Impact of routine use of intraoperative trans-esophageal echocardiography during cardiac surgery

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Purpose: To determine the relative impact of each category-based TEE indication according to the ASA guidelines.

Methods: In 851 patients undergoing cardiac surgery, TEE clinical indications were classified as category I or II according to the ASA guidelines. Category I indications are patients in which TEE is considered useful and category II are those where TEE is potentially useful but indications are less clear. All TEE examinations were reviewed by two anesthesiologists with advanced training in TEE. For each patient, the clinical impact of TEE in the clinical management was assessed using five criteria: 1) change of medical therapy; 2) change in the surgical procedure; 3) confirmation of a suspected diagnosis; 4) positioning of an intravascular device, and 5) substitute to a pulmonary artery catheter (PAC).

Results: TEE had greater utility in category I than in category II indications (15/53 (28%) vs 110/798 (14%) respectively) ($P < 0.01$). The nature of the clinical impact was as follows: modification of medical therapy in 67/125 (53%), modification of planned surgical intervention in 38/125 (30%), confirmation of a diagnosis in 34/125 (27%). The impact on therapy was higher in complex surgical procedures (39%) than in valvular replacement (19%) ($P < 0.01$) and coronary artery bypass surgery (10%) ($P < 0.001$).

Conclusions: Our findings validate the usefulness of the ASA practice guidelines demonstrating a greater impact of TEE on clinical management for category I indications than for category II. TEE also had a greater clinical impact in complex surgical procedures and in valvular replacement.

Objectif : Déterminer l'effet relatif de l'indication de l'ETO basée sur chacune des catégories relevant des recommandations ASA.

Méthode : Chez 851 patients devant subir une intervention chirurgicale cardiaque, les indications cliniques de l'ETO ont été classées en catégorie I ou II selon les recommandations de l'ASA. Dans la catégorie I, ce sont les patients pour qui l'ETO est considérée utile et dans la catégorie II, ceux pour qui l'ETO est probablement utile, les indications n'étant pas aussi claires. Tous les examens d'ETO ont été révisés par deux anesthésiologistes de formation poussée en ETO. Les répercussions cliniques de l'ETO sur le traitement clinique de chaque patient ont été évaluées selon cinq critères: 1) la modification du traitement médical 2) un changement de technique chirurgicale 3) la confirmation d'un diagnostic présumé 4) la mise en place d'un appareil intravasculaire 5) un substitut au cathéter de l'artère pulmonaire (CAP).

Résultats : L'ETO a présenté une plus grande utilité avec les indications de catégorie I qu'avec celles de catégorie II (15/53 (28 %) vs 110/798 (14 %) respectivement) ($P < 0,01$). La nature de l'effet clinique a été : une modification de traitement médical chez 67/125 (53 %), un changement d'intervention chirurgicale chez 38/125 (30 %), la confirmation d'un diagnostic chez 34/125 (27 %). Les conséquences sur le traitement ont été plus grandes pour des interventions chirurgicales complexes (39 %) que pour le remplacement valvulaire (19 %) ($P < 0,01$) et le pontage aortocoronarien (10 %) ($P < 0,001$).

Conclusion : Nos résultats confirment l'utilité des recommandations de pratique de l'ASA qui démontrent une plus grande influence de l'ETO sur le traitement clinique pour les indications de catégorie I que pour celles de catégorie II. L'ETO a aussi un effet plus important sur les interventions chirurgicales complexes et sur le remplacement valvulaire.

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SINCE its initial use on an experimental basis in the late 1970s,¹ transesophageal echocardiography (TEE) has become useful as a monitoring and diagnostic tool in cardiac surgery. Several indications for perioperative TEE have become well established and include evaluation of mitral valve repairs,^{2,3} most congenital heart repairs requiring bypass,⁴ and evaluation of patients in life-threatening conditions.^{5,6} However, its routine use in the management of patients undergoing coronary artery bypass surgery remains controversial.

In April 1996, guidelines for perioperative transesophageal echocardiography were published jointly by the Task Force Commission of the American Society of Anesthesiologists (ASA) and the Society of Cardiovascular Anesthesiologists.⁷ These guidelines were developed to define categories of indications for TEE in the perioperative setting. Based upon supporting evidence from studies of perioperative TEE and on expert opinion, three categories of indications were defined. Category I indications are those where TEE is considered useful, category II are those where TEE may be useful but appropriate indications are less clear, and category III are those where TEE is infrequently useful in improving clinical outcome.⁷ Although these guidelines are generally accepted, their usefulness in the clinical management of patients undergoing cardiac surgery has been evaluated only in a few studies.⁹ The purpose of this study was to review the clinical impact of perioperative TEE in our clinical practice and to determine the usefulness of category-based TEE indications.

Methods

Following approval from the Research Ethics Board of the Centre Hospitalier de l'Université de Montréal (CHUM), Campus Notre-Dame, all TEE examinations performed by anesthesiologists from October 1993 to February 1997 (41 mo) were recorded and analyzed using a specific data sheet. Category I, II and III indications were defined according to the ASA guidelines on perioperative TEE.⁷ For example, perioperative lifethreatening hemodynamic disturbances, intraoperative evaluation of mitral valve or congenital heart repairs are considered category I indications. Examples of category II indications include monitoring of regional or global cardiac function perioperatively in high-risk patients. The TEE examinations were done using a multiplane 5-MHZ transducer (Sonos 1500, Hewlett-Packard, Andover, MA) or a uniplane probe (Sonoline CF, Siemens, Pleasanton, CA). Each examination comprised a two-dimensional imaging of the aorta, a four-chamber view and a short-axis transgastric view. The

latter view was also used for continuous monitoring during the procedure. A two-chamber view and a long axis trans-gastric view of the left ventricle and left ventricular outflow tract were also examined when using the multiplane probe. Colour Doppler interrogation of the mitral, aortic and tricuspid valves was also performed. A second opinion by a cardiologist was requested for more specific examinations such as evaluation of unexpected mitral valve regurgitation or to assess the result of valvular repair.

TABLE I Transesophageal echocardiography examination data

	Total Number	Modification in Therapy (%)
Number of examinations performed by anesthesiologist		
Basic training	59 (26-89)	15 ± 6
Advanced	535 (350-721)	21 ± 1
Number of patients		
Category I	53 (6%)	15 (28%)*
Category II	798 (94%)	110 (14%)
Number of surgical procedures	851	125 (11%)
Revascularization procedures		
CABG	559	58 (10)
Repeat CABG	47	5 (11)
MIDCAB	18	2 (11)
Total	624	65 (10)
Valvular replacement		
AVR	56	6 (11)
Repeat AVR	6	0 (0)
MVR	34	5 (15)
Repeat MVR	12	5 (42)
TVR	1	0 (0)
AVR-MVR	17	7 (41)
MVR-TVR	3	1 (33)
Total	129	24 (19)‡
Other surgical intervention		
Complex procedures ¹	75	29 (39)†§
ASD closure	7	2 (29)
Heart transplantation	8	2 (25)
Tamponade	8	3 (38)
Total	98	36 (37)

CABG = coronary artery bypass graft surgery

MIDCABG = minimally invasive direct coronary artery bypass graft surgery

AVR = aortic valve replacement

MVR = mitral valve replacement

TVR = tricuspid valve replacement

ASD = atrial septal defect

¹ Complex procedures involve two or three different types of procedure either revascularization, valvular, vascular, pulmonary or congenital procedure

**P* < 0.01 compared with category II

†*P* < 0.001 and ‡*P* < 0.01 compared with revascularization procedures

§*P* < 0.01 compared with valvular replacement

TABLE II Summary of surgical modifications related to the use of TEE

<i>Modification</i>	<i>Total number</i>
Return on bypass for:	
Revision of CABG	4
Modification of planned surgery	
Valvular replacement cancelled	5
Valvular replacement or repair	11
Pleural drainage	3
Detection of air emboli before aortic unclamping	2
Surgical exploration for hemodynamic instability	7
Femoral artery bypass for aortic dissection	2
Others	
Ventricular aneurysm resection	1
Aortoplasty	1
Cancellation of aortic dissection (diagnostic error)	1
Left ventricular assist device	1
Total	38

CABG = coronary artery bypass graft surgery

Nine of our anesthesiologists performing cardiac surgery had basic training in TEE and two had advanced training as defined by the ASA guidelines.⁷ All TEE examinations and data sheets were reviewed by those with advanced training in TEE (A.D and P.C.). These two anesthesiologists were also certified from the National Board of echocardiography in peri-operative transesophageal echocardiography. In the review, the clinical impact of TEE on current therapy or patient management was noted. This was further classified using five criteria: 1) TEE findings altered medical therapy, for instance, adding an inotrope or volume expansion; 2) TEE findings altered surgical management, such as an unplanned intervention or a return to cardiopulmonary bypass (CPB) support; 3) TEE findings confirmed a suspected diagnosis; 4) TEE findings were useful in assisting positioning of intravascular devices; 5) TEE was used as a substitute for PAC for monitoring purposes.

The clinical impact of TEE in altering medical therapy was assessed by two anesthesiologists with advanced TEE training and a decision was reached by consensus. The data were rejected if insufficient clinical information was provided or if no consensus was reached. TEE was considered to have altered surgical management if the cardiac surgeon stated that he would not have performed a surgical procedure without the TEE findings. Some TEE examinations met more than one criterion for effectiveness. For instance, TEE findings confirmed a suspected diagnosis and was useful in positioning a PAC. However, the category of indications according to the ASA guidelines⁷ were mutually exclusive.

FIGURE 1 Changing management subcategories. There were 145 therapeutic modifications in 125 examinations in five subcategories: change in medical therapy (medical therapy); a change in surgical therapy (surgical therapy); confirmation of diagnosis (diagnosis); substitution to pulmonary artery catheter (Swan-Ganz); and positioning of an intravascular device (positioning).

Statistical analysis

Chi-square analysis or Fisher's exact test were used when indicated to compare the impact of TEE according to the categories and subcategories indications. Statistical analysis was done using Statview 4.1 program software (Abacus Inc, Berkeley, CA).

Results

During the 41 mo study period, 1,585 cardiac procedures were performed and TEE was used in 851 (54%). The multiplane transducer probe was used in 668 patients, the uniplane probe in 167, and the type of probe was not specified in 16 patients. Using the ASA guidelines, 53 (6%) of patients had category I indications and 798 (94%) patients had category II indications. No category III indication was observed in our cardiac surgical population.

Among the 851 patients, TEE findings caused 145 changes in medical management in 125 (11%) patients (Table I). The clinical impact was greater in category I indications where it altered therapy 28% of the time compared with category II indications where therapy was modified only 14% of the time ($P < 0.01$). Anesthesiologists with basic training in TEE performed an average of 59 examinations (range: 26 to 89) and therapy was modified $15 \pm 6\%$ of the time. Anesthesiologists with advanced training performed

FIGURE 2 Changing management and subcategories. The impact was greater on the surgical procedure in category I than II ($P < 0.05$).

FIGURE 3 Clinical impact and category. The total number of patients was 851. The impact is reported as a change in medical or surgical therapy.

* = $P < 0.0001$ for surgical therapy when category I and II were compared.

535 examinations (range: 350 to 721) and the therapeutic impact was $21\% \pm 1\%$. The total number of examinations performed by all the anesthesiologists was higher than 851 because, in certain circumstances, the examination was reviewed by another anesthesiologist and was considered to have been performed by both anesthesiologists. The clinical impact of TEE was greater in patients with complex surgical procedures such as combined revascularization and valvular, vascu-

lar, pulmonary or congenital surgical procedures (39%) than in patients with valvular surgery (19%) ($P < 0.01$) or in patients with coronary artery bypass surgery (10%) ($P < 0.001$). The impact was also greater in patients undergoing valvular surgery than in patients undergoing coronary artery bypass surgery ($P < 0.01$).

Figure 1 illustrates the clinical impact by criteria in the 125 patients. The most frequent reason for changing clinical management was a modification of medical therapy in 67 patients (53%), followed by an unplanned surgical intervention in 38 patients (30%) and the confirmation of a diagnosis in 34 patients (27%). The reasons for surgical therapy modifications are further detailed in Table II. The impact of TEE was further detailed using category I and II indications for the 145 modifications in Figure 2. The impact in altering the surgical procedure was greater in category I than in category II ($P < 0.05$) whereas the impact in changing medical therapy was greater in category II than in category I ($P < 0.01$). When assessing the overall impact of TEE on the alteration of both medical and surgical therapy, excluding the other subcategories, we found that TEE altered medical therapy in 2% and 8% (NS) and surgical therapy in 17% and 4% ($P < 0.0001$) of the category I and II indications respectively (Figure 3).

Discussion

We reviewed our experience in the use of perioperative TEE to determine the relative impact of category-based TEE indications according to the ASA guidelines⁷ in unselected patients undergoing cardiac surgery. We found that TEE was used more frequently for category II (94%) than for category I (6%) indications. However, the impact was greater in category I indications, changing therapy in 28% of the patients, compared with 14% for category II indications. Unplanned surgical intervention (17% *vs* 4%, $P < 0.0001$) as a result of the TEE examination was more common in category I than II but no difference was found for altering medical therapy (2% *vs* 8%, NS). These results, obtained prospectively in a large group of patients from a single centre, support the greater impact of TEE on clinical management for category I than category II indication.⁷ As secondary findings, we documented that TEE influenced most often medical therapy (53%), followed by a change in surgical therapy (30%) and in confirming a suspected diagnosis (27%). The other changes in clinical management based on TEE examination were much less frequent and include on-line positioning of IABP, vascular catheter and use of TEE as a substitute for a pulmonary artery catheter.

This is the first study from a single centre to examine the relative impact of intraoperative TEE in cardiac surgery in regard to category-based TEE indications.⁷ One recent study reported their experience with real-time intraoperative TEE in 5,016 patients.⁸ The overall utility of TEE examinations for changing management in their study was 26.7% for CABG and 12.5% for valvular surgery. They did not, however, determine the relative impact of category-based TEE indications. Another study has also evaluated the influence of transesophageal echocardiography on intraoperative decision making.⁹ This European study included 224 patients, undergoing cardiac and non-cardiac surgery, from nine participating centres. Results from multicentre trials may have limitations because results may differ among institutions, due to differences in patient population, surgical technique or training of anesthesiologists among the centres. The total number of cardiac surgical procedures in the latter study and the percentage in which TEE was performed was not provided. Although, the impact was lower in our study, their results are in agreement with our observations, resulting in 30% change in overall management, with a greater impact in category I than in category II indication.⁹ Our results documented that, in a larger group of patients obtained in a single centre, the routine use of TEE often has a strong influence on intraoperative clinical decision making in cardiac surgery.

The finding that the use of TEE has a greater impact on clinical decision making in category I indications is not surprising. For example, the influence of TEE during cardiac valve surgery^{2,3} or in unstable patients in the intensive care unit^{5,6} is well documented. However, its clinical utility for category II and III indications is less clear. Few studies have addressed this question.¹⁰⁻¹³ In one, Bergquist *et al.*,¹⁰ evaluated the influence of intraoperative TEE on decision making in 75 patients undergoing myocardial revascularization. They found that 17% of intraoperative clinical interventions were influenced predominantly by information obtained from TEE and an additional 43% were based on supportive data from TEE (combined with information from other monitors). The majority of interventions influenced by TEE in their study involved fluid administration or anti-ischemic therapy.¹⁰ Our study is in general agreement with their results, with a total impact of 12% for altering medical and surgical therapy in category II indications based on TEE findings, with the majority (8%) of interventions being a modification in medical therapy (inotropes, vasodilators, fluid management, decision to insert an IABP). However, we did not evaluate the

incidence where TEE was supportive and, consequently, the overall clinical usefulness of TEE for category II indications may have been underestimated because it is likely that information from different monitors act jointly to influence most clinical decisions during surgery. Our data also compare well with that of Deutsch *et al.*,¹¹ who evaluated the diagnostic value of intraoperative TEE. They found that routine use of TEE for CABG was valuable or essential in 12% of patients. Two studies found the impact of TEE during CABG surgery to be higher than was observed in our study. In one of these, Savage *et al.*¹² suggested that high risk patients undergoing coronary artery bypass surgery could benefit most from intraoperative TEE with a change in surgical management in 57% of patients, and alteration in anesthetic or hemodynamic management in 73% of patients. Preliminary data from Goldman *et al.*¹³ also suggested that TEE had a considerable impact during CABG surgery, particularly in elderly patients where, in 18% of patients, the operative course was altered. They observed that surgical therapy was most often influenced by a change provided by new information regarding the mitral valve. However, we did not evaluate these aspects in our patients undergoing CABG surgery.

Another important finding of our study was that, among category II indications, TEE monitoring had a greater impact on decision making in complex procedures (39%) and valvular surgery (19%) than in revascularization surgery (10%). Although the utility of intraoperative TEE for mitral valve repair is well recognized,¹⁴ our study also suggests a considerable impact in valve replacement. These results confirm similar observations from Sheikh *et al.*³ They studied 154 patients, the majority undergoing mitral or aortic valve replacement, but with a substantial number of mitral valve repairs (26% of their patients). Prebypass TEE yielded unsuspected findings that assisted or changed the planned operation in 19% of the patients while post-bypass TEE revealed unsatisfactory results that required immediate reintervention in 6% of patients. Postbypass left ventricular dysfunction, necessitating prompt administration of inotropic agents was identified in 13% of their patients.³

Although we did not directly compare the impact of monitoring with TEE and PAC, intraoperative TEE has several potential advantages over PAC to monitor cardiac function during cardiac surgery. It provides an accurate and reliable assessment of intracavitary dimensions, global and regional right and left ventricular wall motion, valve function, and imaging of the great vessels.¹⁵ Critical information is obtained faster.¹⁶ Although the use of TEE is not without risk,

it is much less invasive than PAC and is probably associated with fewer complications.^{17,18} In contrast, although the PAC has been widely used for more than two decades, many physicians do not accurately analyze the data provided by this diagnostic tool.¹⁹ Considerable morbidity and mortality are associated with both the catheterization procedure and the prolonged presence of the catheter in the patient's central circulation. Furthermore, cardiac cavity sizes, volumes, and function cannot be predicted easily and accurately from the pressure readings and thermodilution flow measurements provided by the PAC. Recent retrospective studies have suggested that PACs are associated with increased mortality.²⁰

There are limitations in this study. First, data were analyzed from an observational database. Although we evaluated the usefulness of TEE in an unselected population undergoing cardiac surgery, we did not include all patients undergoing cardiac surgery during the study period. Our sample represents 54% of patients undergoing a cardiac surgical procedure. The determination as to whether a patient received TEE monitoring was made by the anesthesiologist responsible for that patient's care and, therefore, was not random. Consequently, it is subject to bias in patient selection. It is also unknown if the patients in whom TEE was used are truly representative of all patients undergoing cardiac surgery. The second limitation relates to the training required to perform TEE. Most anesthesiologists who performed the examinations in this study had a basic level of training,⁷ and their examinations were reviewed off-line by two experienced anesthesiologists trained in TEE. It is possible that a more advanced level of training would have resulted in a higher impact of real-time TEE, as suggested by Bergquist *et al.*,²¹ who found that a formal training in TEE increases the recognition of regional wall motion abnormalities. We did not observe that advanced training was associated with more impact in modifying therapy. Third, the impact on clinical outcome resulting from changes in medical or surgical therapy has not been evaluated. This question needs to be addressed in a prospective, randomized trial. There are also limitations to the use of TEE during cardiac surgery. The technology is expensive, complex to use, and training is necessary to perform and interpret TEE examinations properly.²² TEE examination is also time consuming and can divert attention from other intraoperative responsibilities.²³ Finally, we did not examine other diagnostic uses of TEE such as detection of aortic atheroma. The overall clinical usefulness of TEE may have been greater if additional applications were examined. Despite these limitations,

we found that real-time intraoperative TEE had an impact on clinical management in a high proportion of patients undergoing cardiac surgery.

In summary, our results, obtained prospectively in a large group of patients undergoing cardiac surgery from a single centre, confirm the greater impact of TEE on clinical management for category I than category II indications.⁷ We also documented that TEE had a clinical impact in a high proportion of category II indications, particularly during valvular replacement and complex procedures. The possibility that intraoperative TEE also had an important impact on high risk coronary artery bypass was not assessed in this study. It is also unknown if these results are reproducible in other settings. Studies involving large numbers of patients are necessary to validate conclusively the impact of intraoperative TEE on patient outcome.

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References

- 1 Frazin L, Talano JV, Stephanides L, Loeb HS, Kopel L, Gunnar RM. Esophageal echocardiography. *Circulation* 1976; 54: 102-8.
- 2 Reichert SLA, Visser CA, Moulijn AC, *et al.* Intraoperative transesophageal color-coded Doppler echocardiography for evaluation of residual regurgitation after mitral valve repair. *J Thorac Cardiovasc Surg* 1990; 100: 756-61.
- 3 Sheikh KH, de Bruijn NP, Rankin JS, *et al.* The utility of transesophageal echocardiography and Doppler color-flow imaging in patients undergoing cardiac valve surgery. *J Am Coll Cardiol* 1990; 15: 363-72.
- 4 Stevenson JG, Sorenson GK, Gartman DM, Hall DG, Rittenhouse EA. Transesophageal echocardiography during repair of congenital cardiac defects: identification of residual problems necessitating reoperation. *J Am Soc Echocardiogr* 1993; 6: 356-65.
- 5 Reichert CLA, Visser CA, Koolen JJ, *et al.* Transesophageal echocardiography in hypotensive patients after cardiac operations. Comparison with hemodynamic parameters. *J Thorac Cardiovasc Surg* 1992; 104: 321-6.
- 6 Heidenreich PA, Stainback RF, Redberg RF, Schiller NB, Cohen NH, Foster E. Transesophageal echocardiography predicts mortality in critically ill patients with unexplained hypotension. *J Am Coll Cardiol* 1995; 26: 152-8.

- 7 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: 896–1006.
- 8 Mishra M, Chauhan R, Sharma KK, et al. Real-time intraoperative transesophageal echocardiography: how useful? Experience of 5,016 cases. *J Cardiothorac Vasc Anesth* 1998; 12: 625–32.
- 9 Kolev N, Brase R, Swanenvelder J, et al. The influence of transesophageal echocardiography on intra-operative decision making. A European multicentre study. *Anaesthesia* 1998; 53: 767–73.
- 10 Bergquist BD, Bellows WH, Leung JM. Transesophageal echocardiography in myocardial revascularization: II. Influence on intraoperative decision making. *Anesth Analg* 1996; 82: 1139–45.
- 11 Deutsch HJ, Curtius JM, Leischik R, et al. Diagnostic value of transesophageal echocardiography in cardiac surgery. *J Thorac Cardiovasc Surg* 1991; 39: 99–204.
- 12 Savage RM, Lytle BW, Aronson S, et al. Intraoperative echocardiography is indicated in high-risk coronary artery bypass grafting. *Ann Thorac Surg* 1997; 64: 368–74.
- 13 Goldman ME, Fisher D, Guarino T, Mindich B. Impact of intraoperative echo in patients with coronary and mitral disease: review of 1936 patients. (Abstract) *J Am Soc Echocardiogr* 1996; 9: 372.
- 14 Stewart WJ, Currie PJ, Salcedo EE, et al. Intraoperative Doppler color flow mapping for decision-making in valve repair for mitral regurgitation. Technique and results in 100 patients. *Circulation* 1990; 81: 556–66.
- 15 Oxorn D, Edelist G, Smith MS. An introduction to transesophageal echocardiography: II. Clinical applications. *Can J Anaesth* 1996; 43: 278–94.
- 16 Benjamin E, Griffin K, Leibowitz AB, et al. Goal-directed transesophageal echocardiography performed by intensivists to assess left ventricular function: comparison with pulmonary artery catheterization. *J Cardiothorac Vasc Anesth* 1998; 12: 10–5.
- 17 Stoddard MF, Longaker RA. The safety of transesophageal echocardiography in the elderly. *Am Heart J* 1993; 125: 1358–62.
- 18 Pearson AC, Castello R, Labovitz AJ. Safety and utility of transesophageal echocardiography in the critically ill patient. *Am Heart J* 1990; 119: 1083–9.
- 19 Iberti TJ, Fischer EP, Leibowitz AB, et al. A multicenter study of physicians' knowledge of the pulmonary artery catheter. *JAMA* 1990; 264: 2928–32.
- 20 Connors AF Jr, Speroff T, Dawson NV, et al. The effectiveness of right heart catheterization in the initial care of critically ill patients. *JAMA* 1996; 276: 889–97.
- 21 Bergquist BD, Leung JM, Bellows WH. Transesophageal echocardiography in myocardial revascularization: I. Accuracy of intraoperative real-time interpretation. *Anesth Analg* 1996; 82: 1132–8.
- 22 Savage RM, Licina MG, Koch CG, et al. Educational program for intraoperative transesophageal echocardiography. *Anesth Analg* 1995; 81: 399–403.
- 23 Weinger MB, Herndon OW, Gaba DM. The effect of electronic record keeping and transesophageal echocardiography on task distribution, workload, and vigilance during cardiac anesthesia. *Anesthesiology* 1997; 87: 144–55.