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# Epiaortic Ultrasound Assessment of the Thoracic Aorta in Cardiac Surgery

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## 1. Introduction

A considerable burden of cerebral embolism in association with cardiac surgery reflects dislodgement of aortic atheroma caused by manipulating the aorta during a surgical procedure (Barbut and Gold 1996; Van Zaane, Zuithoff et al. 2008; Whitley and Glas 2008; Yamaguchi, Adachi et al. 2009). It clearly makes logical sense to identify and attempt to avoid dislodgement of aortic atheroma. This strategy depends on two key elements; the accurate detection of atheroma in the aorta, and the surgeons ability to avoid or otherwise minimise manipulation of atheromatous disease.

In this chapter we will describe how epiaortic echocardiography is essential to the complete examination of the ascending aorta and aortic arch for the detection of atheroma, and what surgical options may be available for the avoidance or minimisation of aortic atheroma manipulation.

## 2. Background summary of the literature

### 2.1 Intraoperative cerebral embolism and brain dysfunction

Whilst clinical stroke is relatively infrequent in cardiac surgery (1-3%) (Calafiore, Di Mauro et al. 2002; Douglas and Spaniol 2009; Rosenberger, Shernan et al. 2008; Shroyer, Coombs et al. 2003), such events can be properly viewed as major cerebral injury. Subclinical brain injury on the other hand is not often clinically apparent but may be detected by subtle neurocognitive testing and this is frequently present (20-60%) (Hammon, Stump et al. 1997; Mahanna, Blumenthal et al. 1996; Zamvar, Williams et al. 2002). MRI studies post cardiac surgery similarly highlight a far higher frequency of cerebral embolic events than the clinical assessment of neurological status would suggest (Deslauriers, Saunders et al. 1996; Djaiani, Fedorko et al. 2004; Vanninen, Aikia et al. 1998). Brain injury may be caused by other factors related to cardiopulmonary bypass, systemic inflammatory response syndrome, tissue oedema, air embolism, post-operative hypotension, anaesthetic agents used, ischaemia and reperfusion injury, or alternative causes of embolism. Nevertheless, the *predominant cause* of embolic brain injury reflects surgical manipulation of the atheromatous aorta and thus offers the greatest prospect for changing outcome.

## 2.2 Assessment of the aorta

Surgeons traditionally assess the aorta by manual palpation prior to the placement of the cannula and clamp. This is problematic because it relies on the detection of calcified plaques in the wall of the aorta that are accessible to the finger; which predominantly reflects the anterior and right sides of the ascending aorta, and anterior aspect of the aortic arch. Other areas of the aorta are really not accessible or not easily accessible to manual palpation. The detection of calcified plaques infers resistance being offered to the surgeon's finger, and our previous data found that detection of such plaques was relatively accurate under these circumstances. What are not accurately detected are soft (not calcified) plaques, which do not offer counter resistance to the examining finger. However the propensity of these to disrupt and embolise the contents or components is potentially greater than for calcified plaques. Thus the manual examination of the ascending aorta by the surgeon should be considered as frequently inaccurate (Royse, Royse et al. 2000; Royse, Royse et al. 1998; Suvarna, Smith et al. 2007; Sylivris, Calafiore et al. 1997; Whitley and Glas 2008).

Transoesophageal echocardiography is not able to visualise the distal ascending aorta or the proximal aortic arch. This is because the distal trachea and right main bronchus lie between oesophagus and these structures, and so the ultrasound signal is not transmitted leading to poor or absent imaging. Furthermore, the anterior aortic wall is further than near structures in relation to the probe, further diminishing resolution. Yet the most frequent locality for placement of the aortic cannula for cardiopulmonary bypass is in the distal ascending aorta proximal or aortic arch. Equally, the aortic clamp is placed immediately proximal to the aortic cannula whereby there is substantial aortic manipulation. Thus, the key areas of aortic manipulation related to the use of cardiopulmonary bypass occur in the "blind spot" of transoesophageal echocardiography.

This point was reinforced by a meta-analysis performed by van Zaane comparing transoesophageal vs. epiaortic echocardiography (Van Zaane, Zuithoff et al. 2008). Transoesophageal had a sensitivity of only 21% (95% confidence interval (CI) 12-32%); but a specificity of 99% (95% CI 96-99%). Simply TOE is accurate at assessing the aorta that can be visualised, but not all of the aorta can be imaged. Therefore, the accurate assessment of all parts of the thoracic aorta require a combination of transoesophageal and epiaortic (epivascular) surface ultrasound.

## 2.3 The precise anatomical location of aortic atheroma

Of critical importance to the use of epiaortic ultrasound, is the ability to precisely locate atheroma in relation to anatomical landmarks. The use of TOE provides for relative anatomical locality by finding lesions relative to the locality of other landmarks seen, such as the aortic valve. TOE alone will therefore lead to imperfect localisation of the aortic atheroma; whereas use of a handheld probe provides definitive locality of aortic atheroma (since the lesion is present immediately beneath the probe). This is crucial when precise locality on cannulation or clamping is required in order to avoid atheroma.

## 2.4 Prevalence of thoracic aortic atheroma

Surprisingly, coronary bypass patients do not uniformly have aortic atheroma, even in the presence of extensive small vessel arterial disease. But the danger for surgeons (and

patients) is assuming that the presence of important aortic atheroma is predictable. Indeed the unpredictability of the presence, location and severity of aortic atheroma is the most powerful argument in favor of routine comprehensive ultrasound examination of the entire thoracic aorta being performed. Specifically, the absence of atheroma seen in the descending aorta or proximal aorta by TOE does *not always predict* the absence of clinically important atheroma in the distal ascending aorta or proximal arch (the TOE "blind spot") (Royse, Royse et al. 1998).

We described six zones for the thoracic aorta; three in the ascending aorta, two in the aortic arch and the descending aorta. TOE typically images zones 1-2 and 5-6 well; and epiaortic echocardiography images zones 1-4 well. For reference, most aortic cannulations and clamping occurs in zones 3-4; proximal aortic graft anastomoses in zone 2 and aortic incision for valve replacements in zone 1. An intra-aortic balloon pump will be deployed in zone 6. Within these zones, the site of the atheroma is further subcategorised into cross sectional quadrants of the aorta - anterior, posterior, left or right lateral.

We found that the prevalence of atheroma increased with distance from the aortic root. There was a marked increase in frequency and severity distal to the aortic arch. Increasing age resulted in greater prevalence. Considering moderate or severe atheroma in zones 1-4, the prevalence was 29% in patients aged 70-79, and 34% in those aged more than 80 years (Royse and Royse 2006).

2.5 Assessment of aortic atheroma severity

A variety of definitions have been published, but most commonly this simple classification is used, Table 1 (Royse, Royse et al. 1998). The greater the severity of atheroma, the greater the likelihood that manipulation will result in embolism; excepting that most believe embolism is unlikely to arise from "mild" atheroma. In clinical practice the term "clinically important atheroma" generally refers to moderate or severe atheroma.

Grade	Criteria
Nil	Intimal thickening < 2 mm
Mild	Intimal thickening 2 – 4 mm
Moderate	Flat intimal thickening > 4 mm
Severe	Complex intimal thickening > 4 mm or any mobile atheroma

Table 1. Classification of atheroma grade

The morphology of the atheromatous plaque may further predict the likelihood of embolism. Without good data, it would seem intuitive that a soft friable, frond-like atheromatous plaque is more likely to break free and embolise, than a flat, fibrous plaque.

3. Strategies to avoid aortic atheroma dislodgement

The detection of aortic atheroma does not directly lead to the avoidance of atheroma dislodgement and embolism. The actual avoidance of dislodgement requires a change to the surgical strategy. Thus the detection of atheroma is the important first step, and allows a

decision to be made that then subsequently leads to the avoidance of embolism. This highlights one of the key difficulties for surgeons. It may be that a surgical alternative is not possible for the patient; or the skill, capability or surgical repertoire of the surgeon themselves limits potential alternative strategies being employed. This may vary with training, experience and technical capability as well as patient factors such as absence of suitable conduits and so forth. Thus there is no commonly applied solution available.

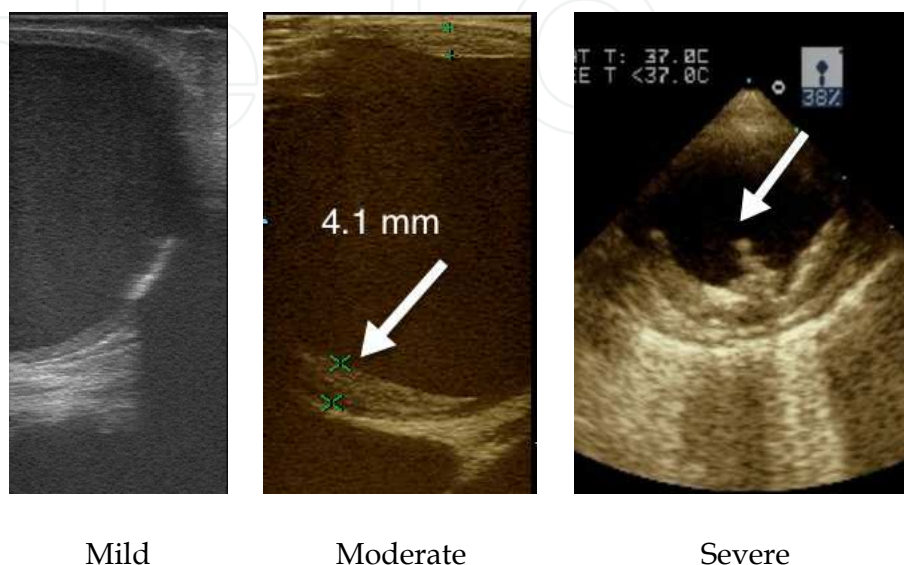


Fig. 1. Ultrasound images of aortic atheroma.

In principle however, there are few significant options available for surgical alteration. In the case of the use of cardiopulmonary bypass, aortic calculation and clamping sites may be altered so as to manipulate the aorta near to but not involving the atheroma. Certain operations preclude alteration of manipulation position, and so alternative sites for aortic cannulation or alternatives for aortic clamping need to be considered. In practice, often the surgeon simply accepts the need to manipulate atheromatous segments of the aorta and proceeds anyway. An example may be the performance of an aortic valve replacement; whereby there is very limited scope for alteration of the aortic incision, and it may not be possible to entirely avoid atheroma in this locality.

Coronary artery bypass surgery provides more opportunity to alter the surgical operation so as to avoid atheroma. The construction of proximal aortic anastomoses is predominantly situated in the mid ascending aorta; the proximal aorta is rarely used as this will kink the grafts and the distal ascending aorta is occupied by the aortic clamp and antegrade cannula. So unless the grafting strategy is altered, the detection of aortic atheroma and the need to move the site of cannulation and clamping is impeded by the inability to move the proximal aortic anastomoses. By performing a composite graft (Y-graft), the aortic anastomoses can be eliminated, thereby allowing the freedom to move sites of aortic manipulation (Royse, Royse et al. 2000; Royse, Royse et al. 1999), see Fig. 2. Should there be extensive aortic atheroma, consideration of "off pump" coronary revascularisation would allow the complete avoidance of any aortic manipulation - the ideal solution from this perspective. Many surgeons however, are not comfortable or skilled in these techniques, thereby limiting their use.

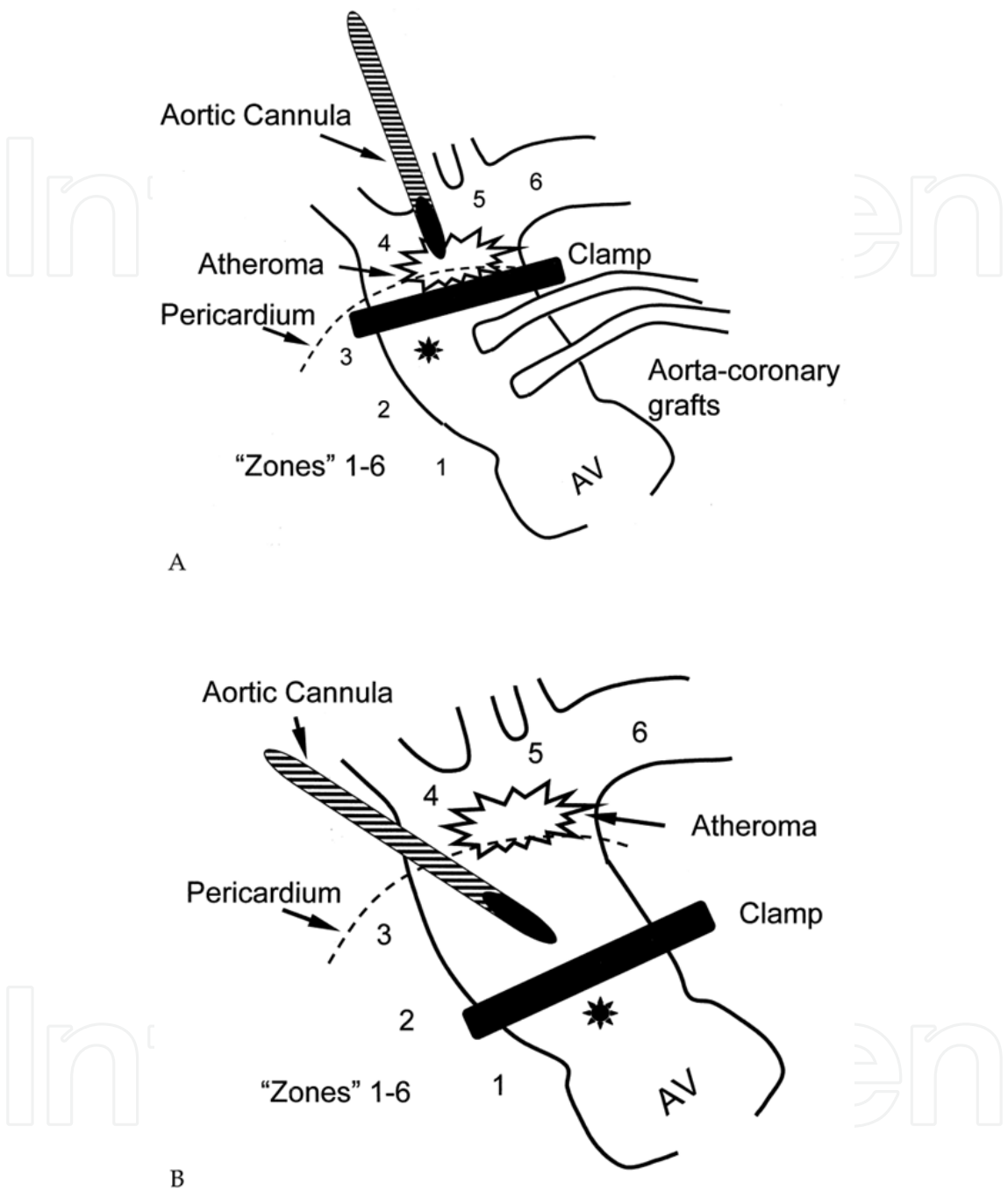


Fig. 2. Freedom to move sites of aortic manipulation. The sites of aortic manipulation are shown for (A) aorta-coronary and (B) Y graft techniques. Construction of aortic anastomosis limits movement of aortic cannulation and clamp sites away from detected atheroma illustrated in the distal ascending and proximal aortic arch. The atheroma is easily avoided by using the exclusive Y graft technique by moving the sites of cannulation and clamping away from the atheroma. (Small star (\*) is antegrade cardioplegia cannulation site; AV is aortic valve.)



The technique of aortic clamping itself varies, with the repeated application of the aortic clamp rather than the "single clamp" technique; and use of the partial occlusion clamp for the construction of proximal aortic coronary anastomoses, further manipulates the aorta and will lead to greater propensity for dislodgement of any existing aortic atheroma. In particular, the typical Kaye-Lambert partial occlusion ("side biting") clamp will usually occupy the majority of the ascending aorta in a vertical plane and about half of the cross sectional diameter of the aorta in the horizontal plane, see Fig. 3. This clamp will therefore manipulate a considerable part of the ascending aorta even with only one application; and repeated applications would be common.

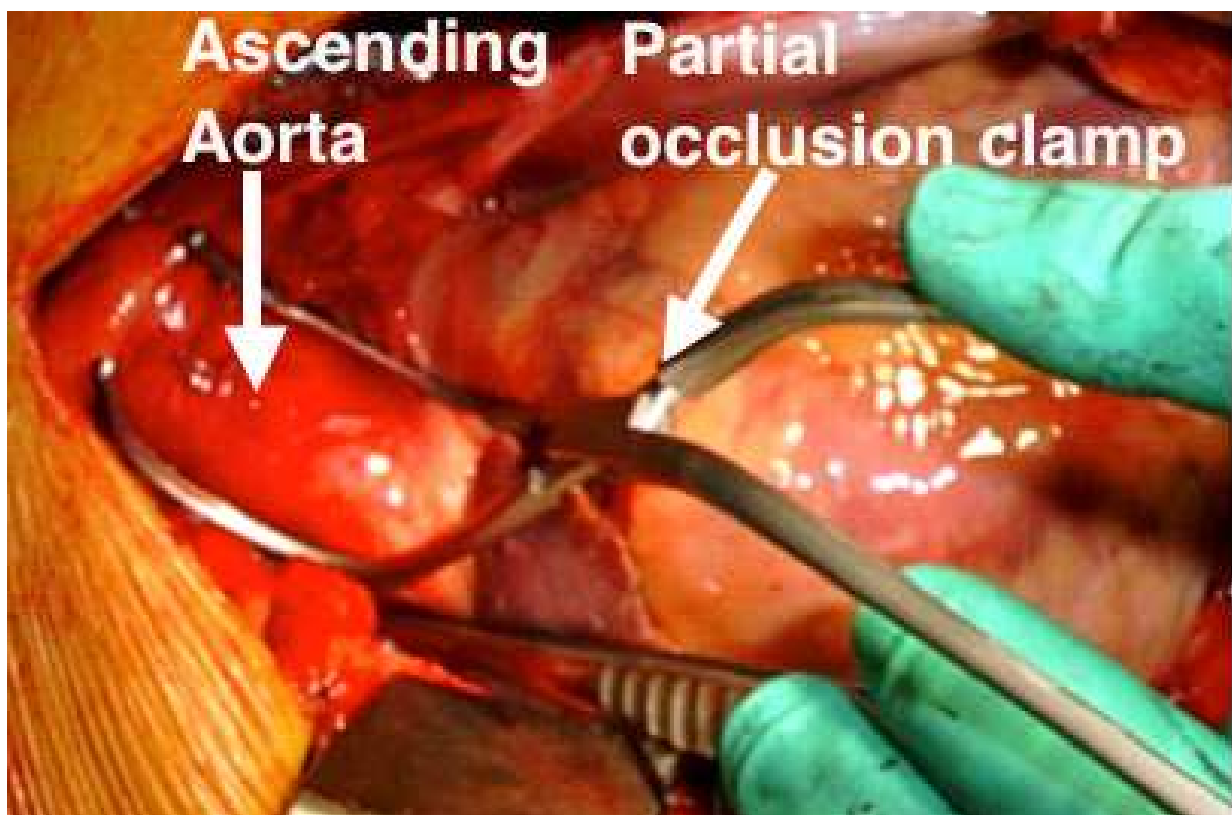


Fig. 3. Partial occlusion clamp manipulates most of the ascending aorta

#### 4. Technique of epiaortic (epivascular) ultrasound examination

The sequence and technique have been previously published (Royse and Royse 2006) Fig. 4 or with Guidelines (Glas, Swaminathan et al. 2008). One important point to appreciate is that the orientation of the aorta to orthogonal planes is highly variable. For accurate cross-sectional dimensions, the ultrasound probe needs to be oriented at 90 degrees to the aorta irrespective of the relationship to the orthogonal plane, Fig. 5. This is not difficult to achieve, and it is obvious as you simply rotate the probe to produce a circle on the screen; yet it is a common failing in the early learning experience.

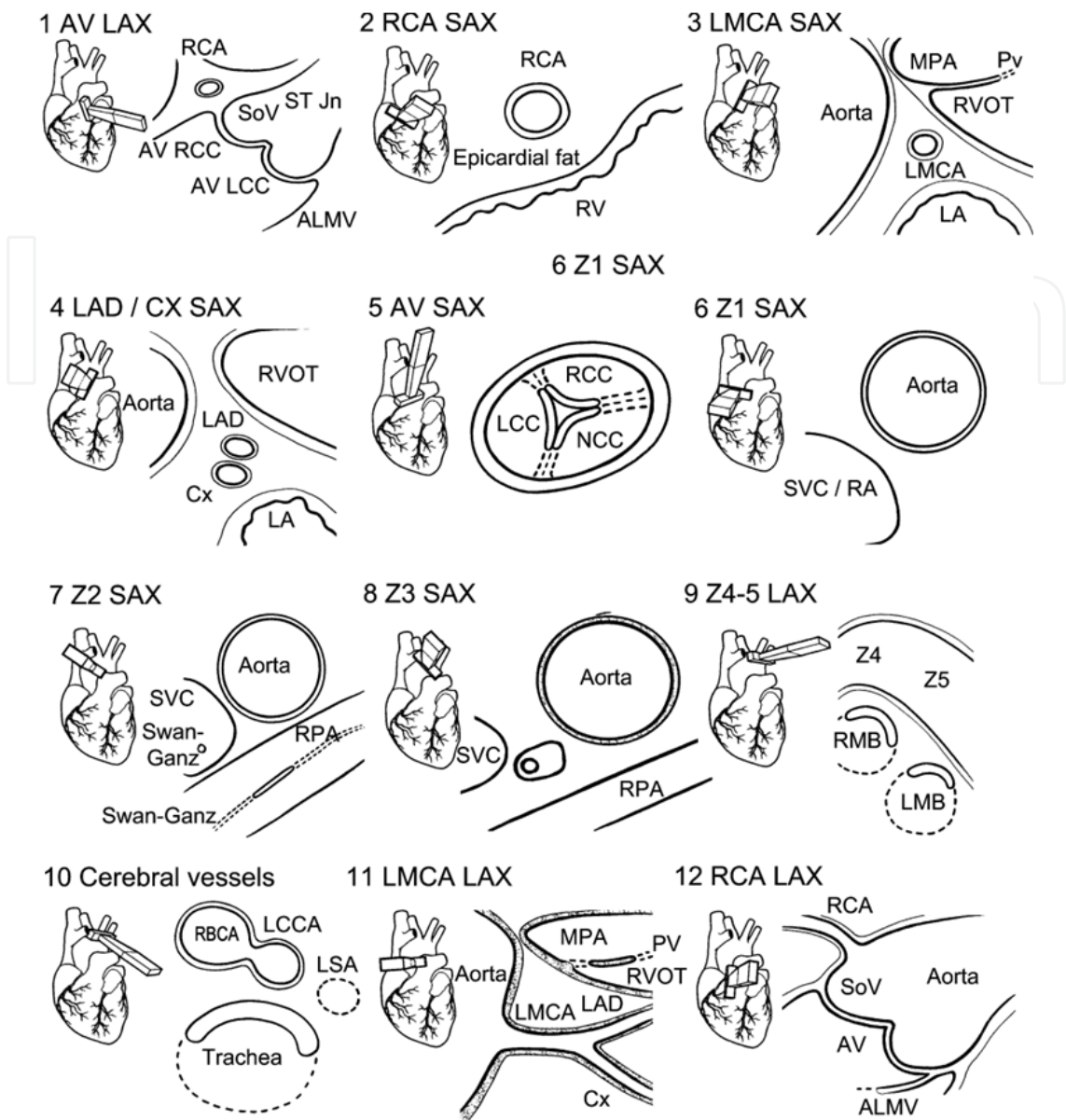


Fig. 4. Standardised epiaortic echocardiography examination. (Royse and Royse 2006)  
Intraoperative ultrasound examination of the aorta and proximal coronary arteries 10 standard views, 2 supplementary views. LAX, longitudinal axis, SAX, short axis, RCA, right coronary artery, SoV, Sinus of Valsalva, AV, aortic valve, RCC, right coronary cusp of aortic valve, LCC, left coronary cusp, NCC, non coronary cusp, ST Jn, sinotubular junction of aorta, ALMV, anterior leaflet of mitral valve, RV, right ventricle, RVOT, right ventricular outflow tract, MPA, main pulmonary artery, PV, pulmonary valve, LA, left atrium, LAD, left anterior descending artery, Cx, circumflex coronary artery, SVC, superior vena cava, RA, right atrium, RPA, right pulmonary artery, Z1, zone 1 or proximal ascending aorta, Z2, zone 2 or mid ascending, Z3, zone 3 or distal ascending, Z4, zone 4 or proximal aortic arch, Z5, zone 5 or distal aortic arch, RMB, right main bronchus, LMB, left main bronchus, RBCA, right brachiocephalic artery, LCC, left common carotid artery, LSA, left subclavian artery. Reproduced from Royse A and Royse C. A standardised intraoperative ultrasound examination of the aorta and proximal coronary arteries. *Interact CardioVasc Thorac Surg* 2006;5:701-704. © 2006 European Association of Cardio-Thoracic Surgery with permission from the European Association of Cardio-Thoracic Surgery.



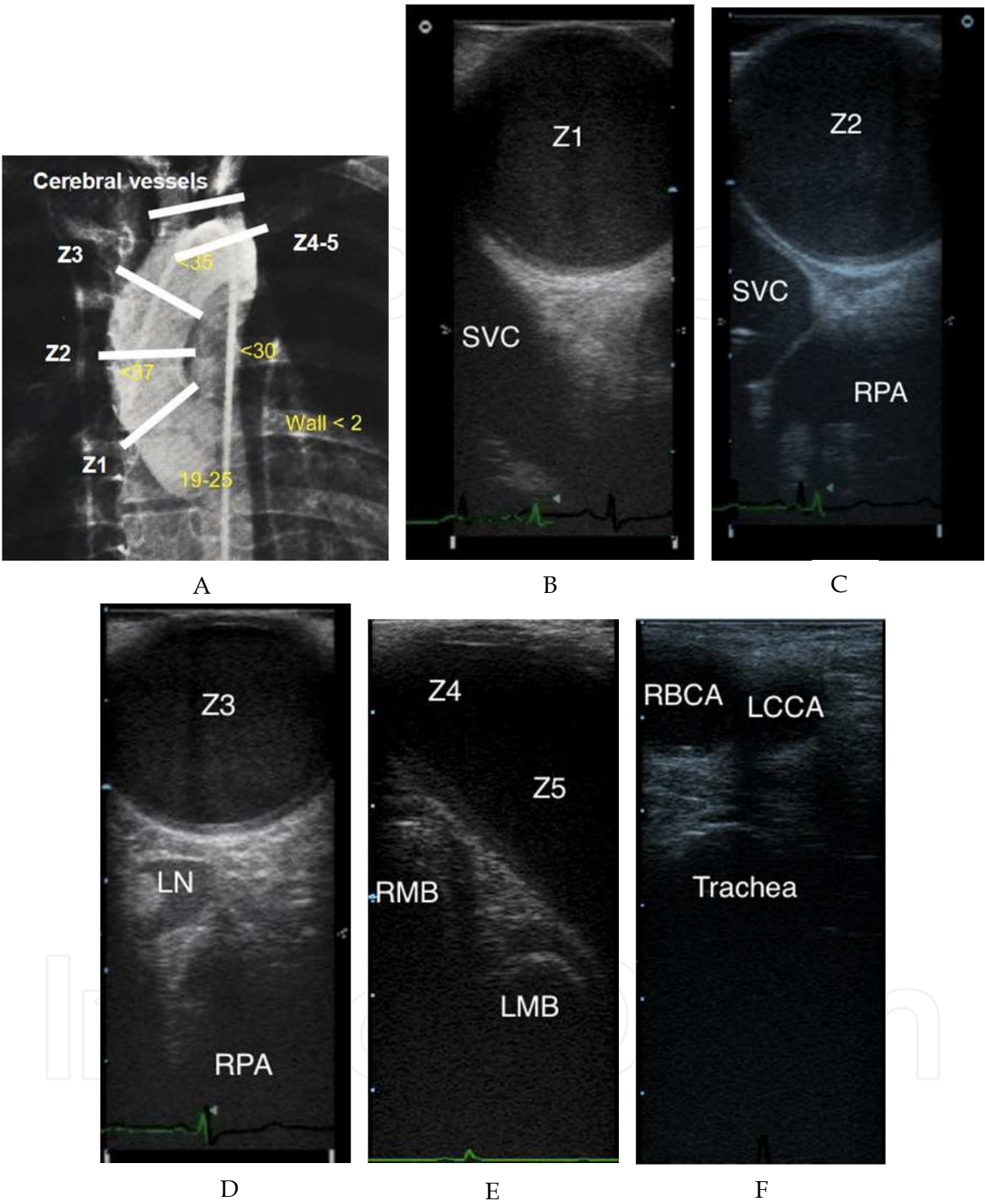


Fig. 5. Ultrasound images of aorta. A angles of ultrasound probe. B Zone 1, C Zone 2, D Zone 3, E Aortic arch, F Cerebral vessels. Other abbreviations as for Fig. 4. Ultrasound probe selection is important. A phased, linear array probe with a frequency in the range 8-12 Mhz is preferred. Some attention to the physical size is also important as a large probe may not easily fit in the sternotomy wound, and a round probe is difficult to hold or to maintain orientation. If the frequency is too high, then the depth of penetration may be sufficiently limited so as to preclude adequate imaging of the posterior aortic wall.

A variety of ways exist to allow a sterile acoustic interface for the probe. The simplest is to partially fill a sterile plastic cover with saline - either a custom made bag or a bag adapted from another use such as an endoscopic camera cover. Alternatively, sterile gel may be placed within the bag as the internal acoustic couple. Some fill the pericardium with warm saline to enhance the external acoustic couple; most do not. One important point that is often overlooked is the issue of “near field crowding”. What this refers to is the need to maintain some distance between the ultrasound probe and the structure being imaged in order for the ultrasound to travel some distance, and then be reflected from the structure back to the probe. This is important for visualising the superficial (anterior) aortic wall. This wall cannot be adequately imaged when the probe is resting directly on the surface; and in order to adequately image this part of the aorta, the probe needs to be moved away from the aorta by 0.5-1.0 cm. Of course the acoustic coupling between the probe and the structure in question needs to be maintained, but generally this is not a problem when saline has been used within the plastic bag in which the probe is suspended.

There is no rationale or valid reason for any particular order or protocol to be followed whilst performing a study. However, it makes logical sense to follow a routine in order to efficiently complete a comprehensive study. See Fig. 4 for a proposed sequence. Special-purpose ultrasound examinations may be performed without the need for a comprehensive examination. One example may be to interrogate flow in the right coronary artery following an aortic valve replacement where there is some doubt as to whether the prosthesis was obstructing the flow to this coronary artery.

The operator performing the ultrasound examination is (or should be) the surgeon. The anaesthetist should be recording sample images or video loops as the examination is being performed so that appropriate archiving of the findings occurs. The fascinating thing about the subject of atheroma detection and this ultrasound examination is that very little new knowledge or new techniques have occurred in the past 10-15 years. The evidence is very strong that the performance of this study accurately establishes the presence and location of aortic atheroma and provides the surgeon with a greater range treatment options. Remarkably, this is not a routine part of every cardiac surgical procedure! Indeed only the minority of surgeons actually perform epiaortic ultrasound examinations and even fewer still, perform this on a routine basis.

## 5. Training

This ultrasound examination pertains almost exclusively to cardiac surgery. It could quite easily be applied to any other forms of surgery involving examination of large arteries or veins. At the current time intraoperative transoesophageal echocardiography is routine in many parts of the Western world, and becoming more common in the developing world. Therefore generally there is a good level of basic ultrasound experience and knowledge amongst surgical staff from the general observation of ultrasound being performed. However, at present few will be actively performing ultrasound examinations such as transthoracic echocardiography, ultrasound guided procedures or venous duplex studies all of which are becoming standard practice in advanced cardiac surgical centres. With this familiarity, the performance of epiaortic ultrasound examination is extremely simple to implement and to teach since there is significant underlying theoretical and practical experience. For those who have not performed ultrasound examinations before themselves;

or have quite limited theoretical knowledge of ultrasound technologies, learning this examination is a little more difficult. The emphasis here is on the word “little”, highlighting that this examination is quite straightforward and simple to perform and therefore to learn. Also, interpreting the images is equally very simple since it is obvious from first principles without any formal training, and the precise locality of atheroma is similarly very easy to appreciate since it is always directly beneath the ultrasound probe at the time. Surgeons do not require additional anatomy training; indeed the level of anatomy knowledge is the greatest of all specialties and even trainees have an extremely good understanding of anatomy. It would be expected that an advanced surgical trainee should be able to competently and confidently perform an epiaortic ultrasound examination after about 10-20 supervised cases. With previous practical and theoretical experience in ultrasound or echocardiography, it may only be 5-10 cases.

Learning epiaortic ultrasound examination may be a sufficient enough stimulus to engage in a wider use of ultrasound technologies. In the current advanced cardiac surgical management, the use of ultrasound by cardiac surgeons should become a matter of routine daily practice. Performing transthoracic echocardiography in the pre-and post-operative settings, ultrasound guided procedures including pleural drainage and ultrasound lung examinations are quite straightforward and simple to learn. However, specific postgraduate training in addition to advanced surgical training should be undertaken; specifically it is not yet integrated as part of an advanced training program. A variety of postgraduate courses are available including university-based courses. These may cater for general (non-cardiac) clinical practice, or for an advanced diagnostic (cardiac) practice. Our program may be reviewed at [www.heartweb.com](http://www.heartweb.com)

## 6. Summary and recommendations

The predominant cause for cerebral atheroma embolism in cardiac surgery using cardiopulmonary bypass relates to dislodgement of aortic atheroma with embolism caused by manipulation of the aorta. Transoesophageal echocardiography is not able to visualise the distal ascending aorta and proximal aortic arch due to the presence of air in the bronchi crossing between aorta and oesophagus. Epiaortic ultrasound is able to assess this portion of the aorta; and in addition is far more accurate than manual assessment by the surgeon's finger. Avoiding the atheroma however, requires a change to the surgical strategy.

A standardised comprehensive echocardiography protocol is proposed. The performance of this ultrasound examination is relatively straightforward and is fairly easily taught. It is recommended that it be before routinely.

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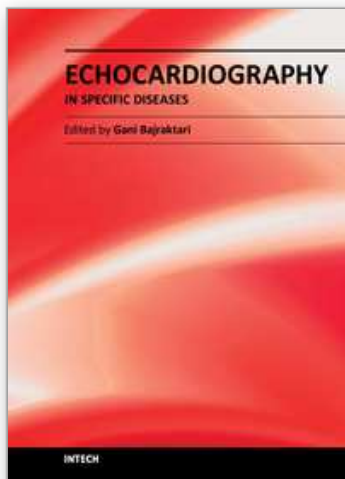
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## **Echocardiography - In Specific Diseases**

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The book "Echocardiography - In Specific Diseases" brings together contributions from well-known researchers from around the world, some of them specialized in imaging science in their clinical orientation, but also representatives from academic medical centers. Each chapter is structured and written to be accessible to those with a basic knowledge of echocardiography but also to be stimulating and informative to experts and researchers in the field of echocardiography. This book is primarily aimed at cardiology fellows during their basic echocardiography rotation, fellows of internal medicine, radiology and emergency medicine, but also experts in echocardiography. During the past few decades technological advancements in echocardiography have been developing rapidly, leading to improved echocardiographic imaging using new techniques. The authors of this book tried to explain the role of echocardiography in several special pathologies, which the readers may find in different chapters of the book.

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