quite possible to miss correct diagnosis during preoperative transthoracic echocardiography (TTE) in an inadequately sedated child, especially in a busy outpatient setting. It is a routine practice in our center to do baseline TTE after induction of anesthesia followed by pre and postcardiopulmonary bypass (CPB) transesophageal echocardiography (TEE) in all CHD patients thus helping us review our surgical plan.

Materials and methods: All pediatric patients <18 years undergoing cardiac surgery from January 2013 to December 2013 at our tertiary care center in whom perioperative echocardiograhy was done were included. Appropriate sized TTE and TEE probes were used with the Philips iE33 echocardiography platform (Philips, Andover, MA) .

Results: Out of total 352 pediatric cardiac surgical patients, perioperative echocardiography was done in 347(98.5%) patients. Baseline TTE showed new findings leading to change in surgical plan in 11 (3.1%) patients while additional new findings in baseline TEE were seen in 9 (2.6%). Post bypass TEE showed residual lesions requiring a CPB rerun in 19 (5.5%) patients. Intraoperative echocardiography was found to be cost effective with an estimated savings per patient of ₹ 3950 to 5373($61 - 83).

Conclusion: Intraoperative echocardiography is an important tool in armamentarium of perioperative physician which can be used to review diagnosis and help to formulate an informed surgical plan. Post-bypass transesophageal echocardiography is also useful as it identifies the residual lesions and establishes anatomical correction, which ultimately translates to lesser redo surgeries and a better postoperative outcome.

Keywords: Intraoperative echocardiography, Pediatric cardiac surgery, Congenital heart diseases, Transesophageal echocardiography.

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INTRODUCTION

Congenital heart diseases (CHD) present with a wide spectrum of lesions leading to diagnostic dilemmas and it is quite possible to miss correct diagnosis during preoperative transthoracic echocardiography (TTE) in an inadequately sedated child, especially in a busy outpatient setting. Over the past few decades, perioperative echocardiography has solidified its role as a critical diagnostic and perioperative management tool for patients with congenital heart disease (CHD).[1] In addition to TTE, intraoperative transesophageal echocardiography (TEE) has proved to be invaluable in confirming preoperative diagnosis, formulating the surgical plan, evaluating immediate operative results, identifying patients with residual defects and guiding surgical revisions.[2] According to practice guidelines for perioperative TEE, established by Society of Cardiovascular Anesthesiologists and American Society of Anaesthesiologists, there is strong evidence for the usefulness of TEE in CHD surgery as it can significantly improve clinical outcome.[3] TEE allows continuous monitoring throughout the intraoperative period without transgressing the sterile operative field. With the development of smaller probes, better software, easy availability of resources for learning, image generation and interpretation of echocardiography, there is a parallel improvement in surgical management of congenital lesions. Perioperative echocardiography is an expensive tool requiring costly echocardiography machines and probes along with exhaustive and time-consuming training, particularly for CHD. Few authors have specifically addressed the cost-effectiveness of intraoperative echocardiography in pediatric

population, especially so in the context of the Indian subcontinent. The purpose of our study was to find out the impact and cost effectiveness of routine intraoperative TTE and TEE in the management of CHD surgery.

MATERIALS AND METHODS

In this prospective observational study, all children under 18 years of age undergoing CHD surgery from January 2013 to December 2013 were included with institutional ethics committee's approval. Surgical plan was formulated on the basis of transthoracic echocardiography done under conscious sedation on outpatient basis and further imaging studies, such as cardiac angiography or computerized tomography, were performed in patients in whom they were deemed necessary to devise a complete surgical plan. All children underwent preoperative evaluation regarding physical health, birth history, comorbid illness, current medications, drug allergy and previous anesthetic experience. TEE probe was not placed in children with history of dysphagia or prior esophageal surgery, unrepaired tracheoesophageal fistula, esophageal diseases, like stricture, diverticulum or varices, severe respiratory depression, severe coagulopathy and seropositivity for hepatitis viruses or human immunodeficiency virus. Elective patients were kept nil per oral as per standard protocol. Echocardiography (TTE and TEE) studies were done after induction and intubation as per institutional protocol for pediatric cardiac patients.

ECHOCARDIOGRAPHY

For TTE, we used S5-1 (1-5 MHz) or S-12-4 (4-12 MHz) transducers. For TEE S7-3t sector array (3-7MHz) was used for patients who weighed ≥ 8 kg while patients weighing less than 8 kg were examined by S8-3t microTEE (3-8 MHz) transducer. Examinations were performed using Philips iE33 echocardiography platform (Philips Company, Andover, MA, USA) equipped with pulsed-wave, continuous-wave and color Doppler capabilities.

Intraoperative echocardiography of the patient was first done by a cardiac anesthesia fellow posted exclusively for echocardiography. The anesthesia fellow posted on echocardiography did not review the patients file for preoperative TTE or catheterization reports, instead intraoperative TTE and TEE was performed with a prefixed sequence to cover all possible standard views, cardiac structures and functions. Relevant images were stored for future review and comparison. The anesthetic management and monitoring of patient was performed by a primary anesthesia fellow posted in the operating room (OR). After comprehensive echocardiographic examination of the patient, the findings were documented and validated with consultant operating room (OR) anesthesiologist who had reviewed the preoperative TTE/angiography/computed tomography (TT) findings and intraoperative TTE/TEE. The fellow doing intraoperative echocardiography underwent formal echocardiography training (2 months each of TTE and TEE, with at least 50 pediatric and adult patients each). The consultant OR anesthesiologist were all cardiac anesthesiologist with at least 5 years experience in TTE and TEE. In case of any new finding obtained by either TTE or TEE, the concerned cardiac surgeon and primary/ on call cardiologist were consulted. The new findings were documented as new or unanticipated ECHO finding. After the consensus team meeting, any change in surgical plan was conveyed to the patient's health care proxy and the data was prospectively entered in the dedicated data base as a major or minor change in surgical plan.

TEE examination was done at the end of cardiopulmonary bypass (CPB) to look for adequacy of surgical correction, cardiac function and any significant residual lesion and the findings were conveyed to the operating surgeon. Peak right ventricular outflow tract gradient of >40 mm Hg with pressure ratios between right and left ventricles (pRV/LV) value of > 0.8 was considered significant residual gradient.[4] Valves were assessed as per standard ASE guidelines and any lesion graded more than or equal to moderate was considered significant. Any significant residual lesion, requiring surgical revision or second CPB was noted as an impact of TEE on surgical decision making. TEE examination was also repeated after the second CPB. Cases where revision of surgery or second CPB was deferred due to technical reasons were also documented. The patients were observed and evaluated for residual lesions and complications during the ICU stay.

The primary end-point of the study was the incidence of alterations in surgical management (including the need for repeat bypass run) supported by TEE findings and cost effectiveness of intraoperative echocardiography. Secondary end-points included the incidence of a new/ unanticipated diagnosis and diagnostic exclusions.

COST ANALYSIS

Echocardiography costs included machine costs calculated on the basis of a mean cost per year assuming a life span of 10 years and no resale value at the end of its working life, a service contract, one probe breakage every year, and annual maintenance cost used in provisions for storage, cleaning and recording.[5] We did not include the costs of the anesthesiologist performing the TEE or of the consulting cardiologist because no separate consultant is posted for intraoperative TEE practice in our institution and social

Table 1: Preoperative diagnosis and overall perioperative echocardiography coverage

Diagnosis	*No. of cases (%)*	*TTE only (108)*	*TEE only (16)*	*Both (223)*
Cyanotic heart disease	181 (52.16%)	–	–	–
TGA	24 (6.9%)	14	–	10
TAPVC	12 (3.5%)	6	–	6
TOF	129 (37.2%)	30	8	91
Ebstein's anomaly	4 (1.2%)	2	–	2
Tricuspid atresia	10 (2.9%)	5	–	5
HLHS	2 (0.6%)	2	–	–
Acyanotic heart disease	148 (42.7%)	–	–	–
VSD	56 (16%)	18	2	36
AV septal defect	12 (3.5%)	5	–	7
ASD closure	35 (10.1%)	10	2	23
PDA	28 (8.1%)	8	–	20
Coarctation	17 (4.9%)	12	–	5
Others	18 (5.2%)	–	–	–
Valvular	12 (3.4%)	–	4	8
Pericardial	6 (1.7%)	–	–	6

Table 2: TTE leading to change in surgical plan

Preoperative diagnosis	*Surgery planned*	*Pre-CPB finding*	*Change of plan*	*No. of patients*
TOF with infundibular stenosis	ICR/infundibular resection	Valvular + infundibular PS	ICR with transannular patch	3
TOF with good sized pulmonary arteries	ICR	PA size not adequate for ICR	Modified BT shunt	2
AV septal defect	ASD + VSD closure	No VSD visualized	ASD closure only	3
PDA with COA	PDA ligation + coarctation repair	No significant COA	PDA ligation only	2
VSD with COA	VSD closure + COA repair	No significant COA	VSD closure only	1

TOF: tetralogy of fallot; PA: pulmonary artery; ASD: atrial septal defect; VSD: ventricular septal defect; PDA: patent ductus arteriosus; CoA: coarctation of aorta; ICR: intracardiac repair

model of healthcare has fixed costs for the consultants. However, we included the cost of training an anesthesiologist in TEE every year. This cost per year was considered for cost per pediatric patient. Similarly, the cost of reoperation including cost of surgery, materials for CPB, anesthesia, ICU stay and bed occupancy in ICU was considered for both uncomplicated and complicated late reoperations.

STATISTICAL ANALYSIS

Demographic data are presented in mean ± standard deviation. Descriptive statistics were presented as total and percent unless otherwise specified. Cost analysis was performed assuming a conversion cost of ₹ 65 to one USD. As this is a first of its kind cost effectiveness observational study, sample size analysis was skipped. Analysis was performed with the statistical package SPSS 17.0 (Chicago, IL, USA).

RESULTS

A total of 352 pediatric patients underwent cardiac surgery in this tertiary care institution. Out of these, 210 (59.7%) were males and 142 (40.3%) were females. Cardiac surgery was performed at a median age of 1.5 years (range 0-17.8 years) and a median weight of 7.5 kg (range 1.9-72 kg). Perioperative echocardiography was done in 347 (98.5%) out of these 352 patients. Five cases were not included due to nonavailability of appropriately sized probe, emergent nature of the surgery or echocardiography machine being busy in other operation theaters.

Table 1 shows preoperative diagnosis as per operative list and overall coverage of perioperative echocardiography. Baseline TTE showed new pre CPB findings in 13 (3.7%) patients which led to change in surgical plan in 11 patients. Additionally, new findings in baseline TEE were seen in 11 (3.1%) patients (Tables 2 and 3). This led to further change of surgical plan in nine patients. Post bypass TEE showed residual lesions in 29 (8.36%) patients and second CPB run was performed in 19 of these patients (Table 4). Thus, perioperative echocardiography at any point of time resulted in change in surgical plan in 11.24% (39/347) of cases. Findings were mostly relating to anatomical details like level/severity of RVOT/pulmonary stenosis in TOF, grading of valvular insufficiency and exclusion of wrong preoperative diagnosis.

Table 3: TEE leading to change in surgical plan

Preoperative diagnosis	*Surgery planned*	*Pre-CPB TTE finding*	*Change of plan*	*No. of patients*
TOF with infundibular/ valvular pulmonary stenosis	ICR with transannular patch	OS ASD/PFO (pentalogy of fallot)	ICR + ASD closure	2
TOF	ICR	Hypoplastic LV	BD Glenn shunt	2
AV septal defect with mild MR	ASD + VSD closure	Severe MR	ASD/VSD closure+ mitral valve repair	2
VSD with severe MR	VSD with mitral valve repair	Low moderate MR (even on provocation test with low dose phenylephrine)	VSD closure only	1
RHD with severe MR	Mitral valve replacement /repair	Severe TR with tricuspid annular dilatation	MV + tricuspid valve repair	2

TOF: tetralogy of fallot; LV: left ventricle; MR: mitral regurgitation; PAH: pulmonary hypertension; TR: tricuspid regurgitation; ASD: atrial septal defect; VSD: ventricular septal defect; PFO: patent foramen ovale

Complications

All necessary precautions to minimize TEE-related complications including gentle insertion of probe with limited manipulation were taken. Complications occurred in six patients (2.5%), and all were related to ventilation problems: one incidental tracheal extubation occurred prior to the start of surgery which was immediately identified and child was reintubated after removal of probe and, in five patients, we saw difficulty in ventilation associated with sudden rise in airway pressures (while using volume controlled ventilation mode) even on minimal probe manipulation. These problems resolved with the removal of TEE probe.

COST ANALYSIS

In our institution (a mixed population of adults and children), we performed 1,071 perioperative examinations per year with one echocardiography machine, yielding a cost per examination of about ₹ 1074 ($16.52) (Table 5). Because we did not observe any significant postoperative morbidity secondary to the use of TEE, we kept this value as a standard cost for each examination. This adds up to a total cost of ₹ 453,529($6,977) for the 347 pediatric patients studied.

In our model, the cost of a late reoperation was estimated to be between ₹ 96,000 and 1,22,000($1477 -1877) as mentioned in Table 6. We must stress here that the reoperation costs used in our study are estimated on basis of what patients incur in our hospital which being a public sector hospital has discounted rates for various services and surgical items. The actual cost incurred in some other setup may be much higher.

Again using the figure of 19 patients, who obviously benefited by the bypass rerun and a reoperation was possibly prevented, global benefit for our cohort was between ₹ 1, 824,000 and 2,318,000 ($28062-35662). If we subtract the global cost of routine echocardiographic examinations from this last amount, we estimate an average saving of ₹ 1,370,471 to 1,864,471 ($ 21,084-28,684) meaning an estimated savings per patient of ₹ 3950 to 5373($61- 83).

It has to be pointed out that by doing calculation like this one cannot sum up the benefits obtained in the cases in which there was a change in plan of surgery before the cardiopulmonary bypass as well as the value of perioperative echocardiography as a monitoring tool which helps in management of hemodynamics and provides guidance at various levels during the surgery. Hence, we think the ultimate benefit derived from the TEE would be still higher.

Table 4: Post-CPB residual lesions requiring bypass rerun

Post-CPB lesions	*No. of cases*	*CPB rerun*
Residual VSD	10	6
Significant gradient across RVOT	11	8
Residual PFO	3	1
Significant residual MR/TR	5	4

RVOT: right ventricular out-flow trait

Table 5: Estimated costs for 1 year of perioperative echocardiography service

Item	*Cost per year*
Machine cost per year	Cost of machine/10 years = ₹ 600,000/ year ($9231/year)
Service contract	₹ 100,000 ($1540)
Probe replacement/repair	₹ 500,000($7693)
Storage cleaning, video recording	₹ 50,000 ($770)
Cost of training an anesthesiologist for TTE and TEE	₹ 150,000 ($2308)
Total cost per year	₹ 1400000 ($17692)
Cost per patient (total cost/total no. of patients)	₹ 1307 ($20.11)
Cost for pediatric patients (cost per patient* no. of pediatric patients)	347 × 1307 = ₹ 453,529 ($ 6977)

Table 6: Costs of hospitalization

First hospitalization day	₹ 5,000 ($77)
Following days (per day)	₹ 1,000 ($15.4)
ICU days (per day)	₹ 2,000 ($30.8)
Surgery	₹ 10,000 ($154)
Surgical assistance	₹ 1,000 ($15.4)
Anesthesia	₹ 5,000 ($77)
Operating room	₹ 1,000 ($15.4)
Material for cardiopulmonary bypass	₹ 50,000 ($770)
Other material	₹ 20,000 ($308)
Uncomplicated late reoperation (1 week hospitalization with 2 days ICU)	₹ 96,000 ($1,477)
Complicated late reoperation (3 weeks hospitalization with 1 week ICU)	₹ 1,22,000 ($1877)

Table 7: Summary of reported changes to surgical procedure related to intraoperative TEE

Kolev et al[21]	1998	9/224 (4%)	Europe
Couture et al[22]	2000	34/851(4%)	Canada
Schmidlin et al[23]	2001	12/182 (7%)	Switzerland
Forrest et al[24]	2002	109/2343 (5%)	Australia
Fanshawe et al[5]	2002	24/430 (6%)	USA
Eltzschig et al[25]	2008	880/12566 (8%)	USA
Klein et al[26]	2009	312/2103 (15%)	UK
Kumar A et al[27]	2013	65/726 (8.9%)	India
Present study*	2014	39/347 (11.24%)	India

DISCUSSION

TEE has been used in adult cardiac patients since mid-1980s for the evaluation of valvular repair and prosthetic valve function and for monitoring of myocardial ischemia and left ventricular preload.[6-14] Development of miniaturized probes in 1990 has generated a number of studies, which have demonstrated that TEE can be performed safely in the pediatric population and provide substantial benefit as well.[15-18]

Several authors have reported on the positive impact of intraoperative echocardiography on patients' outcomes.[1] The field of applications for this monitoring and diagnostic technique is ever expanding as more evidence emerges for the benefits of intraoperative echocardiography. Anesthesiologists can utilize TTE/TEE to assess ventricular function, preload, valve dysfunction, and intracardiac/great artery pathology. TEE allows for prompt recognition of significant additional and residual defects and thus affects the surgical plan. Immediate revision of planned surgical procedure improves patient outcomes by avoiding subsequent reoperations thereby reducing morbidity, mortality and cost. TEE also helps anesthesiologists to manage hemodynamics by guiding fluid management, anesthetic drug titration and selection of appropriate inotropic/vasoactive agents. TEE can be an excellent hemodynamic monitoring tool in unstable patients. Intraoperative TEE can also detect complications associated with the performed procedure in the post-bypass and postoperative periods (such as graft occlusion, bleeding and aortic dissections).

Yumoto et al reported 2.4% change in surgical plan in pediatric cardiac cases based on intraoperative TEE findings.[20] Our investigation has revealed a higher incidence of alteration to planned surgery, 39 out 347 (11.24%). This may be because Yumoto attempted TEE in 90/200 cases only as opposed to 239/347 in our center and they did not have multiplane pediatric probe at the time of study. Our results are comparable to many other studies which included adult patients as well (Table 7).[19-25]

TEE is not without risk, though this may be difficult to quantify. Serious thermal or physical injury has previously been estimated to occur in <1 in 500 of patients. A more recent study of 516 cases demonstrated an incidence of major gastrointestinal complications of 1.2%. This study showed a high rate of late endoscopic detection of esophageal ulcer, perforation or tear.[28] It is important to never force TEE and to have the courage to abandon it if resistance to insertion of the probe is perceived.

Stevenson reported 2.4% incidence of complications, a figure that is in accordance with our incidence of 2.5%.[29] The absence of prolonged complications or morbidity attributable to the TEE examination in our series is noteworthy. We observed no major morbidity attributable to TEE even though it was performed by fellow anesthetists initially. Our compliance with published guidelines and proper training for basic intraoperative TEE may have resulted in better implementation in practice.[30]

Leaving the final decision until the child is anesthetized on the operating table compromises the consent process and renders risk and financial evaluations inaccurate. This is a very important evolving aspect, considering the fact that echocardiography is increasingly being used as the sole imaging technique for surgical decision making. Hence, anesthesia and surgical teams should inform the possibilities of change in surgical plan based on intraoperative echocardiography to the patient while taking informed consent preoperatively. It must be emphasized that there are, as yet, no data regarding the outcome of patients whose surgery is changed in this manner, and further study is planned.

In the present study, we found that perioperative echocardiography for pediatric cardiac surgery is not only safe and clinically beneficial but is also cost-effective. Although this issue has been studied by few authors, ours is the first study to address the cost effectiveness of the routine use of perioperative echocardiography in pediatric cardiac surgery performed by anesthesiologists in India.

We did not use cardiology staffing and ultrasound technicians as done by some authors.[25,26] All of our examinations were performed by cardiac anesthesiologists. We did not include the cost of the anesthesiologists because that is considered a pre-existing fixed cost independent of the use of TEE or other routine devices and we do not have a system of reimbursing for any intraoperative TEE examination separately.

The cost-effectiveness of TEE in simple operations like elective VSD has been questioned by few authors, but we found residual defect in nine patients with VSD. Residual defects can be easily handled in a second bypass run without substantially increasing morbidity, but if left uncorrected, they might increase the risk of prolonged ICU stay with difficult weaning and complications like infective endocarditis. So, we recommend routine use of TEE and not the selective one. The other inherent advantage that echocardiography has over other methods like using needle and transducing pressures to check residual gradients and taking blood gas samples to check step up is that echocardiography can provide the exact site of the lesion (e.g. residual VSD *vs* a second VSD at a different location) and thus can be of great help during surgical correction of the lesion.

There are several limitations to our study. Epicardial imaging is not performed routinely at our center. Number of patients who definitely benefited from a second bypass run is unknown. We did not follow the patients after discharge from hospital. The impact of echocardiography on the five cases that did not undergo intraoperative echocardiography could not be calculated and results might have varied either way if included. There is no way to determine the true cost of a reoperation or of a complication related to a residual defect; we had to extrapolate information acquired from the financial department of our institution based on the usual invoice criteria. We did not include the impact of TEE on perioperative hemodynamic monitoring and medical management, both of which play a substantial role in reducing postoperative morbidity and mortality of residual defects. Also, the possible costs and benefits associated with changes in surgical plan, immediate versus a late surgical revision, were not addressed separately.

CONCLUSION

Perioperative echocardiography is a valuable adjunct to intraoperative anesthetic and surgical management of pediatric patients. It is associated with improved outcome, decreased need of resurgery and helps in choice of appropriate surgical technique. In this study, we made liberal estimates of the cost of reoperation based on expenditure incurred in our public sector hospital (social health care) and the actual cost in other institutions which lack the government grant can be much higher. In spite of using conservative estimates for expenditure saved by perioperative echocardiography, our analysis indicates that the financial benefits of TEE in pediatric cardiac surgery are substantial and outweigh the costs.

Although the use of TEE in the young age groups is considered to be safe and complications occur rarely, the risk-benifit ratio should be examined in every case and physicians should be vigilant of the risks associated with this imaging modality and monitor patients accordingly. One should be extremely cautious against pushing the TEE probe against resistance and monitor respiration closely during probe manipulations, especially in neonates.

REFERENCES

1. Siwik ES, Spector ML, Patel CR, et al. Costs and costeffectiveness of routine transesophageal echocardiography in congenital heart surgery. Am Heart J 1999;138:771-776.
2. Muhiudeen IA, Roberson DA, Silverman NH, et al. lntraoperative echocardiography for evaluation of congenital heart defects in infants and children. Anesthesiology 1992;76:165-172.
3. Practice guidelines for perioperative transesophageal echocardiography: A report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. Anesthesiology 1996;84:986-1006.
4. Kaushal K, Radhakrishanan S, Dagar KS, Iyer Pu, Girotra S. Significant intraoperative right ventricular outflow gradients after repair for tetralogy of Fallot: to revise or not to revise? The Annals of Thoracic Surgery 1999;68:1705-1712.
5. Fanshawe M, Ellis C, Habib S, Konstadt SN, Reich DL. A retrospective analysis of the costs and benefits related to alterations in cardiac surgery from routine intraoperative transesophageal echocardiography. Anesthesia and Analgesia 2002;95:824-827.
6. Bettex DA, Pretre R, Jenni R, Schmid ER. Cost-effectiveness of routine intraoperative transesophageal echocardiography in pediatric cardiac surgery: a 10-year experience. Anesth Analg 2005;100:1271-1275.
7. Goldman M, Guarino T, Fuster V, Mindich B. Mitral valvuloplasty is superior to valve replacement for preservation of leftventricular function: an intraoperative two dimensional echocardiographic study. J Am Co11 Cardiol 1987;10:568-575.
8. Taams M, Gussenhoven E, Cahalan M, et al. Transesophageal Doppler color flow imaging in the detection of native and Bjork-Shiley mitral valve regurgitation. J Am Co 11 Cardiol 1989;78:95-99.
9. Nellessen U, Schnittger I, Appleton Cl, et al. Transesophageal two-dimensional echocardiography and color Doppler flow velocity mapping in the evaluation of cardiac valve prostheses. Circulation 1988;78:848-855.
10. Van Der Brink R, Visser C, Basart D, et al. Comparison of transthoracic and transesophageal color Doppler flow imaging in patients with mechanical prosthesis in the mitral valve position. Am J Cardiol 1989;63:1471-1474.

11. Leung JM, O'Kelly B, Browner WS, et al. Prognostic importance of post-bypass regional wall-motion abnormalities in patients undergoing coronary artery bypass graft surgery. SPI Research Group. Anesthesiology 1989;71:16-25.
12. Smith JS, Cahalan MK, Benefiel DJ, et al. Intraoperative detection of myocardial ischemia in high-risk patients: electrocardiography versus two-dimensional transesophageal echocardiography. Circulation. In: Debrujin N, Clements F, editors Transesophageal echocardiography. Boston: Martinus Nijhoff 1987. 1985;72:1015-1021.
13. Abel M, Nishimura R, Calahan M, et al. Evaluation of intraoperative transesophageal two-dimensional echocardiography. Anesthesiology 1987;66:64-68.
14. Harpole DH, Rankin JS, Wolfe WG, et al. Assessment of left ventricular functional preservation during isolated cardiac valve operations. Circulation 1989;80:1111-1119.
15. Benson M, Cahalan M. Cost-benefit analysis of transesophageal echocardiography in cardiac surgery. Echocardiography 1995;12:171-183.
16. Ritter SB, Thys D. Pediatric transesophageal color flow imaging: smaller problems for smaller hearts. Echocardiography 1989;6:431-440.
17. Ritter SB. Transesophageal echocardiography in children: new peephole to the heart. J Am Co 11 Cardiol 1990;16:447-450.
18. Lam J, Neirotti RA, Nijveld A, et al. Transesophageal echocardiography in pediatric patients: preliminary results. J Am Sot Echocardiogr 1991;4:43-50.
19. Stumper OF, Elzenga NJ, Hess J, Sutherland GR. Transesophageal echocardiography in children with congenital heart disease: an initial experience. J Am Co 11 Cardiol 1990;16:433-441.
20. Yumoto M, Katsuya H. Transesophageal echocardiography for cardiac surgery in children. J Cardiothorac Vasc Anesth 2002;16: 587-591.
21. Kolev N, Brase R, Swanevelder J, et al. The influence of transoesophageal echocardiography on intra-operative decision making. A European multicentre study. European Perioperative TOE Research Group. Anaesthesia 1998;53:767-773.
22. Couture P, Denault AY, McKenty S, et al. Impact of routine use of intraoperative transesophageal echocardiography during cardiac surgery. Canadian Journal of Anaesthesia 2000;47:20-26.
23. Schmidlin D, Schuepbach R, Bernard E, et al. Indications and impact of postoperative transesophageal echocardiography in cardiac surgical patients. Critical Care Medicine 2001;29: 2143-2148.
24. Forrest AP, Lovelock ND, Hu JM, Fletcher SN. The impact of intraoperative transoesophageal echocardiography on an unselected cardiac surgical population: a review of 2343 cases. Anaesthesia and Intensive Care 2002;30:734-741.
25. Eltzschig HK, Rosenberger P, Loffler M, et al. Impact of intraoperative transesophageal echocardiography on surgical decisions in 12,566 patients undergoing cardiac surgery. Annals of Thoracic Surgery 2008;85:845-852.
26. Klein AA, Snell A, Nashef SAM, Hall RMO, Kneeshaw JD, Arrowsmith JE. The impact of intra-operative transoesophageal echocardiography on cardiac surgical practice. Anaesthesia 2009;64:947-952.
27. Kumar A, Puri GD, Madhavan JS, Mishra A. Routine intaroperative transesophageal echocardiography: Impact on intraoperative surgical decision making, a single centre interim analysis. Journal of Perioperative Echocardiography 2013; 1(1):16-20.
28. Massey SR, Pitsis A, Mehta D, Callaway M. Oesophageal perforation following perioperative transoesophageal echocardiography. Br J Anaesth 2000;84:643-646.
29. Stevenson JG. Incidence of complications in pediatric transesophageal echocardiography: Experience in 1650 cases. J Am Soc Echocardiogr 1999;12:527-532.
30. Aronson S. Adherence to physician training guidelines for pediatric transesophageal echocardiography affects the outcome of patients undergoing repair of congenital cardiac defects. [Letter]. J Am Soc Echocardiogr 1999;12(11):1008.