Guidelines for the Performance of a Comprehensive Intraoperative Epiaortic Ultrasonographic Examination: Recommendations of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists; Endorsed by the Society of Thoracic Surgeons

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The introduction of transesophageal echocardiography (TEE) in the mid-1980s extended the use of ultrasound to the intraoperative diagnosis and monitoring of cardiac and great vessel pathology. Intraoperative epicardial echocardiography has been used both as an adjunct to TEE, and as a primary diagnostic tool in patients with contraindications to TEE. The earliest applications of intraoperative epicardial imaging included the diagnosis of intracardiac pathology such as valvular heart disease.[1] More recently, direct epivascular or epiaortic ultrasonographic (EAU) imaging of the ascending aorta and aortic arch has gained prominence as part of a multipronged intraoperative strategy to reduce atherosclerotic emboli. Although atheromatous disease of the descending aorta has been used to screen for disease in the ascending aorta,[2] Konstadt et al[3] demonstrated that the interposition of the bronchus might prevent adequate visualization of the ascending aorta by TEE, making it unsatisfactory for a comprehensive atheroma evaluation. Furthermore, surgical palpation as a method of assessing atherosclerotic plaque grossly underestimates the presence and severity of disease.[4] Thus, because atherosclerosis of the ascending aorta has been shown to increase the risk of embolic neurologic complications in both medical and surgical populations,[5,6] EAU imaging has been promoted as an intraoperative tool for the accurate assessment of ascending aortic pathology in patients with cardiac surgical conditions.

The purpose of this document is to provide the rationale for the routine performance of EAU imaging, and to present a standardized sequence of imaging planes for a comprehensive examination. Training guidelines along with indications, techniques, and use of this procedure are discussed. Grading of the severity of atherosclerosis is addressed, and a summary of various currently available grading systems is provided.

RATIONALE FOR AN EAU EXAMINATION

Perioperative stroke is a major cause of morbidity and mortality in the cardiac surgery population. The incidence of stroke varies widely depending on the surgical procedure: 1.9% for off-pump coronary artery bypass graft (CABG) surgery, 3.8% for on-pump CABG, 4.8% for aortic valve surgery, 8.8% for mitral valve surgery, and 7.4% for combined CABG and valve surgery.[7-14] Patients with stroke have significantly longer intensive care department stays, have a 5-fold increase in postoperative mortality,[7] and are a significant financial burden on the health care system.[15] Risk factors associated with perioperative stroke include advanced age, female sex, history of cerebrovascular disease and/or peripheral vascular disease, diabetes, hypertension, previous cardiac surgery, preoperative infection, urgent operation, cardiopulmonary bypass

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time of greater than 2 hours, need for intraoperative hemofiltration, transfusion requirement, and proximal aortic atherosclerosis or a calcified aorta.[11,16] The surgical approach can also have a significant impact on the occurrence of perioperative stroke. Kapetanakis et al[17] demonstrated in 7272 patients undergoing isolated CABG that by simply minimizing aortic manipulation, the incidence of stroke can be diminished by 50%. Similarly, the lower stroke rate reported by some investigators after off-pump CABG surgery versus conventional CABG suggests that disruption and embolization of atheromatous plaques during aortic cannulation, cross-clamping, and surgical manipulation of the ascending aorta may increase the risk for postoperative neurologic injury.[18,19]

The routine use of EAU imaging and TEE to identify and manage aortic atheromatous disease may allow the surgeon to individualize the surgical technique and potentially reduce the incidence of embolic stroke. Although some physicians still rely on direct surgical palpation to evaluate the ascending aorta, EAU imaging has been consistently shown to be superior. In a study by Marshall et al,[20] 58% of patients with CABG had atherosclerotic ascending aortic disease when assessed by EAU scanning whereas surgical inspection and palpation identified atheromatous disease in only 24%. To date, no prospective, randomized clinical trial has evaluated the relationship between stroke rate and EAU-altered surgical technique. In a small study, Hangler et al[21] used EAU data to change surgical technique, and compared their results to a historical control group. Patients whose therapy was modified on the basis of EAU imaging had a lower stroke rate (2.9%) than the control group (4.4%).

INDICATIONS FOR EAU EXAMINATION

A rationale for the use of EUA imaging for all patients with cardiac surgical conditions could be realistically justified based on an intuitively favorable risk-benefit ratio. However, based on currently available evidence, this committee recommends EAU imaging primarily for patients with an increased risk for embolic stroke (as defined above) including those with a history of cerebrovascular or peripheral vascular disease and in those patients who have evidence of aortic atherosclerosis or calcification by other imaging modalities including a preoperative or intraoperative TEE, magnetic resonance imaging, computed tomography scan, or chest radiograph.

ULTRASOUND PROBE

EAU imaging should be performed using a high-resolution (>7 MHz) ultrasound transducer. Most commonly, either a transthoracic or specially designed epiaortic (epivascular) probe using a phased- or linear-array transducer is used. Although a few intraoperative probes can be sterilized, most cannot, and must be inserted into a sterile sheath filled with either sterile saline or ultrasound transmission gel before being placed on the aorta for examination. Some echocardiographers recommend the use of two sheaths to increase the margin of safety with this procedure. Warm sterile saline should also be used to fill the mediastinal cavity to enhance acoustic transmission. The use of excessively cold or hot fluid can lead to hemodynamic compromise and is, therefore, not recommended. The individual manipulating the probe can either be a member of the echocardiography team, or a surgical team member guided by an echocardiographer with advanced-level training as defined in the Guidelines for Training in Perioperative Echocardiography.[22] In either case, appropriate sterile techniques including the use of hand scrubbing, gown, and gloves must be adopted. A video demonstration of the EAU technique may be accessed on the World Wide Web at http://www.asecho.org/epiaortic_ultrasound.php.

Linear Sequential Array Transducers

Linear-array transducers were initially developed for the assessment of vascular structures but, in recent years, linear-array probes with a small footprint have been developed specifically for EAU imaging. Because these probes generate a rectangular image that is never wider than the transducer (Figure 1), it is often difficult to include the entire ascending aorta in a single image. Linear sequential array probes generally do not require a standoff device for adequate visualization of the anterior surface of the aorta.

Phased-array Transducers

A standard phased-array adult or pediatric transthoracic transducer (ideally > 7 MHz) may be inserted into a sterile sheath as described above. Because the image created by a phased-array transducer is fan or sector shape (Figures 2 to 4), it is necessary to hold the probe approximately 1 cm above the aorta to obtain optimal imaging of the anterior surface of the aorta in the near field. The technician performing the examination can accomplish this with a standoff device, or by manually holding the probe above the aorta within the fluid-filled sheath. The entire aorta can usually be seen in a single long-axis (LAX) imaging plane, whereas surrounding structures can be used to orient the left and right side.

Matrix-array Transducers

A matrix-array transducer enables the acquisition of real-time, 3-dimensional images in the form of a pyramidal volume. The principal advantage of matrix-array transducers is the ability to acquire simultaneous 2-dimensional EAU images in two orthogo-

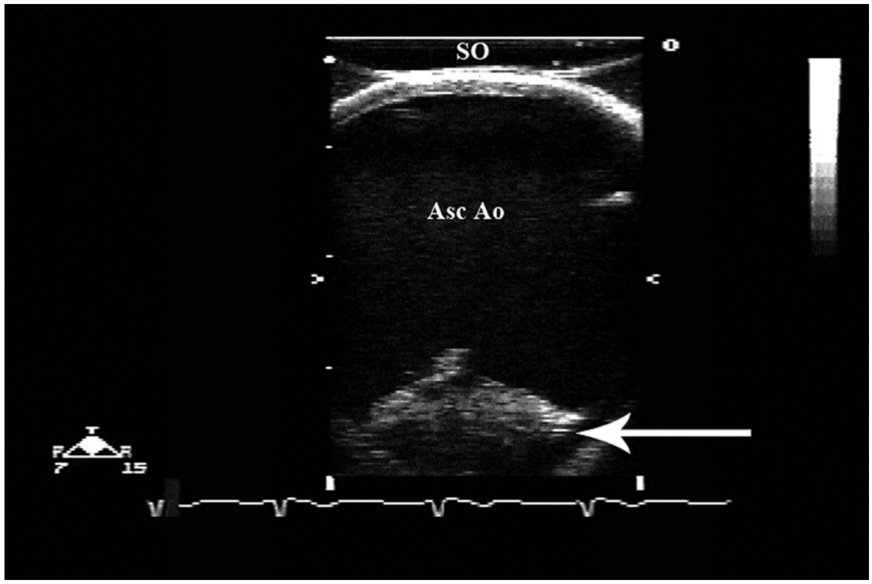

Figure 1 Epiaortic ultrasonographic short-axis image of mid ascending (*Asc*) aorta (*Ao*) with significant atheroma (*arrow*) obtained with linear-array transducer. *SO*, Saline standoff.

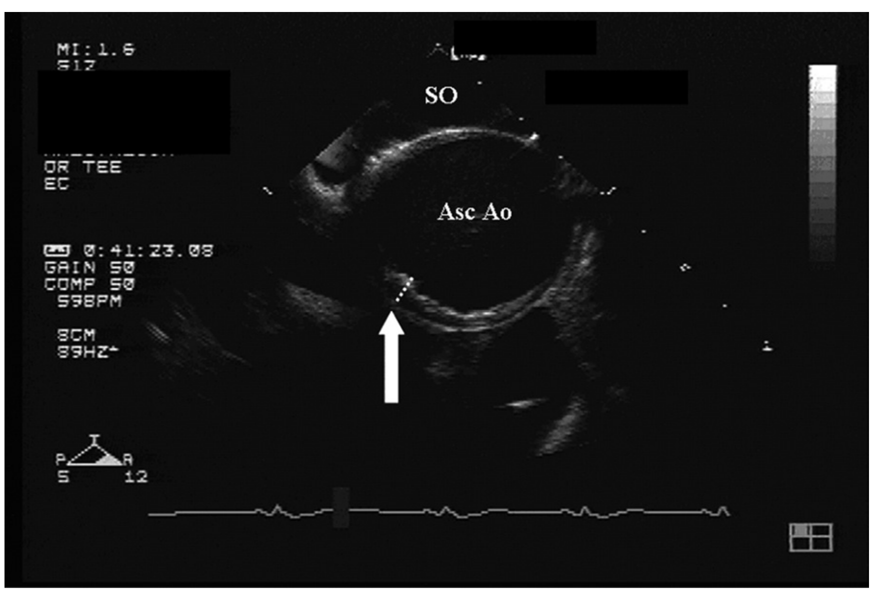

Figure 2 Epiaortic ultrasonographic short-axis image of the mid ascending (*Asc*) aorta (*Ao*) with significant atheroma (*arrow*) obtained with phased-array transducer. Linear measurement of plaque height/thickness is shown (*hashed line*). *SO*, Saline standoff.

nal planes, also known as biplane or x-plane imaging (Figure 5), thus, eliminating the need to physically turn the probe to obtain short-axis (SAX) and LAX images of the ascending aorta. Other advantages include improved spatial orientation of intra-aortic pathology, and greater accuracy in the estimation of volume. Recent innovations in transducer technology have resulted in the production of smaller matrix arrays with higher frequency ranges (up to 7 MHz) that permit improved resolution of the ascending aorta. Matrix-array transducers are still somewhat limited by the size of the pyramidal volume, which has a sector width of 64 degrees, compared with the 90-degree sector width of conventional 2-dimensional image. Thus, despite the use of an adequate standoff, it may not be possible to view all the walls of the ascending aorta in a single imaging plane.

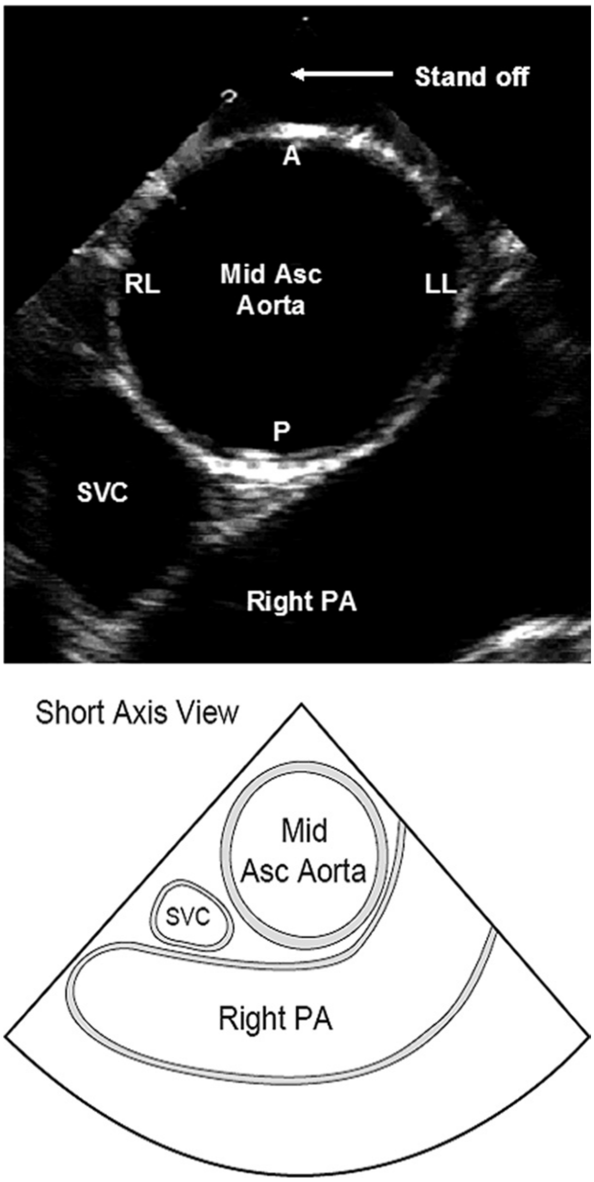

Figure 3 Epiaortic ultrasonographic image of the normal ascending (*Asc*) aorta in short-axis view obtained with phased-array transducer. Aortic wall areas that can be imaged in short axis include anterior (*A*), posterior (*P*), right lateral (*RL*), and left lateral (*LL*) walls. *PA*, Pulmonary artery; *SVC*, superior vena cava.

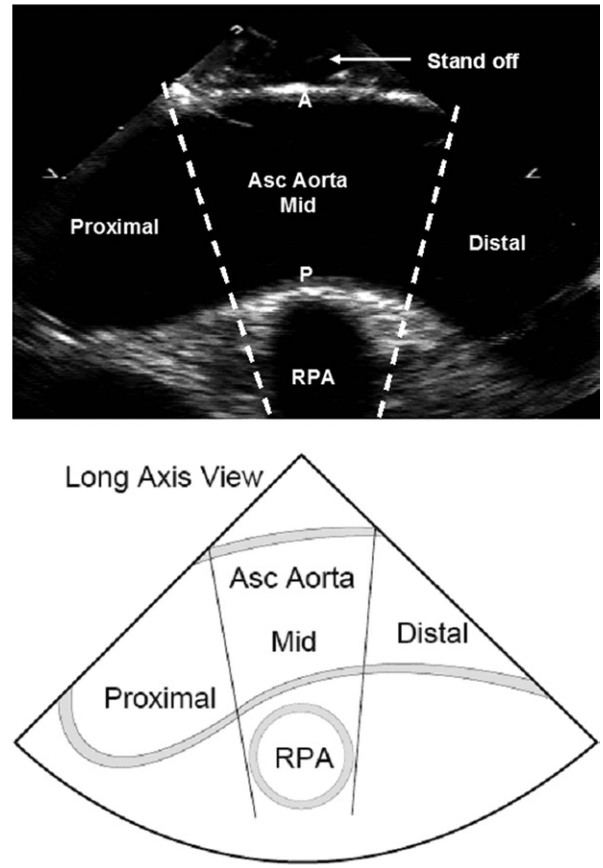

Figure 4 Epiaortic ultrasonographic image and accompanying diagram of normal ascending (*Asc*) aorta in long-axis view obtained with phased-array transducer. Aortic wall areas that can be imaged include anterior (*A*) and posterior (*P*) walls in each of proximal, mid, and distal segments. *RPA*, Right pulmonary artery.

IMAGING PLANES

The recommended comprehensive EAU examination includes a minimum of 5 views for the evaluation of the ascending aorta from the sinotubular junction to the origin of the innominate artery, and the aortic arch. The ascending aorta should be assessed in SAX in each of the proximal, mid, and distal segments. A LAX view of the ascending aorta including visualization of the proximal, mid, and distal segments should also be acquired. Although the distal aortic arch can usually be visualized adequately with TEE, the proximal arch often cannot. Therefore, an LAX EAU examination of the arch that includes visualization of the proximal arch is indicated, and a view including all 3 arch vessel origins should be attempted. Anatomic variations or time constraints may limit the ability to perform each component of a comprehensive EAU examination for every patient.

The ascending aorta can be divided into 12 areas including the anterior, posterior, left, and right lateral walls within the proximal, mid, and distal ascending aorta segments (Figures 3 and 4). The proximal ascending aorta is defined as the region from the sinotubular junction to the proximal intersection of the right pulmonary artery. The mid ascending aorta includes that portion of the aorta that is adjacent to the right pulmonary artery. The distal ascending aorta extends from the distal intersection of the right pulmonary artery to the origin of

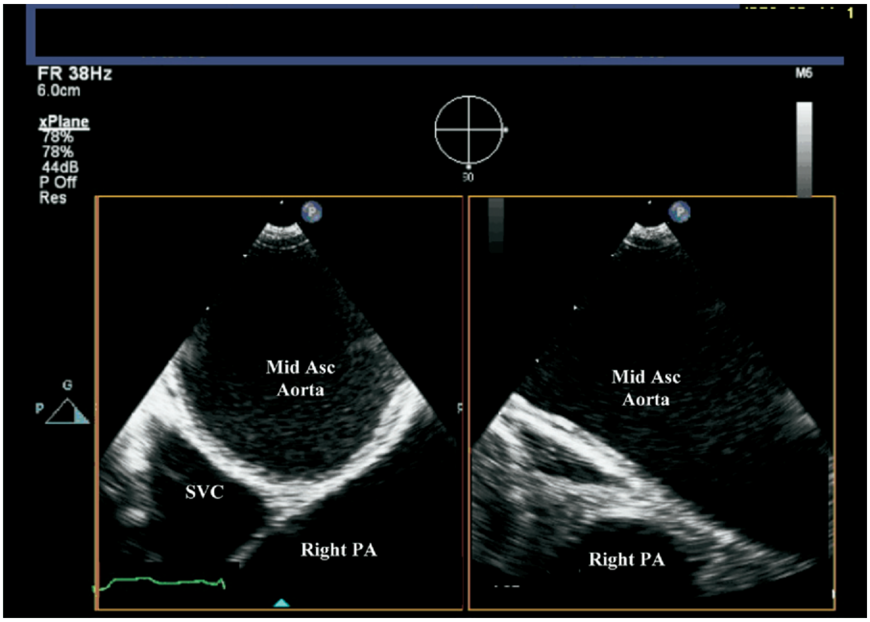

Figure 5 Simultaneous epiaortic biplane imaging of ascending (*Asc*) aorta in short (*left*) and long (*right*) axis demonstrating smaller sector angle obtained with matrix-array 3-dimensional transducer. *PA*, Pulmonary artery; *SVC*, superior vena cava.

the innominate artery. The diameter of each aortic segment should be measured as the maximum diameter in the SAX orientation, from the near-field inner edge to the far-field inner edge (internal diameter), as previously recommended by the American Society of Echocardiography's Chamber Quantification Writing Group.[23] Although the leading edge to leading edge measurement of aortic size has historically been recommended using M-mode echocardiography, currently available high-resolution transducers and advanced echocardiographic imaging modalities allow precise determination of the internal diameter of the aorta–a measure that is likely more clinically relevant.

SAX Examination

The ultrasound probe is positioned on the ascending aorta as proximally as possible, with the orientation marker directed toward the patient's left shoulder. Minor manipulations in the angulation of the probe are necessary to center the aorta within the imaging plane, and to develop the imaging plane perpendicular to the aorta (Figure 3). A significant difference between the antero-posterior and medial-lateral dimensions is an indicator of an orthogonal view. Measurements made in such a plane will be inaccurate. After identifying the proximal ascending aorta, where it is frequently possible to image the aortic valve, slowly advancing the probe distally in a cephalad direction along the aorta permits visualization of the mid ascending aorta, and finally the distal ascending aorta toward the aortic arch at the origin of the innominate artery. During the transit toward the innominate artery, it is necessary to rotate the probe in a clockwise fashion to maintain the SAX orientation. Advancing the probe slightly further permits examination of the proximal aortic arch.

LAX Examination

The LAX orientation is achieved by rotating the probe 90 degrees from the SAX orientation (Figure 4). Proximally, the sinus of Valsalva, sinotubular junction, and aortic valve can be visualized. The probe is then advanced distally in a cephalad direction along the aorta, changing the rotation and angulation accordingly to keep the aorta in a longitudinal LAX view. Imaging of the ascending aorta should extend to the origin of the innominate artery and slightly further, to visualize the aortic arch and the origins of the left common carotid and left subclavian arteries.

IMAGE ACQUISITION, STORAGE, AND DATA COLLECTION

Still images, videoloops, or both of the proximal, mid, and distal ascending aorta should be obtained in both SAX and LAX orientations. In addition, a LAX view of the proximal aortic arch should be recorded. Additional views demonstrating significant pathology such as atheromatous plaques or dissection flaps may also be warranted. If a mobile atheromatous plaque is identified, a re-evaluation of this location after completion of aortic manipulation and decannulation should be performed to document any changes in the integrity of the plaque. Digital image acquisition and storage is recommended for all recorded images.[24] Furthermore, all images should be immediately available to the surgical and anesthetic care teams during the operative procedure. A verbal report of pertinent findings should be provided to the surgical team members before manipulation of the ascending aorta, and a written report documenting examination findings should be available in the patient's chart within 24 hours of completion of the examination.[25]

GRADING OF AORTIC ATHEROSCLEROSIS

Cardiac surgery is unique in that manipulation of the ascending aorta is almost routine. However, as noted above, surgical handling of a diseased aorta is not without risk. In an attempt to objectively define the risk of aortic atheromatous embolization, several grading systems have been developed that largely classify atheroma on the basis of echocardiographic characteristics (Table). Katz et al[26] introduced a widely used grading protocol in 1992 that classified TEE-detected aortic arch atheroma on a 5-point scale. Patients undergoing cardiac surgery with mild to moderate disease with intimal thickening, but without protruding atheromas (<3 mm into the aortic lumen), were classified as having grade I, II, or III disease. Patients with atheromas protruding more than or equal to 5 mm into the aortic lumen, or any mobile components, respectively, were classified as having grade IV or V disease. These investigators concluded that patients with mobile atheroma (grade V disease) and those with aortic arch atheroma were at the highest risk for stroke. Although many studies have demonstrated the association between severity of aortic atherosclerosis and adverse neurologic injury, none have established the superiority of one grading system over another.[27,28] Nonetheless, a review of the literature suggests that a higher risk of neurologic injury is associated with the presence of certain plaque characteristics including a height/thickness that exceeds 3 mm, any mobile components, or an ascending aortic location.[29] Thus, during a comprehensive examination the following 3 measurements should be recorded and reported for each of the 3 ascending aortic SAX segments and for the aortic arch: (1) maximal plaque height/thickness; (2) location of the maximal plaque within the ascending aorta; and (3) presence of mobile components. Additional measurements indicating atheroma burden, such as circumferential plaque area of maximal plaque obtained by planimetry, are recommended but not required. When plaque area is measured, aortic diameter should also be noted to quantify atheroma burden as a ratio of plaque area to aortic area.[30] In case of multiple plaques, these measurements may be repeated as necessary. An example of plaque height/thickness measurement is shown in Figure 2.

A comprehensive evaluation of grading systems is complex, because cross-validation between studies is hampered by inconsistencies in population studied (medical vs surgical), equipment used (TEE, EAU imaging), location of aorta assessed, and definition of adverse outcome used (stroke, embolic events). Moreover, some grading systems use subjective echocardiographic descriptions of atheroma, including differences in echodensity, presence of calcification, ulceration, and irregular edges that are difficult to quantify. Thus, until additional studies are undertaken that clearly demonstrate the superior prognostic value of a particular grading system, no current grading system of aortic atherosclerotic burden severity can be recommended. Nevertheless, the use of a 5-point grading scale has merit for consistency and ease of communicating disease severity. Therefore, although the use of a currently available grading system may be continued, we encourage the prospective collection of all 5 measurements listed above, in preparation for the development of a large, multicenter data base. In addition, as a result of the preponderance of data demonstrating an increased risk of adverse neurologic outcomes associated with plaques that are greater than 5 mm in thickness, or those that possess a mobile component, the presence and location of these plaques should be discussed with the surgeon before aortic manipulation.

Training Guidelines

Trainees in perioperative echocardiography should participate in the evaluation of 25 EAU examinations, at least 5 of which must be personally directed by the individual. This training may include either direct manipulation of the probe using appropriate sterile technique, or directing the surgeon in the manipulation of the probe. Because the American Society of Echocardiography and Society of Cardiovascular Anesthesiologists Task Force Guidelines for Training in Perioperative Echocardiography include EAU imaging as a core component of advanced training,[22] it is our recommendation that all training be performed under the direct supervision of an echocardiographer with advanced level training, and that the trainee achieve an advanced training level before any independent interpretation and application of the EAU information to perioperative clinical decision making.

Summary of Recommendations

The recommended comprehensive EAU examination includes 5 views for the evaluation of the ascending aorta from the sinotubular junction to the origin of the innominate artery, and the aortic

Table Reported grading systems for aortic atheroma based on echocardiographic appearance

Reference	Grades	Description of grades	Population studied	Outcome
Katz et al[26]	I	Normal to mild intimal thickening	Cardiac surgery (n = 130)	Stroke
	II	Severe intimal thickening without protruding atheroma		
	III	Atheroma protruding < 5 mm into lumen		
	IV	Atheroma protruding ≥ 5 mm into lumen		
	V	Any thickness with mobile component or components		
Amarenco et al[31]	I	<1 mm	Stroke (n = 250) vs control (n = 250)	Stroke*
	II	1-1.9 mm		
	III	2-2.9 mm		
	IV	3-3.9 mm		
	V	≥4 mm		
Davila-Roman et al[4]	None	No identifiable intimal thickening	CABG surgery (n = 44)	Agreement between two ultrasound techniques†
	Mild	<3.0 mm Intimal thickening without irregularities		
	Moderate	≥3.0 mm Intimal thickening with diffuse irregularities and/or calcification		
	Severe	>5.0 mm Intimal thickening and ≥1 protruding debris or thrombus, calcification, or ulcerated plaque		
Acarturk et al[32]	I	Smooth internal surface without lumen irregularities or increased echodensity	Coronary angiography (n = 60)	Coronary artery disease severity
	II	Increased echodensity of intima without lumen irregularity or thickening		
	III	Increased echodensity of intima with well-defined atheroma < 3 mm		
	IV	Atheroma ≥ 3 mm		
	V	Mobile atheroma		
Ferrari et al[27]	I	Plaque with a thickness ranging from 1-3.9 mm	Patients referred for TEE examination (n = 1112)	Mortality, embolic events‡
	II	Plaque of >4 mm in thickness		
	III	Any plaque, whatever its thickness, with an obvious mobile component (aortic debris)		
Blackshear et al[33]	Simple	Sessile plaque < 4.0 mm	Atrial fibrillation (n = 786)	Descriptive study§
	Complex	Plaque ≥ 4.0 mm with ulceration, pedunculation, or mobile elements		
Trehan et al[28]	I	Simple smooth-surfaced plaques, focal increase in echodensity, and thickening of intima extending < 5 mm into the aortic lumen	CABG surgery (n = 3660)	Stroke, embolic events‖
	II	Marked irregularity of intimal surface, focal increase in echodensity, and thickening of adjoining intima with overlying shaggy echogenic material extending > 5 mm into aortic lumen		
	III	Plaques with a mobile element		
Nohara et al[34]	I	Normal or thickening of the intima extending < 3 mm into the aortic lumen	CABG surgery (n = 314)	Stroke, embolic events¶
	II	Smooth-surfaced plaques and thickening of the intima extending > 3 mm into the aortic lumen		
	III	Marked irregularity of the intimal surface and thickening of the intima extending > 3 mm into the aortic lumen		
	IV	Plaque with a mobile element		

CABG, Coronary artery bypass graft surgery; *TEE*, transesophageal echocardiography.
*TEE findings in 250 patients admitted with stroke were compared with 250 control subjects.
†Atheroma grade was compared between biplane TEE and epiaortic ultrasound in all patients studied.
‡Aortic atheromas were found and graded in 12% of the 1112 patients referred for a TEE examination for several reasons including history of stroke. The grading system was adapted from the earlier study by Amarenco et al.[31]
§Stroke Prevention in Atrial Fibrillation (SPAF) III trial including 382 patients at high risk and 404 patients at low risk for stroke. All patients had atrial fibrillation.
‖From the population 3660 CABG surgery patients, only those with mobile or grade III atheromas (104 or 2.8%) were included for outcome analysis.
¶Atheromas were studied in context of gray-scale echodensity rather than size alone.

arch. These include 3 SAX views of the ascending aorta (proximal, mid, and distal), one LAX view of the ascending aorta, and one LAX view of the proximal aortic arch. Additional views within each segment may be acquired as indicated by presence of disease.

During a comprehensive examination, the following 3 measurements should be recorded and reported for each of the 3 ascending aortic SAX segments and for the aortic arch: (1) maximal plaque height/thickness; (2) location of the maximal plaque within the ascending aorta; and (3) presence of mobile components. The maximal aortic diameter in SAX may also be recorded, and strong consideration should be given to assessment of atheroma burden in diseased segments.

A verbal report of pertinent findings should be provided to the surgical team members before manipulation of the ascending aorta, and a written report documenting examination findings should be available in the patient's chart within 24 hours of completion of the examination.

As a result of the increased risk of adverse neurologic outcomes associated with plaques that are greater than 3 mm in thickness, or those that possess a mobile component, the presence and location of these plaques should be discussed with the surgeon before aortic manipulation.

Trainees in perioperative echocardiography should participate in the evaluation of 25 EAU examinations, at least 5 of which must be personally directed by the individual under the direct supervision of an echocardiographer with advanced level training. Independent interpretation and application of the EAU information to perioperative clinical decision making should only be performed once all training in EUA is completed, and an advanced level of perioperative echocardiography training has been acquired.

Conclusion

As the risk profile of patients with cardiac surgical conditions shifts toward higher risk populations predisposed to increased perioperative morbidity and mortality, the use of perioperative echocardiography is becoming increasingly more evident to anesthesiologists, cardiologists, and surgeons. EAU imaging is a superior technique compared with TEE for the detection and localization of ascending aortic atherosclerosis when compared to manual palpation and TEE. An EAU examination can be performed rapidly, and provides valuable information for the management of atheroma burden in patients with cardiac surgical conditions who require aortic manipulation. Further studies are warranted to determine the optimal atheroma grading scale, and to delineate management strategies directed toward plaque avoidance and improving patient outcomes.

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APPENDIX

Members of the Council for Intraoperative Echocardiography of the American Society of Echocardiography

Chair: Joseph P. Mathew, MD, FASE
Vice-Chair: Stanton K. Shernan, MD, FASE
Mark Adams, RDCS, FASE
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