Impact of Intraoperative Transesophageal Echocardiography on Surgical Decisions in 12,566 Patients Undergoing Cardiac Surgery

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Background. **The utility of intraoperative transesophageal echocardiography (TEE) for different types of cardiac surgical procedures has not been thoroughly investigated despite its increasing popularity. Therefore, we retrospectively evaluated the impact of before and after cardiopulmonary bypass (CPB) TEE on surgical decisions in 12,566 consecutive patients undergoing cardiac surgery at a single institution.**

Methods. **We analyzed all patients undergoing cardiac surgical procedures who had an intraoperative TEE examination between 1990 and 2005 at the Brigham and Women's Hospital. Results of the TEE examinations were entered into a database. Previously undiagnosed TEE findings from the pre- and post-CPB examinations that directly impacted surgical decisions were evaluated.**

Results. **Before and after CPB TEE examinations influenced surgical decision making in 7.0% and 2.2%, respectively, of all evaluated patients (n = 12,566). In patients undergoing only coronary artery bypass graft surgery (CABG [n = 3,835]), surgical decisions were influenced by 5.4% of the pre-CPB and 1.5% of the post-CPB TEE examinations, and in 6.3% and 3.3%, respectively, of those patients undergoing isolated valve procedures (n = 3,840). In combined CABG and valve procedures (n = 2,944), surgical decisions were influenced by 12.3% of the pre-CPB and 2.2% of the post-CPB TEE examinations.**

Conclusions. **Intraoperative TEE influences cardiac surgical decisions in more than 9% of all patients in the presented study population, with the greatest observed impact in patients undergoing combined CABG and valve procedures.**

(Ann Thorac Surg 2008;85:845–53)

Since the introduction of intraoperative echocardiography into clinical practice in the 1980s, its popularity has steadily increased. Today, more than 90% of training programs in the United States use intraoperative transesophageal echocardiography (TEE) as a diagnostic and monitoring tool [1]. The American Society of Anesthesiologists, the American Society of Echocardiography, and the Society of Cardiovascular Anesthesiologists have issued guidelines for the intraoperative use of TEE [2–4]. Previous studies have suggested that in cardiac surgical patients, TEE provides essential before and after cardiopulmonary bypass (CPB) information regarding cardiac performance [5], valve function [6, 7], great vessel pathology [8], and congenital anomalies that has been shown to have a favorable impact on perioperative clinical outcomes [9–12].

Despite the increasing popularity of intraoperative TEE, its impact on perioperative decision making as well as on clinical outcomes has been questioned [9]. Ideally, intraoperative TEE should prevent unnecessary surgical procedures and associated morbidity. In addition, TEE can identify previously undiagnosed pathology and residual defects after surgical intervention to enable an immediate correction if necessary. Several clinical studies that have investigated the impact of TEE on surgical decision making have been limited by only enrolling a relatively small number of patients, focusing only on a particular surgical procedure, or reporting only post-CPB findings [9–19]. Therefore, we

Accepted for publication Nov 5, 2007.

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Drs Shernan and Fox disclose that they have a financial relationship with Philips Medical Systems, Inc.

Published by Elsevier Inc

0003-4975/08/$34.00
doi:10.1016/j.athoracsur.2007.11.015

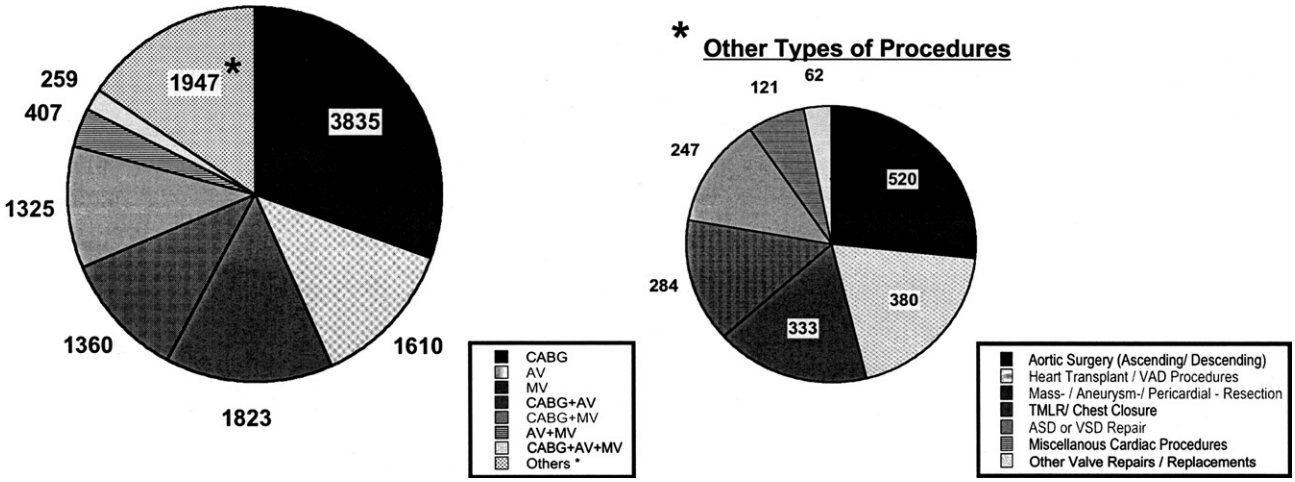

*Fig 1. Overview of surgical procedures performed in 12,566 cardiac surgical patients who underwent intraoperative transesophageal echocardiography examination. *Other types of procedures (n = 1,947). (ASD = atrial septal defect repair; AV = aortic valve replacement or repair; CABG = coronary artery bypass grafting; MV = mitral valve replacement or repair; TMLR = transmyocardial laser revascularization; VAD = ventricular assist device placement; VSD = ventricular septal defect repair.)*

conducted a study to assess the influence of intraoperative TEE on surgical decision making, in 12,566 patients from a single institution who underwent different types of cardiac and thoracic aortic surgical procedures.

Patients and Methods

Patient Population

The study population consisted of a consecutive series of all cardiac surgical patients from the Brigham and Women's Hospital in Boston, Massachusetts, in whom intraoperative TEE was performed between 1990 and 2005. The decision to perform TEE was determined together by the attending cardiac anesthesiologist and the cardiac surgeon for each case. Specific criteria for the examination included known or suspected ventricular dysfunction, valve dysfunction, great vessel pathology, and congenital anomalies. This retrospective study was approved by the Institutional Review Board, and need for individual patient was waived.

Technique of TEE Examination

All TEE probes (Siemens, Mountain View, California; or Philips Medical Systems, Andover, Massachusetts) were inserted after induction of general anesthesia. Complete and comprehensive intraoperative TEE examinations were performed by cardiac anesthesiologists, all of whom had extensive training and experience in perioperative echocardiography. Results of the examinations were discussed with the attending cardiac surgeon. Data from the intraoperative TEE examinations were recorded on videotape, and stored on a digital database for offline review and analysis.

Study Design

Patient demographic and echocardiographic data were obtained from the departmental digital database, which included information pertaining to the impact of intraoperative echocardiography on perioperative surgical decision making. For intial data collection, a prospectively designed clinical data form was utilized. Intraoperative TEE findings that were not known preoperatively, despite a comprehensive preoperative workup, were considered new pre-CPB findings. Only new findings that resulted in an alteration in surgical management were included in this study. Alter-

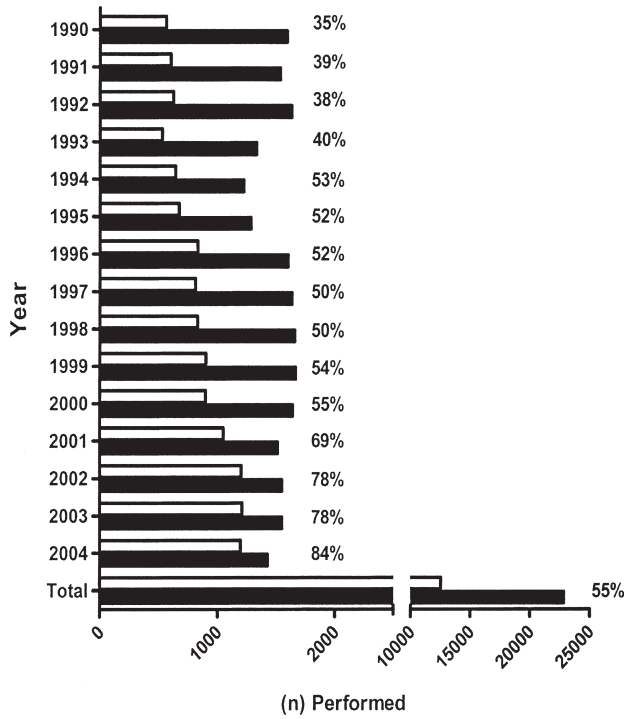

Fig 2. Percent transesophageal echocardiography (TEE) performed per year. Overview of TEE (open bars) performed per year in 12,566 cardiac surgical patients who underwent intraoperative TEE examination. (Black bars = surgeries.)

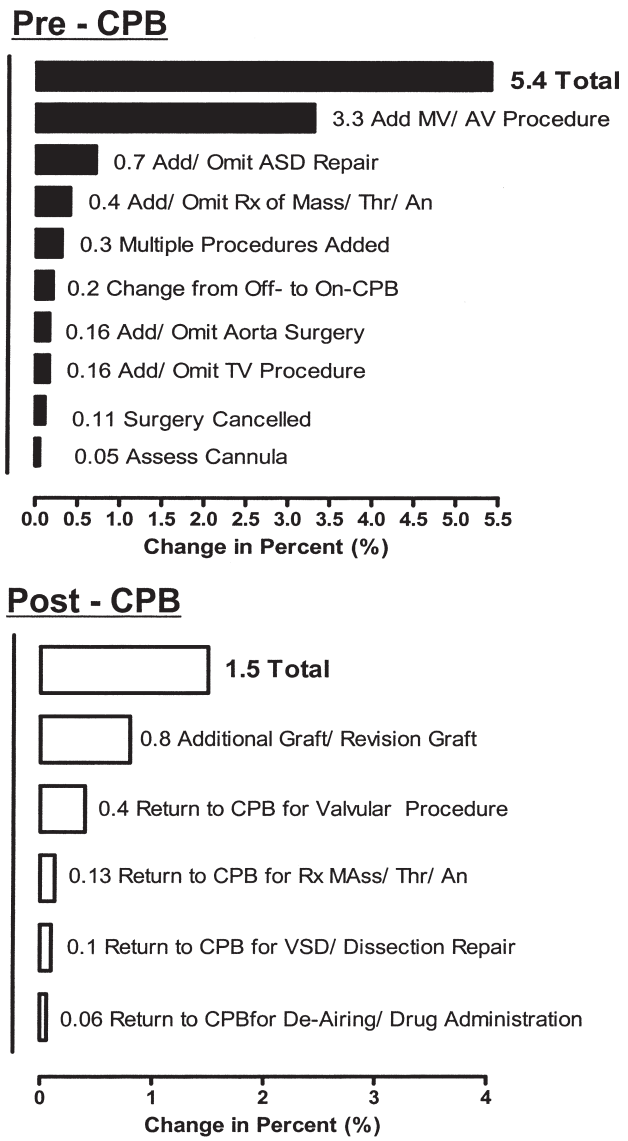

Fig 3. Changes in 3,835 patients undergoing isolated coronary artery bypass graft surgery. Impact of before (pre-) and after (post-) cardiopulmonary bypass (CPB) intraoperative transesophageal echocardiography (TEE) on surgical decision making in 3,835 patients undergoing isolated coronary artery bypass graft surgery. (An = aneurysm; ASD = atrial septal defect; AV = aortic valve; MV = mitral valve; Rx = resection; Thr = Thrombus; TVP = tricuspid valve repair; VAD = ventricular assist device; VSD = ventricular septal defect.)

ations in surgical management were defined as the addition of an unplanned surgical procedure or the omission of a planned procedure.

A new post-CPB finding was defined as an intraoperative TEE diagnosis of unexpected residual pathology. Only those new post-CPB findings that led to a return to CPB for the correction of this finding were documented in this study. Any diagnosis obtained by TEE that led only to an alteration in hemodynamic or anaesthetic management was not considered in the analysis of the present study.

Results

Patients and Total Impact

A total of 22,840 patients underwent cardiac or thoracic aortic surgery at the Brigham and Women's Hospital during the study period between 1990 and 2005. The TEE

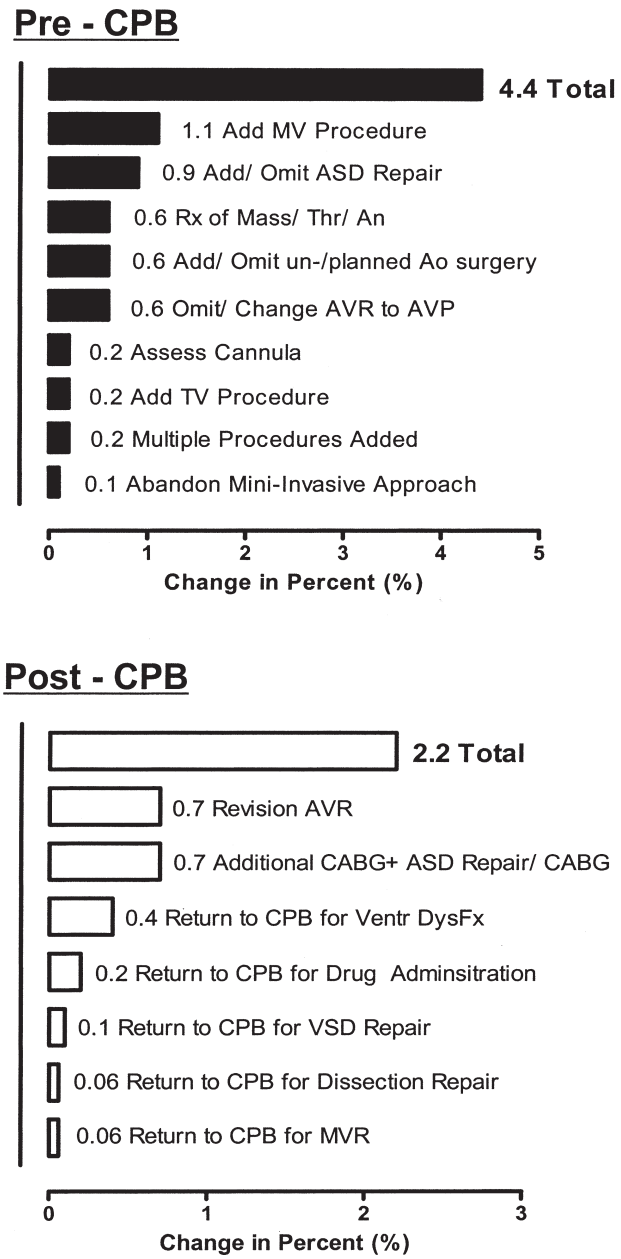

Fig 4. Changes in 1,610 patients undergoing aortic valve replacement (AVR). Impact of before (pre-) and after (post-) cardiopulmonary bypass (CPB) intraoperative transesophageal echocardiography on surgical decision making in 1,610 patients undergoing aortic valve surgery. (An = aneurysm; Ao = descending thoracic aorta; ASD = atrial septal defect; AVP = aortic valve repair; CABG = coronary artery bypass grafting surgery; MV = mitral valve; MVR = mitral valve replacement; Rx = resection; Thr = thrombus; TV = tricuspid valve repair; Ventr DysFx = ventricular dysfunction; VSD = ventricular septal defect.)

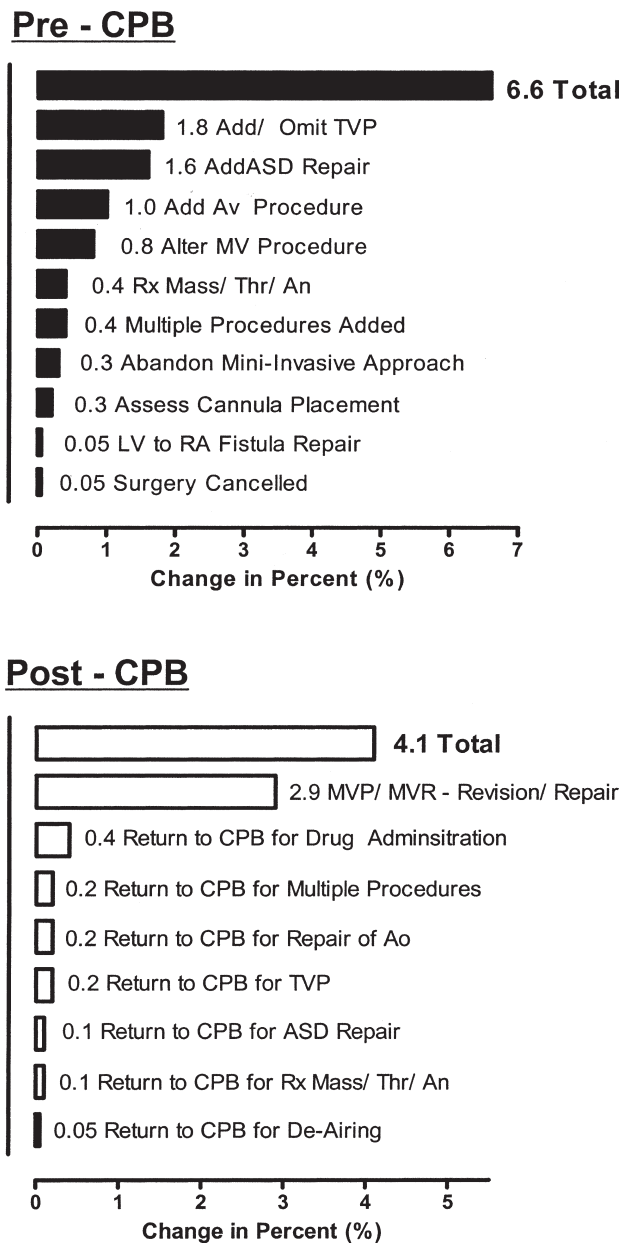

Fig 5. Changes in 1,823 patients undergoing mitral valve replacement (MVR) or repair (MVP). Impact of before (pre-) and after (post-) cardiopulmonary bypass (CPB) intraoperative transesophageal echocardiography on surgical decision making in 1,823 patients undergoing MVR or MVP. (An = aneurysm; ASD = atrial septal defect; AV = aortic valve; CABG = coronary artery bypass graft surgery; Desc Ao = descending thoracic aorta; LV = left ventricle; MV = mitral valve; RA = right atrium; Rx = resection; Thr = thrombus; TVP = tricuspid valve repair.)

was performed in 12,566 (53%) of these patients (7,749 male, 4,817 female patients). From the total population of cardiac surgical patients, intraoperative TEE was performed in 3,835 of 10,300 (37%) CABG-only patients; 3,833 of 5,056 (76%) valve-only surgery patients; 2,951 of 3,934 (75%) combined CABG–valve surgery patients; and 1,947 of 3,550 (76%) cardiac surgical patients undergoing miscellaneous cardiac or thoracic aortic procedures (Fig 1). The percentage of TEE performed per year is demonstrated in Figure 2. New intraoperative TEE pre-CPB diagnoses that altered the surgical plan occurred in 880 patients (7.0%) in the entire study population. Similarly, new findings diagnosed post-CPB that led to reinstitution of CPB for surgical correction was found in 273 patients (2.2%). In 6 patients (4 patients with CABG, 1 patient with mitral valve replacement, and 1 patient with aortic valve replacement), TEE led to a change pre-CPB and post-

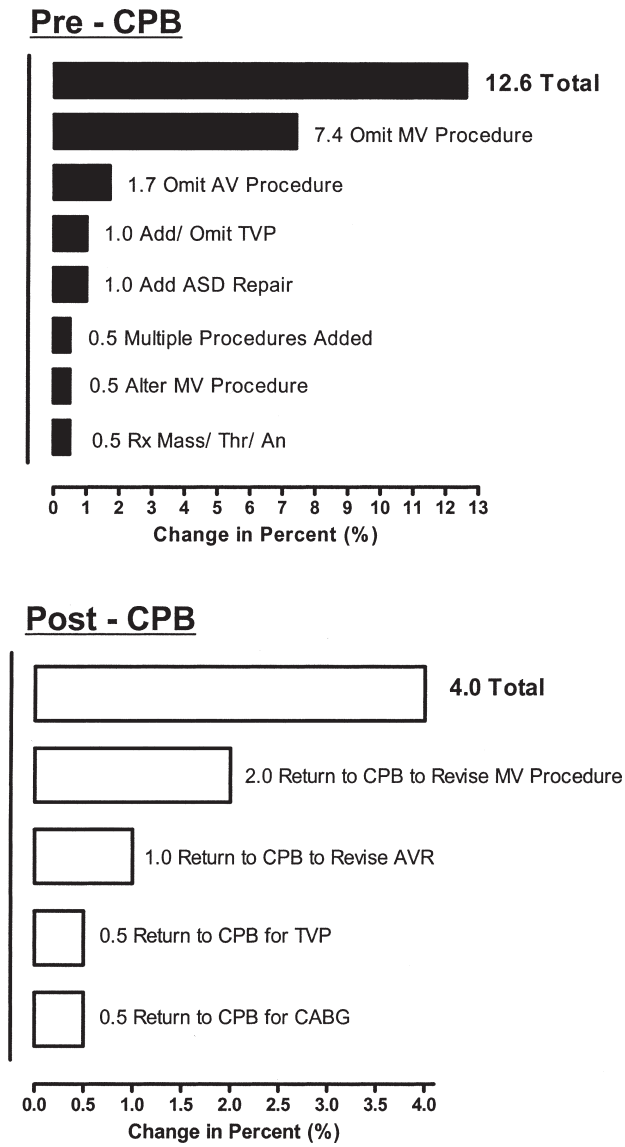

Fig 6. Changes in 407 patients undergoing aortic valve replacement (AVR) plus mitral valve replacement (MVR) or repair (MVP). Impact of before (pre-) and after (post-) cardiopulmonary bypass (CPB) intraoperative transesophageal echocardiography on surgical decision making in 407 patients undergoing combined AVR and MVR or MVP. (An = aneurysm; ASD = atrial septal defect; AV = aortic valve; CABG = coronary artery bypass graft surgery; MV = mitral valve; Rx = resection; Thr = thrombus; TVP = tricuspid valve repair.)

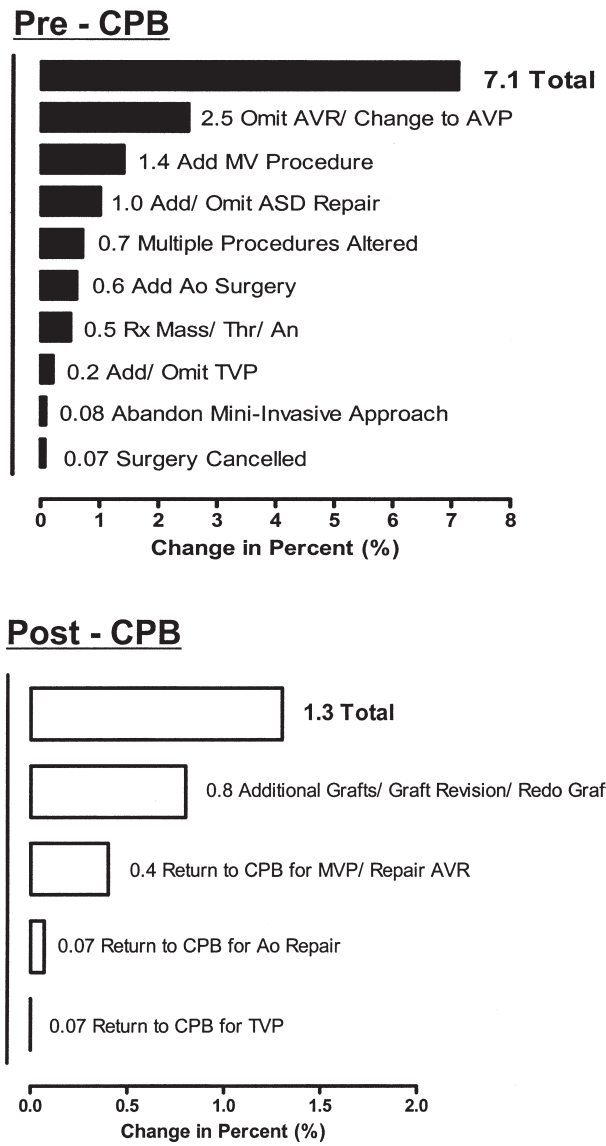

Fig 7. Changes in 1,360 patients undergoing coronary artery bypass graft surgery (CABG) plus aortic valve (AV) surgery. Impact of before (pre-) and after (post-) cardiopulmonary bypass (CPB) intraoperative transesophageal echocardiography on surgical decision making in 1,360 patients undergoing combined CABG and AV surgery. (An = aneurysm; Ao: descending thoracic aorta; ASD = atrial septal defect; AVP = aortic valve repair; AVR = aortic valve replacement; MV = mitral valve; Rx = resection; Thr = thrombus; TVP = tricuspid valve repair.)

CPB. However, given the large number of patients included in the study population, the overall impact of TEE was not influenced by these 6 patients.

Patients Undergoing Isolated CABG

Before–cardiopulmonary bypass TEE examinations influenced surgical decision making in 207 of 3,835 patients (5.4%) undergoing CABG-only surgery, including 130 patients (3.3%), in whom a mitral valve (MV) or aortic valve (AV) procedure was added (Fig 3). After–cardiopulmonary bypass CPB TEE examinations influenced surgical decision making in 58 patients (1.5%).

The detection of new isolated regional wall motion abnormalities during post-CPB TEE influenced the surgeon to return to CPB to revise a corresponding coronary artery bypass graft in 31 patients of all CABG patients (0.8%). Further changes in the surgical decision making

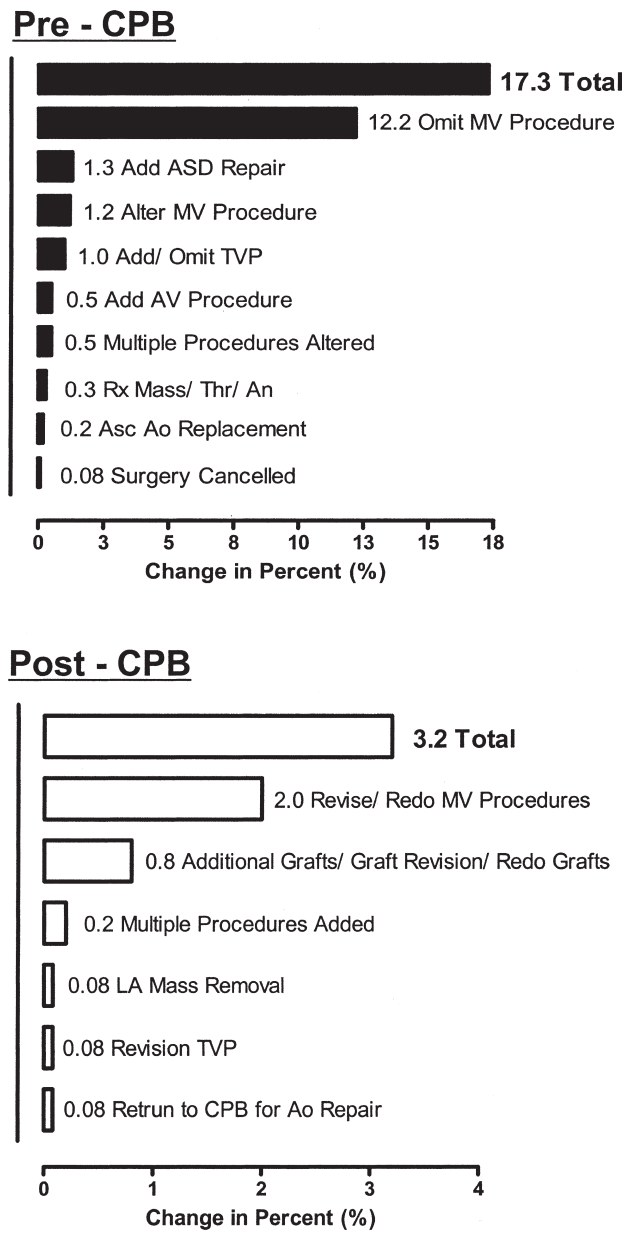

Fig 8. Changes in 1,325 patients undergoing coronary artery bypass graft surgery (CABG) plus mitral valve (MV) surgery. Impact of before (pre-) and after (post-) cardiopulmonary bypass (CPB) intraoperative transesophageal echocardiography on surgical decision making in 1,325 patients undergoing combined CABG and MV surgery. (An = aneurysm; Ao = descending thoracic aorta; Asc Ao = ascending thoracic aorta; ASD = atrial septal defect; AV = aortic valve; LA = left atrium; Rx = resection; Thr = thrombus; TVP = tricuspid valve repair.)

Ann Thorac Surg
2008;85:845–53

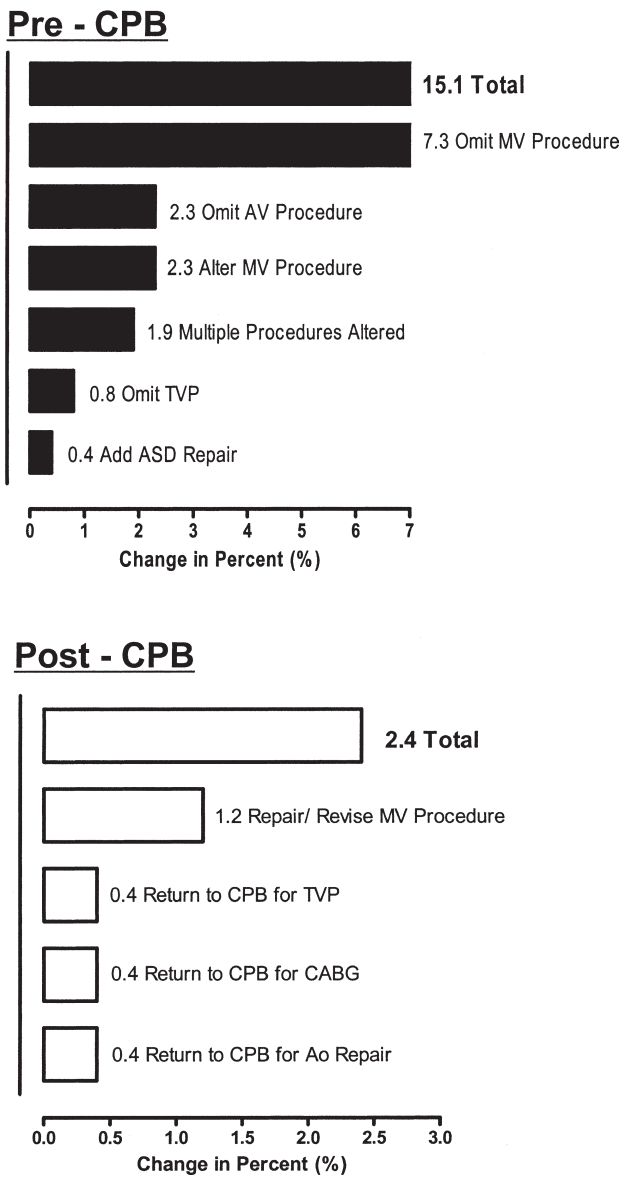

Fig 9. Changes in 259 patients undergoing coronary artery bypass graft surgery (CABG) plus mitral valve (MV) plus aortic valve (AV) surgery. Impact of before (pre-) and after (post-) cardiopulmonary bypass (CPB) intraoperative transesophageal echocardiography on surgical decision making in 259 patients undergoing combined CABG and AV and MV surgery. (Ao = descending thoracic aorta; ASD = atrial septal defect; TMLR = transmyocardial laser revascularization; TVP = tricuspid valve repair.)

in patients undergoing isolated CABG that were based on post-CPB TEE findings are shown in Figure 2.

Patients Undergoing Valve Surgery

Before–cardiopulmonary bypass TEE examinations influenced surgical decision making in 242 of the 3,835 patients (6.3%) undergoing valve procedures. The most common alterations in the surgical procedure included the addition or omission of a MV procedure (1.3%), and the addition or omission of an atrial septal defect repair in 47 patients (1.2%).

During isolated AV procedures, surgical decisions were influenced by 4.4% of the pre-CPB and 2.2% of the post-CPB TEE examinations (Fig 4). The most common alterations in the surgical procedure influenced by pre-CPB TEE diagnoses included the addition of an MV procedure. The post-CPB TEE most commonly influenced the decision to revise the AV procedure. Intraoperative TEE had a generally greater impact on patients undergoing isolated MV surgery compared with patients undergoing AV procedures. During isolated MV procedures, surgical decisions were influenced by 6.6% of the pre-CPB and 4.1% of the post-CPB TEE examinations. For example, an addition/omission of a tricuspid valve procedure (1.8%) or atrial septal defect repair (1.6%) occurred more frequently among patients undergoing isolated MV procedures than AV procedures (Fig 5). In addition, the post-CPB TEE had its greatest impact on influencing the decision to revise a MV repair or replacement in 2.9% of patients undergoing isolated MV surgery. The decision to repair an atrial septal defect or patent foramen ovale was considered to be guided by intraoperative TEE only when these diagnoses were made before left or right atriotomy. Even greater percentages of changes in surgical management associated with intraoperative TEE diagnoses were observed in the 407 patients undergoing combined AV and MV surgery, including 9.1% of the patients in whom one of the two valve procedures was omitted (Fig 6). In addition, post-CPB TEE examinations most commonly provided information that led to the decision to revise the initial MV procedure or aortic valve replacement in 3% of the patients.

Patients With CABG and Valve Surgery

Among the 2,944 patients scheduled for combined CABG and valve procedures, the surgical plan was altered by a new pre-CPB TEE diagnosis in 363 patients (12.3%). The most frequent alteration was a change in the planned valve surgery in 286 patients (9.7%).

In patients undergoing CABG with AV surgery, the omission of the AV procedure or the addition of a MV procedure was the most frequent change in surgical management, in 2.5% and 1.4% of the patients, respectively. Post-CPB graft revision was the most common change to the planned surgical procedure that was guided by TEE (Fig 7). The pre- and post-CPB changes in patients undergoing CABG and MV procedures are shown in Figure 8. In this subpopulation, the most frequent pre-CPB alteration was the omission of the planned MV procedure in 12.2% of the patients. After CPB, a revision of the MV (2.0%) was the most common surgical management changes influenced by TEE.

The greatest influence of pre-CPB intraoperative TEE on planned valve surgery was observed in patients scheduled for CABG with both an AV and MV procedure (Fig 9). A revision of the MV procedure was again the most frequent post-CPB change in the surgical management of this group, as in the other combined procedure groups.

Patients Undergoing Other Miscellaneous Procedures

The patients allocated to the miscellaneous procedures group underwent a wide variety of surgical procedures, including repair or replacement of the tricuspid valve or pulmonic valve (PV), aortic surgery, heart transplantation, transmyocardial laser revascularization, isolated atrial septal defect/ventricular septal defect repairs, ventricular assist device procedures, removal of an intracardiac mass, thrombus, and pericardiocentesis (Fig 1).

New pre-CPB TEE diagnoses that altered the surgical plan occurred in 3.5% of the patients. Most commonly, a valve procedure was added, in 22 patients (1.1%). The most common decision post-CPB was to revise the performed procedure in 0.5% of the patients (data not shown).

Comment

The utility of intraoperative TEE has become increasingly more evident as anesthesiologists, cardiologists, and surgeons continue to appreciate its potential application as an invaluable diagnostic tool and monitor of cardiac performance for the management of cardiac surgical patients [9–12]. Despite several favorable reports, the routine use of intraoperative TEE during cardiac surgery remains controversial, especially for lower risk patients scheduled only for CABG procedures [14]. Previous investigations have focused on CABG patients with questionable valvular pathology, and have included a low percentage of all patients undergoing CABG in their institution [17]. Therefore, we examined the utility of TEE in 12,566 selected patients undergoing different types of cardiac and thoracic aortic procedures, and demonstrated that the pre- and post-CPB TEE examinations influenced surgical decision making in 7.0% and 2.2%, respectively, of all evaluated patients.

A comprehensive pre-CPB TEE examination allows the cardiac surgeon and anesthesiologist to validate the preoperative indication for surgery, and therefore to avoid an unnecessary intervention with its associated morbidity. In addition, newly identified pathologic findings can provide the opportunity to change the planned procedure, and possibly improve patient outcome or avoid an additional surgical procedure in the future. In our patient population, the most frequent pre-CPB finding that influenced surgical decision making was either undetected valve dysfunction or a change in the preoperatively diagnosed valve pathology. For example, a MV procedure was omitted in 12.2% patients scheduled for CABG and MV surgery.

Although the use of intraoperative TEE to diagnose MV pathology has never been specifically mandated as a "standard of care," guidelines and recommendations published by the American Society of Echocardiography, American Society of Anesthesiologists, and Society of Cardiovascular Anesthesiologists strongly support its use to guide surgical decision making by providing insight into the mechanism of mitral disease before repair [19, 20]. Such guidelines and recommendations have been developed based on numerous studies that have speculated on the purported reduction in perioperative morbidity associated with the use of TEE in cardiac surgical patients undergoing MV procedures [15, 20]. Similarly, TEE can be useful for the assessment of the tricuspid valve or AV for replacement or repair. For example, AV surgery was altered in 103 of the patients undergoing CABG, MV, or AV procedures (1.0%) in this study. Nonetheless, the decision to perform a valve procedure should not only be dictated by the presence or absence of valve dysfunction diagnosed by intraoperative TEE on surgical decision making among a selected group of patients undergoing a full spectrum of cardiac surgical procedures, but should also consider the patient's comorbidity, the additional technical difficulty and morbidity in performing combined procedures, and the influence of hemodynamic changes associated with general anesthesia that may affect the echocardiographic grading of valve stenosis and regurgitation.

In addition to its utility as a valuable diagnostic tool in the pre-CPB period, intraoperative TEE also provides important post-CPB information [10]. The post-CPB TEE examination can provide a direct and immediate assessment of the surgical procedure, and therefore can expedite the decision to return to CPB when necessary. In our study, CPB had to be reinstituted in 4.1% of the patients undergoing MV surgery. Among patients undergoing combined CABG, AV, and MV procedures, this percentage was 1.3 %. Aortic valve repairs and replacements required revision in 0.7% of the total 1,610 patients scheduled only for an AV procedure. Alternatively, in the combined CABG, MV, AV procedures, there were no aortic valve replacement revisions necessary. In addition to its valuable role in valve surgery, TEE is also used as a continuous monitor of cardiac performance by permitting a direct assessment of ventricular volume and both regional and global function [21]. Moreover, TEE is very sensitive in detecting post-CPB myocardial ischemia and new regional wall motion abnormalities associated with possible graft kinking or occlusion [22]. In our study, a revision of previously placed grafts was required in 53 cases, 0.8% of the patients who underwent CABG, which is consistent with the results of Mishra and colleagues [15].

This study is the largest published investigation that has examined the influence of intraoperative TEE on surgical decision making in a diverse population of cardiac surgical patients. Nonetheless, because intraoperative TEE examinations were not performed in all patients, there was most likely a bias toward examining higher risk patients in whom a favorable impact of TEE was more likely to occur. Specific reasons why intraoperative TEE was not performed in the remaining 10,274 cardiac surgical patients were not available from the database. However, historically in our institution, intraoperative TEE has not been performed in patients undergoing only CABG who also had a preoperative ejection fraction of 40% or greater. In addition, a previously published study on the safety of a consecutive series of 7,200 patients from this group, reported that intraoperative TEE was not performed in 0.5% of these patients in

whom it was contraindicated, and 0.18% of this population in whom esophageal insertion of the probe was unsuccessful [23]. Alternatively, our use of relatively conservative definitions for determining when the influence of intraoperative TEE on surgical decision making was significant may have actually contributed to lower incidences and an underestimation of impact in our study compared with some others reported in the literature [10]. Finally it is difficult to assess the true effectiveness and benefit of TEE on perioperative clinical outcomes, as this should ideally be accomplished in a prospective, randomized trial. Considering its expanding popularity and the accepted indications for intraoperative TEE, the practical and ethical limitations of conducting such a definitive study may be prohibitive.

In conclusion, the present study highlights the utility of intraoperative TEE for a large variety of cardiac surgical procedures. We have demonstrated that intraoperative TEE has the potential to significantly influence clinical decision making for more than 9% of cardiac surgical patients in our study population. However, as the the risk profile of cardiac surgical patients continues to shift toward higher risk populations predisposed to increased perioperative morbidity and mortality, the value of this important diagnostic tool and monitor of cardiac performance may increase substantially.

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INVITED COMMENTARY

Eltzschig and colleagues [1] are to be commended for providing the cardiac surgery community with compelling evidence for the benefits of intraoperative TEE. The experience summarized in this report of 12,566 patients validates what most of us have experienced since TEE was introduced to the cardiac surgical suite. The increase in TEE utilization (35% to 84%) over the 15-year span in this study mirrors that of our institution and likely reflects the perception that intraoperative TEE improves patient outcome. This perception was reinforced by the observation that the surgical plan was changed in over 9% of all patients in this series and in over 14% in those undergoing CABG/valve procedures. In fairness, one has to bear in mind that this was a selected (likely to benefit from TEE) group of patients that reflected only 53% of the cardiac surgical population at the Brigham during the

0003-4975/08/$34.00
doi:10.1016/j.athoracsur.2007.12.034