FOCUS ON: VASCULAR ANAESTHESIA

Anaesthetic considerations for endovascular abdominal aortic aneurysm repair (EVAR)

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\textbf{KEYWORDS}
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\begin{abstract}
Over the previous decade, the management of vascular disease has changed considerably. Abdominal aortic aneurysm can now be definitively treated by means of endovascular stenting. Though significant short- and long-term morbidity has been reported, this less invasive procedure is increasing in popularity and has been championed by some as an alternative option for high-risk patients who might otherwise be offered conservative management. We review the perioperative management of endovascular abdominal aortic aneurysm repair (EVAR) and cover the issues pertinent to anaesthetists.
\end{abstract}

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\section*{Introduction}

Patients who present for abdominal aortic surgery represent a group carrying a high risk of significant morbidity and mortality due to the very nature of the surgery and the commonly associated co-morbidities. The aetiology of aortic aneurysm is multifactorial, and relates to the degradation of elastin within the aortic arterial wall coupled with disruption of collagen. This causes weakening of the wall and can eventually lead to rupture, due to a reduction in the tensile strength of the aortic wall. Abdominal aortic aneurysm (AAA) is a life-threatening condition and a successful outcome will depend on many factors, including surgical and anaesthetic expertise, adequate hospital infrastructure to deal effectively with complications (e.g. cardiology, critical care and renal support) and also general co-operation on perioperative management between different specialties. A recent report by NCEPOD has called for an improvement in how services in the UK are delivered to these patients, and suggested that perhaps centralising aortic surgery to produce smaller numbers of centres with a large volume of aortic work may reduce poor outcome.\textsuperscript{1} Preoperative assessment soon after diagnosis, led by a consultant anaesthetist with a special interest in vascular surgery is considered by many to be beneficial. It helps to reduce last minute cancellations on the day of surgery, unplanned admissions to critical care and inappropriate referrals for investigations that will not necessarily change perioperative management. It also allows time to

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develop a risk profile for each patient, encourage multidisciplinary discussion, and to plan the patient’s whole package of care. Structured clinics provide a means of disseminating information to all clinicians caring for the patient and provide a focus for future research and audit.

Patients who present for AAA surgery may be offered either a conventional open repair or endovascular repair (EVAR). Once the decision to operate has been made, the surgery should be expedited in order to improve long-term prognosis from the vascular disease. As the size of the AAA increases the annual risk of rupture increases exponentially, and related complications of AAA such as distal limb embolisation and thrombosis may also lead to significant morbidity and mortality. Abdominal aortic aneurysms are five times more common in men, with an incidence of 1.5% in patients over 50 years old, the majority occurring below the origin of the renal arteries. The incidence of the disease is much higher in smokers and is considered a significant risk factor. The benefit of aneurysm screening has been advocated by many since The Multicentre Aneurysm Screening Study was published in 2002. Indeed over the next decade we expect to see an increase in the number of patients diagnosed earlier with AAA due to the proposed introduction of the national screening programme in the UK of men aged between 65 years.

### Indications and planning for surgery

Many AAAs are discovered incidentally whilst investigating back pain or urinary symptoms in middle aged or elderly men. Routine abdominal ultrasonography commonly accounts for the unexpected detection of aortic aneurysms. Once discovered, the decision to operate is made after consideration of the size and on symptoms. Patients are usually offered surgery once the antero-posterior diameter reaches approximately 5.5 cm. After this, the annual risk of rupture increases to above the average risk of death following open repair (see Table 1). Not only this, but once aortic aneurysms reach this size they generally increase in an exponential manner, markedly increasing the annual risk of rupture. The 30-day mortality associated with ruptured AAA is widely believed to be approximately 80%; of those that reach hospital alive and undergo emergency surgery, approximately 40% will die within 30 days of surgery. Hence, there is a big incentive for our surgical colleagues to offer an elective operation as early as possible. Medical therapies that have been shown to be of value in the reduction in the growth of AAA in animals include statins and tetracyclines. However, they are not thought to be effective in humans and surgery remains the only viable alternative to treatment.

Elective surgery prevents death and morbidity from rupture, the surgical options being either open or endovascular aneurysm repair (EVAR). Open repair carries with it significant risk of morbidity and mortality, much of this risk is concentrated into the perioperative period. The mortality in the in the UK for elective open infra-renal AAA repair is approximately 6.2–7.5%. The 30-day mortality with EVAR ranges from 1.7% in patients deemed fit for open repair up to 9% in those deemed unfit for open repair. Open repair utilises a large number of intensive care bed days, requires lengthy hospital stay and consumes many other hospital resources. If the correct package of care is not available on the day of operation (in particular a lack of bed capacity in critical care) then this leads to postponement, adding further to the cost.

Since the early 1990s EVAR has grown in popularity as a minimally invasive alternative. This technique was pioneered by Parodi et al. and Volodos et al. In essence it is the placement of an endograft under fluoroscopic guidance to exclude the aneurysm sac. The aneurysm is accessed via the femoral arteries and will be described in more
detail below. In recent years, there have been two large randomised trials which have compared outcomes following EVAR with outcomes following conventional open repair.\(^8^,\)\(^12^) In the EVAR 1 trial, patients who were considered fit for open repair were randomised to either EVAR or open repair.\(^8^) Aneurysm related mortality and morbidity rates were 3% lower compared to open. However, the EVAR1 trial demonstrated an increased need for re-intervention and the cost per case was much greater than open repair. Complications that require re-intervention include endoleak, thrombosis, kinking of the graft and device migration.

EVAR was initially hoped to be a viable alternative for those thought unfit for open repair, the EVAR 2 randomised patients considered unfit for open repair to either conservative management or EVAR. However, the results of the EVAR 2 were disappointing in this respect. EVAR still had considerable 30-day mortality (9%) and long-term survival was no different in each group.\(^9^) The problems with this trial, which have led to numerous criticisms by authorities in the United States are the significant crossover between the two groups, a long delay between randomisation and treatment such that some patients in the EVAR group actually died before their operation. Another concern is that the term unfit for open repair was subjective. However, it still remains to be seen whether the advantages of reduced perioperative complications will continue to be outweighed by poorer mid-term and long-term outcome. The all cause mortality after EVAR as compared with open repair was similar after 4 years of follow up in the EVAR 1. Similar conclusions were drawn from the mid-term results of the DREAM trial conducted in Holland.\(^12^) A recent retrospective analysis followed 115 patients who were deemed to have a high perioperative risk of death for open aortic surgery.\(^13^) Of these, 92 entered the study and underwent EVAR providing they had favourable anatomy. The authors quoted an operative mortality of 4.3%, the survival rate at 3 years was 85% and long-term technical success was high (as defined by types of endoleak). However, patients over the age of 80 were considered high risk, which is at odds with many authorities and probably based on the findings of one study which demonstrated higher mortality rates following open aortic aneurysm repair in those over 80 years of age.\(^14^) Many consider physiological age and co-morbidities to be more important considerations than chronological age alone. Indeed, commonly used cardiac risk indices such as Lee et al.’s do not consider age as a significant independent risk factor for perioperative cardiac mortality and morbidity.\(^15^) Considering only 18% of patients were classified as ASA 4, as compared to the majority of patients who were enrolled into EVAR 2, it would appear that the patient population were not at all similar and hence should not be compared.

If developments in endograft technology and imaging continue to gather pace, EVAR may become the first choice operation for all patients with AAA.

**Surgical conduct of EVAR (see Figures 1–3)**

EVAR involves the use of a stent-graft to exclude aneurysms of the abdominal aorta. A stent-graft is a self-expandable stent, similar to that used when treating occlusive vessel disease, with an outer (endo-skeleton) or inner (exo-skeleton) lining of fabric. This fabric is either Dacron or polytetrafluorethylene (PTFE), very similar to the graft used for open aneurysm repair. The stent-graft is positioned between normal artery proximal to the aneurysm and normal artery distal to the aneurysm, such that blood flows from normal artery through the stent-graft and back into normal artery. The remaining blood in the aneurysm sac will thus clot off and the aneurismal sac should remain static or shrink with time. The area where the stent-graft is in contact with normal artery is known as the sealing zone. The outward radial force of the stent is what causes a seal in this area preventing the flow of blood outside the stent-graft and into the aneurismal sac. The proximal sealing zone is the non-aneurysmal infra-renal aortic neck. Since almost all AAAs extend to the aortic bifurcation or beyond, the distal sealing zone is both common iliac arteries for purely aortic aneurysms and the external iliac arteries for aorto-iliac aneurysms. All current devices for elective cases are therefore of a bifurcated (trouser) configuration.

When considering the endovascular management of infra-renal AAAs a proximal and distal landing (or sealing zone) of 1.5 cm is recommended. A shorter landing zone will result in the radial force of the sealing stent being exerted over a reduced area and therefore a greater risk that, with time, the stent will migrate distally with loss of the seal between normal artery and stent. In an attempt to prevent distal migration most current stent-grafts have a bare suprarenal component, i.e. the most proximal stent is not covered by graft so that it can be positioned above the renal arteries, thereby increasing the surface area over which the stents radial force is applied. There is now good evidence that having bare metal stents across the renal orifices does not effect renal perfusion and function. The stent-graft most commonly used in
our unit also has hooks/barbs on these supra-renal stents to further prevent migration. Using this stent-graft we have treated patients with infra-renal necks shorter than the recommended 1.5 cm, thereby increasing the number of patients who benefit from endovascular repair. Another factor affecting patients’ suitability for EVAR is the angle between the non-aneurysmal infra-renal neck and the aneurysm. An angle of up to 60° is normally recommended; however, more flexible stent-grafts are making such recommendations obsolete.

Stent-grafts come in various sizes. The proximal diameter of the main body is chosen to be 20% larger than the outer diameter of the neck of the assembled device.
aneurysm. The distal diameter of the iliac limbs is chosen to be 10% larger than the outer diameter of the iliac vessels. The length of the main body and limbs depends on the type of stent-graft used, but in most cases is dependent on the distance from the lowermost renal artery to the aortic bifurcation and the internal iliac artery origins.

Stent-grafts are packed (compressed) in an outer sheath (tube) with a pusher rod at their distal end. When the sheath is withdrawn backwards over the pusher rod, the stent-graft is exposed and opens as a result of the radial force of the self-expanding stent. Most current stent-grafts are trimodular (main body for the aorta and two limbs for each iliac artery) or bimodular (main body and limb for one iliac as one component and contralateral iliac limb as the second component). The sheath containing the stent-grafts measures 18–22 Fr for the main body and 14–16 Fr for the iliac limbs. The stent-grafts are usually introduced through the common femoral arteries. Most surgeons will perform a surgical cut-down onto the vessels due to the size of the sheaths. Closure devices such as Perclose and Sutura are used in some centres where a totally percutaneous procedure is performed. The risk of groin complications is however significant with these closure devices and we personally perform a cut-down in both groins using transverse skin crease incisions. We prefer these to longitudinal incisions since they affect less dermatomes and therefore are associated with less postoperative discomfort. We only use longitudinal incisions if additional procedures such as a femoral crossover graft or an endarterectomy may be required. There are occasions where the iliac arteries may be too small to safely advance the sheathed stent-graft without damaging these vessels (the main device requires an iliac diameter of 7–8 mm). In such a situation, one may expose the iliac artery and use a Dacron conduit anastamosed to this vessel to introduce the stent-graft.

Once the common femoral arteries are exposed, a J-wire (similar to that used to introduce a central venous line, but much longer) is introduced through an arterial puncture needle. Under fluoroscopic guidance, the J-wire is advanced proximally to the descending thoracic aorta. In the case of very tortuous or diseased arteries, the J-wire is swapped for a hydrophilic (Teruma) wire. Various shaped catheters are then used to guide this wire proximally. On the side through which the main body is to be introduced, the J-wire is exchanged (through a catheter such as a RIM or COBRA) for a very stiff wire (Lunderquist or Mayer wire). Such a stiff wire will straighten the vessels making it easier to advance the device and will also not kink. On the contralateral side, a PIG-TAIL catheter is advanced over the J-wire and then connected to a power injector such that contrast can be injected very rapidly and at high pressures, opacifying the abdominal aorta and its visceral branches. If the patient is under a general anaesthetic, the anaesthetist will be asked to suspend respiration whenever digital subtraction angiography is performed. This is because if there is even the slightest movement, the X-ray image with contrast will be slightly different from that without contrast, and when the latter image is subtracted from the former, a very blurred picture would result. The pig is positioned just above the level of the renal orifices as may be determined from the CT-angiograms. The stent-graft is then introduced over the stiff wire and positioned such that the junction between covered and uncovered stent is just below the lowermost renal orifice. This area usually has gold-markers stitched to it so that it is easily identifiable on fluoroscopy. A digital subtraction angiogram is obtained to confirm correct positioning of the stent-graft in relation to the renal orifices. The stent-graft is moved up and down as required and further digital subtraction angiograms obtained until one is definitely satisfied.
with the position. When this is the case, the stent-graft is deployed under fluoroscopic control by withdrawing the outer sheath distally whilst fixing the position of the pusher rod. The next step is to cannulate the contralateral limb of the main body from the contralateral common femoral artery. This is achieved by using a hydrophilic wire and catheters of varying shape. This part of the procedure may sometimes be very fiddly and is the main factor affecting the duration of the procedure. Once the contralateral limb is cannulated, the hydrophilic wire is swapped for a stiff wire and the contralateral limb stent-graft is inserted and deployed such that its distal edge is just above the origin of the internal iliac artery. Depending on the type of stent-graft being used an ipsilateral limb stent-graft may also be required. Some stent-graft manufacturers recommend that a moulding (semi-compliant) balloon is blown up at all the sealing zones (including the aortic neck) to further fix the stents in place. One of the stiff wires is then swapped for a pigtail and a final digital subtraction angiogram obtained to confirm that the stent-graft has been deployed in the correct position with preservation of both renal and internal iliac arteries and that there is no filling of the aneurysm sac. If this is satisfactory, all sheaths, catheters and wires are withdrawn. Vascular clamps are applied proximal and distal to the main body and the arteriotomy resulting from insertion of the stent-graft is then swapped for a pigtail and a final digital subtraction angiogram obtained to confirm that the stent-graft is deployed under fluoroscopic control by withdrawing the outer sheath distally whilst fixing the position of the pusher rod. The next step is to cannulate the contralateral limb of the main body from the contralateral common femoral artery. This is achieved by using a hydrophilic wire and catheters of varying shape. This part of the procedure may sometimes be very fiddly and is the main factor affecting the duration of the procedure. Once the contralateral limb is cannulated, the hydrophilic wire is swapped for a stiff wire and the contralateral limb stent-graft is inserted and deployed such that its distal edge is just above the origin of the internal iliac artery. Depending on the type of stent-graft being used an ipsilateral limb stent-graft may also be required. Some stent-graft manufacturers recommend that a moulding (semi-compliant) balloon is blown up at all the sealing zones (including the aortic neck) to further fix the stents in place. One of the stiff wires is then swapped for a pigtail and a final digital subtraction angiogram obtained to confirm that the stent-graft has been deployed in the correct position with preservation of both renal and internal iliac arteries and that there is no filling of the aneurysm sac. If this is satisfactory, all sheaths, catheters and wires are withdrawn. Vascular clamps are applied proximal and distal to the arteriotomy resulting from insertion of the stent-grafts. The arteriotomies are closed with a fine prolene suture.

As may be seen from above, the main limitations to perform EVAR are the absence of a proximal landing zone (short or wide neck), and poor access, i.e. the iliac vessels are smaller than 8 mm in diameter (to allow a 22 Fr device to be advanced safely). The absence of a distal landing zone means the presence of common iliac aneurysms. This is usually resolved by embolising (putting metallic coils) in the internal iliac arteries to prevent back bleeding from this vessel into the aneurysm sac and using the external iliac artery as the distal landing (sealing) zone. Embolising the internal iliac carries a small risk of buttock claudication, impotence and pelvic ischaemia. In order to prevent such complications, iliac limbs with side branches to perfuse the internal iliac artery are used in our unit. The use of such devices requires advanced endovascular skills, significantly lengthens the procedure and may require higher doses of contrast. The absence of a proximal landing zone may be resolved by using custom made fenestrated devices. These devices are designed specifically for the individual patient such that small holes (fenestrations) are pre-cut into the graft based on the CT-reconstructions to correspond with the openings of the appropriate relevant vessels. The gap between these fenestrations and their target vessels is bridged using covered stents similar to the bare stents used for treating renal artery stenosis. Such procedures are very complex and lengthy. Depending on the number of fenestrations, they can take several hours. High doses of contrast may be required. Since the visceral vessel origins are usually around 6 mm in diameter there is no room for error and if the stent-graft is not deployed in the correct position the patient could infarct a kidney or develop ischaemic bowel.

**Preoperative considerations**

These patients require careful preoperative assessment and present major challenges to the vascular team, the anaesthetist and critical care. Patients are usually elderly, have limited cardio-respiratory reserve and have a high prevalence of coronary artery disease. Anaesthetists may find themselves working with a surgical team that is early on in the endovascular experience and may be asked to work in the radiology department, which in itself may cause logistical difficulties. This may result in increase in the duration of EVAR, more likelihood of conversion and increased blood loss than originally anticipated at preoperative assessment. A gradual continuous loss of blood from around the introducer site can lead to significant blood loss over the course of the procedure and may be easily missed. The average volume of blood lost during EVAR is approximately 400 mL compared to 800 mL with open repair. It is important that wherever EVAR is performed, the specifications of the facilities used are adequate to manage conversion to open repair in an emergency. The same standards apply to the personnel involved. There is widespread variation across the UK with regard to the location, some prefer to use a vascular theatre whilst others have used the radiology department from the start. Clearly depending upon local facilities and geography the issues vary. The portable imaging equipment in operating theatres provides poorer quality images compared to those that can be obtained in radiology departments, though this is acceptable for most cases. The exceptions are obese patients (difficult imaging) and complex fenestrated devices that require higher imaging specification to complete the procedure to a high standard. The ideal scenario would be to have a custom built vascular imaging theatre, which for many hospitals is prohibitively expensive. A cheaper alternative is to develop
existing radiology suites to the same specification standard as a theatre, preferably located near a critical care unit and theatre recovery.

**Cardiac**

Cardiac complication still accounts for much of the significant morbidity and mortality following EVAR. The risk stratification and risk-modification strategies that may prove useful have been discussed in detail in the accompanying manuscripts and will not be discussed in great detail here. Broadly speaking the goal is to evaluate the current medical co-morbidities and in the context of the proposed surgery to consider further investigations that may change management. This will help provide a clinical risk profile for the patient and clinical team and will hopefully inform the whole periooperative process. This is achieved by taking a careful history and performing a thorough physical examination, followed by routine laboratory investigations. Of particular importance is to consider the functional capacity of the patient which can be assessed subjectively using the Duke Activity Status Index. However, more objective measures of cardiopulmonary fitness can be obtained from cardiopulmonary exercise testing. This should be combined with a risk assessment specific to the surgery planned and use a clinical risk index such as Lee’s Revised Cardiac Risk Index to identify those patients at greatest risk of a perioperative cardiac event. Guidelines from the American College of Cardiology and American Heart Association (ACC/AHA) are a useful reference point for the cardiac evaluation of AAA patients, and anaesthetists should be familiar with their recommendations. In terms of surgery specific risk; the ACC/AHA place EVAR in the intermediate risk category for cardiac complications. In general EVAR has many advantages that make it a very attractive option (Table 2). It is as yet unclear as to whether the same preoperative assessment should accompany those intended for EVAR compared with those listed for open repair. The authors currently feel that whilst EVAR is still a relatively new procedure and because there is the possibility of having to convert to open repair, an identical assessment should take place. Not only that, the patient population is the same, they have the same pathology and many centres will offer EVAR to patients who are considered “unfit” for open repair. A significant number of patients do not have many years left to live, and repairing their aortic aneurysm may hasten their death. Risk stratification using CPET may give clinicians more confidence to balance the risk versus benefit of EVAR and help inform the consent process.

**Respiratory**

Anaesthetists should make an assessment of the severity of respiratory disease present, exclude an active respiratory infection and ensure that optimal medical therapy is in place. A concise review of the patients’ recent oral steroid usage and previous need for non-invasive ventilation may prove helpful in planning which type of EVAR procedure is undertaken. There are variations from “standard EVAR” (e.g. use of an iliac bifurcation device) that may confer some “vascular” advantage but may put the patient at more risk owing to an increase in the length of the procedure, the use of greater volumes of intravenous contrast and also the need for general anaesthesia. For those with smoking related lung disease, the practice of using small groin incisions, use of regional or local anaesthesia and early ambulation are likely to reduce the risk of pulmonary basal atelectasis and respiratory infections. Though respiratory failure is not as common after EVAR, a significant number of patients still suffer postoperative respiratory complications (10.9% after open repair versus 2.9% after EVAR). Many patients undergo EVAR using regional anaesthesia, but complex EVAR usually requires general anaesthesia because patients may become restless and agitated if required to lie still for many hours and because of increased risk of blood loss and associated coagulopathy.

Prediction of postoperative respiratory complications in specific patients is difficult in minimally invasive techniques due to their relatively low incidence. Forced spirometry (with reversibilities for the effects of bronchodilators if appropriate) to confirm a particular diagnosis and assess severity is commonplace, but as yet no single investigation lends itself to predict respiratory complications in

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<td>Minimally invasive</td>
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<td>Reduced blood loss</td>
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<td>No cross clamp</td>
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EVAR. As a general rule, it is desirable to convert those on short acting beta agonists to longer acting agents in the perioperative period so as to minimise the potential side effects related to the withdrawal of shorter acting agents. Other adjuncts available that are considered by many to be helpful in reducing the incidence of significant pulmonary complications are chest physiotherapy, incentive spirometry and early ambulation.

Renal

The prevalence of chronic renal impairment varies between 3% and 20% of patients undergoing this type of surgery. These patients are more likely to suffer a clinically significant renal insult because they have a reduced safety margin. Chronic renal impairment is associated with long-standing hypertension, diabetes mellitus, atherosclerosis and renal artery stenosis and may also be related to the close proximity of the aneurysm. Contrast-induced nephropathy (CIN) is a potential complication following EVAR and has been defined as an absolute increase in serum creatinine of 44 μmol/L or a relative increase of 25% from baseline, provided other causes of renal dysfunction are excluded. The contrast media available are all tri-iodinated benzene derivatives, varying only in their degree of ionisation and osmolarity. Newer agents with no ionicity, lower osmolarity and being water soluble are associated with a lower incidence of CIN in high-risk patients. Part of the difficulty in defining the problem lies in the definition of “significant renal damage”, the spectrum ranges from a minor decrease in creatinine clearance in some studies, which is barely detectable with routine blood testing to those who go on to require renal replacement therapy. Though serum creatinine is useful and easy to measure reference point, it is more helpful to use estimated GFR to identify those patients with modest reductions in their renal function (despite normal serum creatinine levels). Anaesthetists need to consider whether a clinically significant renal insult is likely and also to look at strategies to reduce this risk. Risk factors associated with the development of CIN are listed in Table 3. The degree of pre-existing renal impairment is an important factor in affecting numerous outcome measures. Patients with a baseline creatinine greater than 2.5 mg/dL appear to have a higher incidence of perioperative mortality, length of ITU stay, incidence of postoperative renal and cardiac failure compared with those with normal preoperative values. Strategies to reduce CIN include: generous perioperative intravenous fluid administration, minimal use of contrast, increasing the interval between contrast CT angiography and EVAR (to spread the cumulative renal insult over a longer period) and perhaps to consider less complex procedures in those with significant renal impairment (e.g. creatinine greater than 2.5 mg/dL). Adequate hydration with intravenous fluids prior to radiological procedure appears to confer considerable benefit. The postoperative use of antiplatelets should be considered in relation to chronic renal impairment too.

There has been much interest in the use of prophylactic antioxidants to prevent CIN, in particular N-acetylcysteine. Some meta-analyses have suggested a benefit but individual studies looking specifically at its use in EVAR have not demonstrated this effect.

Anaesthesia techniques

General considerations

Any anaesthetic should be tailored to patient and surgical factors, and options with EVAR are numerous. Early attempts at EVAR were lengthy procedures involving teams who were unfamiliar with the technique, and the incidence of perioperative surgical complications was greater, which tended to favour the use of general anaesthesia. In the early days of thoracic EVAR, surgeons often requested cardiac standstill at the point of stent deployment which also favoured general anaesthesia, but this practice is now no longer thought to be necessary.

Although conversion to open repair rates are low (less than 2%) the anaesthetist needs to be prepared for open repair and massive haemorrhage. The bare minimum of general management should include the use of two large-bore intravenous cannulae, invasive arterial monitoring, a urinary catheter and immediate access to a rapid infusion device. Regular intraoperative and
postoperative measurements of haematocrit, haemoglobin blood gas exchange and clotting parameters are easily done from an arterial pressure line. It is also more comfortable for awake patients in theatre not to be subjected to very frequent non-invasive blood pressure measurements throughout the duration of the procedure. Patients are cross matched for the same as for open repair (usually six units of packed red cells). The use of forced air warming devices and intravenous fluid warmers is strongly recommended as duration can easily exceed 3 h and large volumes of fluid occasionally need to be administered.

There is wide variation amongst anaesthetists with regards to the preferred method of monitoring intravascular volume and cardiac output in those patients with moderate cardiac and/or renal failure. The use of a central venous catheter, pulmonary artery catheter, oesophageal Doppler or pulse contour analysis may be beneficial in guiding meticulous fluid balance in these patients undergoing EVAR. However, whether or not these practices will reduce cardiac or renal complications following EVAR is not currently known. For the vast majority of patients, central venous access (with its attendant risks) is an unnecessary procedure and should be limited to those with cardiac/renal failure and to those in whom larger fluid shifts or blood loss is anticipated or where complex procedures are planned (e.g. fenestrated stents).

When considering regional anaesthesia, thought must be given to the concomitant perioperative use of anticoagulants and dual antiplatelet agents. Most patients are given approximately 100 IU/kg of unfractionated heparin before stent deployment, and most are on at least one antiplatelet drug therapy. There is debate over the optimal timing of regional anaesthesia in patients who are prescribed clopidogrel alone, or in combination with aspirin. If regional anaesthesia is the preferred choice, the only sensible recommendation in those undergoing elective EVAR is to stop clopidogrel at least 7–10 days prior to surgery (as per the manufacturers’ recommendations). This is provided that the patient has not had a drug eluting coronary stent inserted within the last 18 months. Cessation of clopidogrel in these circumstances can precipitate fatal perioperative in-stent thrombosis.32

In some more complex cases, the vascular team may wish to start clopidogrel as soon as possible after EVAR due to concerns over side branch perfusion. However, it is necessary to remove an indwelling epidural catheter before starting clopidogrel. This also needs to be timed with the intraoperative use of unfractionated heparin. It is our practice not to give heparin earlier than an hour after the insertion of an epidural and the catheter is removed at least 4 h after the last dose. The clotting profile is also checked and the activated partial tissue thrombolastin time must be less than 1.5 times the normal range before removal. Clopidogrel is then administered 1 h after the removal of the epidural catheter. Following prophylactic doses of low molecular weight heparins (LMWH), most authorities agree that insertion of a neuraxial block is safe after 12 h have elapsed, and that LMWH should not be given until 4 h have elapsed from the insertion of a neuraxial block. These times increase to 24 h following the administration of treatment doses of LMWH.

The pain experienced by patients after two small groin incisions is mild and we do not continue the epidural infusion outside of the theatre. Most patients manage pain adequately with paracetamol and codeine phosphate. The patient mobilises faster and cardiovascular stability is better preserved. This practice may have the added advantage of allowing earlier detection of lower limb ischaemia (of which pain is a presenting symptom). Although it is not used, the epidural catheter is not actually removed, but left in situ for 12 h, hence if there are postoperative complications that necessitate the patient returning to theatre for emergency surgery it can be used again (e.g. for limb ischaemia).

**General versus regional or local anaesthesia**

As experience in EVAR has increased, the use of regional/local anaesthesia has also increased. There are variations in EVAR such as the use of iliac bifurcated devices or fenestrated endografts and/or concomitant open surgery (e.g. femoro–femoro crossover graft) that increase the duration and complexity of the procedure, favouring the use of general anaesthesia. Many patients cannot tolerate lying still for more than 3 h and develop a tendency to become restless which can be incompatible with the latter half of the procedure where a certain amount of patient co-operation is required (e.g. breath holding).

There is growing evidence that the use of regional or local anaesthesia may confer a reduction in postoperative complications in patients undergoing EVAR.33 The EUROSTAR data base was analysed by this group, who looked at 5557 patients who had undergone EVAR from numerous centres across Europe. They looked at many variables and outcomes including: duration of stay, admission to ICU, pulmonary, renal and cardiac complications.
They concluded that cardiac complications were significantly reduced in those patients who had local or regional anaesthesia. Not only this, but that duration of stay in ITU and duration of hospital length of stay were reduced too. However, it should be noted that the local anaesthesia group only represented 6% of all the cases analysed, and most of those were from the same tertiary centre.

Those who are able to tolerate EVAR under LA are generally a highly selected group; usually with more favourable arterial access, undergoing no additional procedures and are less likely to be overweight (making surgical access straightforward). Unfortunately many patients do not reach these criteria. However in this paper by Ruppert et al., regional anaesthesia (combined spinal and/or epidural) also seemed to be associated with a better complication profile than GA. Approximately 25% of patients analysed had undergone regional anaesthesia and represented a group more similar to those that underwent general anaesthesia. They demonstrated a statistically significant reduction in cardiac mortality of 2.9%, compared to those under GA who had a rate of 3.7%, but did not report a reduction in pulmonary or renal morbidity unlike other studies such as that by Verhoeven et al.\textsuperscript{34} This prospective non-randomised study followed 239 patients undergoing EVAR in one hospital. Local anaesthesia infiltration was used as the standard technique; again regional or general anaesthesia was reserved for those who were overweight, had difficult surgical access or required additional surgical procedure. There was no statistically significant difference between the different anaesthesia groups in relation to perioperative mortality. They did however, show fewer renal and respiratory complications in those who had local anaesthesia. This is most likely because of the lower risk profile of this group, and it is unwise to draw strong conclusions from this study due to the fact it was non-randomised, was subject to significant patient selection bias and because the higher risk patients received different types of anaesthetics. Other studies have concluded that the risk profile of the patient appears to be more important than the influence of any given anaesthetic technique.\textsuperscript{35} The ACC/AHA do not advocate a specific mode of anaesthesia for patients with cardiac disease as the evidence base has not been substantiated.\textsuperscript{19} This re-iterates the great importance placed upon preoperative risk stratification in vascular patients.

In a retrospective analysis by Bettex et al.\textsuperscript{36} different modes of anaesthesia were compared in 91 patients listed for infra-renal aortic aneurysm repair with EVAR. They compared local infiltration with epidural and general anaesthesia. As one might expect, more fluid was given in the regional and GA groups, and they demonstrated a large difference in the eventual postoperative destination of patients according to which type of anaesthesia was used. Whereas 70% of patients went to ITU in the GA group, only 27% of those operated on under LA were admitted to ITU with the regional group being approximately 50% (\(p<0.01\)). The length of stay in hospital was also significantly less in the LA group (3 days versus 5.5 days in the GA group, \(p<0.01\)).

All these studies report that EVAR under regional or local anaesthesia is feasible and effective, and none appears to show worse outcomes. However, no definitive evidence exists that they are superior techniques over general anaesthesia. The evidence supporting the use of regional or general anaesthesia for EVAR is lacking, most studies on this subject are descriptive in nature and should be interpreted with caution.\textsuperscript{33–36} The choice of anaesthesia will inevitably be tailored to the individual case. It is also worth bearing in mind that the technical success of EVAR does not appear to be related to the mode of anaesthesia.\textsuperscript{13,33–36}

Postoperative management and complications

The complications following EVAR can be of such magnitude (see Table 4) that close postoperative surveillance is crucial. Currently in the UK, it seems that most go to a level 2 critical care area, but will depend upon local facilities and guidelines. We do not start EVAR without the availability of an HDU bed, though some of our patients are discharged to the vascular ward, provided that certain clinical criteria are met as follows: preoperatively the patient is stratified into low risk on the grounds of clinical co-morbidities, the procedure planned is standard EVAR on an infra-renal aortic aneurysm, the procedure (including anaesthesia) was smoothly executed with no apparent immediate complications and the patient is cardiovascularly stable and passing urine in recovery. For the rest who go to HDU, continued invasive blood pressure monitoring allows regular measurement of gas exchange, haemoglobin, haematocrit, serum electrolytes and clotting parameters. Regular lower limb arterial assessment both clinically and with Doppler is essential.

Patients are usually eating and drinking on the same day; however, continued intravenous fluid therapy is encouraged to reduce the likelihood of CIN.
A common though often relatively benign complication noted after EVAR is postimplantation syndrome. The clinical characteristics of which include pyrexia, leukocytosis and elevated inflammatory markers. Clinically it appears similar to sepsis, but without the presence of infection. Serious life-threatening complications such as multi-organ failure and coagulopathy may occur but are rare. Exclusion of larger aneurysms with endografts may result in significant fibrinolysis secondary to thrombus generated within the aneurysm sac leading to a state of coagulopathy. However, the majority of cases of postimplantation syndrome are self-limiting and usually settle within 2 weeks of surgery. It is important to exclude an infectious cause, and symptomatic management with antipyretics and intravenous fluids is all that is usually necessary. Otherwise most patients are discharged within 4 days of surgery.

Conclusion

Although the benefits to short-term morbidity and mortality are accepted, the long-term complication rates make the decision to undertake EVAR in high-risk patients with limited life expectancy very difficult, and can only be done on an individual basis. Randomised trials focusing on the benefits of EVAR in higher risk patients need to be conducted now that experience with the technique has increased significantly.

Future developments in endovascular surgery are gathering pace, as are the indications and treatment possibilities. Treatment of ruptured aortic aneurysms under local infiltration is being practiced in some UK centres, including our own. The complex type 4 thoraco-abdominal aortic aneurysm can also be stented with custom made endografts. These procedures are exciting developments that will continue to challenge anaesthetists in the years ahead. As the range of patients being considered for EVAR continues to widen, including those who were assessed previously unfit for open surgery, the anaesthetist must continue to be integral in their preoperative assessment in order to impact upon outcome.

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