Transesophageal echocardiography as an alternative for the assessment of the trauma and critical care patient

David D. Rose, CRNA, MAEd
Sacramento, California

Transesophageal echocardiography was first described and used to monitor cardiac function in 1976. Initially adopted by cardiac anesthesiologists and cardiologists, it has gained acceptance as an important diagnostic tool in the monitoring and assessment of cardiac status in the critically ill and trauma patient population. Comparative data suggest that transesophageal echocardiography provides rapid real-time noninvasive monitoring of the critically ill and avoids the morbidity and mortality that is associated with more invasive methods of patient monitoring. In addition, transesophageal echocardiography affords the practitioner reliable cardiac filling volumes based on direct left ventricular assessment compared to pressure data that are based on indirect right ventricular and pulmonary occlusive pressures.

In a healthcare environment that seeks optimum patient assessment while requiring an approach that encourages cost-effective, noninvasive, and minimal patient risk, those nurse anesthetists who work in institutions that have transesophageal echocardiographic capabilities should learn this newer technology and begin to incorporate it into their practice.

Key words: **Critical care, pulmonary artery catheter, transesophageal echocardiography, trauma.**

The purpose of this article is to acquaint the reader with the benefits of transesophageal echocardiography (TEE) and compare its use to the more commonly practiced technique of pulmonary artery catheter (PAC) measurement in the critically ill and trauma population. It is not intended to provide the technical methodology of echocardiography. It will, however, contribute to the reader's understanding of the historical development and basic physical properties of TEE. More importantly, it will review the literature regarding the use of TEE compared with the PAC in providing accurate and direct cardiac measurement. Complications associated with its use and significant benefits of TEE also will be described.

Historical information

Transesophageal echocardiography is a relatively new method that is gaining popularity as a diagnostic tool in the evaluation and management of hypovolemia in critical care patients. The technology dates back to the first m-mode (motion mode) echocardiograph in 1976.[1] Its use was later described to continuously monitor left ventricular function during cardiac surgery.[2] The first 2-dimensional, phased array transducer was mounted on the tip of a flexible gastroscope at the University of Hamburg, Hamburg, Germany, in 1982.[3] Finally, in the mid-1980s doubling the number of the crystal elements in the probe (piezoelectical crystals) made the echocardiograph images powerful enough for TEE to be incorporated for intraoperative cardiovascular assessment.

Technology of transesophageal echocardiography

A brief overview of the physical properties of the TEE is appropriate to educate the reader on the basic workings of this device. Piezoelectric crystals are the transmitters and receivers of the sound waves used in echocardiography. The actual ultrasound is produced by the vibration of the quartz crystals when electrically stimulated at a rate between 2.5 and 7.5 million cycles per second (megahertz) and is undetectable by the human ear. The "m-mode" refers to motion echocardiogram, which originally was 1-dimensional. The m-mode is principally used now to view rapidly moving structures such as valve leaflets and can produce up to 1,000 images per second. In this mode, the TEE can only view a small portion of the heart at 1 time.

Pulsed wave Doppler provides information about blood flow velocity and volume by looking at a small section of the heart through a 2-dimensional area called the "sample volume." Pulsed wave Doppler can define blood flow velocities and their location within the heart and great vessels. This is especially helpful when assessing flow through valves and ventricular outflow tracts and is an essential step in evaluating intravascular volume.

Continuous wave Doppler uses 2 separate crystals: one to continuously emit ultrasound and the other to continuously receive the impulses. It is essentially a pulsed wave Doppler with an infinite pulse repetition frequency. Continuous wave Doppler defines higher blood flow velocities than pulsed wave, but continuous wave Doppler cannot precisely define the location of the velocities. It can provide useful information regarding maximum flow velocity across stenotic valves.

Color Doppler flow imaging is a form of pulsed wave Doppler. Color codes the flow toward (red) and away (blue) from the transducer. Lighter and darker shades of red and blue respectively denote relatively faster and slower velocities. Color Doppler flow is helpful in viewing turbulent flow observed in regurgitation and stenosis. It is, however, considered semiquantitative.

Three-dimensional TEE is emerging as a clinically significant tool to visualize the heart and its structures and flows either directly or after reconstruction. The process involves data acquisition and storage of the 2-dimensional images with the appropriate synchronization of the electrocardiograph and respiration followed by the data processing of these images with the final rendering of a 3-dimensional display. With rapid advances in computer technology, 3-dimensional TEE imaging will be processed quickly and provide meaningful structural and volumetric information to the practitioner.

Monitoring in critical care

The monitoring of critical care patients in North America has traditionally incorporated the use of the PAC. Modifications to the PAC have lead to its enhanced capabilities. Some of these enhancements include continuous cardiac output, the ability to estimate derived right ventricular volumes, and continuous mixed venous oxygen saturation.

Pulmonary artery catheter use has recently come under scrutiny because of its safety. A recent study found that patients who underwent right heart catheterization for noncardiac surgery had a 3-fold increase in the incidence of major postoperative cardiac and noncardiac outcomes.[4] These complications included major cardiac events (myocardial infarction and unstable angina), congestive heart failure, and major noncardiac events (bacterial pneumonia, pulmonary embolism, noncardiogenic pulmonary edema, respiratory failure requiring intubation, renal failure requiring dialysis, cerebrovascular accident, and gastrointestinal bleeding). Previously, similar safety concerns with PAC use also were reported by the Anesthesia Patient Safety Foundation and others regarding higher incidences of nosocomial infections and other catheter associated complications.[5-7]

Because of the significant safety issues regarding the use of pulmonary artery catheters, many anesthesiology and critical care practitioners began to examine the feasibility of substituting transesophageal echocardiography for the pulmonary artery catheter. This has led to a number of comparative studies between the 2 modalities. Unfortunately, many of the comparative data investigate TEE and PAC from different parameters. This is evident upon a review of the literature regarding TEE and its ability to gain comparative data to the PAC.

One early study in 1994 used the technique of automated border detection with TEE and compared it to the thermodilution catheter (PAC).[8] The continuous online estimation of cardiac output with the TEE using automated border detection of the left ventricle was equal to the PAC use of thermodilution. Early work with automated border detection was found to be tedious but provided safe and accurate determination of stroke volume.[9]

In work done by Kraut and colleagues,[10] it was discovered that right ventricular volume using a right ejection fraction PAC overestimated left ventricular preload when compared to the TEE estimations. These investigators reported that the evaluation of right ventricular end-diastolic volume by the right ejection fraction PAC to estimate left ventricular preload significantly overestimated the volume when compared to actual left ventricular end diastolic volume as measured by TEE. Therefore, the PAC uses right ventricular end-diastolic volume as an indirect measure to assess left ventricular preload volume. This technique for estimation of preload can cause under-resuscitation and lead to a false sense of security regarding the volume status of the hypovolemic patient. Conversely, a study using 3-dimensional TEE of the left ventricle reported that this technique correlated well with thermal dilution assessment of stroke volume and cardiac output.[11] This study, however, used the older thermodilution PAC and not the newer right ejection fraction catheter.

The assessment of intravascular volume is an important aspect of resuscitation, especially in hypovolemic shock due to trauma. Although not studied in this population, additional literature has reenforced the use of TEE as a means to effectively evaluate volume status in critically ill patients.

Swenson and colleagues[12] demonstrated the efficacy of TEE to assess intravascular volume during fluid loading. This group evaluated an animal model that compared TEE to the PAC. Pulmonary capillary wedge pressure did not demonstrate a significant relationship to changes in cardiac output and left ventricular systolic work. There was, however, a significant relationship between automated border detection with TEE and ventricular preload. The ability to estimate ventricular preload is important when attempting to define an endpoint to volume replacement. Another important benefit of automated border detection with TEE is that this technique is not affected by artifact introduced by positive pressure ventilation that may be influenced by right heart pressure measurements. It is well established that there is a nonlinear relationship between pulmonary capillary wedge pressure and intracardiac volumes. This is due to the variability in ventricular compliance and alterations produced by artifacts in intrathoracic and intrapericardial pressures.[13] Therefore, relying solely on the PAC to establish confidence in volume replacement may provide a false sense of security that the vascular system is adequately filled. It should be emphasized that as the heart fills, small changes in volume will result in large changes in pressure. Finally, left heart function is indirectly measured by the PAC regardless of which measurement is used (pulmonary arterial wedge pressure or right heart pressure) and may cause under-resuscitation of the trauma patient.[10,12-14]

Several studies have strengthened the argument regarding the utility of TEE in the assessment of cardiac function.[15-17] Although a large proportion of these data are from perioperative cardiac surgical and critical care patients, the conclusions can be generalized to include hypovolemic trauma patients to some extent.

In an in-depth review of the literature, there were no articles that advocated the use of TEE for intraoperative volume assessment in the trauma population. Although the indications are obvious for its incorporation as an effective method of measurement, no evidence of its use could be found.

The review of the literature did provide some additional benefits to the use of TEE during the perioperative care of the trauma patient. One author reported that the TEE Doppler was valuable in providing reliable noninvasive monitoring of a pediatric burn patient.[18] The TEE also was effective in another study that examined the hemodynamic effects of rapid small volume infusions of 250 to 500 mL in critically ill patients.[19] It was discovered that the common treatment of rapidly infusing small amounts of saline did not significantly increase hemodynamics or the left ventricular area based on PAC and TEE measurements respectively. There was, however, a small but significant increase in pulmonary artery occlusive pressure reinforcing the concept of occlusive right-sided pressures not being indicative of left heart fullness.

In addition to the benefits of TEE to assess real-time intravascular and intracardiac filling, a review of the literature also provided additional advantages that need mentioning for completeness of this article.

In an early report, it was shown that TEE was effective in assessing the quality of chest compressions during cardiopulmonary resuscitation.[20] The authors reported that TEE provided valuable information regarding the effectiveness of ventricular compression and valvular movement during the chest compressions.

Other authors reported the use of TEE as an excellent method of examining the heart and major vascular structures for potential injury after blunt trauma. Transesophageal echocardiography was equal to computed tomography scanning in the diagnosis of aortic injury and associated cardiac trauma.[21] This same author found TEE was accurate in diagnosing aortic dissection and traumatic disruption.[22] Others also reported the superiority of TEE in the evaluation of aortic trauma.[13,23] The added benefit of both rapid ongoing assessments of cardiovascular dynamics and cardiac injury enhances the need for TEE in trauma.

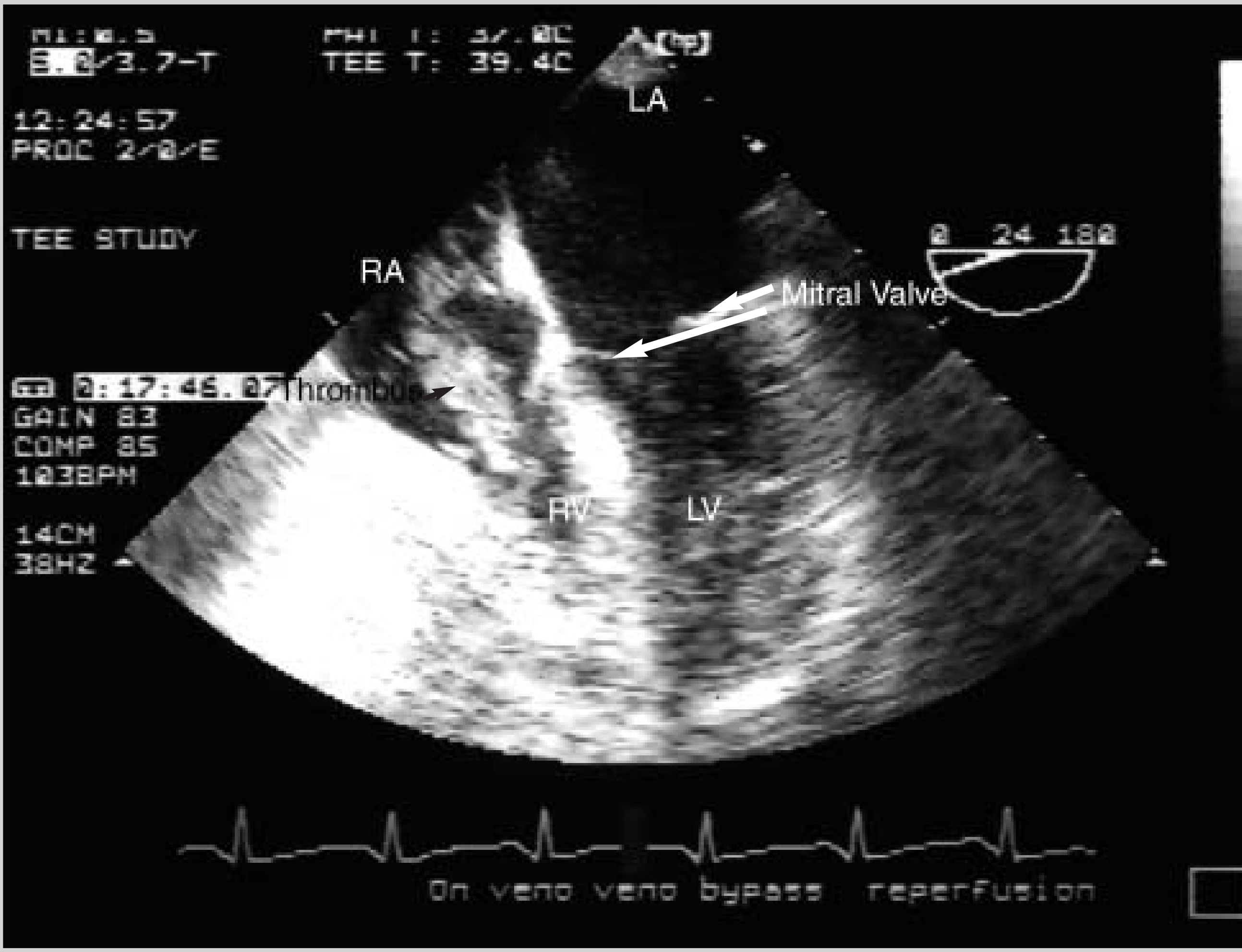
In addition to the benefits mentioned above, TEE also might provide enhanced monitoring of the elderly trauma patient. The elderly population is involved in a significant amount of trauma. The majority of injuries are from falls and motor vehicle accidents, which result in blunt trauma.[24] Incorporating TEE during the perioperative assessment has many benefits. In addition to evaluating cardiac filling, TEE also can provide information regarding any preoperative cardiac wall motion and structural abnormalities. Left ventricular hypertrophy can be detected as well as hypokinetic areas of the myocardium.[25,26]

Another potential benefit to TEE in the management of the elderly trauma patient is the well-known fact that careful volume resuscitation is a formidable challenge. Transesophageal echocardiography allows for the real-time ongoing assessment of volume replacement and provides simultaneous information regarding cardiac filling and myocardial wall motion. The ability to evaluate vascular structures for injury such as the aorta is also possible. Thus, with the insertion of the TEE, a rapid evaluation of an injury that can have potential negative consequences to resuscitation is identified.

The use of TEE should be considered as a potentially more informative and lower risk alternative when a PAC is planned principally for intraoperative monitoring.[27] Transesophageal echocardiography also should be considered in monitoring for air embolism during neurosurgical procedures. It is considered one of the more sensitive monitors for detecting intravascular air.[28,29]

An example of how TEE is instrumental in identify-

Figure. **A long axis 4-chamber view of a transesophageal echocardiogram (TEE) showing a thrombus migration after unclamping of hepatic vessels during liver transplantation**



Note how the thrombus freely passes through the tricuspid valve in a to-and-fro motion between the right atrium and ventricle. TEE shows the heart at the end of systole and beginning of diastole.
LA indicates left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

ing intracardiac emboli and thrombi is shown in the Figure. During a liver transplant procedure, the TEE identified a large thrombus that migrated into the right atrium after the cross clamps were removed and reperfusion of the liver began. The thrombus was noted to move freely between the right atrium and ventricle through the tricuspid valve until it was observed to flow into the pulmonary circulation via the right ventricular outflow tract. The patient was closely monitored and observed for any changes in her vital signs. Fortunately, no adverse signs or symptoms were manifested, and the patient went on to an uneventful postoperative course.

Complication associated with TEE

Most of the complications with TEE have essentially occurred in the outpatient population and were associated with stress that the awake or minimally sedated patient experienced while swallowing the probe.[30] An early report described 2 patients who sustained unilateral vocal cord paralysis with TEE monitoring during "sitting" craniotomies.[28] It was thought that the paralysis was caused by the patient being positioned in a nearly full neck flexion that resulted in injury to the recurrent laryngeal nerve when the endotracheal tube, larynx, and the shaft of the gastroscope were compressed by the chin and vertebral column. Transient hoarseness also has been reported.[31]

More recently, a review of the complications in a single-center retrospective series of 7,200 adult patients who underwent cardiac surgery that included TEE for intraoperative cardiac monitoring were evaluated (Table).[32] This large population study reveals a minimal risk associated with the use of TEE.

In an attempt to lessen the risk of damage or injury to delicate anatomical structures during the placement of the TEE, it has been recommended that the nasogastric tube, if in place, should be removed. In addition, temporary deflation of the endotracheal tube cuff, a forward mandibular movement, and the use of direct laryngoscopy for TEE insertion also have been advocated.[33] In a study of 36 consecutive intubated patients undergoing TEE, 5 (13%) required removal of the nasogastric tube, 3 (8%) required deflation of the endotracheal tube cuff, and 1 (3%) required direct laryngoscopic assistance.[34]

Conclusion

The monitoring of the critically ill and trauma population is an important concept in the care of these patients. In the trauma setting, rapid real-time cardiovascular measurement is essential for optimal management. Oftentimes the rapid tempo of the resuscitation makes invasive techniques impractical and sometimes impossible because of the surgical prepping and operative site. In addition, placing pulmonary artery and central venous pressure catheters may pose an enhanced risk to the patient because of inadvertent carotid puncture, pneumothorax, and hemopneumothorax. The author recalls a personal case where during a subclavian approach to PAC placement, the subclavian artery was inadvertently punctured causing significant bleeding and resulted in cardiac tamponade. A midline sternotomy was required to repair the rent in the artery, and the scheduled craniotomy had to be cancelled. Quick identification of the problem and an available heart team saved the patient's life.

Besides the risks previously described, other issues need discussion. No study to date has examined the cost of invasive monitoring, namely PAC compared with TEE. It is important to consider the use of TEE as a quick, reliable, and inexpensive tool for the evaluation of a hypovolemic patient. The TEE can provide the practitioner with information as to whether the hypovolemia is from volume deficit, embolus, or thrombus formation; injury to the heart valves or great vessels; or ineffective myocardial contractility. PAC may be appropriate for longer-term volume assessment and cardiac evaluation in the extubated and nonsedated patient.

Another significant advantage is that TEE is relatively noninvasive compared to PAC. The current thrust is to provide quality care and control escalating costs. TEE may be instrumental in the trend to enhance monitoring of critically ill patients in a noninvasive manner without adding to patient costs because of equipment and morbidity.

Finally, TEE is destined to become a standard monitoring device for trauma and critical care patients. It is understandable that TEE is expensive and currently bulky in its design; however, nurse anesthetists who have the technology in their institutions need to step forward and become familiar with the technique that is certain to be the future in noninvasive real-time monitoring.

Table. Complications associated with transesophageal echocardiography in 7,200 cardiac patients[32]

Complication	Incidence No. patients (%)	% all complications
Overall morbidity	14 (0.20)	100
Overall mortality	0 (0)	0
Odynophagia	7 (0.10)	50
Dental injury	2 (0.03)	14
Upper gastrointestinal hemorrhage	2 (0.03)	14
Endotracheal tube malposition	2 (0.03)	14
Esophageal perforation	1 (0.01)	8
Unsuccessful placement	13 (0.18)	N/A

REFERENCES

1. Frazin L, Talano JV, Stephanides L, Loeb HS, Kopel L, Gunnar RM. Esophageal echocardiography. *Circulation.* 1976;54:102-108.
2. Matsumoto M, Oka Y, Strom J, et al. Application of transesophageal echocardiography to continuous intraoperative monitoring of left ventricular performance. *Am J Cardiol.* 1980;46:95-105.
3. Schluter M, Langenstein BA, Polster J, et al. Transesophageal cross-sectional echocardiography with phased array transducer system. Technique and initial clinical results. *Br Heart J.* 1982;48: 67-72.
4. Polanezyk CA, Rohde LE, Goldman L, et al. Right heart catheterization and cardiac complications in patients undergoing noncardiac surgery. *JAMA.* 2001;286:309-314.
5. Truman KJ, Prielipp RC, Morell R. Debate: The pulmonary artery catheter, Is it safe? *Anesthesia Patient Safety Foundation Newsletter.* Spring 1997;12:4-5.
6. Ali MJ, Omran AS, Rakowski HR, William WG. Pulmonary valve injury: Swan-Ganz or surgery. *Can J Cardiol.* 2001;17:467-470.
7. Brown M. CDC publishes new guidelines for prevention of intravascular device-related infections. *American Society of Anesthesiology Newsletter.* May 1997;61:7-9.
8. Pinto FJ, Siegel LC, Chenzbraun A, Schnittger I. On-line estimation of cardiac output with a new automated border detection system using transesophageal echocardiography: a preliminary comparison with thermodilution. *J Cardiothorac Vasc Anesth.* 1994;8: 625-630.
9. Martin RW, Bashein G. Measurement of stroke volume with three-dimensional transesophageal ultrasonic scanning: comparison with thermodilution measurement. *Anesthesiology.* 1989;70:470-476.
10. Kraut EJ, Owings JT, Anderson JT, Hanowell L, Moore P. Right ventricular volumes overestimate left ventricular preload in critically ill patients. *J Trauma.* 1997;42:839-845; discussion 845-836.

11. Kuhl HP, Franke A, Janssens U, et al. Three-dimensional echocardiographic determination of left ventricular volumes and function by multiplane transesophageal transducer: dynamic in vitro validation and in vivo comparison with angiography and thermodilution. *J Am Soc Echocardiogr.* 1998;11:1113-1124.

12. Swenson JD, Harkin C, Pace NL, Astle K, Bailey P. Transesophageal echocardiography: an objective tool in defining maximum ventricular response to intravenous fluid therapy. *Anesth Analg.* 1996; 83:1149-1153.

13. Hanowell LH, Anderson JT, Kraut EJ, Bear JD. Transesophageal echocardiography in the perioperative assessment of intravascular volume. *Seminars in Anesthesia, Perioperative Medicine and Pain.* 1998;17:252-266.

14. Royse CF, Royse AG. Afterload corrected fractional area change (FACac): a simple, relatively load-independent measurement of left ventricular contractility in humans. *Ann Thorac Cardiovasc Surg.* 2000;6:345-350.

15. Pai RG, Jintapakorn W, Tanimoto M, Cao QL, Pandian N, Shah PM. Three-dimensional echocardiographic reconstruction of the left ventricle by a transesophageal tomographic technique: In vitro and in vivo validation of its volume measurement. *Echocardiography.* 1996;13:613-622.

16. Nakao T, Shimizu M, Kita Y, et al. Noninvasive measurement of left atrial functions using transesophageal echocardiography. *Jpn Heart J.* 1996;37:227-238.

17. Declerck C, Hillel Z, Shih H, Kuroda M, Connery CP, Thys DM. A comparison of left ventricular performance indices measured by transesophageal echocardiography with automated border detection. *Anesthesiology.* 1998;89:341-349.

18. Gueugniaud PY, David JS, Petit P. Early hemodynamic variations assessed by an echo-Doppler aortic blood flow device in a severely burned infant: correlation with the circulating cytokines. *Pediatr Emerg Care.* 1998;14:282-284.

19. Axler O, Tousignant C, Thompson CR, et al. Small hemodynamic effect of typical rapid volume infusions in critically ill patients. *Crit Care Med.* 1997;25:965-970.

20. Redberg RF, Tucker KJ, Cohen TJ, Dutton JP, Callaham ML, Schiller NB. Physiology of blood flow during cardiopulmonary resuscitation. A transesophageal echocardiographic study. *Circulation.* 1993;88:534-542.

21. Vignon P, Spencer KT, Rambaud G, et al. Differential transesophageal echocardiographic diagnosis between linear artifacts and intraluminal flap of aortic dissection or disruption. *Chest.* 2001;119:1778-1790.

22. Vignon P, Boncoeur MP, Francois B, Rambaud G, Maubon A, Gastinne H. Comparison of multiplane transesophageal echocardiography and contrast-enhanced helical CT in the diagnosis of blunt traumatic cardiovascular injuries. *Anesthesiology.* 2001;94: 615-622; discussion 5A.

23. Rosenzweig BP, Guarneri E. Transesophageal echocardiography in the evaluation of aortic trauma. *Echocardiography.* 1996;13:247-258.

24. Gupta KJ, Parr MR. Epidemiology of trauma. In: Grande CM, Smith CE, eds. *Anesthesiology Clinics of North America.* Vol 17. Philadelphia, Pa: WB Saunders Company; 1999:20-27.

25. Royse CF, Royse AG, Blake DW, Grigg LE. Instantaneous end diastolic stiffness (IEDS): a simple, load independent measurement of left ventricular diastolic function in patients undergoing cardiac surgery. *Ann Thorac Cardiovasc Surg.* 2000;6:203-210.

26. van Daele ME, Sutherland GR, Mitchell MM, et al. Do changes in pulmonary capillary wedge pressure adequately reflect myocardial ischemia during anesthesia? A correlative preoperative hemodynamic, electrocardiographic and transesophageal echocardiographic study. *Circulation.* 1990;81:865-871.

27. Cahalan MK, Ionescu P, Melton HJ, Adler S, Kee LL, Schiller NB. Automated real-time analysis of intraoperative transesophageal echocardiograms. *Anesthesiology.* 1993;78:477-485.

28. Cucchiara RF, Nugent M, Seward JB, Messick JM. Air embolism in upright neurosurgical patients: detection and localization by two-dimensional transesophageal echocardiography. *Anesthesiology.* 1984;63:353-355.

29. Glenski JA, Cucchiara RF, Mechenfelder JD. Transesophageal echocardiography and O_2 and CO_2 monitoring for detection of venous air embolism. *Anesthesiology.* 1986;64:641-645.

30. Rafferty T, LaMantia KR, Davis E, et al. Quality assurance for intraoperative transesophageal echocardiography monitoring. *Anesth Analg.* 1993;76:228-232.

31. Messina AG, Paranicas M, Fiamengo S, et al. Risk of dysphagia after transesophageal echocardiography monitoring: a report of 846 patients. *Am J Cardiol.* 1991;67:313-314.

32. Kallmeyer IJ, Collard CD, Fox JA, Body SC, Shernan SK. The safety of intraoperative transesophageal echocardiography: a case series of 7200 cardiac surgical patients. *Anesth Analg.* 2001;92: 1126-1130.

33. Gunasegaran K, Yao J, De Castro S, Nesser H.J, Pandian NG. Three-dimensional transesophageal echocardiography (TEE) and other future directions. In: Foster E, ed. *Cardiology Clinics.* Vol 18. Philadelphia, Pa: WB Saunders Company; 2000:893-910.

34. Khoury A, Afridi I, Quinones MA, et al. Transesophageal echocardiography in critically ill patients: Feasibility, safety, and impact on management. *J Am Heart Assoc.* 1994;127:1363-1371.

AUTHOR

David D. Rose, CRNA, MAEd, is chief nurse anesthetist, Department of Anesthesiology and Pain Management, University of California Davis Medical Center, Sacramento, Calif, and is a doctoral student, Department of Physiological Nursing, University of California San Francisco, San Francisco, Calif.