Complex endovascular aortic aneurysm repair

The use of EVAR in the management of complex aneurysms has expanded in recent years. For the purpose of this review, the term ‘complex aneurysm’ refers to aneurysms of the upper abdominal aorta that involve any combination of its visceral branches such as renal, superior mesenteric or coeliac vessels and, therefore, will mostly cover repair of juxta-renal and Type IV thoraco-abdominal aneurysms. The advantages of endovascular techniques over the equivalent open repair include a reduction in blood loss and avoidance of the associated complications of laparotomy and aortic cross clamping. Although the long-term benefits are still under investigation, many vascular specialists believe that, due to rapidly advancing technology and increasing worldwide experience, it is likely that endovascular techniques will become a routine treatment option for patients with complex aneurysms.

Improvements in three-dimensional thin-slice CT imaging and fluoroscopy techniques, low-profile delivery systems that can negotiate tortuous iliac arteries, and the development of percutaneous techniques have further enhanced endovascular aneurysm repair. With such rapid technological advances and increasing operator experience, vascular specialists are taking on the challenge of managing complex aneurysms using endovascular techniques. The experience and ability to maintain perfusion to aortic branches and hence treat aneurysms involving the aortic arch, descending thoracic, peri-renal and iliac arteries is gathering pace. These advances have broadened the spectrum of patients who are eligible for intervention. Randomized trials have clearly demonstrated a reproducible benefit in terms of in-hospital mortality and morbidity after standard EVAR when compared with open repair. \(^1\) \(^2\) Results pertaining to the endovascular repair of complex aneurysms are encouraging; however, there are no published randomized trials in ‘complex aneurysm’ repair and this treatment option therefore remains confined to the specialized vascular unit.

Complex aortic aneurysms

Juxta-renal aortic aneurysm

With the increasing application of the EVAR approach for infra-renal aneurysms, it has long been appreciated that not all patients were candidates for ‘standard EVAR’. Standard EVAR stent grafts required at least a 1.5-cm neck length (distance from the renal arteries to aneurysm sac, also known as ‘landing zone’) to allow for adequate proximal sealing of the stent graft device. Deploying a stent graft with <1.5 cm neck length may result in either coverage of the renal arteries or a leak around the seal zone into the aneurysmal sac (also known as an endoleak). Approximately 20% of the patients have an inadequate aneurysm neck for a standard stent graft. To deal with these short-necked juxta-renal aneurysms, specialized endografts were designed to accommodate the renal arteries while achieving a supra-renal seal. These ‘fenestrated’ stent grafts allow incorporation of these vital aortic branches thus enabling perfusion of the kidneys.

Thoraco-abdominal aortic aneurysm

Aneurysms of the descending thoracic aorta extending into the abdominal aorta and involving the celiac, superior mesenteric, and renal arteries are difficult aneurysms to treat and are relatively uncommon in general vascular practice. Total endovascular treatment approaches are now routinely advocated in centres specializing in treating these complex aneurysms and have many advantages but also a number of procedure-specific challenges which are discussed later.
Special endografts

Stent grafts can be classified based on several characteristics: whether they are self-expanding, balloon-inflated, consist of one single continuous body or have attachable iliac segments. The skeleton is manufactured from stainless steel, cobalt chromium alloy, or nickel alloys (nitinol); the fabric is usually made from ePTFE or polyester. Grafts impregnated with collagen are currently being developed which it is hoped will lead to better incorporation with native tissues.

Fenestrated stents (abdominal)

Fenestrated stents are used in the treatment of juxta-renal aneurysms, being designed to allow the proximal sealing zone of the stent to incorporate the aorta at the level of the renal and visceral vessel ostia. The flow to the side branches is preserved through fenestrations in the stent-graft fabric (Fig. 1). Fenestrations are reinforced with a nitinol ring sutured to the perimeter of the fenestration to improve the fixation and seal of the stent bridging into the aortic side branch. An indentation at the end of the fabric may serve as an incomplete fenestration and is commonly referred to as a scallop (Fig. 1). Thus, using a combination of fenestrations and scallops, endovascular exclusion of the aneurysm (usually juxta-renal) can be achieved whilst maintaining the patency of the visceral and renal arteries. Precise location of the fenestrations within the graft is vital to success and this is achieved by careful preoperative imaging and planning. 3D reconstructions are, therefore, mandatory for the planning of advanced stent grafts; the customization of these grafts necessitates a time-lag of several weeks between the decision for endovascular intervention and completion of the procedure.

Branched stent grafts

Branched stent grafts were developed for aneurysms that involve vital aortic side branches such as supra-renal and Type 4 thoraco-abdominal aneurysms or even the pre-cerebral vessels (e.g. aortic arch aneurysm). However, unlike the fenestrated grafts, which have only pre-made windows for the visceral and renal artery origins, branched grafts have branches already attached to the body of the endograft that are themselves deployed into the visceral and renal arteries. The branch of the stent graft bridges the gap between the stent graft and the native aortic wall and serves to preserve perfusion of the aortic side branch and provide a seal. Experience with these devices is limited and long-term data on their efficacy are still awaited.

Chimney stent grafts

Fenestrated and branched custom-made stent grafts are expensive and require 6–8 weeks to design and produce. Not all patients fit the anatomical criteria for such stents. As a result, vascular specialists have developed the ‘chimney graft technique’ (AKA the periscope or snorkel) for patients who are deemed ‘unfit’ for open surgery, require urgent intervention or in whom a custom-made stent cannot be designed. This technique utilizes off-the-shelf covered stents. In the case of a juxta-renal aneurysm, covered stents are first deployed in the renal arteries usually via the axillary artery and out into the aorta in an upward direction (appearance is like that of a chimney using fluoroscopy) into proximal aorta. Following this, a conventional bifurcated stent graft is deployed in line with the covered stents. Long- and short-term outcomes are limited, but preliminary data are encouraging.

Preoperative assessment

The European VASCUNET Report of 2007 demonstrated that mortality after elective infra-renal aortic aneurysm surgery in the UK was higher than many other European and non-European countries. Since this report, a framework of care has been developed (The Abdominal Aortic Aneurysm Quality Improvement Programme: AAAQIP; www.aaaqip.com). Although these
recommendations relate to infra-renal repair, it seems sensible to extrapolate these general principles when making assessments on patients being considered for more complex intervention. Of note to anaesthetists, the AAAQIP framework strongly recommends that preoperative anaesthetic assessment should occur early in the clinical pathway and should be integral to the decision to operate. The AAAQIP also states that this assessment should be undertaken by a consultant vascular anaesthetist (i.e. a consultant with a regular clinical commitment to elective aortic surgery). With the advent of the UK Abdominal Aortic Aneurysm Screening Program and a move to centralization of vascular services across the UK, it seems likely that vascular units will be able to tender for aortic surgery services if they can deliver on a number of predefined standards, including a standardized approach to preoperative assessment.

This assessment process should be tailored to the surgical urgency, complexity of aneurysm anatomy, comorbidities, and functional capacity of the patient. The cardiac assessment should follow the ACC/AHA or the European guidelines on perioperative cardiovascular evaluation for non-cardiac surgery. There is no single useful risk stratification model for vascular surgery, let alone endovascular surgery. Some anaesthetists will use risk scores such as the revised cardiac risk index* and/or the modified customized probability index* (m-CPI) when risk stratifying patients for endovascular surgery. However, the sensitivity of these indices as predictors of mortality after elective aortic surgery is not high but perhaps show more promise in the identification of the low-risk patient. With this in mind, we should focus our assessment on whether the patients’ longer term survival is likely to be of such duration that they can enjoy the benefit of aneurysm repair.

In the author’s institution, all AAA patients undergo cardiopulmonary exercise testing (CPET) to obtain an objective measure of their cardiac and respiratory reserve. This is used as a screening tool for occult cardio-respiratory disease such as cardiac failure and/or cardiac ischaemia. This allows for the development of an early focused optimization strategy of functionally limiting cardiorespiratory disease before the intended surgical intervention. This may be managed by the anaesthetist or by referral to the appropriate medical specialty. The rest of the assessment should focus on optimization of common medical conditions (e.g. hypertension, chronic obstructive pulmonary disease, and diabetes mellitus) and assessing risk factors for common postoperative complications such as acute kidney injury (AKI). A local referral pathway to allied specialties should be developed for advice on more complex patients and this also helps identify a point of contact for future referrals. Centres without CPET should attempt to assess functional reserve as objectively as possible using methods such as the Shuttle Walk Test together with more subjective measurements (e.g. The Duke Activity Status Index). Patients with poor functional reserve (≤4 METs) and a number of risk factors for the presence of ischaimic heart disease should perhaps be screened with non-invasive cardiac stress tests such as stress myocardial perfusion or dobutamine stress echocardiography. In the vast majority, they confirm or refute the need to commence appropriate medical therapy. A small proportion of these patients will be identified as having critical myocardial ischaemia that in itself warrants coronary angiography and possibly revascularization. Resting echocardiography is rarely helpful in identifying high-risk patients, but is useful in the diagnosis and evaluation of a newly identified heart murmur.

**Monitoring and anaesthesia**

There is very limited evidence on the best choice of anaesthesia for standard EVAR and even less for complex EVAR. The literature is limited to descriptive, retrospective studies on patients undergoing infra-renal EVAR and is open to selection bias and should be interpreted cautiously. Hence, the selection of techniques falls to the choice of patient and anaesthetist and should take into consideration the experience of the vascular team, choice of procedure, complexity of the aneurysm, and premorbid state of the patient. Endovascular repair can take between 4 and 12 h and patient comfort alone is difficult to achieve under regional anaesthesia. Coupled with arterial access often being required from axillary, femoral, and occasionally carotid artery, any technique other than general anaesthesia is likely to be very difficult for all concerned. Tracheal intubation and positive pressure ventilation using the predictable and rapid emergence characteristics of remifentanil and desflurane are useful techniques for this type of surgery. Postoperative analgesia requirements are minimal and so this technique works well with wound infiltration using local anaesthetics and simple oral analgesics. Due to the coagulopathy and high incidence of AKI, non-steroidal anti-inflammatory drugs (NSAIDs) should always be avoided.

Patients require a large-bore i.v. access, invasive arterial monitoring, a urinary catheter, warming devices, and central venous access. Patients undergoing chimney procedures or branched endograft often have a guide wire and sheath placed in the left axillary or left brachial artery (to avoid wires traversing the aortic arch unnecessarily), so it is advisable to use the right radial artery for invasive arterial monitoring. Patients are usually positioned supine, however when arterial access is required from the upper limbs; both the arms are usually abducted behind the head with flexion at the elbows. Intra-operative monitoring of arterial blood gases (early detection of gut ischaemia), haemoglobin, and clotting parameters are essential. Before cannulation of visceral arteries, heparin is given in a dose of 100–150 IU kg⁻¹. Assessment of the anticoagulant effect with near-patient testing devices is essential during cannulation of the visceral vessels, at this time the activated clotting time (ACT) is usually kept between two and three times the patient’s preoperative value in an attempt to prevent thrombosis of the stent endograft(s).

Branched devices and complex chimneys (e.g. chimney stents to both renal arteries, superior mesenteric and coeliac) are often associated with a consumptive coagulopathy, significant blood loss and AKI (incidence 20%). It is advisable to place a central venous catheter to cater for the various infusions [e.g. potassium,
magnesium, heparin, N-acetylcysteine (NAC), blood and blood products] that may need to be administered in the perioperative period. Non-invasive cardiac output monitoring such as the oesophageal Doppler can provide useful information in the assessment of circulatory volume status, not least because of the difficulty in accurate estimation of blood loss (from the introducer sites). The use of such monitors may identify internal/hidden bleeding at an earlier stage. However, the patient population tend to have a heavy atheromatous load in their aorta that can occasionally make the detection of blood flow in the thoracic descending aorta difficult. Due to (intermittent) intra-aortic balloon inflation and the presence of a partially opened endograft in the aorta for a large proportion of the procedure, the readings from oesophageal probes cannot always be reliably interpreted. Non-invasive cardiac output monitors that rely upon pulse contour analysis or bioreactance may be a useful alternative.

It is the authors’ view that postoperative management of complex endovascular patients should be carried out in a critical care environment regardless of their co-morbid state due to any number of early complications that can occur after surgery. Earlier identification of such complications should prompt earlier intervention and may improve outcomes.

**Peri-procedural considerations and complications**

**Acute kidney injury**

There is a strong association between AKI and in-hospital mortality. It is worth remembering that even small and transient changes in baseline renal function may be associated with a reduction in longer term survival. The magnitude of the perioperative renal insult observed appears to be proportional to short- and long-term survival after surgery. It is unclear as to whether this is a causal relationship or whether other factors influence this observation. The incidence of AKI after EVAR is between 10 and 20% and is thought to increase along with the complexity of the procedure. With respect to fenestrated EVAR, contributory factors include the embolization of atheromatous plaque from within the aorta into the renal vessels by the endograft, guide wire insertion into the renal vasculature, and contrast-induced nephropathy (CIN). There are a number of risk factors shown in Table 1. The incidence of AKI after EVAR is significantly greater in patients with pre-existing renal impairment. AKI can be diagnosed and graded using simple scoring systems such as the RIFLE or AKIN criteria which use the changes in serum baseline creatinine and/or urine output to grade severity.

CIN can occur in patients with normal renal function but is more commonly seen in those with chronic renal impairment. It is a significant contributory factor in AKI after EVAR. CIN has been defined as an absolute increase in serum creatinine of 44 μmol litre⁻¹ or a relative increase of 25% from baseline, provided other causes of renal dysfunction are excluded. It is difficult to rule out other causes in complex EVAR, but CIN will likely play a part in the aetiology of most cases. There is a linear relationship between the amount of contrast used and increasing nephrotoxicity. Vascular units should try to limit the amount of contrast used in all patients but particularly those at greatest risk. Low and iso-osmolar agents (e.g. ioxitalam) are associated with less CIN and their use is encouraged.

Some patients undergo iliac artery coiling and/or CT angiography just before EVAR. This extra ‘contrast load’ is thought to be an important risk factor in the development of CIN (due to the increased cumulative dose over a relatively short time period). Hence, it is advisable to undertake such procedures at least 1 week before the intended date of surgery.

Numerous strategies have been adopted to reduce the incidence of CIN. Simple and proven steps include pre-procedure i.v. fluid therapy and limitation of the contrast dose administered. Other interventions such as NAC and bicarbonate therapy have been investigated. A number of trials and meta-analyses indicate that NAC may offer an additional renoprotective effect in comparison with hydration alone in high-risk patients. This evidence mainly comes from studies investigating patients undergoing diagnostic procedures. However, given that NAC is a relatively innocuous agent, this has led many clinicians to adopt its use in higher risk patients despite the fact that conclusive evidence of benefit is lacking. Sodium bicarbonate has also been demonstrated to prevent CIN in patients undergoing imaging procedures. The evidence to date suggests that it brings about a reduction in the incidence of CIN but has not been shown to reduce mortality or the incidence of unanticipated renal replacement therapy. Large randomized trials are still awaited on this potential role.

Routine ‘drug holidays’ are likely to be beneficial and all potentially nephrotoxic drugs should be avoided for 24 h before the procedure and re-introduced only when risk of kidney injury is considered minimal. These drugs include angiotensin converting enzyme (ACE) inhibitors, angiotensin receptor antagonists, and NSAIDs. Clinicians can usually halt the progression of AKI with i.v. fluid loading, maintaining baseline mean arterial pressure and obtaining early advice from a nephrologist. This is particularly important in patients with a 2-fold increase in baseline serum creatinine. The decline in renal function can be rapid and a very small proportion of patients will require renal replacement therapy. Patients who improve but then stabilize with an estimated GFR of <30 ml min⁻¹ should be referred to nephrology review for longer term surveillance and review.

**Table 1** Summary of risk factors for acute kidney injury

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age &gt;70 yr</td>
<td>Age over 70 years</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>Presence of diabetes mellitus</td>
</tr>
<tr>
<td>Cardiac failure</td>
<td>Presence of cardiac failure</td>
</tr>
<tr>
<td>Preoperative e-GFR &lt;60 ml min⁻¹ (i.e. CKD stage 3a and above)</td>
<td>Estimated glomerular filtration rate below 60 ml min⁻¹</td>
</tr>
<tr>
<td>Perioperative dehydration</td>
<td>Dehydration during surgery</td>
</tr>
<tr>
<td>ACE-I, angiotensin receptor blockers, aminoglycosides, and diuretics in the perioperative period</td>
<td>Use of ACE inhibitors, angiotensin receptor blockers, aminoglycosides, and diuretics in the perioperative period</td>
</tr>
<tr>
<td>Repeated exposure to contrast within 7 days of EVAR</td>
<td>Multiple exposure to contrast within 7 days of EVAR</td>
</tr>
<tr>
<td>Complex EVAR (*fenestrated, chimney, branched)</td>
<td>Complex EVAR (fenestrated, chimney, branched)</td>
</tr>
</tbody>
</table>

*The table above lists risk factors associated with acute kidney injury.*

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Ischaemia to the liver (coeliac) and bowel (coeliac/SMA) due to dissection or thrombotic deposits being dislodged are serious complications. Regular blood gas analysis may allow for early detection of ischaemia and provide the vascular team with useful information regarding optimal stent deployment. Early detection may also allow time to consider rescue therapies to recanalize a vessel.

**Blood loss and coagulopathy**

Blood loss is secondary to a constant leakage from the arterial access sites rather than from acute haemorrhage. We recommend a cross-match of four units for fenestrated and six units for branched EVAR procedures. Cell salvage is valuable and limits the volume of allogeneic blood transfused; it is possible to carefully salvage blood from around the entry sites of the stent-graft delivery system. Heparin therapy coupled with antiplatelet agents and inadvertent perioperative hypothermia can exacerbate blood loss. Doses of heparin in excess of 1.5 mg kg⁻¹ are often administered, it is helpful to monitor the dose response with a point of care testing device that measures activated clotting time (ACT). A baseline ACT should be recorded before any heparin is given and the response to heparin measured and recorded. Administration of i.v. protamine at the end of the procedure (0.5–1.0 mg for every 100 IU heparin administered) should be considered if the patient appears to have developed a coagulopathy that is clinically apparent and is accompanied by an ACT greater than twice the patient’s baseline measurement. The use of protamine carries a small risk of thrombosis in the stents and/or in the visceral vessels that dissuades some vascular teams from using it. Protamine should only be administered when heparin therapy has been clearly demonstrated (with bedside testing and in the absence of other causes) to be the most significant contributory factor to clinically problematic coagulopathy. The risk of hypothermia is much less compared with open surgery, but standard precautions should be taken to avoid hypothermia with the use of warmed i.v. fluid and forced air warmers.

**Post-implantation syndrome**

The incidence of post-implantation syndrome is between 30 and 40%. The syndrome comprises of pyrexia, leucocytosis, and elevated C-reactive protein in the absence of sepsis. The cause is postulated to be an inflammatory and immune response to the inserted graft material or from alterations in the vascular endothelium from intra-aneurysmal device manipulation, or as a result of residual thrombotic material isolated by the endograft. It is usually mild and self-limiting, lasting 2–10 days. Serious life-threatening complications such as multi-organ failure and coagulopathy may occur but are rare. Management includes exclusion of an infective cause and symptomatic treatment with antipyretics and i.v. fluids.

**Endoleaks**

Persistent blood flow into the aneurysm sac after graft implantation is referred to as an endoleak. There are four important types of endoleak, the most important being those that relate to continued high-pressure blood flow into the aneurysm sac and thus leaving the patient at continued risk of rupture. They are briefly classified as follows:

- **Type 1** is due to a stent graft seal failure at the graft ends (proximal or distal)
- **Type 2** is due to the aneurysm sac filling from via a branch vessel (e.g. lumbar or inferior mesenteric)
- **Type 3** is due to leak through the graft fabric (e.g. stent graft separation)
- **Type 4** is due to porosity of the graft (often intentional).

Type 1 and 3 endoleaks leave the aneurysm at risk of continued expansion and rupture.

With type 1 and 3 endoleaks, it is reasonable to complete the EVAR procedure and consider open surgery at a later date. Many endoleaks can be managed using endograft extensions or angioplasty in the short or long term. Life-long CT surveillance of the endograft and the aneurysm sac will detect new endoleaks, of which the majority can be successfully managed with simple radiological intervention. Type 2 endoleaks are common after EVAR (10–25%), but their significance remains debatable and controversy still exists regarding optimal management.

**Declaration of interest**

None declared.

**References**


Please see multiple choice questions 25–28.