An Update on Endovascular Management of Acute Thoracic Aortic Disease and Future Directions

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Thoracic endovascular aortic repair (TEVAR) has become an alternative treatment option for acute thoracic aortic disease. This review focuses on current endovascular treatment of acute thoracic aortic disease and future directions of TEVAR. TEVAR is a promising alternative approach to open surgery, with lower early mortality and morbidity rates, especially in high-risk cohorts. Furthermore, with accumulating experience and improving device technology and imaging modalities, TEVAR has become safer and has potential to expand treatment options to include ascending and arch pathologies.

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KEY WORDS

Thoracic endovascular aortic repair • Acute aortic dissection • Thoracic descending aneurysm • Stent graft

In 2005, the US Food and Drug Administration (FDA) approved the Gore® TAG® device (WL Gore & Associates, Flagstaff, AZ), for thoracic endovascular aortic repair (TEVAR) to treat descending aortic aneurysms.[1-3] Since then, TEVAR has gained increasing acceptance and is now becoming an important treatment option for aortic diseases such as aneurysms, acute and chronic dissections, and traumatic aortic injuries. Given the current prevalence of acute aortic pathologies in the range of 2 to 3.5 cases per 100,000 person-years,[4] centers of excellence readily offer TEVAR as a first-line treatment for older patients. This review focuses on the role of TEVAR in the treatment of acute thoracic aortic disease.

TEVAR for Thoracic Descending Aneurysm

Aneurysms of the descending aorta occur in approximately 10 out of 100,000 person-years.[5] Aside from medical therapy with aggressive blood pressure control and pain management, open surgical repair (OSR) has been the gold standard for treatment in the past. Both medical and open surgical treatment are still associated with high mortality and morbidity rates.[6,7]

Since the introduction of the first TEVAR device in 2005, there have been two additional devices approved by FDA for use in the United States: the Zenith® TX2® endovascular graft (Cook Medical, Bloomington, IN) and the Talent® Thoracic Stent Graft (Medtronic Vascular, Santa Rosa, CA).

Makaroun and coauthors[8] published the 5-year results of the Gore TAG trial in 2008. Early data showed a significantly lower aneurysm-related mortality after endovascular repair compared with OSR after 5 years (2.8% vs 11.7%; $P < .008$), but no differences in survival after 5 years (68% vs 67%; $P = .43$). Over the years, the TEVAR group was less likely to have major adverse events (57.9% vs 78.7%; $P < .01$) or an additional intervention (15.0% vs 31.9%; $P < .01$).[8]

Matsumura and coworkers[9] reported their experience with 230 patients with thoracic descending aneurysm (TDA) enrolled in a multicenter study from 2004 to 2006. In the Study of Thoracic Aortic Aneurysm Repair with the Zenith TX2 Thoracic Aortic Aneurysm Endovascular Graft (STARZ-TX2) clinical trial, 160 patients were treated with the Zenith TX2 TEVAR system and 70 patients underwent OSR. The 30-day mortality was lower for the TEVAR group compared with the OSR group (1.9% vs 5.7%; $P < .01$), and the cumulative major morbidity scores were significantly lower in the TEVAR group (1.3 ± 3.0 vs 2.9 ± 3.6; $P < .01$).[9]

The Medtronic Vascular Talent Thoracic Stent Graft System for the Treatment of Thoracic Aortic Aneurysms (VALOR) clinical trial enrolled 195 patients with TDA who had undergone TEVAR between 2003 and 2005. The results were compared with those obtained in 189 patients after OSR for TDA. The TEVAR group had better acute procedural outcomes compared with OSR ($P < .001$), fewer 30-day major adverse events (41% vs 84.4%; $P < .001$), a lower perioperative mortality rate (2% vs 8%; $P < .01$), and decreased 12-month aneurysm-related mortality (3.1% vs 11.6%; $P < .002$), respectively.[10]

All three systems have been shown to be safe and effective alternatives to OSR for treating descending thoracic aneurysms with better short-term results compared with OSR and much better early quality of life, but no significant advantage in long-term survival.

TEVAR for Acute Thoracic Aortic Dissection

In the presence of a type A acute aortic dissection (AAD), the patient should undergo emergent surgery with replacement of the ascending aorta.[11] In general, patients with AAD present to the emergency department with the acute onset of mid-sternal or upper back pain. If a computed tomography (CT) scan or transesophageal echocardiography (TEE) performed immediately reveals uncomplicated type B AAD, the patient should be treated in a cardiac intensive care unit for aggressive blood pressure control and pain management. Telemetry monitoring, invasive blood pressure monitoring, and supplemental oxygen should be administered. Priority should be given to cross-matching blood samples.[12]

Antihypertensive therapy should include β-blockers such as labetalol, esmolol, and metoprolol to reduce blood pressure and prevent reflex tachycardia. Reflex tachycardia may increase the maximum left ventricular contraction force (dP/dt) and has to be strictly avoided in the acute phase of the disease.[12] If β-blockers cannot be used, calcium channel blockers may be an equally efficacious alternative, without inducing reflex tachycardia. The target heart rate should be < 60 beats/min and the target systolic blood pressure < 100 mm Hg. An effective pain control regimen using morphine is recommended to tranquilize the patient and reduce stress-induced hypertension.[13-17] Hemodynamic stabilization in the acute setting is important to decrease the risk of secondary adverse events such as further dissection, branch vessel malperfusion, and weakening of the aortic wall.[18]

In the setting of a hemodynamically unstable patient with complicated type B AAD, active bleeding or septic shock should be suspected. Those patients are at risk of spinal cord ischemia, stroke, visceral ischemia, and acute renal failure.[12] If the patient's hemodynamic condition continues to worsen, intubation under general anesthesia should be performed. Additionally, resuscitation with crystalloids, colloids, and packed

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erythrocytes will help maintain hemodynamic stability and provide sufficient perfusion pressure perioperatively.

In patients with complicated type B AAD who are at high risk for open surgery, emergency TEVAR is an emerging alternative treatment option. Accurate measurements using advanced imaging software that allow three-dimensional reconstructions are of paramount importance.[19-22]

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The goal of endovascular treatment is to cover intimal entry tears with the stent graft to seal off the false lumen, redirect flow, and allow for remodeling of the true aortic lumen.[17] With regard to the expected location of the intimal tears, landing zones need to be defined and a suitable stent graft is selected, taking the iliac diameter into account. The proximal landing zones are classified into zone 0 (innominate artery), zone 1 (left carotid artery), zone 2 (left subclavian artery), zone 3 (proximal ⅓ of the descending thoracic aorta), and zone 4 (distal ⅔ of the descending thoracic aorta).[23,24]

The selection of the appropriate device is very important for TEVAR outcome and depends on the planned procedure.[25] In TEVAR, a radial or brachial artery access may be required (4F) in addition to the femoral access (12F or 14F sheath). For initial arterial access using the Seldinger technique, a nonhydrophilic-coated Bentson-type starter wire (Boston Scientific, Natick, MA, or Cook Medical, Bloomington, IN) can be used.

For intravascular ultrasound (IVUS), Platinum Plus™ guidewire (Boston Scientific), or Meier wire (Boston Scientific) is useful. If tortuous vessels are encountered, an Amplatz Super Stiff wire (Boston Scientific) or a Lunderquist Extra Stiff wire (Cook Medical) should be used instead.

Various diagnostic catheters (selective/nonselective), with diameters ranging from 4F to 6F, are used: pigtail, straight, tennis racket, and multipurpose. For aortography, a standard pigtail catheter should be used (eg, Royal Flush® Plus Pigtail, Cook Medical). For selective catheterization of aortic branches or abdominal branches, catheters with one or two curves are preferable, such as Berenstein (Boston Scientific), Vitek (Cook Medical), Headhunter (Terumo Medical, Somerset, NJ), and Simmons or Sidewinder (AngioDynamics, Latham, NY). In general, there are radiopaque markers on the catheters, which make a measurement of intraluminal distances possible.

After achieving safe vascular access, the adequate stent graft has to be selected. An oversizing of 10% to 20% from the healthy aortic diameter is commonly used for aneurysms; less oversizing is recommended for dissections. This, and a proximal landing zone of 2 to 2.5 cm (without significant calcification or circumferential thrombus), have to be taken into account. Subsequent repeat ballooning may be necessary only in the case of a type I endoleak.[13]

During stent deployment, antiimpulsive therapy is recommended to prevent stent migration in this phase.[13] This can be accomplished with medication, as well as by using rapid right ventricular pacing. The combined administration of heparin, aspirin, and clopidogrel significantly reduces the risk of embolic events.[13] The intraprocedural use of IVUS offers a more accurate measurement of the proximal and distal landing zones, a better description of the side branch anatomy, and a verification of the wire position in the true lumen in aortic dissections. After stent graft release, the adequate deployment and the complete apposition to the vessel wall can be verified and the possibility of endoleaks can be evaluated. Additionally, the use of IVUS reduces the amount of contrast medium and fluoroscopy exposure to the patient and the surgical team.[26]

If imaging reveals that the intimal tear is not sufficiently covered or the false lumen is still perfused, there is a risk of late aneurysmal degeneration. Therefore, intraoperative check for endoleaks is essential. If a type I or III endoleak is present, it must be treated. Furthermore, scheduled CT or ultrasound imaging is necessary following the procedure after 3, 6, and 12 months, and annually thereafter.[17]

The treatment of symptomatic IMH with TEVAR must be performed with regard to its basic cause, such as penetrating aortic ulcer (PAU) or vasa vasorum hemorrhage in media, as well as the progression of the disease, including enlargement of the aneurysm and ongoing dissection.

Symptomatic patients with an intramural hematoma (IMH), which occurs in approximately 5% of elderly patients and is most often located in the descending aorta,[27-30] should be managed like patients with acute type B dissections.[31] The treatment of symptomatic IMH with TEVAR must be performed with regard to its basic cause, such as penetrating aortic ulcer (PAU)

or vasa vasorum hemorrhage in media, as well as the progression of the disease, including enlargement of the aneurysm and ongoing dissection.[32] PAU is often associated with extensive atherosclerosis, with or without IMH, as well as pseudoaneurysms.[33,34] In PAU, the aortic pathology is regional and therefore the result of endovascular repair is promising.[35-38]

Prevention and Management of Complications

Vascular access injury is a major issue in TEVAR with potentially fatal sequelae. Incidence of injury to access vessels occurs in 1% to 15% of patients.[13,39-41] Using large-caliber systems (20F-24F), dissection, rupture, tear, and thrombosis of the access artery may occur with serious complications if left undertreated, ranging from claudication to severe limb ischemia and amputation.[40]

Another serious potential complication of TEVAR is paraplegia or paraparesis due to spinal cord ischemia (SCI). The European Collaborators on Stent/Graft Techniques for Aortic Aneurysm Repair (EUROSTAR) investigators[42] identified four independent risk factors for SCI: left subclavian artery covering without revascularization, renal failure, concomitant open abdominal aorta surgery, and the use of three or more stent grafts. Additionally, intercostal patency and perioperative hypotension contribute to SCI,[43] which can be prevented by placing a cerebrospinal fluid drain and increasing mean arterial pressure to 65 to 70 mm Hg. The recommended pressure in the spinal channel is 10 to 12 mm Hg.[43,44] In case of paraplegia, a catheter has to be placed emergently into the spinal channel to decrease the intraspinal pressure and thus improve the spinal cord perfusion pressure. In most cases, paraplegia can be reversed. The incidence of permanent paraparesis ranges from 0% to 4.5% and may be increased in patients with previous aortic surgery.[39]

Numerous intraoperative factors can be associated with perioperative acute ischemic stroke. The incidence varies from 3.5% to 5.5%.[8,45,46] The risk increases with arch involvement.[47] Also, the proximal landing zones 0 to 2 increase the risk of stroke due to coverage of the carotid arteries or embolization of debris. The risk of stroke can be reduced by performing staged debranching of the arch prior to TEVAR.[48] Similarly, the best approach to prevent ischemic events in the brainstem and posterior cerebral circulation is to maintain perfusion of the vertebral arteries.[49]

It is expected that any manipulation in an atherosclerotic aortic arch with guide wires and devices could lead to cerebrovascular complications secondary to plaque disruption, air embolism from deployment systems, and inadvertent coverage of arch branches. Additionally, strokes may occur during massive blood loss with hypotension or severe cardiac arrhythmias.[23] In the past, the use of transcranial Doppler ultrasound has helped surgeons select proper catheters, wires, and maneuvers to significantly reduce the embolization.[50] Furthermore, maintaining stable hemodynamics and therapeutic anticoagulation, and performing the procedure expeditiously, may further decrease the risk of stroke.[13,47]

Outcome

Any complication related to AAD, such as aortic rupture, hemorrhagic shock, and malperfusion (stroke, spinal cord injury, visceral ischemia), and any complication that cannot be managed sufficiently, increases the in-hospital mortality rate and leads to a poor outcome.[24,51]

TEVAR has shown promising results in life-threatening situations from complicated AAD. In 2009, the International Registry of Acute Aortic Dissection group reported a 20% complication rate after TEVAR and an in-hospital mortality rate of 10.6%—significantly lower rates than the respective risks of open surgery.[52]

The STABLE investigators recently published the results of a prospective single-arm multicenter study with 40 patients using a composite TEVAR for treatment of complicated aortic dissections. The study reports a 5% in-hospital mortality rate and a 90% survival rate after 1 year. A combination of covered and uncovered stent grafts demonstrated a low incidence of SCI and a paraplegia rate of 2.5%.[53,54]

In 2011, Goodney and colleagues[55] compared and analyzed data from 12,573 patients treated with OSR versus 2732 patients treated with endovascular repair. In line with results from other studies, these data show the lower perioperative mortality rate for TEVAR patients compared with OSR patients, but a worse 5-year outcome for the TEVAR group. The authors conclude that TEVAR is offered more frequently to patients at highest risk with a predictably worse long-term outcome due to their clinical situation and numerous comorbidities. This expands the number of patients treatable with TEVAR, but the adjusted long-term survival remains better in the OSR group.[55] Lee and associates[56] also discussed this problem. They reported on 400 consecutive patients receiving TEVAR with a 30-day mortality rate of 6.5% (rising to 20% in emergency cases), a SCI rate of 4.5%, and a stroke rate of 3%; the 3-year survival rate was 78%. The

authors stated clearly that their discussion about the inferior long-term survival of TEVAR patients was inadequate with regard to their preinterventional critical situation in AAD. Careful patient selection is necessary to distinguish those who will benefit from TEVAR.

The current results cannot clearly determine a long-term prognosis after TEVAR.[24] There is limited evidence as to whether TEVAR or OSR has a better long-term survival rate. Randomized studies are required to shed further light on this question.

Trends and Future Directions in TEVAR

Total Percutaneous TEVAR

Total percutaneous TEVAR without the need for inguinal dissection is an important tool to minimize postoperative complications, such as lymphocele or wound-healing complications. Percutaneous closure devices are designed to place sutures into the arterial wall prior to large sheath introduction. After the procedure and removal of the large-bore deployment devices, the previously placed sutures can be approximated and the entry deficit of the arterial wall can be closed. The Perclose ProGlide (Abbott Vascular, Redwood City, CA) device, for example, has a success rate ranging from 88% to 100%. Shorter overall procedural times as well as reduced complications, such as wound-healing problems, have been achieved.[57-60] However, deployment of these devices should be done with caution. Known contraindications are obesity, severe atherosclerosis, morbid obesity, multiple previous procedures in the target area, and an anatomically high femoral bifurcation.[61] The benefit of these devices with very low short- and midterm complications is obvious,[62] but in case problems with percutaneous closure occur, a conversion to open surgical access arterial repair is strictly recommended to avoid late complications such as pseudoaneurysms or limb ischemia.[40]

Low-profile TEVAR Devices

Major limiting factors in TEVAR are compromised vascular access and arterial tortuosity. Commonly used delivery sheath sizes are 20F to 25F with required vascular diameters from 7.3 to 9.2 mm. Low-profile devices with increased flexibility will expand TEVAR availability to patients with suboptimal vascular access, as well.[63,64] Future generation of thoracic stent grafts will focus on lower profile to reduce vascular injury in this patient cohort.

Branched and Fenestrated Grafts for TEVAR

If aneurysms or dissections involve aortic segments with important side branches such as carotid and visceral arteries, the endovascular repair has to be performed either in a two-step operation with debranching followed by endovascular graft exclusion, or totally endovascularly, using branched or fenestrated grafts. Rodd and colleagues[65] studied 70 consecutive patients with thoracic abdominal aortic aneurysms. Only 60% of the patients were identified as suitable for complete endovascular repair. In 1999, Inoue and colleagues[66] implanted surgeon-made stent grafts (1-3 side branches) into 15 patients with thoracic aortic aneurysm with a primary success rate of 60% and a median follow-up of 12.6 months; there were two late deaths. Uchida and associates[67] reported on a case of an ascending aortic rupture that was treated endovascularly using a custom-made fenestrated stent graft introduced via the femoral artery. These examples demonstrate that experience with branched endovascular aortic repair (BEVAR) and fenestrated endovascular aortic repair (FEVAR) is still limited.[68,69] Therefore Chuter and coauthors[70] are developing branched stent grafts with a simplified modular approach to make branched and fenestrated TEVAR technology ready for a more widespread use. Dijkstra and associates[71] evaluated current imaging technologies and the combinations of intraoperative imaging techniques to reduce radiation and contrast medium exposure especially in BEVAR and FEVAR cases. To date, clinical experience with BEVAR and FEVAR remains low, but it will increase using new devices and techniques.[17,67]

Devices for Ascending TEVAR

Patients with various pathologies of the ascending aorta, such as dissections, aneurysms, or pseudoaneurysms, usually end up in the operating room for open ascending aortic replacement. TEVAR for type A AAD is not yet routinely implemented.[72] The stent grafts that have been used for this purpose are commercially available descending thoracic aorta stent grafts. Taking the aortic pathology into account, antegrade access may offer better access to the true lumen.[73] Retrograde deployment is more difficult and could put the entire supra-aortic trunk perfusion at risk or trigger a rupture of the false lumen.

Only a few case reports and small series have been published. In 2004, Rayan and colleagues[74] described the endovascular repair of a mycotic ascending aortic pseudoaneurysm in a 54-year-old man using 28.5-mm × 3.3-cm Gore Excluder aortic cuff that was deployed via the left subclavian artery by cut-down. Three years later, Lin and associates[72] reported the same

procedure in 78-year-old man with an ascending pseudoaneurysm after cannulations of the aorta for coronary artery bypass graft. Its dimension was 8 × 12 cm, located in the mid segment of the ascending aorta compressing the pulmonary arteries. Due to his comorbidities, the patient was not suitable for open surgery. Under general anesthesia, using fluoroscopy and TEE, a Zenith aortic cuff device (32 × 36 cm) was delivered via the left common carotid artery with transient cardiac arrest using intravenous adenosine. No complication occurred and the 1-month follow-up CT scan identified a successful procedure without endoleak.[72] Similar case reports support feasibility and safety of ascending aortic stent grafting.

Kolvenbach and coworkers[75] reported their experience with endovascular treatment of 11 patients with ascending aortic intramural hematoma and floating thrombus after chronic type A AAD and PAU. Patients included were high risk according to the American Society of Anesthesiologists classification ≥4. Patients with acute type A AAD were excluded due to an absent ethical board approval. The combined mortality and morbidity rate was 18%. Bavaria and colleagues[76] treated 27 patients with distal arch aneurysms with a hybrid procedure consisting of debranching followed by ascending aortic stenting. They report a successful stent deployment of 100% and a 30-day mortality rate of 11%. These data were encouraging when considering hybrid repair for ascending or arch aneurysms in high-risk patients.

In order to perform TEVAR for ascending aortic pathology, such as type A aortic dissection, the available devices must be adapted accordingly, with shorter distal tips and elimination of bare springs. Problems and technical pitfalls, such as penetrating bare springs, risk of cerebral and myocardial emboli, a very short landing zone, and the risk of aortic rupture must be considered when planning the procedure.

Development of TEVAR specifically designed to address ascending aortic pathologies would be advantageous compared with open surgery and would eliminate the need for extracorporeal circulation, deep hypothermia, and circulatory arrest. Currently, we concur that ascending TEVAR should only be reserved for high-risk patients. But if the future brings a broad special device portfolio for ascending aortic TEVAR, the number of treated patients will increase.

Conclusions

TEVAR is a promising alternative approach to open surgery for treatment of acute aortic disease with lower early mortality and morbidity rates, especially in high-risk cohorts. Patient selection is important and TEVAR should be offered to those patients who will benefit the most from this endovascular procedure. The number of physicians who are performing TEVAR as a routine clinical procedure is increasing and it is leading to a broader spectrum of indications. Furthermore, with accumulating experience along with improving device technology and imaging modalities, TEVAR has become safer and holds the promise to expand treatment options to include ascending and arch pathologies. ■

Development of TEVAR specifically designed to address ascending aortic pathologies would be advantageous compared with open surgery and would eliminate the need for extracorporeal circulation, deep hypothermia, and circulatory arrest.

MAIN POINTS

- Since 2005, thoracic endovascular aortic repair (TEVAR) has gained increasing acceptance as a treatment option for aortic diseases such as aneurysms, acute and chronic dissections, and traumatic aortic injuries.
- In patients with complicated type B acute aortic dissection who are at high risk for open surgery, emergency TEVAR is an emerging alternative treatment option.
- Vascular access injury and paraplegia or paraparesis due to spinal cord ischemia, are serious potential complications of TEVAR.
- Development of TEVAR specifically designed to address ascending aortic pathologies would be advantageous compared with open surgery and would eliminate the need for extracorporeal circulation, deep hypothermia, and circulatory arrest.

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