Chapter 5

Endovascular treatment of traumatic thoracic aortic injury—should this be the new standard of treatment?

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INTRODUCTION

Blunt trauma to the thoracic aorta is a potentially life-threatening condition that can lead to death in 75% of cases at the time of injury, as a result of either aortic transection or acute rupture.[1] Although it accounts for <1% of adult admissions to level I trauma centers, blunt aortic injury represents the second most common cause of death due to blunt trauma, second to head injury.[2] It is estimated that only 25% of patients who sustain aortic injuries due to blunt thoracic trauma remain alive upon arrival to the hospital. The prognosis for patients who survive the initial injury remains poor: nearly 30% will die within the first 6 hours, and 50% of these patients will not live beyond the first 24 hours after the injury.[3]

This high mortality rate has previously prompted traditional management of blunt aortic injury to establish early diagnosis and rapid surgical intervention to prevent a catastrophic rupture. This belief has been modified to allow delay of the operative intervention to first manage other serious concomitant injuries and lessen the high surgical mortality rate associated with emergent aortic repair.[4] Despite advances in modern trauma care, emergent operative intervention for blunt aortic injury is associated with significant cardiac, pulmonary, neurologic, and hemodynamic complications.[4,5]

The classic injury mechanism of blunt thoracic aorta is related to the combination of sudden deceleration and traction at the relatively immobile aortic isthmus, which represents the junction between the relatively mobile aortic arch and the fixed descending aorta. The isthmus is the most common location for rupture (50% to 70%), followed by the ascending aorta or aortic arch (18%) and the distal thoracic aorta (14%).[3] Patients with blunt trauma to the thoracic aorta typically have multiple associated injuries to

other organs that can not only compound therapeutic challenges in their surgical management but also increase their overall morbidity and mortality.

The objectives of this chapter are to review current treatment strategies of blunt aortic injury, including both conventional open repair and endovascular treatment approach. Further discussions are provided on technical maneuvers to facilitate endovascular treatment, potential limitations of endovascular therapy, and clinical results of this treatment modality in blunt aortic injury.

CONVENTIONAL OPEN REPAIR

The traditional therapy for blunt thoracic aortic injury is open surgical repair. Key components of this surgical approach typically involve a left thoracotomy, single-lung ventilation, systemic anticoagulation, aortic cross-clamping with interposition bypass grafting, and potential left heart bypass with partial or total cardiopulmonary reperfusion, all of which can lead to significant physiologic stress that results in perioperative complications. The operative mortality rate from emergency surgical repair of blunt aortic injury is 15% to 30% in contemporary series.[3,5-7] In addition to the high perioperative mortality rates associated with an open repair, patients who sustain blunt aortic trauma frequently have associated pulmonary contusions as well as potential abdominal or cranial injuries that may preclude safe or timely open surgical repair.

There have been several advances over the past decade with respect to the conventional open repair of blunt aortic injury. These adaptations of open surgical interventions have decreased operative morbidity and improved treatment outcome. Physicians who advocate both passive and active methods of cardiopulmonary bypass during aortic cross-clamping have reported decreased spinal cord ischemia and reduced mortality rates.[3,8]

Frequently, a patient with blunt aortic injury may be unstable because of severe concomitant injuries such as myocardial or pulmonary contusions that make it difficult to perform open repair. Researchers have adapted delayed operative intervention with stabilization of other concomitant injuries and medical optimization in an effort to improve outcome and decrease operative complications in

appropriately selected patients.[9,10] Despite advances in critical care medicine and refinement in surgical techniques, a recent meta-analysis showed no definite improvement in operative mortality over the past decade after open repair in patients with blunt aortic injury.[5]

Perioperative complications after open repair for blunt aortic injury can include bleeding, myocardial infarction, stroke, respiratory failure, renal failure, and bowel infarction.[3,6] Perhaps the most catastrophic adverse event following an open repair is paraplegia. A recent meta-analysis reported by von Oppell et al[5] assessed the outcome of 1492 patients from 87 studies who underwent operative repair for acute aortic trauma. The authors compared paraplegia and hospital mortality rate with the surgical technique used in aortic repair. The clamp-and-sew technique resulted in a paraplegia rate of 19% and a mortality rate of 16%, whereas distal perfusion techniques resulted in rates of 6.1% and 15%, respectively.[5]

In another study, Kadali et al[11] reported a 20-year experience of immediate operative repair for thoracic aortic trauma and noted an incidence of paraplegia of 28.5% when the clamp-and-sew technique was used, whereas patients treated with distal perfusion had a lower incidence of paraplegia of 3.8%. Despite the possible benefit of distal perfusion in reducing paraplegia rate, certain complications are associated with this technique partly because of the need for full systemic anticoagulation, which may adversely affect concomitant injuries involving the brain, liver, or lungs and result in fatal hemorrhagic outcome.

Once patients overcome the possibility of these perioperative complications following open surgical repair, they invariably may face a prolonged convalescent period before regaining their baseline physical capacity. The increased length of hospital stay after an open repair may incur increased costs for hospitalization. The surgical treatment strategy must always take into account the complexity of the open chest procedure and the suboptimal outcome often attained in patients with multiple trauma or increased age. These concerns related to conventional open surgical repair have prompted both physicians and endovascular device industries to consider alternative treatment strategies using a less invasive catheter-based modality.

ENDOVASCULAR REPAIR

Endovascular repair of a traumatic aortic injury is obviously a less invasive and attractive treatment alternative compared with a conventional open repair. Early reports by Semba et al[12] and Kato et al,[13] who used homemade aortic endograft devices in the treatment of acute traumatic aortic rupture, highlighted that this treatment strategy can be performed successfully with a low mortality rate and no neurologic sequelae. Over the past several years, many researchers have similarly attested to the benefits of this treatment strategy and reported their experience in the treatment of blunt aortic trauma using aortic endografts with high technical success and low mortality rates.[14-19]

Endovascular treatment of blunt thoracic aortic disruptions offers many practical benefits and technical advantages compared with conventional open repair in patients with thoracic aortic injuries. The deployment of a stent-graft in the descending aorta with a focal traumatic lesion, particularly in patients with adequate proximal and distal aortic neck, can be performed in a straightforward manner. In patients with adequate femoral artery access, this procedure can even be performed under local anesthesia without incurring significant cardiopulmonary stress. Commonly encountered physiologic insults associated with an open repair such as thoracotomy, aortic cross-clamping, extracorporeal bypass, and single-lung ventilation can all be avoided in the setting of an endovascular thoracic aortic endografting procedure. Exclusion of a descending aortic disruption with an endograft does not necessitate cross-clamping the thoracic aorta. As a result, the avoidance of aortic cross-clamping minimizes significant blood pressure shifts and coagulopathy. This also reduces operative blood loss as well as ischemic events involving the spinal cord, viscera, and kidneys. Moreover, avoidance of a thoracotomy has obvious convalescent advantages in patients who might be disabled from other multiple organ injuries.

Because the traumatic force responsible for blunt aortic disruptions frequently results in concomitant injuries involving other bodily organs, prompt endovascular exclusion of a traumatic aortic pseudoaneurysm or aortic transection can be performed without undue delay in surgical interventions of other concomitant injuries. This advantage is in sharp contrast to an open aortic repair, which would require a patient to initially recover from any major operative intervention or intensive therapy for life-threatening complication of blunt trauma. In addition, the use of systemic anticoagulation with heparin during an endovascular aortic procedure can be reduced to a minimum, which is particularly beneficial in patients with concomitant intracranial or abdominal injuries.

Endovascular repair has many obvious advantages compared with conventional open repair, but one might keep in mind potential shortcomings of this treatment strategy. The possibility of persistent endoleak after endovascular exclusion of traumatic aortic pseudoaneurysm has been reported.[16,19,20] Late complications, such as endograft migration or device infection caused by fistula formation, are still a concern.[21] Furthermore, given the limited commercially available endovascular devices, not all patients with traumatic aortic disruptions have adequate aortic morphology to undergo this repair. Finally, critics of this treatment strategy often cite the lack of long-term durability studies to justify the use of an aortic endograft in young trauma victims who may well tolerate the physiologic stress associated with an open repair.

Anatomic consideration in endovascular repair of traumatic aortic injury. Several fundamental differences in the anatomic morphology between patients with atherosclerotic thoracic aortic aneurysm and traumatic aortic injuries may impact on the choice of endograft devices and deployment techniques. In patients with descending thoracic aneurysms, adequate proximal and distal aortic neck length is critical to ensure proper device fixation and aneu-

rysm exclusion. The diameter of aortic neck is similarly important for device selection. Because the diameter of an aortic neck may be subject to continual expansion caused, in part, by aneurysm progression, many stent-graft devices have incorporated components such as hooks and proximal bare metal to reinforce device fixation and minimize stent-graft migration.

Other pertinent factors in treating patients with thoracic aortic aneurysms include proximity to the celiac artery, thrombus in the aneurysm sac, length of aneurysm involving intercostal arteries, and pre-existing thrombus in the aortic landing zones. These considerations may play critical roles in subsequent aneurysm remodeling following endovascular repair, which may result in aneurysm size regression and alter stent-graft fixation. Access vessels are also an important consideration. Since most patients with thoracic aneurysms are elderly men with underlying atherosclerotic disease, the insertion of a large thoracic endovascular device using a 21F introducer may require a retroperitoneal access with the creation of an iliac artery conduit.

Many of these considerations are different when patients with traumatic aortic disruption are treated. Because most aortic disruptions are located in the proximal descending thoracic aorta, the proximal landing zone is generally near the left subclavian artery. The distal landing zone, on the other hand, is usually not a critical factor because the long segment of normal descending thoracic aorta is more than sufficient to permit proper device fixation. To ensure proper proximal device fixation in traumatic aortic injury, many have raised the concern that the left subclavian artery will be intentionally covered by the endograft in a significant number of patients. Clinical experiences have shown that critical limb-threatening ischemia of the left arm rarely occur and, if necessary, can be reversed by an elective left carotid-to-subclavian artery bypass grafting procedure (Fig 1).[22-24] Because the endograft device is anchored in relatively normal proximal and distal aortic segment, there is very little concern regarding the possibility of subsequent aortic neck enlargement that is the case in the aneurysm population. The possibility of device migration or late endoleak in the trauma population, while possible, is less likely and worrisome compared with the aneurysm cohorts.

The main anatomic challenge of endovascular treatment of traumatic aortic injury is related to the relatively small aortic diameter in these young victims compared with elderly patients with thoracic aortic aneurysm. Although the GORE TAG Thoracic Endoprosthesis (W. L. Gore & Associates, Flagstaff, Ariz) is currently the only device that has received the United States Food and Drug Administration (FDA) approval for clinical application, this device is designed for patients with thoracic aortic aneurysms who typically have larger aortic diameters.

In a recent study by Borsa et al,[25] who analyzed the angiographic morphology of 50 traumatic victims with thoracic aortic disruptions, the mean aortic diameters adjacent to the aortic injury was 19.3 mm. The available GORE TAG devices range from 26 mm to 40 mm in diameter.
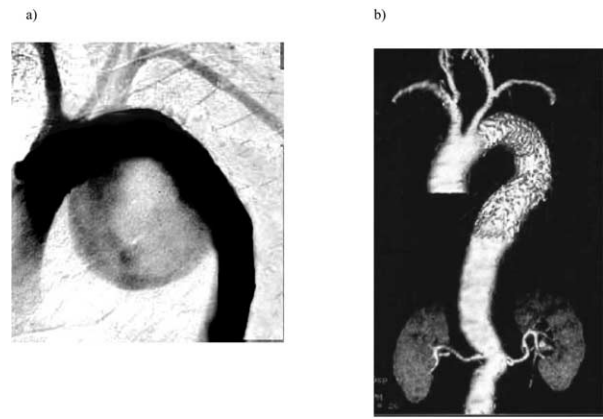

Fig 1. A, A thoracic aortogram demonstrates a large aortic pseudoaneurysm caused by a blunt thoracic injury that occurred just distal to the left subclavian artery. **B**, Computed tomography angiography of the chest following successful endovascular pseudoaneurysm exclusion with a left carotid-to-subclavian bypass graft.[24]

Because this device was not designed in the treatment of traumatic aortic injuries, placement of even the smallest available GORE TAG device in trauma patients will likely represent a significant and inappropriate device oversize, which might lead to inadequate device fixation. This scenario was highlighted by a recent case report in which a GORE TAG device was used in a 20-year-old trauma victim.[26] The severe device oversize caused the GORE TAG device to collapse within the aortic lumen, and this was subsequently treated by another stent-graft insertion which unfolded the collapsed endograft.[26] Appropriately sized thoracic endografts with smaller diameters must be made available for endovascular therapy to be a viable treatment strategy in patients with traumatic aortic injuries.

Adjunctive maneuvers to facilitate endovascular placement of thoracic endografts. Several adjunctive endovascular techniques have been described that may facilitate the deployment of a thoracic stent-graft. These maneuvers, which have been used in the endovascular treatment of both traumatic and aneurysmal aortic lesions, include gaining brachial artery access, femoral artery guidewire placement, controlled hypotension, and transient asystole induced by adenosine administration.

A. Accessing the brachial artery and femoral artery guidewire placement. Because most traumatic aortic disruptions occur distal to the left subclavian artery, accessing the left brachial artery followed by the placement of a diagnostic catheter allows continuous visualization of the left subclavian artery. This greatly enhances the identification of the proximal landing zone when a thoracic stent-graft is deployed.[24] To facilitate the delivery of an endograft to the proximal descending thoracic aorta, a useful technique is to place a stiff guidewire from the femoral artery to the right axillary artery via the innominate artery. This provides an excellent tracking of the device through the

descending thoracic aorta at the level of the left subclavian artery.[27]

In a situation where a severe tortuous aortic arch is encountered, a 260-cm stiff guidewire may be exteriorized from both the femoral and right brachial access site. This can be accomplished by first placing a soft floppy guidewire in the aortic arch from the femoral artery. A snare catheter is used from the right brachial artery to capture the floppy wire, which is exteriorized through the right brachial artery introducer sheath. A guidewire exchange is performed in which a long, stiff guidewire is placed between the femoral and right brachial artery. Tension on both ends of the stiff wire may then be used to help the large-access sheaths traverse regions of angulation in the iliac vessels or within the aortic arch. The subclavian and the innominate arteries should be protected from direct trauma caused by the shearing of the stiff guidewire. This can be accomplished by placing an angiographic catheter over the guidewire within the aortic arch. Both the guidewire and angiographic catheter should remain together throughout the procedure.

B. Controlled hypotension to facilitate stent-graft deployment. Many early clinical studies documented the propensity of stent-graft displacement or caudal movement during deployment, a phenomenon largely caused by the high blood flow in the descending aorta.[28-30] This scenario was particularly problematic with stent-grafts composed of a balloon-expandable stent attached to a graft material, particularly in many early clinical reports of the use of home-made devices.[29,31,32]

Many physicians have reported the benefit of controlled hypotension to lower the mean arterial blood pressure to between 50 to 60 mm Hg by administration of intravenous sodium nitroprusside. This is performed just before the stent-graft deployment in an effort to reduce the risk of downstream migration caused by intra-aortic blood flow during deployment. When the stent-graft position is appropriate and the blood pressure is optimal, the stent-graft is deployed by rapidly withdrawing the sheath while the pusher mandrel is held firmly in position. Immediately after stent-graft deployment, the nitroprusside infusion is discontinued to normalize the blood pressure.

C. Adenosine-induced cardiac asystole during stent-graft deployment. The administration of intravenous adenosine to produce temporary cardiac asystole to enhance the precision of placement of thoracic endoluminal devices was first reported by Dorros and Cohn in 1996.[33] The effectiveness of this agent in transiently arresting cardiac flow during thoracic endovascular procedure has also been reported by others.[34-36] The administration of intravenous adenosine produced a predictable and reproducible period of asystole of 15 to 30 seconds before spontaneous return of sinus rhythm. Asystole allowed graft deployment without the risk of displacement by blood flow, particularly in the upper thoracic aorta. The bolus dose required to produce this effect ranged from 12 to 45 mg and was reproducible in the same patient. No deleterious effects from transient cardiac asystole caused by adenosine infusion during endovascular thoracic aortic procedure have been re-

ported in the literature. Most physicians agree that adenosine may be administered safely in selected patients, particularly those requiring precise deployment of the graft high in the proximal descending thoracic aorta.

Results from clinical series in acute traumatic aortic injuries. Available literature on endovascular treatment of traumatic aortic injuries remains relatively scarce, in contrast to the vast body of literature on endovascular abdominal aortic aneurysm repair. Nonetheless, nearly all reported series underscored significant advantages of endovascular treatment of blunt aortic trauma, which include excellent technical success and low mortality rates (Table I).[12,15-20,27,37-49]

Thompson et al[48] reported on encouraging outcome after endovascular thoracic aortic repair for acute traumatic rupture in five patients. The technical success rate was 100%; no procedure-related complication or death was observed during an average follow-up of 20 months.[48]

Fattori et al[39] described 11 patients with acute and eight with chronic thoracic traumatic injury located at the aortic isthmus treated by endovascular stent-grafting. All procedures resulted in a successful outcome without signs of endoleaks. No death, paraplegia, or other complications were observed. The study group detected one type III endoleak during a mean follow-up period of 20 months, which showed spontaneous thrombosis within 2 months.[39]

Lachat et al[42] reported complete technical success in 12 patients with acute traumatic aortic rupture who were treated by self-expanding stent-grafts.[42] The in-hospital mortality was 8% due to an undetected residual type I endoleak. During the mean follow-up time of 17 months, one patient experienced a perigraft leakage that was treated by an additional stent-graft 12 months postoperatively.[42]

Wellons et al[27] reported nine patients with traumatic aortic injuries who all underwent endovascular repair using infrarenal aortic cuff extenders. There were no procedure-related deaths and technical success was achieved in all patients.

Two recent studies compared the treatment outcome of traumatic thoracic aortic disruption between conventional open repair vs endovascular therapy. Ott et al[16] reported their experience of 18 patients with blunt thoracic aortic injuries during an 11-year period. The authors noted that the open surgical group had a 17% early mortality rate, a paraplegia rate of 16%, and an 8.3% incidence of recurrent laryngeal nerve injury. This is in sharp contrast to the endovascular patient cohorts, who did not experience any perioperative mortality, paraplegia, or recurrent laryngeal nerve injury.[16] Similar findings regarding the benefits of endovascular treatment over open surgical repair were highlighted in another study by Kasirajan et al.[18] These authors noted that patients who underwent endovascular repair had significantly lower perioperative mortality rates compared with those who underwent open repair. The mean procedural time and length of hospital stay were all significantly less in the endovascular group than in the open repair cohort.[18]

Paraplegia, undoubtedly the most feared complication following repair of a traumatic aortic injury, has a reported

Table I. Clinical series of endovascular treatment of acute traumatic aortic injuries

Author	Year	Patients (N)	Technical success (%)	Endograft type	Paraplegia	Follow-up (months)
Bortone[46]	2002	10	100	Gore	None	14
Orend[45]	2002	11	92	Gore, Talent	None	14
Thompson[47]	2002	5	100	Gore, custom	None	20
Fattori[39]	2002	11	100	Gore, Talent	None	20
Lachat[42]	2002	12	100	Gore, Talent	None	9
Kasirajan[18]	2003	5	100	Gore, Talent, homemade	None	10
Karmy-Jones[19]	2003	11	100	AneuRx cuff, Ancure, Talent, homemade	None	16
Iannelli[15]	2004	3	100	Gore	None	13
Wellons[27]	2004	9	100	AneuRx cuff, Excluder cuff	None	6
Kato[41]	2004	6	100	Homemade	None	6
Scheinert[17]	2004	10	100	Gore, Talent	None	17
Czermak[38]	2004	12	92	Gore, Talent	None	9
Morishita[43]	2004	7	100	Homemade	None	12
Neuhauser[44]	2004	10	100	Gore, Talent, Vanguard	None	26
Ott[16]	2004	6	100	Talent	None	16
Uzieblo[20]	2004	4	100	Talent	None	8
Bortone[37]	2004	14	100	Talent, Gore, Zenith, Endofit	None	14

incidence of as high as 18% in patients after open repair for blunt aortic trauma.[6] A postulated mechanism of this complication relates to aortic cross-clamp times >30 minutes. An overview of all available endovascular studies on traumatic aortic injuries showed that the paraplegic complication does not occur. Table I summarizes the treatment outcome of these studies. One possible explanation of this low paraplegic incidence following endovascular treatment is the avoidance of aortic cross-clamping and less blood pressure variation or hemodynamic instability after endovascular repair.

Challenges of endovascular repair of traumatic aortic injury in young patients. Endovascular treatment of traumatic aortic injuries comes with certain challenges. Traumatic aortic injuries tend to affect younger populations, in contrast to the aneurysm population. It is not uncommon that adolescent or pediatric patients may present with this injury. Because of potential vessel expansion as a result of normal aortic growth, placement of a stent-graft in young patients must be viewed with extreme caution. The possibility of stent-graft migration may occur as the aorta enlarges because of expected growth in young patients.

Endovascular repair in selected pediatric patients may be considered as a temporary bridge to a more definitive operative repair at a later stage. In pediatric patients with life-threatening aortic disruption who have other concomitant injuries, it may be appropriate to perform endovascular repair to exclude the aortic injury until the patients fully recover from other injuries and can undergo an elective definitive open repair with proven long-term durability.

An important anatomic consideration in endovascular treatment of traumatic aortic injuries in young patients relates to their tapering luminal diameter of the descending thoracic aorta. Moreover, younger patients typically have higher aortic pulsatile compliance and flow velocity than do elderly patients, which represents a hemodynamic factor that may destabilize aortic endograft fixation.[49,50] Implan-

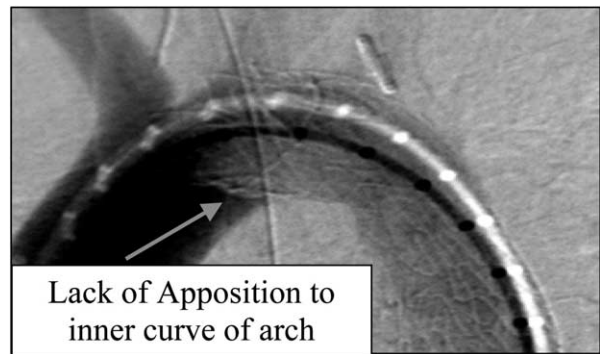Lack of Apposition to inner curve of arch

Fig 2. In the clinical situation of an oversized endograft placed in a small aorta with a tight aortic curvature, the device fails to appose the inner curvature. Infolding of the lower lip of the graft can occur with catastrophic consequences. This has not occurred when the device is sized according to the directions for use.

tation of currently available nontapered thoracic endografts in young trauma victims who have relatively narrow aortic lumens will likely lead to diameter mismatch and endograft oversize. Gross oversizing in a relatively small diameter aorta in combination with a short radius of aortic arch curvature can result in a suboptimal conformability along the inner curve of the aortic arch, which can lead to problems including device fracture, endoleak, migration, and infolding (Fig 2).

It is estimated that these types of device-related complications, such as stent fracture, stent-graft compression, rate of reintervention, device explanation, or endoleak, occurred in approximately 3% when used in traumatic aortic disruptions.[14,15,23,37,39,47,51-54] Moreover, a semirigid stent graft in a tightly curved arch may tend to lift the inferior wall of the lesser curve (Fig 2). Force of cardiac pulsations pushing the stent graft against the outer curva-

ture could further tend to push the inferior wall off the inner curvature. Some stent grafts may also adopt a fish-mouth configuration with the superior-inferior diameter of the proximal graft shortening and the lateral diameter widening, thus decreasing graft-wall apposition superiorly and inferiorly.

Because the GORE TAG device remains the only FDA-approved thoracic endograft at the present time, available reports demonstrated that approximately 9% of its reported applications occur in trauma patients.[14,15,23,37,39,47,51-54] This is the scenario when significant device oversize is most likely to occur due in part to the lack of small diameter endografts to be placed in young trauma patients with relatively narrow thoracic aortic lumen. All adverse events reported to date with the use of GORE TAG device were largely due to device oversize beyond the recommended FDA-approved Instructions for Use (Table II).

Anther important challenge in endovascular repair of traumatic aortic injuries is the limited availability of stent-graft devices. Several authors have reported successful usage of infrarenal aortic endograft cuffs in excluding thoracic aortic injuries, but this remains a less than ideal endovascular solution.[19,27] Current FDA-approved endovascular devices for infrarenal aortic aneurysm such as AneuRx (Medtronic, Santa Rosa, Calif), Zenith (Cook, Indianapolis, Ind), Endologix (Irvine, Calif), and Gore Excluder endograft all have aortic extension cuffs that are designed for delivery to the infrarenal aorta. The lengths of these delivery devices range from 55 cm to 65 cm, which may not be sufficient for juxta-subclavian artery deployment; this may be a particular concern in tall patients (Table III). A retroperitoneal iliac artery conduit may provide an added advantage of delivering an endograft device to a more proximal location, but these cuffs are generally short in length, and multiple aortic cuff placement will likely be required to adequately exclude an aortic disruption. Without clear evidence to demonstrate the efficacy of placing multiple aortic cuffs as an effective treatment in traumatic aortic disruptions, this treatment strategy represents an off-labeled device application and should not be widely encouraged.

Delivering and deploying thoracic endovascular devices may pose certain technical challenges in young trauma victims with aortic injuries. Because younger patients with relatively normal aorta 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 non-flexible device shaft. In some thoracic endovascular devices, such as the Talent endografts (Medtronic) the proximal bare stents need to be deployed higher in the aortic arch. The stent-graft portion of the device is then slowly pulled back in the descending thoracic aorta to allow accurate deployment.

Manipulation of an endograft in the vicinity of the ascending aorta not only is technically difficult but also carries a higher risk of stroke complications. Numerous complications related to manipulation of bulky devices in

Table II. Considerations and requirements for successful endografting in the trauma patient

Anatomic consideration of blunt aortic injury in young trauma patients
- Smaller radius of curvature (compared to older patients with aortic aneurysm)
- Smaller aortic diameter (compared to older patients with aortic aneurysm)
- Small iliac or femoral access vessel diameter
- Aortic disruption typically located immediately distal to the left subclavian artery

GORE TAG Thoracic Endoprosthesis Instructions for Use as approved by the FDA:
- Healthy neck length minimum 2 cm—may cover left subclavian artery if necessary
- The GORE TAG device has been designed to be oversized from 7% to 18%, which has been incorporated into the sizing guide (do not oversize and follow sizing chart)
- Measure flow lumen, 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
- Neck angles <60° recommend more than 2 cm of neck engagement

Device should contact entire circumference of aorta especially the proximal end inner curve
Caution: Given the smallest GORE TAG device has a diameter of 26 mm, placement of such a device can result in varying degree of oversize in various aortic diameter. The following description summarizes varying degree of device oversize in various scenarios of aortic diameters:
- Placement of a 26-mm thoracic endograft in a 20-mm aortic diameter would result in a 30% oversize.
- Placement of a 26-mm thoracic endograft in a 18-mm aortic diameter would result in a 44% oversize.
- Placement of a 26-mm thoracic endograft in a 16-mm aortic diameter would result in a 63% oversize.
- Placement of a 26-mm thoracic endograft in a 14-mm aortic diameter would result in a 86% oversize.

Table III. Delivery system lengths and diameters of aortic extender cuffs currently approved for infrarenal aneurysm repair

Device	Delivery system shaft length	Maximum stent-graft diameter	Stent-graft length
Medtronic AneuRx	55 cm	28 mm	3.75 cm
GORE Excluder	61 cm	28.5 mm	3.3 cm
Cook Zenith	55 cm	32 mm	3.6 cm
Endologix PowerLink	63 cm	28 mm	5.5-7.5 cm

the aortic arch have been reported, including cardiac perforation, aortic valve injury, arch perforation, branch vessel rupture, and cerebral embolization.[12,13,15,29-32,54-57] Significant device refinement, such as a more flexible shaft to accommodate aortic curvature, will undoubted be necessary before this technology can be widely adapted in young patients with traumatic aortic injuries.

Femoral arterial access represents a potential challenge when considering endovascular thoracic aortic repair, par-

ticularly in young trauma patients. Currently available thoracic endograft devices require a minimum 20F introducer sheath. Placement of such a large introducer sheath in a diseased artery or small ileofemoral vessels <8 mm in diameter can result in severe iatrogenic injuries, including arterial dissection and rupture.[58] If significant resistance is encountered during the insertion of an introducer sheath, one should stop the insertion process and carefully withdraw the introducer sheath. A retroperitoneal access with the creation of an iliac or aortic conduit should be considered to limit the risk of iatrogenic rupture associated with small femoral artery access. These conduits can be converted to an ileofemoral or aortofemoral bypass graft to improve the inflow of an ischemic extremity if necessary.

The potential of iatrogenic femoral artery injury in endovascular thoracic repair is highlighted in a study by White et al,[58] who noted a 27% rate of access complications. However, as endovascular devices undergo continual refinement and miniaturization with smaller introducer sheaths, the incidence of iatrogenic access complications will likely be decreased or possibly avoided.

Should endovascular repair be considered the new standard of treatment in traumatic aortic injury? Because of the rarity of traumatic aortic injury, successful endovascular treatment will likely be confined to large trauma centers with a dedicated trauma team working jointly with experienced endovascular surgeons. Moreover, optimal outcome of this treatment strategy will depend on proper imaging equipment and full arrays of readily available endovascular devices. We believe that an emergent stent-grafting is more technically demanding and conceptually challenging than an elective endovascular procedure. In an elective aneurysm stent-grafting procedure, for instance, careful consideration regarding device sizing and device selection can be done in a timely fashion. In contrast, urgent endovascular repair of a traumatic aortic injury requires an experienced team of trauma surgeons, vascular surgeons, anesthesiologists, and operating room nurses ready to perform this procedure in critically injured trauma patients in an around-the-clock fashion. Physicians must rely on their expertise and skills to make critical decisions relating to device selection or arterial access both promptly and accurately. Although all available clinical studies on endovascular treatment of traumatic aortic disruptions showed promising results with excellent technical success and lower mortality rates compared with conventional open repair, long term studies will undoubtedly be necessary to prove the treatment efficacy of this minimally-invasive therapy.

Presently, the Achilles heel of endovascular treatment of traumatic aortic disruption relates to the limited availability of thoracic endografts in all sizes (Table II). Utilizing currently approved thoracic devices in young trauma victims with aortic injuries will likely result in significant device oversize and potentially lead to late device-related complications (Table II). Until further studies that validate this treatment durability are reported and the full array of appropriately sized devices becomes available, physicians must take precautions when performing endovascular repair of traumatic aortic injuries, as this therapy should only be offered in appropriately selected patients.

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