Endovascular Repair of Traumatic Thoracic Aortic Injuries: a Critical Appraisal

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ABSTRACT
Blunt trauma to the thoracic aorta is life-threatening, with instant fatality in at least 75% of victims. If left untreated, nearly half of those who survive the initial injury will die within the first 24 hours. Surgical repair has been the standard treatment of blunt aortic injury, but immediate operative intervention is frequently difficult due to concomitant injuries. Although endovascular treatment of traumatic aortic disruption is less invasive than conventional repair via thoracotomy, this strategy remains controversial in young patients due to anatomical considerations and device limitations. This article reviews the likely advantages of endovascular interventions for blunt thoracic aortic injuries. Potential limitations and clinical outcomes of this minimally invasive technique are also discussed.

Endovascular Traumatic Aortic Repair

Lin

Figure 1. (A) Blunt aortic injury typically occurs in the proximal segment of the descending thoracic aorta, due in part to the sudden disruption of the aortic isthmus. (B) Successful repair of a blunt aortic injury can be accomplished using an endoluminal approach.

descending aorta (Figure 1). The isthmus is the most common site of rupture (50%-70%), followed by the ascending aorta or aortic arch (18%) and the distal thoracic aorta (14%). The objectives of this review are to examine the role of thoracic endovascular aortic repair (TEVAR) of blunt aortic injury, to analyze current literature on TEVAR, and to assess the challenges of this treatment modality.

PROTOCOLS FOR THORACIC ENDOVASCULAR REPAIR OF TRAUMATIC AORTIC INJURY

TEVAR offers many practical advantages compared to conventional open repair. Because most thoracic aortic injuries are located in the proximal portion of the descending thoracic aorta, endovascular exclusion with a stent-graft is a logical consideration. In patients with thoracic aortic injuries who have adequate proximal and distal aortic landing zones, deployment of a stent-graft to cover a focal lesion can be performed straightforwardly. TEVAR should not be undertaken in patients with trivial aortic injury or one based on computed tomography screening alone.

Common physiologic insults associated with open repair of thoracic aortic injury, such as thoracotomy, aortic cross clamping, extracorporeal circulation, and single-lung ventilation, can be avoided by TEVAR. Exclusion of a descending aortic disruption with an endograft does not necessitate cross clamping the aorta, which minimizes blood pressure shifts. This also reduces surgical blood loss and ischemic events involving the spinal cord, viscera, and kidneys. Moreover, avoidance of thoracotomy has obvious convalescent advantages in patients with other organ injuries, particularly to the head or lung.

Because the force responsible for blunt aortic disruption frequently results in injuries to other organs, prompt endovascular exclusion of an aortic pseudoaneurysm or transection can be performed without undue delay for surgery for other injuries. This contrasts with open aortic repair that requires recovery from any major operative intervention or intensive therapy for life-threatening complications of blunt trauma. Moreover, the use of systemic anticoagulation with heparin by some surgeons during endovascular aortic procedures can be minimized, which is particularly beneficial in patients with
intracranial, pulmonary, or abdominal injuries. In those with adequate femoral artery access, this procedure can be performed under local anesthesia, without incurring significant cardiopulmonary stress.

**LIMITATIONS OF ENDOVASCULAR REPAIR OF AORTIC INJURY**

While endovascular repair has some obvious advantages compared to open repair, one must keep in mind potential shortcomings of this treatment. An alarming incidence of persistent endoleak following endovascular exclusion of traumatic aortic pseudoaneurysm has been reported. There are still real concerns of late complications such as endograft migration or device infection due to fistula formation. Furthermore, given the limited commercial availability of endovascular devices, not all patients with traumatic aortic disruption have adequate aortic morphology to undergo this repair. Lastly, critics of this treatment often cite the lack of long-term durability studies justifying the use of an aortic endograft in young trauma victims who may well tolerate the physiologic stress of open repair. Several potential device-related shortcomings and limitations of TEVAR in aortic trauma are discussed below.

**INCOMPATIBILITY OF FDA-APPROVED DEVICES IN THE YOUNG**

The GORE TAG Thoracic Endoprosthesis (WL Gore, Flagstaff, AZ, USA) is currently the only device to receive Food and Drug Administration (FDA) approval for clinical application; it is designed for patients with thoracic aortic aneurysms, who typically have larger aortic diameters. An anatomical challenge of TEVAR for aortic injury in the young is their relatively small aortic diameter compared to elderly patients with thoracic aortic aneurysms. Elderly patients usually have a greater aortic arch curvature, due in part to the aging process, resulting in aortic elongation (Figure 2A). This wide arch curvature is well suited to endograft implantation, with a low risk of device kinking. In contrast, the aortic arch in young trauma victims typically has a more acute curvature (Figure 2B), which may result in poor endograft apposition (Figure 3). Other anatomical considerations in young trauma patients are their smaller iliac or femoral access vessel diameters, and the fact that aortic disruption frequently occurs immediately distal to the left subclavian artery, in contrast to thoracic aneurysms that can occur in any segment of the thoracic aorta.

In a study by Borsa and colleagues who analyzed the angiographic morphology of 50 trauma victims with thoracic aortic disruption, the mean aortic diameter adjacent to the injury was 19.3 mm. The available GORE TAG devices range from 26 to 40 mm in diameter. As this device was not designed for traumatic aortic lesions, placement of even the smallest available GORE TAG device in young patients might lead to inadequate device fixation. The GORE TAG device should not be > 18% of the aortic diameter, according to the FDA-approved instructions for use. As the smallest device has a diameter of 26 mm, placement in aortas of 14-, 16-, 18-, and 20-mm diameter would result in 86%, 63%, 44%, 30% oversizing, respectively.

**ENDOGRAFT COLLAPSE DUE TO OVERSIZING IN THE YOUNG**

The GORE TAG device remains the only FDA-approved thoracic endograft, and available literature indicates that only 9% of applications are in trauma cases. Because the smallest diameter of this device is 26 mm, deployment in patients with aortic diameters < 23 mm represents a device oversize beyond the manufacturer’s recommendation, which may result in suboptimal performance (Figure 3). All adverse events reported to date with the GORE TAG device were largely due to oversizing. Food and Drug Administration-approved instructions for use are: a healthy neck length ≥ 2 cm, which may cover the left subclavian artery if necessary; oversize range of 7%–18% incorporated into the sizing guide; measure lumen flow, do not include adventitia or calcium, but include thrombus if present; use case planning forms; neck taper must be within device sizing range, especially important around the arch transition; and neck angles < 60° for more than 2 cm of neck engagement.

Several reports have described GORE TAG collapse along the aortic arch following TEVAR for aortic injury. Idu and colleagues reported a case of GORE TAG collapse 3 months after endovascular repair: a 26-mm diameter GORE TAG was implanted in a young trauma patient whose aortic diameter was only 19 mm, which represents a 37% device oversize. This resulted in wrinkling of the proximal segment of the endograft. While the initial aortogram revealed no gross abnormality following deployment, wrinkling of the proximal segment eventually led to device collapse, due in part to the high aortic pulsatile force. This condition was ultimately remedied by placing a Talent thoracic endograft to expand the collapsed GORE TAG device.

Muhs and colleagues analyzed various anatomical factors associated with endograft collapse following GORE TAG repair of 5 aortic injuries and 1 aortic dissection. By comparing the anatomical features with those of 5 control patients with similar treatment indications who did not develop endograft collapse, 2 predictors of thoracic endograft collapse were identified: distal aortic sealing zone diameter (18.9 vs 22.7 mm in controls), and minimum aortic diameter within the endograft (18.6 vs 22.4 mm in controls). Age, sex, graft position in the aorta, and operative indication did not influence the occurrence of endograft collapse.
Endovascular Traumatic Aortic Repair

Figure 2. (A) A wide aortic arch curvature is seen in a 65-year-old patient who sustained a blunt aortic transaction injury. (B) Angiogram of a 17-year-old traffic accident victim showing injury to the descending thoracic aorta. Note the acute sharp curvature of the aortic arch.

Figure 3. (A) Aortogram revealing a blunt aortic injury in a 16-year-old male (short arrow). (B) Placement of an oversized Gore TAG endoprosthesis resulted in poor device apposition to the aorta in the proximal landing zone (long arrow).
**Suboptimal Endograft Conformity due to Hemodynamic Factors**

An important anatomical consideration for TEVAR in young patients relates to the tapering luminal diameter of the descending thoracic aorta. Moreover, young patients typically have higher aortic pulsatile compliance and flow velocity than the elderly: a hemodynamic factor that may destabilize endograft fixation.\(^{26,27}\) Implantation of currently available non-tapered thoracic endografts in young trauma victims who have relatively narrow aortic lumens will likely lead to diameter mismatch as well as endograft oversize. Gross oversizing in a relatively small diameter aorta combined with a short radius of aortic arch curvature can result in suboptimal conformability along the inner curve of the aortic arch, leading to problems that include device fracture, endoleak, migration, and infolding (Figures 4 and 5). It is estimated that device-related complications, such as stent fracture, stent-graft compression, re-intervention, device explantation, or endoleak, occur in approximately 3% of cases.\(^{12-21}\) In addition, a semirigid stent-graft in a tightly curved arch may tend to lift the inferior wall of the lesser curve (Figures 4 and 5). The force of cardiac pulsations pushing the stent-graft against the outer curvature could further push the inferior wall off the inner curvature. Some stent-grafts may also adopt a fishmouth configuration with the superior-inferior diameter of the proximal graft shortening and the lateral diameter widening, thus decreasing graft-wall apposition superiorly and inferiorly.

**Potential Aortic Growth in Young Trauma Patients**

Endovascular treatment of aortic injury comes with certain challenges. Aortic trauma tends to affect young people, in contrast to aortic aneurysm. It is not uncommon for adolescent or pediatric patients to present with this injury. Because of potential vessel expansion due to normal aortic growth, placement of a stent-graft in young patients must be viewed with extreme caution. There is a possibility of stent-graft migration as the aorta enlarges. Endovascular repair in selected pediatric patients may be considered as a bridge to definitive repair at a later stage. In pediatric patients with life-threatening aortic disruption who have other concomitant injuries, it may be appropriate to perform TEVAR to exclude the aortic injury until they fully recover and can undergo elective open repair.

**Challenges Related to Femoral Access in Young Trauma Patients**

Femoral artery access is a potential challenge when considering TEVAR, particularly in young trauma patients. Currently available thoracic endograft devices require a minimum 20F introducer sheath. Placement of such a large sheath in a diseased artery or iliofemoral vessels < 8 mm in diameter can result in severe iatrogenic injuries, including arterial dissection and rupture.\(^{28}\) If significant resistance is encountered during insertion, one should stop the process and carefully withdraw the sheath. Retroperitoneal access by creating iliac or aortic conduits should be considered to limit the risk of iatrogenic rupture associated with small femoral artery access. These conduits can be converted to an iliofemoral or aortofemoral bypass graft to improve the flow to an ischemic extremity if necessary. The potential for iatrogenic femoral artery injury in TEVAR was highlighted in a study by White and colleagues\(^{28}\) who noted a 27% rate of access complications. However, as endovascular devices undergo continued refinement and miniaturization with smaller introducer sheaths, the incidence of iatrogenic access complications is likely to decrease.

**Procedural-Related Complications due to Device Deployment**

Delivering and deploying TEVAR devices may pose certain technical challenges in young trauma victims. Because young patients frequently have a sharp aortic angulation just distal to the left subclavian artery, it may be difficult to accurately position and deploy a thoracic stent-graft in a juxta-subclavian artery location, particularly if the endograft has a rigid or relatively inflexible shaft. In some TEVAR devices, such as Talent endografts, the proximal bare stents need to be deployed higher in the aortic arch. The stent-graft portion of the device is then slowly pulled...
Endovascular Traumatic Aortic Repair

Lin

back in the descending thoracic aorta to allow accurate deployment. Manipulation of endografts in the vicinity of the ascending aorta is not only technically difficult but also carries a high risk of stroke. Numerous complications related to manipulation of bulky devices in the aortic arch have been reported, including cardiac perforation, aortic valve injury, arch perforation, branch vessel rupture, and cerebral embolization.18,19,29–37 Significant device refinement, such as a more flexible shaft to accommodate aortic curvature, will be necessary before this technology can be widely adopted in young patients with aortic injuries.

RESULTS FROM CLINICAL SERIES OF ACUTE AORTIC TRAUMA

Available literature on TEVAR remains scarce, in contrast to the vast body of literature on endovascular abdominal aortic aneurysm repair. Nonetheless, nearly all reported series underscore significant advantages of endovascular treatment of blunt aortic trauma, which include excellent technical success and low mortality rates (Table 1).

Taylor and colleagues38 were the first to report clinical benefits of using commercially available thoracic endografts in the management of blunt aortic injury in 2001. Thompson and colleagues60 reported encouraging outcomes of TEVAR for acute traumatic rupture in 5 patients. The technical success rate was 100% and no procedure-related complication or death was observed during a mean follow-up of 20 months. Fattori and colleagues17 treated 11 patients with acute and 8 with chronic trauma at the aortic isthmus by TEVAR. All procedures resulted in a successful outcome with no sign of endoleaks. No death, paraplegia, or other complications were observed. One type III endoleak occurred during a mean follow-up of 20 months, which showed spontaneous thrombosis within 2 months.17 Lachat and colleagues44 described 12 patients with acute traumatic aortic rupture treated with self-expanding stent-grafts, with complete technical success. Hospital mortality was 8% due to an undetected residual type I endoleak. During a mean follow-up of 17 months, 1 patient experienced peri-graft leakage and was given an additional stent-graft at 12 months postoperatively.44 Wellons and colleagues49 treated 9 patients with aortic injuries by TEVAR using infrarenal aortic cuff extenders. There was no procedure-related mortality and technical success was achieved in all patients. Two recent studies compared the treatment outcomes of traumatic thoracic aortic disruption by conventional open repair vs TEVAR. Ott and colleagues’ treated 18 patients with blunt thoracic aortic injuries during an 11-year period. They noted that open surgery had 17% early mortality, a paraplegic rate of 16%, and an 8.3% incidence of recurrent laryngeal nerve

Figure 5. (A) Successful deployment of a GORE TAG thoracic device can be achieved when appropriate device selection is made, as evidenced by the full apposition of the stent-graft in the aortic lumen. (B) When the device is inappropriately oversized relative to the aortic diameter, it can lead to device collapse in its leading segment (arrow). Image courtesy of Dr Michael Dake and WL Gore Associates.
Table 1. Clinical Series of Endovascular Treatment of Acute Traumatic Aortic Injuries

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>No. of Patients</th>
<th>Technical Success</th>
<th>Endograft Type</th>
<th>Paraplegia</th>
<th>Follow-Up (months)</th>
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Injury. In contrast, TEVAR patients did not experience any perioperative mortality, paraplegia, or recurrent laryngeal nerve injury. Similar findings were highlighted by Kasirajan and colleagues who found that patients who underwent TEVAR had significantly lower perioperative mortality compared to those who had open repair. Mean procedural time and hospital stay were significantly less after TEVAR compared to open repair.

Paraplegia undoubtedly remains the most feared complication following repair of aortic injury; the reported incidence is 18% after open repair of blunt aortic trauma. Many factors contribute to paraplegia. One postulated mechanism of cross clamp time > 30 min has probably been overstated, with some studies indicating that the severity of the injury is more important than clamp time. An overview of all available endovascular studies on aortic injuries showed that paraplegia was uncommon. Table 1 summarizes the treatment outcome of these studies. A possible explanation for the low incidence of paraplegia after TEVAR is the avoidance of aortic cross clamping, resulting in less blood pressure variation and hemodynamic instability.
Endovascular Traumatic Aortic Repair

SHOULD ENDOVASCULAR REPAIR BE STANDARD TREATMENT FOR AORTIC TRAUMA?

No single screening, diagnostic, or treatment modality will ever become the standard for this complex injury. Because of the rarity of aortic trauma, successful endovascular treatment will likely be confined to hospitals with experienced endovascular surgeons and interventional radiologists. Moreover, the optimal outcome of TEVAR will depend on proper imaging equipment and a wider range of readily available endovascular devices. It is our belief that emergency stent-grafting is technically more demanding than an elective endovascular procedure. In elective aneurysm stent-grafting, careful consideration of device sizing and selection can be carried out, whereas urgent endovascular repair of aortic injury requires an experienced team of trauma surgeons, vascular surgeons, anesthesiologists, and operating room nurses ready to perform this procedure in critically injured patients at any time of day. Physicians must rely on their expertise to make critical decisions relating to device selection or arterial access, both promptly and accurately. While all available clinical studies on TEVAR of traumatic aortic disruptions show promising results with excellent technical success and lower mortality rates than open repair, long-term studies are necessary to prove the efficacy of this minimally invasive therapy. Presently, the Achilles’ heel of endovascular treatment of traumatic aortic disruption relates to the limited sizes of thoracic endografts available. Utilizing currently approved devices in young trauma victims with aortic injuries results in significant oversizing and potential late device-related complications. Until further studies validate treatment durability, and appropriately sized devices become available, precautions must be taken when performing endovascular repair of aortic injuries as this therapy should only be offered to selected patients.

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