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Thoracic endovascular aortic surgery

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In both acute and elective environments, endovascular aortic repair (EVAR) has become a viable mainstream treatment option for aortic pathology.[1] Technology has advanced with new devices and novel procedures available. Anaesthetists face the challenges of blood pressure control and prevention of paraplegia and stroke.[1] These notes will not address specific anaesthetic considerations for EVAR of the ascending aorta although some of these principles may apply.

Open surgical repair (OSR) has been the gold standard in the treatment of descending thoracic aortic aneurysms (DTAAs).[2] Operative mortality has decreased (2.9%) due to medical advances, but the conventional OSR is still generally associated with substantial morbidity and mortality in patients who are usually elderly and have a large comorbid load.[2] As a result, EVAR has become a standard technique to treat thoracic and abdominal aortic aneurysms with resultant reduced perioperative morbidity and mortality.[3] Due to advances in endograft technology with resultant better procedural success and fewer complications, its use has been expanded to younger patients and uncomplicated dissections.[4]

Thoracic aorta aneurysmal disease has an incidence of 6 per 100 000 population.[4]

Thoracic aorta disease includes aneurysms and dissections that can occur separately or together and can be congenital or acquired.[5] Acquired disease is because of hypertension and atherosclerosis. Congenital causes include connective tissue diseases and polycystic kidney disease.[5]

Thoracic aortic aneurysms (TAAs) are classified according to the Crawford Classification.[4] (Figure 1) The ascending aorta/aortic arch accounts for 60% of TAAs, and the descending thoracic aorta accounts for 40%.[4]

The **risk factors** for aneurysm development are summarised in Table I.[4,7]

Patients are usually offered surgery once the anteroposterior diameter is ≥ 5.5 cm as the risk of rupture increases exponentially thereafter[7] (Table II).

Table I: The most significant risk factors[4,7]

Non-modifiable	Modifiable
• Family history of aneurysmal disease	• Hypertension
• Advanced age	• Tobacco use
• Male	• Hyperlipidaemia
• Connective tissue diseases:	• Infections: Syphilis (rare)
◦ Marfan syndrome	• Inflammatory vasculitis: Takayasu arteritis (rare)
◦ Ehlers-Danlos Type IV syndrome	• Trauma
◦ Loeys-Dietz syndrome	

Table II: Annual risk of rupture with size of aneurysm

Aneurysm diameter (cm)	Annual rupture risk (%)
4.0–4.9	0.5–5
5.0–5.9	3–15
6.0–6.9	10–20
≥ 7.0	20–50

Aortic arch anatomy, the extent of aortic arch disease, and the available landing zones dictate the nature of the endovascular repair.[6]

Thoracic endovascular aortic repair (TEVAR) is a minimally invasive approach to repair thoracic and thoracoabdominal diseases using endovascular technology. TEVAR was originally used to treat poor surgical candidates who would not tolerate an OSR, but it has become the preferred approach to treat:[1,4]

- Fusiform and saccular descending thoracic aortic aneurysms (DTAAs)
- Acute and chronic type B aortic dissection (TBAD) (Figure 1: Standford Dissections Classification)
- Blunt thoracic aortic injury/traumatic aortic injuries
- Penetrating atherosclerotic ulcers (PAUs)
- Extensive thoracoabdominal aortic aneurysms (TAAAs)
- Ruptured aortic aneurysms

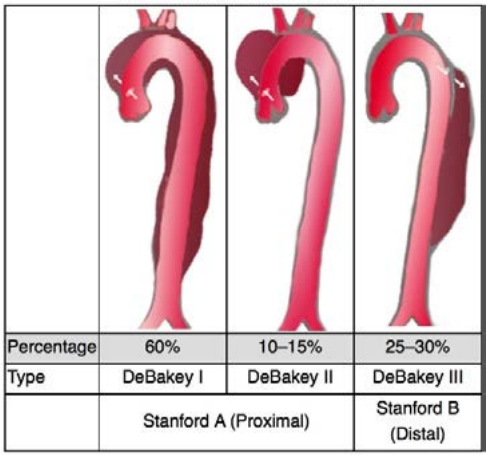
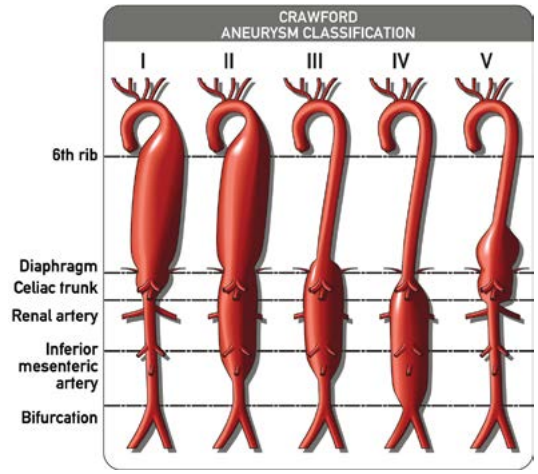
Dissection	Aneurysms
• A *dissection*: results from disruption of the intimal layer of the aorta with bleeding within the wall.[5] • Associated with trauma or an increase in physical activity/stress causing acute hypertension.[5] • The survival rate of untreated aortic dissections is poor.[5] • The usual cause of death is rupture or fatal bleeding.[5]	• A *true aneurysm* of the aorta: a permanent dilatation > 50% than its original size involving all wall layers.[5] • A *pseudoaneurysm*: results from rupture through the layers of the aorta held together by blood and surrounding tissues.[5] • Untreated descending and thoracoabdominal aorta aneurysms > 6 cm in diameter: 14.1% annual rate of rupture, dissection or death.[5] • 5-year survival with conservative management: 10–20%.[5] • Indications for surgery: individual assessment of the patient whereby the predicted operative risks are less than the risks of medical treatment.[5] • Indications include:[5] ◦ Rupture/acute dissection ◦ Symptomatic enlargement: pain/compression of structures ◦ Aneurysm enlargement: > 1 cm/year or rapid increase in size ◦ Absolute size > 6.5 cm/> 6.0 cm with connective tissue disease
Classification of aortic dissection  https://doctorguidelines.com/2017/06/28/acute-aortic-dissection/	 https://commons.wikimedia.org/wiki/File:D3ON0p6B.jpg
Aortic dissection can be described using the DeBakey and Stanford classifications.[5] **(i) DeBakey classification:** comprises three different types, depending on where the intimal tear is located, and which section of the aorta is involved.[5] **Type I:** intimal tear in the ascending portion; involves all portions of the thoracic aorta. **Type II:** intimal tear in the ascending aorta; involves the ascending aorta only, stopping before the innominate artery. **Type III:** intimal tear located in the descending segment; almost always involves the descending thoracic aorta only, starting distal to the left subclavian artery; can propagate proximally into the arch. **(ii) Stanford classification:** comprises two types, depending on which section of the aorta is involved.[5] **Type A:** with any involvement of the ascending aorta, regardless of intimal tear location or extent of dissection; runs a more virulent course. **Type B:** involves the aorta distal to the origin of the left subclavian artery; generally, medically managed unless there is evidence of a life-threatening complication, such as impaired organ perfusion, aortic rupture, severe pain, or uncontrollable hypertension.	TAAAs are described using the location of the aneurysmal sections in the Safi modification of Crawford Classification:[4,6] **Type I** arises from above the sixth intercostal space, usually near the left subclavian artery, and extends to include the origins of the celiac axis and superior mesenteric arteries. Although the renal arteries can also be involved, the aneurysm does not extend into the infrarenal aortic segment. **Type II** aneurysm also arises above the sixth intercostal space and may include the ascending aorta, but extends distal to include the infrarenal aortic segment, often to the level of the aortic bifurcation. **Type III** aneurysm arises in the distal half of the descending thoracic aorta, below the sixth intercostal space, and extends into the abdominal aorta. **Type IV** aneurysm generally involves the entire abdominal aorta from the level of the diaphragm to the aortic bifurcation. **Type V** aneurysm arises in the distal half of the descending thoracic aorta, below the sixth intercostal space, and extends into the abdominal aorta, but is limited to the visceral segment.

Figure 1: Classification of aortic dissection and aneurysm[4,5]

Medical and surgical society guidelines suggest an individualised approach when deciding on endovascular repair, taking into consideration the patient's age and risk factors for morbidity and mortality.[6] The are no randomised control trials directly comparing open and TEVAR but observational studies suggest reduced short-term mortality and complications with reduced length of stay,[6,8] while a retrospective review showed no difference in mortality or spinal cord ischaemia.[8]

The benefits of TEVAR to OSR include:[6,7]

- Avoidance of a sternotomy and thoracotomy, i.e., minimally invasive
- Less of a physiological insult with less haemodynamic instability
- A decreased metabolic stress response
- No need to cross-clamp the aorta
- Less blood loss

- Less pain
- Reduced length of ICU
- Earlier ambulation resulting in a shorter hospital stay
- A lower incidence of end-organ ischaemia
- Fewer complications with fewer episodes of respiratory dependency and
- Quicker recovery with a more favourable 30-day survival
- Suitable for 'inoperable' patients

Surgical considerations

A preoperative review of the surgical approach is necessary to plan the anaesthetic care.[9]

Preoperative imaging is important for reviewing anatomical suitability and adequate stent graft sizing. Advances in imaging allow for an accurate 3-dimensional reconstruction of the aortic aneurysm for precise anatomic measurements.[4] This allows for optimal pre-procedural planning, stent choice and production.[6] It also allows for identification of the exact location of the artery of Adamkiewicz when evaluating the risk for spinal cord ischaemia (SCI).

Imaging should be available for at least 10 mm proximal and 10 mm distal to the affected aortic territory to evaluate for adequate graft landing zones.[4] In highly angulated anatomy more length is frequently required to ensure good sealing.[4]

Planning for TEVAR by vascular surgeons involves: choice of imaging, aortoiliac evaluation, zones of attachment (proximally and distally), choice of the endograft and adequate endograft sizing and evaluating the need for debranching procedures and its timing in relation to the TEVAR.[6]

Anaesthetic considerations

Anaesthetists play a vital role in the perioperative management of vascular patients including:[10]

- Preoperative assessment, risk stratification and optimisation
- Multidisciplinary team (MDT) discussions regarding risk versus benefit
- Intraoperative management to maintain haemodynamic stability and preserve organ function
- Preparation for significant blood loss
- Identification of the optimal level of postoperative care.

Suitability for TEVAR surgery

Location and expertise

Evidence shows reduced mortality from elective repair in centres which carry out more than 32 cases per year. Patients should be discussed at an MDT meeting consisting of vascular surgeons, interventional radiologists, anaesthesiologists with an interest in vascular anaesthesia and intensive care physician. A joint decision should be made, weighing up factors such as technical issues, physiological fitness and life expectancy of the patient, short- and long-term benefit and risks of the procedure and the patient's wishes. Ideally, TEVAR should take place in a specialised radiology suite (remote-site anaesthesia considerations would apply) or in a hybrid operating theatre suite with appropriate angiography facilities and the ability to convert to an OSR if required.[7] All theatre staff must wear radiation-protecting lead gowns while imaging is undertaken with regular exposure audits.

Technical suitability

Discussed under surgical considerations.

Preoperative evaluation and optimisation

The goals for preoperative assessment in TEVARs include:

- An MDT approach
- Optimisation of comorbidities and functional capacity assessment
- Cardiac risk assessment with referral to a cardiologist as indicated
- Pharmacological optimisation
- Renal optimisation

There is no universally accepted single risk stratification tool for vascular surgery.[10] Preoperative cardiovascular risk assessment should be individualised in keeping with institutional preoperative assessment published guidelines used to assess the risk of major adverse cardiac events (Lee's revised cardiac risk index, The American College of Surgeons NSQIP Surgical Risk Calculator, ACC/AHA, ESC, Canadian or South African guidelines for non-cardiac surgery). Scoring systems have limitations.[11] They should be used to supplement the clinical judgement of the involved clinicians in discussion with the patient.[11]Assessment of functional capacity and reserve of each organ system for risk stratification and prediction of postoperative complications.[5] The focus is on age, physiological reserve, risk stratification, antiplatelet and anticoagulant medication cessation/bridging, smoking cessation and optimisation of major cardiovascular, pulmonary, neurological, and renal comorbidities to decrease modifiable risks.[1]

A retrospective analysis of subjects who had a TEVAR found that a significant number had the following comorbidities:[12] hypertension (HT) (87%), coronary artery disease (29%), chronic obstructive pulmonary disease (COPD) (27%), chronic kidney disease (26%) and diabetes (15%).[12] Patients should therefore be evaluated comprehensively preoperatively and prepared as if undergoing an OSR and should address the presenting disease, comorbid conditions, procedural considerations and potential complications.[12]

Functional capacity

A patient's functional capacity should be measured by objective cardiopulmonary exercise testing (CPET) or an incremental six-minute walk test.[11] Results which indicate increased risk in the perioperative period include:[11]

Table III: Preoperative optimisation strategies[4,13]

	Comorbidities	Investigations	Optimisation	Medication
Cardiovascular disease	• Any active cardiac conditions should be referred to a cardiologist for medical and/or interventional optimisation • If for intervention (although rarely performed) – consider revascularisation guidelines not discussed here	• N-terminal pro-brain natriuretic peptide (Pro-BNP) – raised levels suggest increased risk especially with cardiac failure • Baseline Troponin T • Screening electrocardiogram (ECG) – exclude arrhythmias/ischaemia • Transthoracic echocardiography (echo) (TTE) is part of the recommended diagnostic evaluation for patients presenting for TEVAR[4]	In patients with two risk factors and poor functional capacity, it is recommended that a non-invasive cardiac stress test is performed if it will change management[10]	• Cardiac medications such as β-blockers, aspirin, angiotensin converting enzyme inhibitors (ACEI) and statins should be continued perioperatively[10] • Day of surgery – withhold ACEI and ARBs, continue aspirin, other anticoagulants should be stopped or bridged according to guidelines[10]
Respiratory disease	Monitor for respiratory symptoms due to a large aneurysm	• Arterial blood gas • Pulmonary function testing (PFT): in patients with known/suspected COPD to guide preop optimisation, intraoperative ventilation strategies, and postoperative rehabilitation[4]	• Smoking cessation 4–6 weeks prior to surgery • Bronchodilator optimisation with reversible airway disease • Eradication of active infection • Steroid treatment – reduces bronchospasm risk with reactive airway disease • Physiotherapy – incentive spirometry/practice postoperative breathing exercises[13]	Potentially preop steroids or bronchodilator therapies depending on PFT and clinical presentation[13]
Neurologic	Thorough neurological assessment due to potential for stroke and paraplegia with TEVAR Risk factors for paraplegia: • Advanced age • HT • COPD • Renal failure • History of AAA/concomitant AAA repair • The extent of the graft coverage required[4]		High-risk patients – consider a prophylactic cerebrospinal fluid (CSF) drain (though there is little evidence regarding the timing of placement)[4]	
Renal disease	• High risk for acute kidney injury (AKI) postoperatively (incidence: 0.7–2%)[3] due to: ◦ Use of intravenous contrast, increasing age, para-renal stents, multiple comorbidities, complexity of TEVAR, perioperative dehydration, and nephrotoxic medications • Assess volume status and renal function due to the risk of contrast-induced nephropathy (CIN) • Identification allows for early intervention, e.g. maintaining higher intraop MAP	• Preop UCE • Correct any acid-base disturbances	• Overnight intravenous crystalloid hydration • If receiving preop dialysis – appropriate time interval prior to surgery with post-dialysis bloods prior to subsequent surgery • Strategies to minimise AKI: ◦ Maintain adequate hydration ◦ Limiting contrast load ◦ Omitting nephrotoxic drugs • Meta-analyses: not shown compelling evidence for the use of N-acetyl cysteine in the prevention of CIN[13]	• Discontinue nephrotoxic drugs: metformin, aminoglycoside antibiotics, ACEI, high-dose loop diuretics
Diabetes	HBA1C > 8.5%/hypoglycaemic episodes should be referred for optimisation	• Fasting glucose • HBA1C	• Ideally placed first on the list to minimise fasting/allow early resumption of diabetic diet and medications	
Anaemia		• FBC – Hb evaluation	• Elective surgery: aim for haemoglobin (Hb) > 12 g/dL for females and 13 g/dL for males	• Iron or erythropoietin treatment

- Peak oxygen consumption (pVO2) < 16 ml/kg/min
- Anaerobic threshold < 11 ml/kg/minute
- Any cardiac ischaemia induced during testing
- Abnormal CPET may lead to referral to relevant teams for further assessment and optimisation.

Specific anaesthetic considerations related to TEVAR

Potential for open conversion – potential for rupture with catastrophic bleeding and cardiovascular collapse.[2]

Peripheral vascular disease – risk for access-site complications (vascular injury and bleeding) due to the degree of atherosclerotic disease affecting vessel calibre and tortuosity. Ideally should be assessed preoperatively via CTA/MRI.[2]

Adjunctive procedures – debranching procedures and retroperitoneal dissections to create surgical conduits for vascular access are associated with:

- greater blood loss,
- longer procedure times, and
- longer length of hospital stay. (As compared to TEVAR with standard femoral access.[2])

Anaesthesia and intraoperative management

Site and setup

As discussed in location and expertise: four main principles apply, namely: hybrid theatres, remote site considerations, point-of-care testing facilities available and radiation exposure.

Intraoperative monitoring

Standard ASA monitoring which includes 5-lead ECG to detect myocardial ischaemia and/or arrhythmias, pulse oximetry, intermittent non-invasive blood pressure (BP) measurements.[3,10] Temperature monitoring and hourly urine output.[3,11] Cardiovascular and neuromonitoring may be employed.[3] Despite the numerous safety advantages with TEVAR, neurological complications such as stroke (2–8%) and SCI have not been eliminated and remain important causes of postoperative morbidity and mortality.[2,14]

Cardiovascular monitoring includes:

- *Invasive arterial blood pressure measurements* – optimally established in the right arm because the innominate artery may be occluded if the stent covers the left subclavian artery. Additionally, the left arm may be used on occasion for vascular access.[3] Usually inserted aseptically awake under local anaesthesia.[9] This allows for monitoring of potential significant haemodynamic changes that may occur at induction and at any time throughout the perioperative period.[10] It also allows for acid-base analysis, Hb monitoring and point-of-care testing (coagulation status).[10] The surgeon may request to monitor distal limb pressure to evaluate for adequate flow after stent deployment.[3] Pressure tubing connected to the distal limb artery can be attached to the pressure transducer.[3]
- *Central venous catheter (CVC)* – individualised based on the patient's clinical presentation. It is usually only indicated if obtaining large bore intravenous access is difficult or if the use of any vasopressors or inotropes is anticipated.[3,11]
- *Transoesophageal echocardiography (TOE)* – allows for real-time dynamic assessment of cardiac function but is heavily dependent on the operator's ability and interpretation.[11] Its use provides the ability to access aortic anatomy, assist the surgeon with positioning and deployment of the endograft accurately at the target location, and then confirm correct positioning and detect endoleaks.[3] A disadvantage is that it requires the use of general anaesthesia.[3] However, no data demonstrates that TOE monitoring reduces the risk for adverse perioperative cardiovascular events in vascular surgery.[3]

Neuromonitoring for spinal cord ischaemia: the goal is to initiate interventions to immediately treat evidence of spinal cord ischaemia to avoid irreversible injury.[9]

- *Somatosensory evoked potentials (SSEP) and motor evoked potentials (MEP)* – volatiles significantly decrease the amplitude and increase the latency of evoked potentials. Propofol and opioids have a milder effect.[4,9] Therefore, consider a total intravenous anaesthetic or a low-dose volatile anaesthetic concentration to ≤ 0,5 minimum alveolar concentration (MAC) and avoidance of neuromuscular blocking agents.[4,9] Ketamine infusions may be used to augment amplitudes allowing lower doses of other anaesthetic agents.[4,9]
- *Near-infrared spectroscopy (NIRS)* – a minimally invasive modality. Used to monitor cerebral and spinal cord tissue oxygenation to correlate perfusion.[4] Cerebral perfusion with optodes placed on the forehead monitors perfusion originating from the anterior and middle cerebral arteries.[4] Bilateral decrease in regional oxygenation suggests global hypoperfusion and unilateral decrease suggests a focal event, e.g. embolic stroke, new arterial dissection.[4,9] Placement of the optodes on the thoracolumbar paraspinous muscles to measure tissue oxygenation supplied by collateral network vessels of the spinal cord in small studies suggested spinal cord hypoperfusion with the application of cross-clamp or deployment of the endograft (decreased lumbar tissue oxygenation).[4] There is a need for larger prospective studies to support the routine use of NIRS for spinal cord perfusion monitoring.[4,14-16]

  If global hypoperfusion is > 10% compared with baseline, efforts to increase oxygen delivery include:[9]

  - Increasing MAP by administering a vasopressor
  - Ensuring adequate cardiac output
  - Increasing the fraction of inspired oxygen (FiO_2) if necessary to ensure adequate oxygen saturation of systemic arterial blood
  - Maintaining arterial partial pressure of carbon dioxide ($PaCO_2$) > 35 mmHg
  - Deepening the anaesthetic to decrease the cerebral metabolic rate of oxygen consumption ($CMRO_2$)

  - Red blood cell transfusion if haemoglobin < 8g/dL to increase blood oxygen-carrying capacity
- *Spinal cord drains* – the use of CSF drainage is achieved by inserting a catheter into the CSF preoperatively below the level of L1–L2 and draining fluid to a set pressure.[10] Decreased spinal cord perfusion pressure (SCPP) is thought to be the mechanism for SCI during TEVAR.[4] SCPP = MAP – CSF pressure: perioperative strategies for decreasing the incidence of SCI are focused on increasing MAP and CSF drainage to reduce CSF pressure.[4] Target a MAP of 85–100 mmHg and a CSF pressure of 10–15 mmHg to achieve a spinal cord perfusion pressure ≥ 70 mmHg.[1] Catastrophic central nervous system bleeding can occur due to excessive drainage thus avoid draining > 10 ml/hour, 25 ml/4 hours or 150 ml/24 hours.[1] Post-TEVAR drains can be removed after 24–28 hours, depending on the complexity of the repair and whether reliable neurological examination is possible.[1] There is insufficient evidence supporting the routine use in TEVAR.[4] Consider spinal drainage where there will be extensive coverage of the thoracic aorta, previous history of OSR/EVAR or if occlusion of the internal iliac artery is present.[6] There is an opinion that the potential complications of CSF drains (Table V) outweigh the benefits of preoperative placement in low-risk patients, and thus, it is suggested that only if evoked potential monitoring suggests SCI or if motor weakness develops postoperatively that a drain be placed.[4] In a systemic review of 4 714 patients having OSR or TEVAR CSF drainage-related complications were as reflected in Table V and mortality was estimated to be 0.9%.[9]

Anaesthetic goals

The main intraoperative anaesthetic management goals include:

- Maintaining patient comfort for 3–4 hours (if local/regional anaesthetic planned) (and even up to 12 hours in more complex cases).[10]
- To provide haemodynamic stability and preserve perfusion to vital organs.[7]
- To optimise myocardial oxygen supply-demand.[7]
- Maintaining stringent blood pressure control, especially at the time of stent deployment.[10]
- Maintaining intravascular volume with early identification and management of bleeding.[7]
- Maintaining normothermia.[7]
- Monitoring anticoagulation.[10]
- Adequate analgesia.[11]

Anaesthetic techniques/types

TEVAR can be performed using three different anaesthetic techniques, namely local (LA), neuraxial/regional (RA) or general anaesthesia (GA), with no large comparative studies showing superiority of one technique over another.[14,17] The complexity of the procedure should be considered when deciding on the anaesthetic technique.[17]

So, what is the best approach?

Table IV: Anaesthetic type

	Advantages	Disadvantages
Spinal, epidural or LA		
Epidural catheter removal needs to be timed appropriately with postoperative anticoagulants[10]	Patients remain awake	Patient movement/agitation
	Avoids tracheal intubation	Sympathectomy causing hypotension, increasing the risk of SCI
	Less haemodynamic changes as compared to GA/less of an inflammatory response	Airway manipulation can be difficult due to patient position under the C-arm[10]
	Less alteration in pulmonary mechanics[10] (avoidance of mechanical ventilation)	Anticipated prolonged duration[18]
	Early detection of aneurysm rupture as patients complain of retroperitoneal pain[10]	Gross physiological instability[18]
	Postoperative analgesia	Anticipated secondary procedures[18]
GA		
Main aim is to maintain cardiovascular stability during laryngoscopy, intubation, surgical stimulation and extubation[10]	Reduces patient anxiety[10]	Hypotension secondary to sympathectomy[17]
	Reduction of movement due to discomfort[10]	
	Allows optimal patient positioning[10]	
	Allows for suspension of ventilation for stent deployment[10]	
	Time limits of spinal/LA removed[10] (tolerance of long procedures)	
	Allows for easy conversion to an OSR ~ 1% of cases[10]	
	Allows for TOE[18] and neurophysiological monitoring[17]	
	No need for conversion of technique mid-case[18]	
	Used in patients on anti-platelet therapy[7]	

There are no randomised controlled trials favouring one technique over the other;[3] only observational data which is subject to selection bias.[3] My recommendations are:

- Most EVARs can be performed under a local/MAC or regional technique.
- Most TEVAR procedures should be considered under GA based on the anticipated length and complexity of the individual case.

Other intraoperative considerations

Heparinisation

Systemic anticoagulation with heparin is required before the graft introducer is inserted into the arterial system.[4,7] Heparin 5 000–8 000 IU[3] is given intravenously (50–100 IU/kg) to achieve a target activated clotting time (ACT) of 200–250s which should be maintained throughout the procedure until the graft is deployed and the introducer removed.[3,4,7]

Renal protection

The incidence of AKI following TEVAR is 10–15%[6] with less need for renal replacement therapy compared to OSR.[1] The risk of CIN after TEVAR is related to the higher contrast volume and aortic dissection extending into the renal arteries.[1] Important postoperative risk factors for renal dysfunction include:

- Poor preoperative renal function.
- Emboli being dislodged during stent deployment to the renal arteries.[2,10]
- Damage to renal arteries from catheter wires (stenosis or aneurysm).[10]
- Mechanical encroachment of the stent graft on the renal arteries or causing an inflammatory reaction.[2,10]
- Reperfusion injury from prolonged lower limb ischaemia.[10]
- Intraoperative hypotension (hypoperfusion) or hypovolaemia.[10]
- Use of intravenous contrast agents.[2,10]
- The need for a blood transfusion.
- The extent of the thoracoabdominal aortic disease.

To avoid postoperative renal dysfunction:[4,10]

- Maintain adequate hydration – systemic review and meta-analysis have not concluded any evidence of advantage of one type of solution over another.[10]
- Limit the use of contact agents as much as possible.[4]
- Avoid perioperative nephrotoxic agents (e.g. nonsteroidal anti-inflammatory agents and aminoglycosides).[4]

There is no compelling evidence for the use of bicarbonate or N-acetylcysteine in the prevention of CIN.[10]

Blood pressure control

Vasopressor and vasodilator agents should be readily available for immediate and precise blood pressure control.[17] Maintain systolic and mean arterial BP values within 20% of the patient's baseline, with a MAP ≥ 90 mmHg when there are concerns around spinal cord perfusion due to prior thoracic aortic replacement and/or data from ongoing SSEP monitoring.[3]

Blood loss

Blood loss is mainly from access vessels, damage to large vessels during surgery and aneurysm rupture at the time of stent deployment.[10] Cell saver and rapid infusion devices should be readily available.

Device deployment

Occasionally the "windsock" effect can be problematic. This is due to the systolic pressure during the cardiac cycle. It can force a partially deployed stent distally from its intended position, though usually only in the proximal thoracic aorta.[19] To minimise the windsock effect, some thoracic delivery systems have mechanisms to constrain the proximal portion of the stent-graft until the remainder of the device is fully deployed.[19] Where the proximal positioning of a thoracic stent-graft is critical (e.g. in short or angulated necks) overdrive cardiac pacing using a temporary pacemaker[20] (to partially occlude right atrial inflow thus dropping cardiac output) or pharmacological manipulation to lower blood pressure may be used as the device is deployed.[19] Lowering of the MAP at the time of stent deployment to decrease the risk of distal migration of the stent can be accomplished pharmacologically with the use of short-acting anaesthetic or vasoactive agents:[3]

- Propofol 10–30 mg increments
- Esmolol 10–30 mg
- Nicardipine 100–200 mcg

Ventilation is also transiently stopped at the time of stent deployment in an anaesthetised patient, or if the patient is awake, they are asked to hold their breath.[3]

Spinal cord ischaemia

SCI can be a devastating complication after TEVAR.[4] It may be transient or permanent.[4] The incidence after TEVAR is 3–6%, which is lower than with OSR (14%).[4] It, however, remains significant enough to consider aggressive perioperative monitoring and management.[4] It may be caused by occlusion of the spinal cord feeder vessels by the graft (the largest being the artery of Adamkiewicz arising from T9–T12), a thromboembolic event or perioperative hypotension.[10] The artery of Adamkiewicz is at risk of occlusion with stent grafts which extend suprarenally.[7] It supplies most of the anterior spinal arteries and arises from the aorta anywhere between T5–L3 but most commonly from T9–T12.[7] Collaterals to the spinal cord also arise from the internal iliac, inferior mesenteric and middle sacral arteries.[7] More of the thoracic and lumbar collateral arteries to the spine are occluded with long stent grafts.[7] The mechanism of SCI is as a result of crucial coverage of feeder vessels following stent deployment.[7]

Table V: Complications occurring during TEVAR[4]

Surgical complications[4]	Medical complications[4]	CSF drain complications[4,9]
Immediate	SCI, paraplegia	**Severe (2.5% incidence)**[9]
Haematoma at access-site	AKI/CIN	Epidural haematoma
Pseudoaneurysm	Acute coronary syndrome	Intracerebral haemorrhage
Aneurysm rupture	Stroke	Subarachnoid haemorrhage
Organ ischaemia – spinal cord, kidneys, bowel, liver	Mesenteric ischaemia	Meningitis
Failed deployment/maldeployment of stent	Venous thromboembolism	Catheter drainage-related neurological deficits
Long-term	Arrhythmias	**Moderate (3.7%)**[9]
Endoleaks	Postimplantation syndrome	Postdural puncture headache
Thrombosis		CSF leak requiring intervention
Infections		Fractured catheter
Endograft migration		**Minor (2%)**[9]
		Bloody tap
		Puncture-site bleeding
		CSF leak not requiring intervention
		Hypotension
		Occluded/dislodged catheters

Although rarely used, the integrity of the spinal cord pathways is tested using evoked potential monitoring. MEPs monitor the anterior corticospinal tract, and SSEPs the lateral and posterior columns of the spinal cord. Monitoring both allows for continuous monitoring of global cord perfusion.[4] Anaesthesia affects changes in the amplitude or latency of evoked potentials.[4] There is unfortunately limited evidence for using evoked potentials to reduce SCI as decreased signals are not always associated with SCI.[21,22]

SCI risk factors associated with TEVAR include:[1]

- Extent of aortic coverage
- LSA coverage
- Lengthy procedures with large bore iliofemoral sheaths
- Perioperative hypotension
- Previous infrarenal aortic aneurysm repair
- Female sex
- Renal insufficiency

SCI risk may be reduced by using spinal cord CSF drains, pharmacological adjuncts and haemodynamic management.[1]

The main goal to try and avoid SCI is to maintain a normal blood pressure intraoperatively.[10] CSF drains would only potentially be used in complex TEVAR and fenestrated EVARs.[10] Monitoring of the drain usually takes place in the critical care unit due to the complexity of the equipment and the risks involved.[10]

Endograft placement

Technical success rates are generally high.[6] Graft placement is summarised by three goals: vascular access for the sheaths, graft deployment via aortography and finally evaluation for any endoleaks.[6]

Postoperative care

Postoperatively patients are transferred to a high dependency unit or critical care unit depending on the patients' clinical condition.

In the immediate postoperative period:

- Access for complications related to vascular access – most commonly haematomas and pseudoaneurysms from the femoral introducer site.[4]
- Haemodynamic management – maintenance of MAP at the higher end of the autoregulation range and continuous monitoring of vitals. Hypotension can cause impaired perfusion of the spinal cord, kidney and other organs.[4] Excessive hypertension should also be avoided as it can result in bleeding and downstream migration of the endograft.[4]
- Assessment of metabolic state with regular arterial blood gas measurement, haemoglobin, serum electrolytes and coagulation parameters.
- Regular neurological and vascular checks for complications such as stroke, SCI, haematomas, and extremity ischaemia.[6,10] Neurological examination should be performed immediately on emergence if a GA was performed.[2] Motor deficit can present hours to days after the procedure, and early detection is vital for prompt treatment to be instituted.[4,6]
- Patients are usually allowed to eat and drink; however, continuous IV fluid therapy is encouraged to reduce the likelihood of CIN.
- Analgesia – The pain is usually minimal and can be managed with simple oral analgesics or titrated doses of opioids if required.[7,10]
- Recovery is generally rapid in the absence of complications.[6]

Complications of TEVAR[4]

Table V lists the spectrum of perioperative complications associated with TEVAR.[4]

Perioperative mortality

Perioperative mortality for TEVAR electively with second-generation grafts is low (1.9–3.1%)[6] and 30-day mortality for emergency reasons (aortic rupture – 23%/aortic dissection – 6.2%) is higher in a review of the National Surgical Quality Improvement Program (NSQIP) database.[6] Surgical complexity increased mortality and serious adverse events.[6] The overall incidence of perioperative morbidity was 9%.[6]

Ischaemic complications

Stroke

The incidence of perioperative stroke ranges from 2–8% compared to OSR.[2,6,14] Embolic strokes can occur following TEVAR due to the proximal seal zones proximity to the carotid and vertebral arteries.[6]

Risk factors include:[6]

- The need for proximal deployment of the graft
- Presence of mobile atheromata in the arch
- Prior stroke.

Spinal cord ischaemia

SCI and paraplegia can present hours to several days after OSR and TEVAR.[3] Aggressive measures to improve spinal cord perfusion should be employed with new or worsening lower limb motor weakness.[4] Most clinicians wait for a neurological deficit to develop and then immediately place a CSF drain should SCI develop.[3,24] This approach allows for a risk vs benefit approach. Prophylactic use of CSF drainage under TEVAR is associated with moderate risk and questionable benefit.[3] An algorithm for the treatment of SCI after thoracic aortic repair is available online.[3,14,23]

Postimplantation syndrome

Postimplantation syndrome can occur during the early postoperative period after endograft placement; it is thought to be due to endothelial activation (13–60%).[4,6] It is a variant of the systemic inflammatory syndrome with fever, leukocytosis and raised inflammatory markers (CRP, IL-6, TNF-α).[4] The syndrome is usually short-lived and managed conservatively.[6,10] Reactive pleural effusions are not uncommon with TEVAR, with an incidence of 37–73%.[6]

Endoleaks

Endoleaks are defined as "blood flow within the aneurysm sac external to the endograft".[4,10] The incidence of endoleaks following TEVAR is around 3.9–15.3%.[4,6] Ongoing surveillance is necessary.

Endoleaks are classified by their location and cause[4] (Figure 2) (Table VI).

Endoleaks are diagnosed intraoperatively after graft deployment, during the postoperative CT angiogram or much later with surveillance imaging.[4]

Graft migration

The incidence of graft migration (> 10 mm) caudally is 1–2.8% over a 6–12 month period.[6] Predisposing factors include:

- excessive oversizing, and
- tortuous seal zone anatomy.

Ruptured TAAA – key points[14]

- TEVAR is now considered the first-choice treatment in patients with ruptured descending TAAA (rDTAA).[14]
- Rare but life-threatening emergency.
- Annual incidence of 5/100 000.
- Reported overall mortality is up to 97%; therefore, close communication and an understanding of the events during the procedure are vital to improve outcomes.
- rDTAAs account for about 30% of all thoracic aortic ruptures.
- The feasibility of TEVAR is described for haemodynamically stable and unstable patients with ruptured thoracic aneurysms.[14]
- Limited time is available to prepare the patients and preoperative optimisation should be focused.

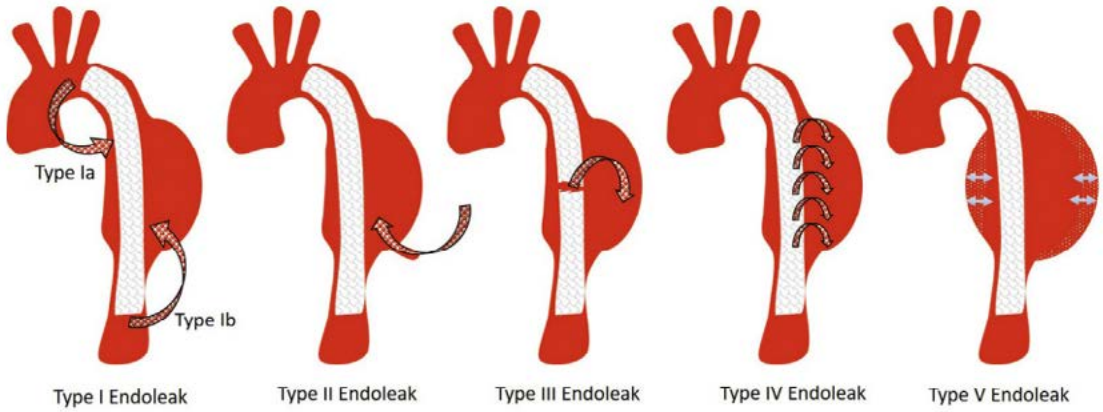


Figure 2: Classification of endoleaks[4]

Table VI: Endoleaks

Type of endoleak[4, 25]	Definition[4]	Intervention[4]
Type I	Leaks into the aneurysm sac from the proximal or distal ends of the endograft	Represent a failure to exclude the aneurysm sac from the systemic circulation and are generally treated at the time of diagnosis using balloon dilation of the existing graft or placement of a new stent
Type II	Leaks from collateral blood vessels	Managed conservatively and treated if they result in aneurysm sac expansion
Type III	Leaks between overlapping endografts or through defects in the endograft	Represent a failure to exclude the aneurysm sac from the systemic circulation and are generally treated at the time of diagnosis using balloon dilation of the existing graft or placement of a new stent
Type IV	Temporary, self-limited leaks through the endograft fabric	Usually seal spontaneously after intraoperative anticoagulation is reversed
Type V	Not true leaks, but the category is used for aneurysm sac expansion in the absence of a leak (Flow visualised but source unidentified)	Treated either with placement of a new endograft or with OSR

- Site invasive lines for monitoring before induction of anaesthesia but should not delay surgical management of haemorrhage.
- Intraoperative consideration remains the same as for elective TEVAR with regards to type of anaesthetic and monitoring. The decision to use LA or GA will depend on careful anaesthetic assessment and the clinical state of the patient.
- During TEVAR, patients should be kept in permissive hypotension prior to stent deployment while maintaining sufficient spinal cord perfusion.[14]
- Prevention of SCI remains an important objective and strategies for protection are still evolving. After stent deployment the MAP should be increased and if a CSF drain is in situ, CSF pressure decreased.[14]

Conclusion

TEVAR has revolutionised thoracic aortic surgery and is fast becoming the treatment of choice for TAAs, thoracic aortic dissections, acute aortic injuries and other conditions affecting the thoracic aorta.[4] Patients tend to have many comorbid conditions requiring optimisation preoperatively. The anaesthetic plan should thus be tailored to the patient and the surgical plan keeping potential complications in mind. The intraoperative management should optimise end-organ perfusion, facilitate neuromonitoring and haemodynamic management. Postoperative care should be in an environment where complications can be rapidly detected and aggressively treated.[4] Other important concerns are the long-term need for imaging surveillance and the costs of the health care related to this procedure.

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