Novel endovascular procedures and new developments in aortic surgery

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Abstract

Endovascular repair has evolved to become a viable mainstream treatment for aortic pathology in both acute and elective settings. As technology advanced, traditional anatomical barriers were progressively tackled using new devices and novel procedures, and there are now multiple options available to the vascular surgeon. In the abdominal aorta, advances in endovascular aneurysm repair have been in the treatment of hostile aortic necks using new sealing concepts and ancillary procedures, and in branch preservation using fenestrations and snorkels. Access challenges have been met with a percutaneous approach and low-profile devices, and standard protocols have improved mortality for ruptured aneurysms. In the thoracic aorta, more invasive hybrid procedures have given way gradually to branched endografts. Particular challenges to the anaesthetist include blood pressure control and the prevention of stroke and paraplegia. Current focus in the thoracic aorta is in treating aortic arch pathology and in optimal management of acute and chronic dissections. This review describes the latest trends in the endovascular treatment of aortic diseases and examines the current evidence for different modalities of management.

Key words: aorta; aortic aneurysm; endovascular procedures

Editor’s key points

- In most vascular surgery centres, 60–80% of abdominal aortic aneurysm repairs are now endovascular.
- New stent designs make it likely that the use of endovascular repair for abdominal aortic aneurysms will increase further.
- Thoracic endovascular aneurysm repair is increasingly used to treat type B thoracic aortic dissections.
- Fenestrated endografts have transformed the treatment of thoracoabdominal aneurysms.

Endovascular repair of abdominal aortic aneurysms

Since its introduction in the early 1990s, endovascular aneurysm repair (EVAR) has become firmly established as a viable treatment...
for abdominal aortic aneurysms. Current commercial aortic stent
grafts are in their third to fourth generation. Most endografts are
based on a modular bifurcated system, with self-expanding
stents on low-porosity fabric and supra- or infrarenal fixation.
The graft is introduced via flexible hydrophilic sheaths through
bilateral common femoral arteriotomies.

The benefits of avoiding laparotomy and aortic cross-
clamping, intensive care stay, reduced blood loss, and lower
morbidity and mortality compared with open surgery have
been well established in randomized trials.1 In most vascular
surgery centres, 60–80% of abdominal aortic aneurysm repairs
are now endovascular. The EVAR involves very little physiological
perturbation and can be completed under monitored anaesthesia
care, with regional or general anaesthesia. A preference for the
latter mainly pertains to control of respiration and better digital
subtraction images.

Modern developments in EVAR focus on several key areas, as
follows: (i) refinement of existing stent graft materials to enable a
lower-profile delivery system yet maintaining endograft strength
and durability; (ii) simplifying steps in delivery; (iii) allowing for
adjustments in positioning for accuracy of placement; (iv) min-
imizing endoleak and stent graft migration with improved and
assisted fixation and seal; (v) improving performance in in-
stances of adverse aortic anatomy; and (vi) extended coverage,
with branch preservation.

Percutaneous approach and lower-profile
devices

Most endograft manufacturers are moving towards lower-profile
endografts that can be introduced percutaneously. With new
material, thinner fabrics, and better sheaths, the latest generation of
EVAR delivery systems have reduced significantly in size from
20–22 Fr to as low as 14 Fr gauge, and they can be introduced
into narrow access vessels <6 mm in diameter. Percutaneous
EVAR (PEVAR) is a completely percutaneous procedure that
involves a pre-close technique, in which percutaneously placed
closure device(s) are applied before the introduction of the stent
graft. PEVAR has been shown to be equally effective and safe,
with minimal access-related complications, and is non-inferior
to standard femoral cut-down.2 3 With PEVAR, the hospital stay
can be further reduced to a 1 day procedure in selected patients.

Endovascular aneurysm repair for ruptured
aneurysms

Where expertise and equipment are available, EVAR has fast
become the gold standard and preferred choice for treating
ruptured aneurysms. Multiple randomized studies have shown
equivalent results to open repair, with lower morbidity and
blood loss in favour of EVAR.4 5 Recent randomized trials have
confirmed that EVAR had similar 30 day and 1 yr mortality
when compared with open surgical repair, yet incurred less
complications, blood transfusions, and intensive care unit
stay.5 Endovascular aneurysm repair also consumes less hospital
resources, with better quality of life and cost-effectiveness, lead-
ing to long-term socio-economic gains.7

Modern management of patients with ruptured abdominal
aortic aneurysms advocates permissive hypotension and a
percutaneously introduced suprarenal aortic balloon to effect
temporary haemostasis before EVAR. In extremely unstable
patients, an aorto-uni-iliac stent graft can achieve an instant
seal of the aneurysm, although a femoral-femoral bypass is
then required. Most experienced clinicians would now prefer to
use a standard bifurcated device. The main limitation of emer-
gency EVAR is postoperative abdominal compartment syndrome,
and occasionally, a laparotomy for decompression has to be car-
rried out after successful EVAR. Patients requiring laparotomy
after emergency EVAR generally have worse prognosis.

Branch preservation and extension of seal:
fenestrated endovascular aneurysm repair

Traditional EVAR requires a healthy infrarenal ‘neck’ length of
about 10–15 mm below the lowest renal artery origin for secure
proximal fixation. Inadequate neck length or excessive angula-
tion are key causes of attachment (type Ia) endoleaks and
graft migration. In patients with a short or unhealthy aneurysm
neck, the proximal landing zone has to be extended upwards.
Fenestrated endografts were designed to land in the suprarenal
aorta, with preservation of vital visceral branches of juxtarenal
aneurysms. These endografts are custom manufactured to
contain scallops (gaps in the fabric on the top of an endograft,
reinforced on three sides) or fenestrations (small circular or
oval ‘holes’ in the graft body reinforced by a nitinol wire ring)
in the fabric to match the origin of ‘target’ vessels, such as the
coeeliac axis, superior mesenteric artery, and both renal arteries.
The main graft is unsheathed, yet restrained by diameter-redu-
cing wires to allow adjustments of position. The target vessels
are then individually accessed via a contralateral femoral (or
brachial) approach and bridged to the main graft body with a
balloon-expandable covered stent (Fig.1). Large series have con-
firmed that this is a viable approach, with low mortality and

Fig 1 A juxtarenal aneurysm treated with a fenestrated endograft. The
coeeliac axis was preserved by a scallop, and three fenestrations to the
superior mesenteric artery and renal arteries were bridged by covered
stents.
morbidity. Long-term mortality is largely not aorta related, despite the need for some secondary interventions to address stent migration and occlusion.9

The limitations of fenestrated endovascular aneurysm repair (FEVAR) are the requirement to develop appropriate technical skills and the long duration of the procedure. Large-diameter or multiple femoral sheaths accommodating several catheters may lead to substantial but unrecognized blood loss from the valves in a lengthy procedure. There are also increased risks of target organ (bowel, kidneys) and lower limb ischaemia because occlusive sheaths are left for extended periods of time. When a difficult procedure is anticipated, some operators may construct a temporary axillo-femoral bypass or place a femoral artery perfusion catheter distally to maintain lower limb flow and minimize reperfusion injury and mortality.10

Currently, fenestrated grafts are custom-ordered according to individual anatomy, with a 3–6 week manufacture time, and are, therefore, unsuitable for urgent procedures. An off-the-shelf design has been proposed to cater for a proportion of juxtarenal or suprarenal aneurysms.11 This endograft has a standard scallop for the superior mesenteric artery and two pivoted renal fenestrations at dedicated clock positions to allow for varying renal artery origins in two available designs. Anatomical studies indicate that they are suitable in as many as 70% of patients.12 13

Chimneys and snorkels

Fenestrated grafts are not universally available and also require a higher level of catheter skills. An alternative to FEVAR for treating juxtarenal aneurysms is the ‘chimney’ or ‘snorkel’ technique, where the target (usually renal) vessels are first cannulated from the proximal end via a transbrachial (or transaxillary) wire and long sheaths. A standard abdominal stent graft is then advanced above the renal origin and deployed, while the patency of the renal artery(s) is protected by expanding a parallel covered stent alongside the oversized EVAR graft (Fig. 2).14 This procedure is simpler to perform and is suitable when FEVAR is not feasible technically or the urgency of the patient’s condition precludes waiting for graft manufacture. The obvious concerns are the durability of these chimneys and the ‘gutter’ leaks between the parallel grafts. Anatomical considerations also limit the number of chimneys to be generally not more than two. Mid-term results, albeit from non-randomized data, support this approach, and few complications have been reported.15

Some physicians have embarked on on-table modification of standard endografts, constructing fenestrations or side-branches as a temporary measure. These physician-modified devices have also proved to be viable, at least in the short term.16 17

Internal iliac artery preservation

The distal landing zone of EVAR is also critical, with a requirement to preserve pelvic blood flow by maintaining patency of at least one internal iliac artery. In patients with an aneurysmal common iliac artery, the distal graft fixation has to be within the external iliac artery. The internal iliac artery will have to be sacrificed by coil embolization; this carries a risk of disabling gluteal claudication or bowel ischaemia. The historical external-to-internal iliac bypass has largely been superseded by the placement of a side-branch endograft incorporating a covered stent into the vessel.

The most widely used device is the iliac branched device. The iliac branched device is essentially an iliac extension graft with a small downward-pointing side-branch in a helical or angled configuration. It is first introduced as a modular component and the target internal iliac artery accessed in a crossover manner by contralateral (or transbrachial) cannulation. The branch and the target internal iliac are then bridged by a covered stent (Fig. 3).18 Several custom variants and improved second-generation devices are now available.19–21 In centres where the iliac branched device is not available, an ingenious crossover chimney technique has been used to preserve internal iliac flow.22

Alternative approaches for short-neck aneurysms

As techniques of EVAR improve, vascular surgeons strive to expand its application to younger patients and to those with adverse anatomy, outside the standard ‘instructions for use’. In this arena, long-term durability and freedom from secondary interventions and conversions are paramount considerations.

Those who prioritize a healthy neck for landing a stent graft believe that one should not compromise on neck length, as there is ample evidence that a neck length of <15 mm, particularly with angulation, is associated with significantly increased risk of proximal type I endoleaks and a higher incidence of reintervention and rupture.23 There is also evidence that almost 30% of infrarenal aortic necks will dilate in as short a time as 24 months after open and endovascular repair.24 Advocates of this approach argue that a secure proximal landing equates with good long-term results and that short necks should be treated with fenestrated endografts.

Recently, newer stent grafts with improved seal characteristics have emerged, using a modification of proximal stent design to accommodate a short (8–10 mm) aortic neck.25 Another approach goes with a series of nitinol rings instead of the traditional vertical stents in the stent grafts for better conformance and kink resistance, and seal aneurysms with highly angulated necks.26 Registry follow-up data on these new grafts are relatively short term, but they do present another option in adverse neck anatomy.
To supplement endograft fixation in questionable landing zones that are short, dilated, or angled, small helical endoanchors have been developed to be placed via a 16 Fr motor-driven transfemoral delivery system into traditional endografts. When applied in numbers in the aortic neck, these small screw-like endoanchors appose the graft and aortic wall, with the goal being to improve the seal and fixation. Early results of these transmural fixations are promising, and they have been extended to treat proximal type Ia endoleaks after both EVAR and thoracic endovascular aneurysm repair (TEVAR), with a 98% technical success rate. These anchors have not been approved for use in the iliac arteries for fear of vessel penetration and bowel injury.

**Polymers and endovascular aneurysm sealing**

The traditional model of a modular, covered stent graft supported by a stainless-steel or nitinol self-expanding skeleton is now being challenged. The radial force exerted by traditional sealing stents on the aorta was thought to cause continuing aneurysm neck expansion and ultimate failure of the seal. The Ovation Prime device (Endologix Inc., Irvine, CA, USA) offers a ‘neck protection’ theory. Instead of self-expanding metal stents, a polymer-filled non-expansile ring is used for sealing the neck. The fast-cure polymer is injected via a side-channel on a collapsible polytetrafluoroethylene body after insertion. The polymer opens the graft body and forms a ring at the neck to achieve a proximal seal. A long suprarenal nitinol stent at the top of the graft provides fixation (Fig. 4). Initial 1 yr results of this very low-profile device showed 99% success, with no migration and very low endoleak rates. This technology may have a special application in reverse-tapering aneurysm necks but remains to be proved in time.

A completely novel concept of endovascular aneurysm sealing (EVAS) has recently emerged to challenge the EVAR principle. Two side-by-side balloon-expandable stents are introduced into the abdominal aortic aneurysm. The stents are attached to two endobags, which are then filled with predetermined volumes of polymer using an injection system under intraluminal pressure monitoring. The cured polymer inside the endobag fills the aneurysm sac completely and obliterates retrograde type II endoleaks from lumbar or inferior mesenteric arteries (Fig. 5). Despite minor concerns of potential rupture, limb occlusion, and polymer leaks, initial results have been promising. This graft has the added potential of allowing sealing in challenging anatomy, such as shorter necks, combined with the use of renal artery ‘chimneys’, and in accommodating common iliac aneurysms up to 35 mm in diameter without sacrificing the internal iliac artery.

These new technologies open entirely new potential areas of revolutionizing abdominal aortic aneurysm treatment in the future, and are testimony to the rapid developments in EVAR. Although long-term efficacy remains to be proved in larger studies, their immediate impact on endovascular repair places demands for new troubleshooting and imaging techniques.

**Thoracic endovascular stent grafts**

The advantages of TEVAR compared with traditional open repair for thoracic aortic disease are potentially even greater than those of EVAR for abdominal aneurysms. Proximal thoracic aortic surgery requires tactics for blood-pressure control, cerebral...
Preserving supra-aortic branches: hybrid procedures

The proximal seal zone for TEVAR required for a secure landing, normally no less than 2 cm, is often short and subject to further degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch. Purposefully covering the great arch vessels becomes necessary in pursuit of degeneration when the pathology is close to the arch.

The most widely practised is a left carotid–subclavian bypass using a supraclavicular incision, performed either simultaneously with TEVAR or as a staged procedure. Sometimes a right axillary-to-left axillary artery subcutaneous bypass is used instead (usually by cardiac surgeons less familiar with the neck). The option of placing a left subclavian ‘chimney’ parallel to the main graft has not been widely accepted for fear of compromising the seal and increasing the risk of retrograde type A dissection. These procedures may also have a bearing on the siting of arterial pressure-monitoring lines during anaesthesia.

In patients for whom the anatomy of the landing zone requires coverage of the left common carotid artery, a carotid–carotid bypass or carotid–carotid–left subclavian bypass can be performed, using a prosthetic graft placed in a retropharyngeal route and two oblique neck incisions. While technically simple, this ‘hybrid’ approach has the disadvantage of complications associated with carotid artery clamping (stroke) and the risk of later occlusions from the single supplying artery.

Addressing true aortic arch pathologies, such as arch aneurysms, in high-risk patients unsuitable for total open arch replacement, a hybrid ‘total debranching’ procedure can be performed. This involves a median sternotomy, side-clamping, and construction of a bifurcated prosthetic bypass graft from the ascending aorta to the innominate and left common carotid arteries (with or without left subclavian). This is followed by total coverage of the aortic arch with a retrogradely placed transfemoral TEVAR or, in those with access difficulties or a tortuous aorta, anterograde from a subclavian. Although less invasive than a total arch replacement, morbidity of this procedure is still high, with immediate concerns of stroke and retrograde aortic dissection, especially in a diseased ascending aorta. Late branch occlusions as a result of kinking in the limited retrosternal space have been reported.

Challenges to anaesthesia in these situations include the added blood loss from a sternotomy, and the need for cerebral perfusion monitoring and control during carotid clamping. Hybrid debranching has been losing favour to less invasive options. Interim solutions using carotid artery chimney(s) or snorkel(s) have been tried with varying success. In situ fenestration techniques have also been attempted in the arch but have not stood the test of time.

Branched aortic arch endografts

The ultimate challenge in endovascular aortic repair is in the aortic arch. Obstacles to successful placement of the stent graft include access issues (large-calibre delivery systems), tortuous descending aortic anatomy, branch preservation, ‘beaking’ and collapse of the stent graft, accurate placement, cerebral protection, blood pressure control, prevention of retrograde dissection, and preservation of coronary and valve function.

Innovative advances include a single-branched thoracic endograft developed in China, in which a small side-branch (or fenestration) can be snared into the left subclavian artery on a preloaded guide wire. Similar attempts in other countries have, so far, not matured into a viable commercial product. Another approach is with custom-made scalloped grafts or a home-made fenestrated graft in the arch to accommodate the supra-aortic branches that is available in Japan. Currently, the most promising product is the branched aortic arch endograft. The prevailing design consists of a tube graft with one or two proximal sealing stents with a maximum of 46 mm diameter in the ascending aorta, with a middle recessed segment containing two internal forward-directed side-branches
accessible through two diamond-shaped depressions. The graft is introduced via the femoral artery on a stiff wire into the left ventricle through the aortic valve and deployed. Owing to the proximity to the heart, accurate positioning is achieved with blood pressure control using either rapid cardiac pacing or inferior vena cava occlusion. The latter preload reduction method involves inflating a balloon in the right atrium placed via the femoral vein and occluding the inferior vena cava return. After the graft is deployed, the recessed section allows blood flow into the cerebral circulation while the left common carotid and innominate arteries are bridged with covered stents (Fig. 6). Preliminary short-term success rates are promising, although there are concerns about the risk of stroke from air or thrombus embolization. About 200 of these procedures have been performed worldwide, with a stroke rate of ~10% in major centres. Two companies produce similar grafts, and it is expected that an off-the-shelf design will be available in the near future. These grafts are still currently custom-made and require a staged left carotid–subclavian bypass. They remain large-calibre systems and, currently, their use is limited to high-risk patients unsuitable for open surgery.

**Ascending aorta**

Owing to the short length, complex pathology, and proximity to the heart, TEVAR in the ascending aorta remains a largely uncharted territory. Small case series reporting the use of short tube stent grafts demonstrated early feasibility only in highly selected patients.

**Thoracic endovascular aneurysm repair in aortic dissections**

One of the increasing indications of TEVAR is in treating type B aortic dissections. A stent graft covering the primary entry tear will depressurize the false lumen while re-establishing true lumen and visceral blood flow. Thoracic endovascular aneurysm repair in the acute stage is generally limited to patients with rupture or end-organ malperfusion, because complications rates are higher. Generally, TEVAR is preferably performed in the subacute setting (<14 days). Used alone or with an adjunct renal or visceral stent, TEVAR is very effective in achieving true lumen re-expansion in the acute stage. The current trend is to place a long, tapered covered stent graft from the left subclavian origin to extend the distal coverage to the lower descending thoracic aorta in order to minimize the chance of a late stent graft-induced new entry tear in the dissection flap (SINE; Fig. 7).

There are a number of choices to treat the distal landing site. Most surgeons would place a single stent graft first and deal with retrograde false-lumen flow on follow-up. Long-term data have emerged from randomized studies indicating that, although the incidence of initial complications and early mortality of TEVAR obviate any advantages compared with medical therapy, after 5 yr there is a distinct survival advantage in type B dissection patients treated with TEVAR compared with best medical management. Thoracic endovascular aneurysm repair also promotes better false-lumen thrombosis and aortic remodelling than medical treatment. Some surgeons prefer a more aggressive approach to extend the stent graft with a distal bare stent segment all the way into the abdominal aorta, referred as the PETTICOAT procedure, in...
an attempt to achieve total true lumen re-expansion or ‘complete attachment’. This may be combined with additional covered stents distally to cover any secondary fenestrations.

Although TEVAR is an effective treatment for complicated procedures, it remains controversial as to whether this should be extended to treat uncomplicated type B dissections. The IRAD (International Registry of acute Aortic Dissections) registry showed a continued survival disadvantage of patients on conservative treatment, because of late mortality from aneurysm formation and rupture. Early treatment by TEVAR may prevent this continuing mortality. There are no definitive randomized studies to address this issue, as some may argue that the theoretical advantage of TEVAR is temporary. Interestingly, with the increase in the use of TEVAR, the literature has also shown a corresponding increase in stent graft-related mortality rates over time.

Chronic dissection is more difficult to treat, and the results are generally less favourable. The dissection flap becomes rigid over time, and retrograde filling of the false lumen, despite TEVAR, can lead to persistent pressurization and expansion. Generally, a proximal thoracic endograft is placed first, while subsequent staged endovascular procedures or fenestrated grafts may be used later to seal additional distal tears. A new innovative approach is to introduce a large-calibre, blind-ended occluder into the false lumen adjacent to the main stent graft to prevent retrograde false lumen fill. Alternatively, a wide-bottomed stent graft may be used to expand the distal landing zone forcefully in order to seal the false lumen (the ‘kickerbocker’) procedure.

Currently, TEVAR for treating type A dissection has been limited to very selected patients, and the use of devices in the ascending aorta remains experimental. In major cardiovascular centres, a hybrid procedure may be contemplated for complicated type A dissections. The ascending aorta and arch may be replaced by an open ‘frozen elephant trunk’ procedure under cardiopulmonary bypass, and a hybrid prosthetic branched graft is sutured proximally. Its distal end consists of a self-expanding stent graft, which is introduced under direct vision (or guide-wire guidance) into the false lumen. This may be the best one-step treatment for suitable patients.

### Thoracoabdominal aneurysms and branched stent grafts

The use of TEVAR or EVAR in patients with true thoracoabdominal aneurysms has evolved rapidly. In the past, an abdominal debranching procedure has been used, whereby separate bypasses are constructed from the healthy lower abdominal aorta or iliac artery to the visceral and renal arteries via a laparotomy. Tube endografts are then deployed to seal the aneurysm and cover the native origins of these vessels. This tedious procedure is not without morbidity and has largely been abandoned in favour of fenestrated and branched devices.

Custom multifenestrated endografts have been used to treat thoracoabdominal aneurysms and dissections. A large contralateral femoral sheath is needed to allow the operator to access multiple target vessels with smaller sheaths and bridge these with covered stents. A high degree of accuracy and planning is necessary, and placement errors and misalignment can have disastrous consequences and even death.

If the aneurysm is large enough, an alternative approach is to design an endograft with multiple downward-pointing side-branches (either angled or helical). This ‘branched’ endograft can be placed first, and the femoral arteriotomy is then closed to preserve lower limb blood flow. Meanwhile, the side-branches would allow visceral vessel perfusion. The target vessels are then cannulated individually from above via the left brachial artery or axillary artery (Fig. 8). The obvious advantages of this procedure are fewer concerns for visceral and lower limb ischaemia, and more flexible positioning of the stent graft. Cannulation from above is also technologically easier, and there will be less instrument clutter. There may also be a durability advantage compared with fenestrated grafts because of the more anatomical position of the caudally directed side-branches. A recent large series on fenestrated and branched grafts for treating type II and III thoracoabdominal aneurysms incorporating 1305 fenestrations and branches reported 96% target vessel preservation, low mortality (7% for type II and 3.5% for type III), spinal cord ischaemia incidence of 4%, and a 7.6% reintervention rate.

Branched thoracic endografts can be combined with a number of fenestrations as a custom design to accommodate various anatomies. A standard off-the-shelf T-branch option has also been developed with a choice of tube extensions and has proved to be equivalent to custom branched grafts in terms of performance and operating time.

As in all instances of extensive thoracoabdominal aortic coverage, paraplegia is the main concern for endovascular repair. Experienced clinicians in some centres have adopted the routine insertion of a cerebrospinal fluid drain for 48 h, controlled hypertension, and preservation of vital side-branches (left subclavian and internal iliacs) to reduce the risk of paraplegia.

In centres where these endografts are not available, surgeons have come up with innovative solutions, including the placement of multiple covered stents in the contralateral limb of a standard bifurcated endograft to act as ‘branches’, on-table

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Fig. 8 A four-vessel branched endograft, with covered stents to visceral vessels, successfully excludes a thoracoabdominal aneurysm.
physician modifications, or a parallel 'sandwich' technique incorporating multiple covered stents. Although ingenious, the durability of these devices is in question, and no doubt they will be replaced by commercial devices once they are available.

**Multilayer flow modulators**

In certain patients with complicated thoracoabdominal aneurysms but who are unfit for open surgery or even endovascular stent grafts, a company has proposed a concept of placing a series of multilayer bare stents in an overlapping fashion in the aorta. The concept is based on haemodynamic principles, and the stents act as a flow modulator to preserve side-branch perfusion yet allow thrombosis in the aneurysm. Reports after years of trials have yielded inconsistent results to justify widespread usage. A recent UK pilot study on 14 patients could not confirm the efficacy to prevent aneurysm expansion, while the rate of stent dislocation was high.50 Further review of this concept is necessary.

**Hybrid interventional operating theatre**

In view of these developments, intraoperative imaging demands are on the increase, and image quality and field of view are vital to successful modern vascular surgery. The vascular surgeons of today work in a purpose-built hybrid operating room environment. Modern fixed C-arm equipment includes software for preoperative planning and fusion of computed tomography (CT) images to intraoperative fluoroscopy. On-table CT scanning can be done on completion of the procedure to check for anatomical positions and endoleaks before the patient leaves the operating table.

Complex endovascular procedures often involve multiple access sites, such as the femoral, left infra- or supraclavicular, and right cervical incisions. One or two teams of operators may need to occupy these positions, coupled with the C-arm and multiple monitors. The placement of the anaesthetic machine and tubes should be anticipated in positioning the patient and discussed before surgery.

As procedures become lengthy, radiation protection is essential both for the patient and for the operators, anaesthetists, and nurses. Although there have been a number studies on radiation exposure in endovascular procedures that confirm operator safety, it is good practice to adhere to rigid screening protection, wear radiation aprons and glasses, and avoid angled C-arm projections. The radiation dose is generally higher in TEVAR than EVAR, and also during digital subtraction acquisition runs. Basic knowledge of radiation protection and good practice are required to minimize the risks of radiation exposure.

**Conclusion**

Vascular surgery has undergone an unprecedented transformation in the last two decades, largely driven by technology and physician innovation. The plethora of procedures and theories described are but a proportion of what is possible. Endografts and procedures may become outdated or superseded by improved versions within a short time, and large-scale randomized trials are difficult to perform. Although not all these technologies are available and operator skills and equipment may vary, everyone involved in managing patients undergoing vascular surgery should strive to keep themselves informed of the latest evidence and exercise meticulous planning and patient selection to ensure continuing success.

**Declaration of interest**

None declared.

**References**


Handling editor: Michael Irwin