Endovascular Stent Grafts in Urgent Blunt and Penetrating Thoracic Aortic Trauma

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ABSTRACT

A traumatic thoracic aortic injury is fatal in the majority of cases. Surviving the aortic injury in addition to the myriad of associated trauma requires comprehensive medical management from many medical services. Balancing these services and coordinating the medical care requires free and open communication between services. Although one might assume a thoracic aortic injury takes precedence over other injuries, an organized plan of care in which the morbidity of the injury as well as the consequences of treatment of each injury helps provide an appropriate “rank order” in the treatment process. A patient with a thoracic aortic injury can be observed for several days while additional injuries are treated, as long as appropriate blood pressure controls are observed. The treatment order for multiple injuries must be reevaluated on a regular basis to adjust for changes in the overall clinical condition. This rank order to treatment and scheduled treatment plan allows for appropriate imaging, evaluation, and coordination of services in preparation for the placement of a thoracic aortic stent graft. The goal of treatment is to reduce the risk of aortic rupture and subsequent fatal hemorrhage. Choosing an open surgical repair versus an endovascular stent graft depends upon physician expertise and clinical status of the patient. In the appropriate clinical setting, endovascular repair of the thoracic aortic injury has become the treatment of choice at the authors’ institution in patients with significant operative risks and extensive comorbid injuries. Specific characteristics of the injured aorta also dictate the type of endovascular device required for repair. Case reviews of a patient with blunt trauma and a patient with penetrating trauma used to demonstrate clinical parameters, imaging options, and details of stent graft choice and placement, are presented followed by a review of the literature.

KEYWORDS: Traumatic aortic injury, emergent stent graft, TEVAR

Objectives: Upon completion of this article, the reader should recall the indications for placing emergent endovascular thoracic aortic stent grafts and state the current endovascular and open surgical mortality for ruptured aortic aneurysms.

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Prior to pursuing aggressive medical and surgical options following major trauma, at some point early in the initial injury evaluation, it is important to consider the survivability of the injuries. Thoracic aortic injuries rarely survive the initial trauma due to the resulting massive mediastinal and intrathoracic hemorrhage. The location of the injury in the thoracic aorta frequently involves attachment points (aortic root, diaphragmatic hiatus, and at the ligamentum venosum attachment). Aortic root, ascending aorta, and proximal arch injuries most likely require emergent surgical interventions and are rarely candidates for endovascular repairs. Due to location and stability, injuries in the descending thoracic aorta (ligamentum venosum and diaphragmatic hiatus) have potential endovascular options for repair. A patient that has survived the initial injury, the transport to emergent care facilities, and subsequent resuscitation attempts has likely contained the blood loss from the transected aorta. The mediastinal connective tissue, aortic wall connective tissue layers, coagulated blood/hematoma, and potentially the pleural lining are the feeble support structures withstanding the pulsing aortic pressure with each heartbeat and preventing catastrophic blood loss into the pleural space. The contained mediastinal hemorrhage maintains a path of least resistance for blood to flow distally to the remainder of the body. If peripheral resistance increases (with subsequent increasing blood pressure) or the supporting mediastinal structures are disrupted, massive bleeding can still occur. Periods of low blood pressure immediately following the initial trauma may assist in the formation of adjacent hematoma and maintain a distal pathway of blood flow. Patients who can maintain stable mediastinal supporting connective tissue/hematoma and a relatively low, stable blood pressure are candidates for endovascular options. Once a stable mediastinal hematoma and stable low blood pressure have been established, other injuries may require attention first. After other life-threatening injuries have been addressed and the decision to pursue endovascular management of the transection has been made, imaging findings and patient characteristics help

guide the choice of stent type and location. Two traumatic thoracic aortic injury cases (one blunt trauma and the other penetrating trauma) illustrate these treatment choices.

CASE 1

PD is an 84-year-old, right-hand dominant, man who presented to the emergency department (ED) under a level 3 trauma alert after a 12-foot fall from a ladder while cleaning leaves from the rain gutters around his home. With normal vitals, unknown loss of consciousness, a Glasgow Coma Score of 14, and otherwise intact neurologic and pulse exam at the scene, he was transported by ambulance to the ED. A scalp laceration, mild confusion (repeatedly asking similar questions), and left hemithorax pain led to cross-sectional imaging. The computed tomography (CT) scan on arrival demonstrated bifrontal subarachnoid hemorrhage, diffuse axonal injury, an occipital skull fracture, left-sided posterior rib and spinous process fractures, a left scapula fracture, as well as a proximal descending thoracic aortic transection with contained mediastinal contrast. Figure 1 demonstrates axial and a three-dimensional reconstruction of the aortic arch. Further evaluation of his CT demonstrated a mild amount of vascular calcification indicating underlying atherosclerotic changes, an acutely angulated aortic arch within 1 cm of the descending thoracic aortic injury (ligamentum venosum injury) and widely patent iliac and femoral vasculature.

CASE 2

LD is a 15-year-old boy referred to our institution 5 days after an accidental small caliber gunshot wound to the left anterior chest. Initial CT scan revealed the bullet trajectory passed inferior to the left subclavian artery, through pulmonary parenchyma, through the proximal descending thoracic aorta ~1 cm from the origin of the left subclavian, and through the T5 vertebral body and spinal cord at that level. The projectile remained palpable and

Figure 1 Axial (A) and left anterior oblique projection (B) of PD's thoracic aortic injury demonstrating the acute angle of the aortic arch, proximity to the origin of the left subclavian and consideration of underlying atherosclerotic changes.

Figure 2 Axial (A) and multiplanar reformat (B) of the cross sectional images of LD's pulmonary contusion, anterior wall and posterior wall aortic injury, as well as the fractured T5 vertebral body and associated spinal cord injury.

lodged under the skin along the right back. Cardiothoracic surgery at presentation elected to pursue a thoracotomy, evacuation of some hematoma, and placement of a chest tube. Given the spinal injury, the decision was made not to approach the stable aortic injury at that time. Sequential CT scans showed the increasing size of the mediastinal hematoma as well as the amount of extravascular contrast both anterior and posterior to the pass through aortic injury over the 5-day period. Upon arrival, his examination demonstrated motor and sensory paralysis from the T4–T5 level down, a small caliber burn/bruise noted at the anterior left chest entry site and palpable pulses. He had an existing left chest tube, general endotracheal anesthesia and sedation had been maintained for control of blood pressure. The diameter of his iliac and femoral access was not available from initial studies. Figure 2 shows a multiplanar reformat of the bullet trajectory outlining the majority of his injuries.

PATIENT EVALUATION

Step 1: What is the Most Life Threatening Injury?

The optimum timing in the treatment of injuries is determined through a complex and systematic process where the consequences of both observation and rushing to treatment must be considered. Open and clear communication between specialty services caring for the patient is an absolute requirement. Input from cardiothoracic surgery regarding stability of the aortic injury is vital to establish this timing. At our institution (even prior to the advent of thoracic aortic endografts), cardiothoracic surgery has urgently/emergently operated on some cases while others have been stable and observed for up to 1–2 weeks. This expertise and experience is vital in

establishing the urgency or priority ranking of the aortic injury and depends upon imaging findings on serial scans, clinical parameters, as well as the urgency of additional injuries. A hemodynamically stable patient, several hours after initial injury with well-controlled blood pressure (mean arterial pressures in the 60–70 mm Hg range and systolic pressures less than 130 mm Hg), with a limited periaortic hematoma is most likely to remain stable, allowing treatment of other injuries. Unstable patients, intermittent hypertensive and hypotensive episodes, and large volume periaortic hematoma with clearly defined contrast outside the luminal walls lead to more urgent treatment of these injuries.

Of note, one must remember consequences of treating the thoracic aortic injury with an endovascular approach. Specifically, to deliver the device, relatively large diameter (18F–24F) sheaths are required, making anticoagulation during delivery a priority. Enough heparin is required to maintain patency of the lower extremity arterial supply that can be nearly occluded by the delivery system. The consequences of heparin with respect to other traumatic injuries (not to mention the aortic transaction) impact the order of treatment. For example, PD with diffuse axonal injury, intraparenchymal and subarachnoid hemorrhage was not a candidate for heparin upon arrival. However, after 10 days of stable blood pressure control and no further perfusion changes or neurologic deficits, a onetime dose of heparin with immediate pharmacologic reversal upon removal of the occlusive delivery sheath, is a reasonable, safe alternative (again with input from both cardiothoracic surgery and neurosurgery). On the other hand, LD had shown progressive growth of the volume of contrast outside the confines of the vasculature during a 5-day period. Moving forward with treatment of the aortic injury in a more urgent manner would be highly recommended.

Step 2: Open Versus Endovascular Approach?

The decision of open versus endovascular approach to the repair is also complex and requires input from several services. In some cases, clinical parameters and aortic morphology may drive the decision process with limited debate between services. For example, unstable patients, with hemodynamic changes limiting the ability to obtain appropriate cardiovascular imaging, likely require urgent/emergent surgical repair. However, after appropriate imaging, the aortic diameter may be inappropriate or the “seal zones” may not be sufficient for any available stent graft, preventing the endovascular approach in this group of patients.

As the open repair would frequently require a large thoracotomy (with potential extension into the abdomen) and subsequent mediastinal drains and chest tubes, comorbid conditions may severely limit the recovery from the extensively invasive procedure. PD's mild underlying emphysema, multiple rib fractures, and 80+ years of age, place him at a mild to moderate risk of complications from the general anesthesia as well as the consequences of the major surgery. In short, PD would not likely recover from such a major operation, making the endovascular repair his only treatment option beyond conservative medical management alone (maintained blood pressure control). In LD's case, both open and endovascular approaches would likely produce similar quality outcomes. However, major complications of an open repair related to thoracotomy, blood loss, and cardiopulmonary bypass could be avoided with the endovascular approach. The dominant endovascular complication of concern (paralysis) was no longer a factor. The aortic stent graft had little chance of altering or extending the extent of paralysis related to the original trauma.

Step 3: Endovascular Anatomy, Stent Graft Options, and Choices

After the decision has been made to treat the patient with an endovascular approach, several imaging findings help guide the choice of treatment graft devices. Several devices and specific characteristics have been reviewed in recent literature in nontrauma thoracic aortic literature.¹⁻⁵ Critical and efficient analysis of the vascular anatomy must be completed. An arterial phase contrast-enhanced CT with ability to obtain three-dimensional reconstructions assist in choosing the appropriate endovascular device. In short, six main factors contribute to this decision: proximal (closest to the heart following the path of the aorta) and distal (farthest from the heart) landing (or “seal”) zones, angulation of the arch between proximal and distal landing zones, length of coverage, what branch vessels need to be covered, and the pelvic vasculature involved in the delivery of the device.

The evaluation of the proximal and distal landing zones for the endograft involves several steps. First, appropriate diameters (measured in a geometric plane perpendicular to blood flow through the vessel) in an area of “normal” aorta both proximal and distal to the injury are obtained to identify appropriate diameter of the appropriate endograft component pieces. If the proximal and distal diameters are similar, a single endograft device may suffice for treatment. If the diameters are significantly different, two or more overlapping devices may be required. In choosing diameters, an endograft that is too large develops infolding and can be treated with additional angioplasty or routine stenting. On the other hand, endografts that are too small in diameter can only be treated by extending the coverage length with another stent graft and potentially covering or excluding additional, unintended key blood vessels. The slightly “oversized” endograft situation is significantly easier to repair than a similarly “undersized” endograft. Second, when building an endograft with multiple devices of different sizes, it is mandatory to position the larger stent graft into the smaller one with an appropriate overlapping segment. The larger endograft extends to the confines of the smaller device and creates an adequate intragraft seal zone between the two pieces. If accidentally done in reverse, a permanent gap will exist between the walls of the smaller and larger endografts that can only be treated with a third overlapping graft. This concept frequently defines whether the proximal or distal endograft is positioned first in the aorta. Finally, the quality of aortic tissue at each of the seal zones helps predict the length of seal required to reduce the risk of type 1 endoleaks. Manufacturing recommendations frequently expect 1–2 cm of apposition between the endograft and aortic wall. In our experience, this length of seal can be adjusted slightly depending upon the quality of the aortic tissue at the seal zone. For example, in a relatively young, healthy, muscular aortic wall that is elastic and compliant, an appropriate seal can be obtained with ~5–7 mm of “seal.” On the other hand, atherosclerotic changes with vascular calcifications and atheromatous plaques with irregular surface structure make the appropriate seal more challenging; therefore, longer seal zones 1.5–2.5 cm are required.

Once appropriate proximal and distal landing zones have been identified, the endografts must conform to the angulation of the arch between proximal and distal landing zones, appropriately cover the length of injury including the proximal and distal landing zones, and adequately exclude intervening branch vessels. If the identified proximal and landing zones are both in the descending thoracic aorta, there is usually no significant angulation present between these two areas and nearly any stent graft would exclude the injury if sized appropriately. On the other hand, with ligamentum venosum

injuries and ectatic, atherosclerotic aortas, the proximal landing zone frequently extends into the aortic arch, resulting in a significant angle between the seal zones. The design of the metal and fabric within the endograft frequently impacts how smoothly the device can unfold and match the curvature of the aortic arch. If the device fits the curvature smoothly, the proximal seal zone is longer, and less likely to result in a type 1 endoleak. On the other hand, stiffer stent grafts conform less, and have a higher risk of failure. In our experience, the TX2[®] Pro Form (Cook Inc, Bloomington, IN) and cTAG (conformable TAG, W. L. GORE & Associates, Flagstaff, AZ) tend to fit extreme corners the best. The coverage length and excluded vessels depend entirely upon the choice of the two landing zones. Increasing length increases the number of thoracic vertebral arteries, bronchial arteries, and potential subclavian/carotid artery origin exclusions and the risk of associated spinal cord injury. If the subclavian or carotid arteries are potentially within the seal zones and coverage of the origin is anticipated, verification of a patent circle of Willis and bilateral vertebral artery to basilar artery communication is required either by computed tomography angiography (CTA) or catheter arteriography.

Finally, the pelvic vasculature involved in the delivery of the device must be evaluated prior to attempting endograft placement. A CTA identifying either left or right common femoral, external and common iliac arteries with diameters 7–8 mm would be ideal. Small focal stenoses can frequently be treated with angioplasty or stenting to assist in delivery. A second arterial access allowing aortic flush injection rates and measurement standards from the contralateral lower extremity (or left upper extremity, if not anticipating to cover the left subclavian origin) always assists in positioning the graft appropriately within the injured aorta. Several books and articles are available describing the basic techniques, equipment, indications, and contraindications for procedures of this type.^{6–9}

CASE 1: DECISION PROCESS AND TECHNIQUES

PD's age, underlying pulmonary function, and intracranial injuries essentially prevented a major thoracoabdominal incision and direct open repair. In fact, the extent of his diffuse axonal injury, subarachnoid and intraparenchymal blood was a key factor in determining the order of repair. Given the relative diameter of the required delivery systems (24F) and diameter of the iliac vasculature, heparin would be required to maintain patency of the blood flow to the lower extremity. With blood pressure control and time, the intracranial hemorrhage was monitored for ~1 week. During this interval, evaluation of the angulated aortic arch identified proximal and distal landing zones in the aortic arch

resulting in coverage across the origin of the left subclavian artery and mid descending thoracic aorta respectively. Given PD's age, mild/moderate atherosclerotic changes seen on the cross sectional imaging study, and presumed compromised aortic wall compliance, the decision to have maximum length of seal, guided the decision to extend coverage across the origin of the left subclavian artery. The extreme angulation (over 110-degree corner) and anticipated coverage of the left subclavian artery supported the choice of the next generation Gore device (cTAG) conformable thoracic aortic stent graft device in a "compassionate use" off-label indication. In the meantime, CTA also demonstrated an intact circle of Willis and bilateral vertebral artery communication via the basilar artery.

Once neurosurgery and neurology teams assisting in his care allowed heparin, the planned case was brought to the Interventional Radiology (IR) suite. A 5F marking flush catheter was advanced into the thoracic aorta from the left common femoral approach for diagnostic assistance. After digital subtraction angiography (DSA) evaluation of the aortic arch confirmed the diameter and location of the seal zones, the appropriate diameter and length conformable thoracic aortic stent graft was selected. Intravenous heparin and prophylactic antibiotics were administered. Two oblique suture-mediated closure devices were deployed (Perclose[®] Proglide, Abbott Vascular, Redwood City, CA) in a "preclose" technique in the right common femoral artery after limited pelvic arteriogram demonstrated an appropriate access and closure location.¹⁰ A 24F delivery sheath was advanced through the right common femoral access into the abdominal aorta over a stiff, exchange length guidewire. The endograft device (Gore cTAG, 37 mm × 20 cm) was advanced into position over the wire under fluoroscopic guidance. Repeat DSA evaluation with magnified oblique projection confirmed placement of the proximal and distal seal zones. The marking flush catheter was pulled back to the abdominal aorta and the device was deployed under fluoroscopic guidance. Angioplasty at the proximal and distal landing zones was performed. Postplacement DSA evaluation confirmed appropriate location of the endograft with a small, proximal type 1 endoleak. The proximal seal zone was again gently secured in position with a tri-lobe angioplasty balloon at 60-degree rotation intervals (allowing complete circumferential wall contact). The stent conformed well to the extreme angulation, the leading edge of the graft material (radiopaque marking line, the "petals" do not have covering fabric in the cTAG device) was located immediately on target next to the origin of the carotid. After repeat angioplasty, the flow through the type 1 endoleak appeared significantly decreased. Given the previous heparin dose and inability to cover the carotid without further surgical intervention, the decision was made to address this at a later date. Follow up CTA ~1

Figure 3 Intraprocedural digital subtraction arteriograms before (A) and after (B) placement of PD's single thoracic aortic stent graft and location relative to the origin of the left subclavian and carotid arteries. Note the early enhancement of the left subclavian artery indicating an endoleak scheduled for reevaluation and potential surgical management in the near future. Also, note the uniform positioning of the stent material within the endograft, allowing for the maximum seal in the extremely angulated aorta.

week later demonstrated evidence of a type 2 leak from the subclavian artery. PD is scheduled to return for repeat arteriogram and potential embolization of the proximal aspect of the subclavian artery. Figure 3 demonstrates the positioning and placement of the endograft device. The 24F sheath was removed with closure of the sutures without incident. Prior to removing the left arterial access site, DSA evaluation of the right lower extremity confirmed adequate closure of the 24F access without bleeding or thrombus formation. The left femoral access site was closed with a metallic clip closure device (StarClose™ Vascular Closure System, Abbott Vascular Devices, Redwood City, CA). PD did report some minor weakness in his left arm after coverage of the origin of the subclavian artery. As he was right-hand dominant, this did not alter activities of daily living and the decision was made to observe prior to considering any additional surgery at this time.

CASE 2: DECISION PROCESS AND TECHNIQUES

LD, on the other hand, was transferred on an urgent/emergent basis after sequential imaging demonstrated significant growth in the pseudoaneurysm. Evaluation of the vasculature demonstrated an ~5–7 mm proximal landing zone between the left subclavian and the injury. Given the otherwise healthy aortic wall endothelial lining and smooth muscle, a plan was devised to exclude the penetrating injury with minimal seal zone. A “backup” plan requiring coverage of the left subclavian artery was also devised. Left common femoral arterial access was used for a 5F marking flush catheter. Intravenous heparin and antibiotics were administered. Two suture-mediated closure devices (Perclose® Proglide)

were deployed in an oblique configuration after pelvic DSA demonstrated adequate arterial access. DSA evaluation confirmed CT planned graft devices large iliac limb extender endografts (Zenith, ESLE 20–55 mm; Cook Inc.). A 16F-delivery sheath (Keller-Timmerman, Cook Inc.) was advanced into the descending thoracic aorta. The endograft device was transferred to the new delivery system via previously described techniques and delivered under fluoroscopic guidance.^{11,12} Poststent placement DSA evaluation confirmed expectations that two devices would be required. The second 20 × 55 mm iliac limb extension device was transferred to the sheath, delivered to the thoracic aorta via the sheath, and deployed under fluoroscopic imaging. The seal zones and overlapping zones were secured with low-pressure angioplasty. Postplacement DSA evaluation demonstrated adequate location and seal without evidence of an endoleak (Fig 4). The 16F sheath was removed with closure of the suture-mediated devices. Minimal manual pressure was required to complete hemostasis. Limited femoral DSA evaluation confirmed adequate closure of the right common femoral access from the remaining left access site. Poststent placement CTA was obtained prior to discharge to a skilled nursing facility for recovery. No endoleak was identified and the stents remained unchanged in position when compared with placement imaging.

DISCUSSION

If a patient has survived the initial injuries and resuscitation attempts after a traumatic thoracic aortic transaction, blood pressure control can be effective in controlling the timing of the repair. Both cases illustrate the importance of prioritizing the injuries and address-

Figure 4 Intraprocedural digital subtraction arteriograms before (A) and after (B) placement of LD's two thoracic aortic stent grafts and location relative to the origin of the left subclavian artery.

ing the most life-threatening conditions first. When necessary, refraining from treatment, allowing other injuries to heal, can be a key step in the treatment. If clinical conditions change, having the appropriate equipment available on an emergent basis assists in the comfort level of the supporting clinical teams during these waiting periods.

Reiterating an important detail we have learned from experience: age and atherosclerotic disease alter the muscular compliance of the aortic wall. Forming a tight seal between an endograft and a poorly compliant aorta requires a maximum overlap with seal zones (at least 2 cm, longer if anatomy permits). Similarly, one might expect noncompliant, brittle, aortic walls to have a tendency to “crack” with oversized angioplasty or stenting. On the opposite end of the discussion, young, healthy aortic walls tend to be more compliant and will conform to an endograft somewhat readily. An appropriate seal in some younger patients may be obtained with a mere 5–7 mm. Plans to extend the graft proximally (with appropriate bypass procedures if necessary) are necessary in the event a longer segment of aorta is required to obtain an appropriate seal in these cases.

LITERATURE REVIEW

The number of publications describing endovascular repair of the thoracic aorta has grown exponentially in recent years. The experience gained in treating the abdominal aorta has expanded the role of endovascular techniques in the thoracic aorta. In evaluating the available data, one must be keenly aware of the differences in patient populations with respect to the indication of the planned thoracic aortic endograft placement.

The outcomes in traumatic aortic injuries include a wide variety of patient populations with a prominent number of coexisting acute injuries. Generalizing the results to or from a population of patients with atherosclerotic changes and different aortic pathology (aneurysms, dissections, penetrating ulcers) can be misleading.

Demetriades et al evaluated a multicenter prospective evaluation of open surgical or endovascular stent graft repair of patients with traumatic aortic injuries.¹³ Of the near 200 patient charts evaluated, ~65% were repaired with endovascular techniques and 35% with open surgical techniques. Overall mortality was reported as 13.5% and was significantly different between treatment groups (operative repair at 23.5% and endovascular repair at 7.2%). The patients were also divided into groups with or without additional “nonchest” traumatic injuries with similar outcomes. Of note, the endograft group trended to a lower procedure-related paraplegia rate (2.9% vs 0.8%, $P = .28$) and developed 32 device-related complications. This review concludes that endograft repair results in lower mortality and fewer blood product transfusions but “serious device-related complications” should guide device development and patient selection.

Hoffer et al prepared a meta-analysis of 19 publications comparing 262 endograft repairs to 376 open surgical repairs.¹⁴ Endovascular techniques compared favorably with a mortality odds ratio of 0.43 (95% CI, 0.27–0.70, $P = .001$) and a procedure related paraplegia odds ratio of 0.30 (95% CI, 0.12–0.76, $P = .01$). They also described early and late endoleak rates of 4.2% and 0.9%, respectively, and arterial access site complications of ~4.1%. In a similar approach and timeframe, Xenos et al also prepared an independent meta-analysis comparing

369 open surgical repairs to 220 endograft repairs with similar results favoring endovascular techniques.¹⁵

Tong et al performed an economic evaluation of the endovascular approach over open surgical repair in a similar group of patients with blunt aortic trauma with results again favoring the nonoperative technique.¹⁶ At 1 year, total costs for the endovascular approach were nearly \$70,400 vs \$72,800 for the open repair. Overall mortality, paraplegia, major complications, intensive care unit (ICU) stay, and hospital length of stay all favored the endovascular approach in the Ontario, Canada study. Consideration for late complications and long-term surveillance imaging in the economic decision tree analysis are minor critiques of this study.

Arthurs et al performed an evaluation of the National Trauma Databank evaluating functional and survival outcomes in blunt traumatic aortic injuries. In this dataset, ~3000 patients with blunt traumatic aortic injuries were included in 1.1 million trauma admissions. Of the nearly 2400 patients surviving transport and triage, 68% did not undergo a vascular repair, whereas 28% were repaired with open techniques and 4% with endovascular techniques. Aortic repair (both surgical and endovascular) decreased mortality ($P < .05$) over patients with no attempted repair. This study does not find any statistically significant difference in survival between the two techniques in evaluation of all patients. However, the mortality rate for a delayed repair (> 72 hours) of a traumatic, blunt, thoracic aortic injury with an endovascular approach was 0% versus 12% for an open repair.

Durham et al reviewed the experience at a “contemporary rural trauma center” regarding similar blunt traumatic thoracic aortic injuries.¹⁷ Of the 56 patients evaluated, 35 received either open or endovascular repair and 21 patients were managed medically. Of note, this study concludes that in the subgroup of patients that arrived from the field hemodynamically stable and were managed medically, there was sufficient time for a thorough evaluation of injuries and planning of an appropriate endovascular repair. The authors suggest that as endovascular techniques become more widely available, a declining proportion of patients in the medical management only group will be identified.

Midgley et al reviewed 30 blunt thoracic aortic injuries at a single institution.¹⁸ Again, endovascular techniques were associated with less mortality and morbidity when compared with operative approaches. The authors also indicate “endovascular repair is replacing open repair as the treatment of choice” at their institution. A German study of 34 patients and a Spanish study of 20 patients describe similar results with successful placement and improved outcomes.^{19,20} Another 103 patients were reviewed comparing 36 surgical cases to 26 endovascular cases (22 did not survive triage and 19 were treated conservatively) with improved morbidity and mortality in the endovascular group.²¹ However,

there were increased costs associated with the endovascular group. Rahimi et al reviewed 18 aortic transection cases in a 3-year period at a New York trauma center. Nine of the 18 patients required the extension of the stent graft over the origin of the left subclavian artery without medical consequences. No strokes or postoperative paraplegia were reported in a 13-month average follow-up period.

In patients with complex and multisystem injuries, there is increasing evidence supporting delayed repair in appropriate situations. Botta et al described their experience with 31 patients with traumatic aortic injuries.²² Sixteen of these patients underwent a delayed endovascular repair (median time from trauma was 1.5 months) after treatment and resolution of associated traumatic injuries. Eleven patients underwent acute treatment (median treatment time at 24 hours) due to hemodynamic changes, inability to medically manage blood pressure, and imaging findings concerning for rupture (i.e., growing pseudoaneurysm, contrast extravasation, and periaortic hematoma). One complication in the acute treatment group included a cerebellar stroke after intended occlusion of the left subclavian artery. In these patients, careful consideration of the proximal landing zone, decision to cover the left subclavian artery, and potential surgical bypass operations restoring flow to the occluded vessels were also incorporated into the treatment algorithm.

Most recently, Hong et al reported the impact of endovascular repair in the management of traumatic thoracic aortic injuries.²³ They found an increasing incidence of endovascular repair and simultaneous decrease in open surgical repair of the aortic injury on a national level. An increasing number of treatment procedures support the concluding argument that the minimally invasive approach is also extending the treatment to those patients not previously considered as safe operative candidates. The endovascular group had a higher incidence of brain injury, lung injury, and hemothorax when compared with the operative group. No difference in abdominal injuries or major orthopedic fractures was identified. No difference in mortality between the endovascular and open surgical groups was identified; however, a shorter hospital stay was noted.

CONCLUSIONS

There is an increasing body of literature supporting the use of endovascular techniques in traumatic aortic injuries. However, continued need for long-term follow-up and outcome data are still lacking. We have no reservations about Case 1, with short-term follow-up, his endoleak will potentially resolve independently or with graft extension and carotid coverage with appropriate bypass procedures. The long-term follow up in PD's case will have limited impact in his treatment plan

as he will likely succumb to other factors in life. However, young LD (as well as a significant proportion of the trauma patients) has several decades of life to live. We do not know what will happen to the endograft or the aorta after 10–20+ years of life. Both cases demonstrate the need to prioritize the complete list of injuries following these extreme trauma situations. Waiting for some injuries to resolve while merely controlling blood pressure can be very effective in maintaining patient survival with regard to traumatic aortic injuries. Choosing the appropriate seal zones and endograft device with consideration of aortic diameter and wall compliance, and appropriate backup plans for extension as needed are vital lessons that have helped make endograft placement in traumatic aortic injuries the standard of care in many trauma centers.

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