Endovascular Repair of Traumatic Thoracic Aortic Injuries

Anatomic considerations, therapeutic limitations, and clinical outcomes.

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Traumatic blunt injury to the thoracic aorta is one of the most formidable challenges surgeons face. This devastating condition can lead to immediate death at the time of injury in the majority of cases, due in part to either aortic transection or acute rupture.[1] Although blunt aortic injury accounts for less than 1% of all adult level I trauma center admissions, this condition represents the second most common cause of death due to blunt injury, second only to head trauma.[2] Approximately 7,500 to 8,000 cases of blunt aortic trauma occur annually in North America, and it is estimated that only 25% of patients who sustained aortic injuries due to blunt thoracic trauma remain alive upon arrival to the hospital.[3] Although these patients survive the initial injury, their prognosis remains poor. Nearly 30% of them will die within the first 6 hours, and 50% of these patients will not live beyond the first 24 hours.[4] 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 in order to first manage other serious concomitant injuries and lessen the high surgical mortality rate associated with emergent aortic repair.[5] Despite advances in modern trauma care, emergent operative intervention for blunt aortic injury is associated with significant cardiac, pulmonary, neurologic, and hemodynamic complications.[5,6]

The classic injury mechanism of blunt thoracic aortic rupture 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

Figure 1. 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 (A). Successful repair of a blunt aortic injury can be accomplished using an endoluminal treatment approach (B).

(Figure 1). 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%).[4] This article examines the role of endovascular aortic repair of traumatic blunt aortic injury, reviews current literature of this treatment, and analyzes the potential challenges of this treatment modality in blunt aortic injury.

LOGIC FOR TEVAR IN TRAUMATIC AORTIC INJURY

Endovascular treatment (TEVAR) of blunt thoracic aortic disruptions offers many practical benefits and
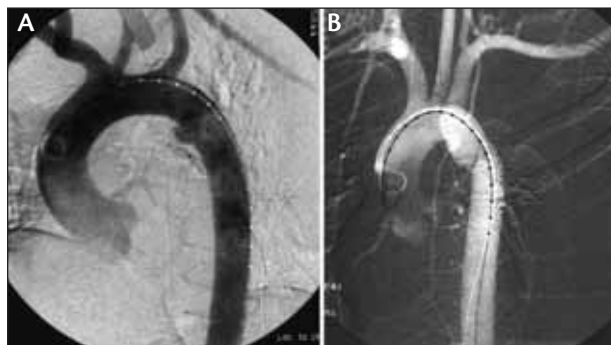
Figure 2. A wide aortic arch curvature is seen in this 65-year-old patient who sustained a blunt aortic transaction injury (A). An angiogram of a 17-year-old victim of an automobile accident showed an aortic injury in the descending thoracic aorta (B). Note an acute sharp curvature of the aortic arch, which is a common anatomical feature in younger patients.
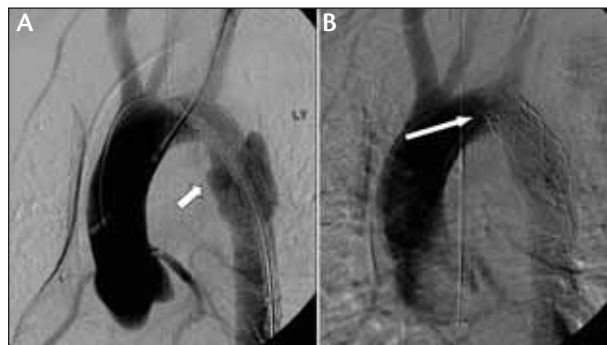

Figure 3. An aortogram revealed a blunt aortic injury in a 16-year-old patient (short arrow, A). Placement of an oversized Gore TAG (Gore & Associates, Flagstaff, AZ) endoprosthesis resulted in poor device apposition to the aorta in the proximal landing zone (long arrow, B).

technical advantages compared to conventional open repair in patients with thoracic aortic injuries. The majority of thoracic aortic injuries are located in the proximal portion of the descending thoracic aorta; therefore, endovascular exclusion of this traumatic injury using a stent graft is a logical treatment. In patients with traumatic thoracic aortic injuries who have adequate proximal and distal aortic landing zones, deployment of a stent graft to cover a focal traumatic lesion can be performed in a straightforward manner.

Commonly encountered physiologic insults associated with an open repair of a descending thoracic aortic injury, 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, including pulmonary contusion.

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 sharply contrasts an open aortic repair, which would require a patient to initially recover from any major operative intervention or intensive therapy of life-threatening complications of blunt trauma. Moreover, the use of systemic anticoagulation with heparin during an endovascular aortic procedure can be reduced to a minimum or completely avoided in selected cases, which is particularly beneficial in patients with concomitant intracranial or abdominal injuries. Lastly, in patients with adequate femoral artery access, this procedure can even be performed under local anesthesia without incurring significant cardiopulmonary stress.

POTENTIAL LIMITATIONS OF TEVAR IN TRAUMATIC AORTIC INJURIES

Although endovascular repair has many obvious advantages compared to conventional open repair, one might keep in mind potential shortcomings of this treatment strategy. The possibility of persistent endoleak after endovascular exclusion of traumatic aortic pseudo-

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TABLE 1. ANATOMICAL CONSIDERATIONS OF BLUNT AORTIC INJURY IN YOUNG TRAUMA PATIENTS

- Smaller radius of aortic curvature, in contrast to older patients with aortic aneurysms who have wider aortic curvatures
- Smaller aortic diameter, in contrast to older patients with aortic aneurysms who tend to have a larger aortic diameter
- Small iliac or femoral access vessel diameter
- Aortic disruption typically located immediately distal to the left subclavian artery, in contrast to patients with thoracic aneurysms, which can occur in any segment of the thoracic aorta

aneurysm has been reported.[7-9] There are still concerns of late complications, such as endograft migration or device infection due to fistula formation.[10] Furthermore, given the limited commercially available endovascular devices, not all patients with traumatic aortic disruptions have adequate aortic morphology to undergo this repair. Lastly, 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. Several potential device-related shortcomings as well as limitations of TEVAR in traumatic aortic injuries will be discussed below.

Small Aortic Diameter and Sharp Aortic Arch Curvature in Young Trauma Victims Relative to Available FDA-Approved TEVAR Devices

Although the Gore TAG Thoracic Endoprosthesis is currently the only device that has received FDA approval for clinical application, it is designed for patients with thoracic aortic aneurysms who typically have larger aortic diameters. The main anatomic challenge of TEVAR of traumatic aortic injury is related to the relatively small aortic diameter in these young victims, as opposed to elderly patients with thoracic aortic aneurysms. Additionally, elderly patients typically have a greater aortic arch curvature due in part to the aging process resulting in aortic elongation (Figure 2A). This wide aortic arch curvature is well suited to accommodate endograft

implantation with a low risk of device kinking. In contrast, the aortic arch in young trauma victims typically has a much sharper or acute curvature (Figure 2B), which may result in poor endograft apposition when deployed within an acute aortic arch curvature (Figure 3). Various anatomical considerations that are commonly encountered in young trauma patients are listed in Table 1.

In a study by Borsa et al that analyzed the angiographic morphology of 50 trauma victims with thoracic aortic disruptions, the mean aortic diameters adjacent to the aortic injury were 19.3 mm.[11] The available Gore TAG devices range in size from 26 mm to 40 mm in diameter. Because the Gore TAG device was not designed for 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 (Table 2).

Endograft Collapse Due to Significant Endograft Oversize in Young Trauma Patients

The Gore TAG device remains the only FDA-approved thoracic endograft at the present time, and available literature demonstrated that approximately 9% of its reported applications occur in trauma patients.[12-21] 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. It is noteworthy that the recommended IFU of the Gore TAG device (as approved by the FDA) indicates this device should be oversized in the range of 7% to 18% in reference to patient's aortic diameter. Because the smallest diameter of the Gore TAG device is 26 mm, it should be used in treating aortic size equal to or larger than 23 mm in diameter. Deployment of a 26-mm-diameter Gore TAG device in patients whose aortic diameter is <23 mm represents a device oversize beyond the manufacturer's recommendation, which may result in suboptimal device performance (Figure 3). All adverse events reported to date with the use of the Gore TAG device were largely due to device oversize beyond the recommended IFU (as approved by the FDA) (Table 3).

Several investigators have reported Gore TAG device collapse along the aortic arch region after TEVAR of traumatic aortic injuries.[22-25] Idu et al reported a case of Gore TAG device collapse 3 months after the endovascular repair.[22] In their reported case, a 26-mm-diameter Gore TAG device was implanted in a young trauma patient whose aortic diameter was only 19 mm, which represented a 37% device oversize. This significant degree of device oversize resulted in the wrinkling of the proxi-

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TABLE 2. EXAMPLES OF INAPPROPRIATE DEVICE OVERSIZE WHEN USING A GORE TAG THORACIC DEVICE IN PATIENTS WITH RELATIVELY SMALL AORTIC DIAMETERS

The Gore TAG thoracic device should not be oversized more than 18% based on the aortic diameter, as indicated by the device Instructions For Use (IFU). Given that the smallest Gore TAG device has a diameter of 26 mm, placement of such a device can result in varying degrees of oversize in various aortic diameter.

- 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 an 86% oversize.

Figure 4. A CT scan of the thoracic aorta revealed an aortic pseudoaneurysm as a result of blunt aortic trauma (short arrow). Deployment of a Gore TAG endoprosthesis resulted in a device collapse (long arrow) due in part to an inappropriate device oversize and acute aortic arch curvature in this young patient.

mal segment of the thoracic endograft. Although the initial aortogram revealed no gross radiograph abnormality after device deployment, the wrinkling of the proximal device eventually led to device collapse, due in part to the high aortic pulsatile force. This condition was ultimately remedied by the placement of a Talent thoracic endograft (Medtronic CardioVascular, Endovascular Innovations, Santa Rosa, CA) to expand the collapsed Gore TAG device.[22]

Muhs et al analyzed various anatomical factors associated with endograft collapse after Gore TAG endovascular repair of traumatic injuries.[24] The investigators analyzed six patients who developed endograft collapse after TEVAR of thoracic aortic pathologies. Among them, five patients underwent TEVAR for traumatic aortic injuries, and one patient developed endograft collapse for an aortic dissection treatment. By comparing the anatomical features with five control patients who did not develop endograft collapse after similar treatment indications, the investigators identified two variables that were predictive of thoracic endograft collapse: distal aortic sealing zone diameter (18.9 mm in the collapsed group vs 22.7 mm in the control group, $P<.05$) and minimum aortic diameter within the endograft (18.6 mm in the collapsed group vs 22.4 mm in the control group,
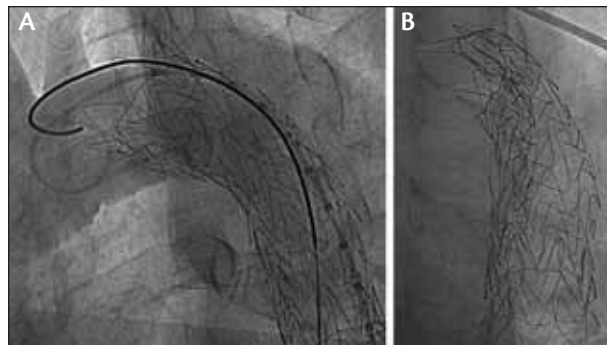

Figure 5. Successful deployment of a Gore TAG thoracic device can be achieved when appropriate device selection was made based on the recommended IFU, as evidenced by the full apposition of the stent graft in the aortic lumen (A). When the device is inappropriately oversized relative to the aortic diameter, it can lead to device collapse in its leading segment (arrow, B).

(Courtesy of Michael Dake, MD, and Gore & Associates.)

$P<.05$). Other variables including age, gender, graft position in the aorta, and operative indication did not influence the occurrence of endograft collapse after TEVAR treatment of traumatic aortic injuries.[24] If the aortic diameters of the landing zones are smaller than 20 mm to 21 mm, off-label use of an abdominal aortic cuff may be safer, although placement of multiple short cuffs along this limited shaft length possesses limitations as well.

Suboptimal Endograft Conformity Due to Hemodynamic Factors Related to Aorta in Young Trauma Patients

An important anatomical consideration in endovascular treatment of traumatic aortic injuries in young patients relates to their tapering luminal diameter of the

TABLE 3. GORE TAG THORACIC ENDOPROSTHESIS IFU 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.

descending thoracic aorta. Moreover, younger patients typically have higher aortic pulsatile compliance and flow velocity when compared to elderly patients, which represents a hemodynamic factor that may destabilize aortic endograft fixation.[26,27] Implantation of currently available nontapered 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 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 (Figures 4 and 5). 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% of patients when used in traumatic aortic disruptions.[12-21] Moreover, 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 tend to 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.

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Potential Aortic Growth in Young Trauma Victims

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.

Challenges Related to Femoral Artery Access in Young Trauma Patients

Femoral arterial access represents a potential challenge when considering TEVAR, particularly for young trauma patients. Currently available thoracic endograft devices require a minimum 20-F introducer sheath. Placing 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.[28] 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 TEVAR is highlighted in a study by White et al who noted a 27% incidence of access complication.[28] However, as endovascular devices undergo continual refinement and miniaturization with smaller introducer sheaths, the incidence of iatrogenic access complication will likely be decreased or possibly avoided.

Procedure-Related Complications
Due to Device Deployment

Delivering and deploying thoracic endovascular devices may pose certain technical challenges in young trauma victims with aortic injuries. Because younger patients with relatively normal aortas 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 juxtasubclavian artery location, particularly if the endograft has a rigid or relatively nonflexible device shaft. In some thoracic endovascular devices, such as the Talent endografts, the proximal bare-metal 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 the endograft in the vicinity of the ascending aorta not only is technically difficult but also carries higher risk of stroke complications. Numerous complications related to

TABLE 4. CLINICAL SERIES OF ENDOVASCULAR TREATMENT OF ACUTE TRAUMATIC AORTIC INJURIES						
Investigator	Year	No. of Patients	Technical Success	Endograft Type	No. of Paraplegic Patients	Follow-Up (mo)
Fajukawa[39]	2001	6	100%	Homemade	0	8
Taylor[38]	2001	5	100%	Gore, Talent	0	6
Bortone[61]	2002	10	100%	Gore	0	14
Fattori[17]	2002	19	100%	Talent, homemade	0	20
Hoffer[53]	2002	3	100%	Gore, Talent, Cook	0	6
Kilaru[62]	2002	1	100%	Gore	0	Not recorded
Lachat[44]	2002	12	100%	Talent, Gore, homemade	0	17
Orend[47]	2002	11	92%	Gore, Talent	0	14
Thompson[21]	2002	5	100%	Homemade	0	20
Doss[51]	2003	16	100%	Talent, Gore, homemade	0	15
Iannelli[18]	2003	3	100%	Gore	0	13
Karmy-Jones[8]	2003	11	100%	AneuRx cuff, Ancure, Talent, homemade	0	16
Kasirajan[42]	2003	5	100%	Gore, Talent, homemade	0	10
Marty-Ane[55]	2003	9	100%	Gore, Talent	0	18
Orford[20]	2003	9	100%	Cook, homemade	0	21
Amabile[63]	2004	9	100%	Gore, Talent, homemade	0	15
Czermak[40]	2004	12	92%	Gore, Talent	0	9
Demers[50]	2004	15	100%	Gore, Talent, Cook, homemade	0	55
Dunham[52]	2004	16	100%	AneuRx cuff, Gore cuff	0	15
Kato[43]	2004	6	100%	Homemade	0	6
Meites[64]	2004	18	100%	Not recorded	0	13
Morishita[45]	2004	7	100%	Homemade	0	12
Neuhauser[46]	2004	13	100%	Gore, Talent, Vanguard	0	26
Ott[7]	2004	6	100%	Talent	0	16
Richeux[58]	2004	16	100%	Gore, Talent, Vanguard	0	15
Scheinert[48]	2004	10	100%	Gore, Talent	0	17
Uzieblo[9]	2004	4	100%	Talent	0	8
Wellons[49]	2004	9	100%	AneuRx cuff, Excluder cuff	0	6
Kuhne[54]	2005	5	100%	Not recorded	0	Not recorded
Melissano[56]	2005	2	100%	Not recorded	0	8
Raupach[57]	2005	7	100%	AneuRx cuff, Ancure, Talent, homemade	1	30
Rousseau[59]	2005	29	100%	AneuRx cuff, Gore, Talent, homemade	0	46
Kwok[65]	2006	15	100%	Custom-made, Talent	0	12

manipulation of bulky devices in the aortic arch have been reported, which include 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 adapted in young patients with traumatic aortic injuries.

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CLINICAL STUDIES

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 4).[5,7-9,14,17,18,20,35,38-59]

Taylor et al were the first the report the clinical benefit of using commercially available thoracic endografts in the management of blunt aortic injury in 2001.[38] Thompson et al reported on encouraging outcomes after TEVAR for acute traumatic rupture in five patients. The technical success rate was 100%; no procedure-related complications or death were observed during an average follow-up of 20 months.[60] Fattori et al described 11 patients with acute and eight with chronic thoracic traumatic injury located at the aortic isthmus treated by endovascular stent grafting.[17] All procedures resulted in successful outcomes 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.[17] Lachat et al reported 12 patients with acute traumatic aortic rupture treated by self-expanding stent grafts and reported a complete technical success.[44] The in-hospital mortality rate was 8% due to an undetected residual type I endoleak. During the mean follow-up time of 17 months, one patient experienced a perigraft leak that was treated by an additional stent graft 12 months postoperatively.[44] Wellons et al reported nine patients with traumatic aortic injuries who underwent endovascular repair using infrarenal aortic cuff extenders.[49] There was no proce-

dure-related mortality, and technical success was achieved in all patients. Two recent studies compared the treatment outcome of traumatic thoracic aortic disruption between the conventional open repair versus endovascular therapy. Ott et al reported their experience of 18 patients with blunt thoracic aortic injuries during an 11-year period.[7] The investigators noted that the open surgical group had a 17% early mortality rate, a paraplegic 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.[7] Similar findings regarding the benefits of endovascular treatment over open surgical repair were highlighted in another study by Kasirajan et al.[42] These investigators noted that patients who underwent endovascular repair had significantly lower perioperative mortality rates compared to those who underwent open repair. The mean procedural time and length of hospital stay were all significantly less in the endovascular group compared to the open repair cohort.[42]

Paraplegia undoubtedly remains the most feared complication after repair of a traumatic aortic injury, which has a reported incidence as high as 18% in patients who undergo open repair for blunt aortic trauma.[3] A postulated mechanism of this complication relates to aortic cross-clamp times in excess of 30 minutes. An overview of all available endovascular studies on traumatic aortic injuries showed that the paraplegic complication was uncommon, which only occurred in one patient.[57] Table 4 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.

CONCLUSION

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. It is our belief that emergent stent grafting is more technically demanding and conceptually challenging when compared to 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 traumat-

ic aortic injury will require 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 to 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. Using 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 3). Until further studies validate this treatment durability 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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