Endovascular treatment of acute traumatic thoracic aortic injuries: A retrospective analysis of 20 cases

Francesca Urgnani, MD, Philip Lerut, MD, Marcio Da Rocha, MD, Domingo Adriani, MD, Fernando Leon, MD, and Vicente Riambau, PhD

Objective: We report our 10-year experience in the endovascular treatment of acute traumatic thoracic aorta rupture at the Hospital Clinic.

Methods: We reviewed 20 patients with an acute traumatic thoracic aorta lesion treated with a thoracic endograft between August 1997 and July 2007. All patients had multi-trauma resulting from high-velocity accidents or accidents with great impact. The diagnosis of aortic injury was made on a clinical basis and conventional imaging, confirmed by computed tomographic angiography. The following parameters were studied: age, sex, type and site of the lesion, type of endovascular graft, endovascular operation time, length of stay in the intensive care unit, length of stay in the hospital, immediate and perioperative complications, and mortality. Follow-up data were recorded, consisting of clinical visits, computed tomographic angiography, and plain chest radiographs at regular intervals (3, 6, and 12 months and every subsequent year). The mean follow-up was 58 months.

Results: All endovascular procedures were technically successful, and the mean operating time for the endovascular procedure was 74 minutes (range, 55–130 minutes). We recorded an external iliac lesion during the procedure as an unique immediate complication, and it was corrected by an iliofemoral bypass. The only perioperative death (perioperative mortality rate of 5%) was unrelated to the aortic rupture or stent placement. There was no intervention-related mortality during the follow-up. Postoperative data showed no severe endovascular graft- or procedure-related morbidity. We recorded 2 cases of stent fracture, diagnosed by chest radiograph and computed tomographic angiography, without clinical impact or signs of endoleak.

Conclusion: The short- and mid-term results of immediate endovascular repair of traumatic aortic injuries are promising, especially when compared with open surgical treatment, indicating that endovascular therapy is preferable in patients with multi-trauma and traumatic ruptures of the thoracic aorta. Nevertheless, long-term follow-up data are necessary to assess the overall durability of this procedure, considering the young age of these patients. The long-term follow-up results will determine whether endovascular treatment should replace open surgery as first-line therapy in thoracic aortic injuries.

Second to head injury, thoracic aortic rupture represents the most common cause of death due to trauma in the Western world.¹ Etiologically, thoracic aortic injuries can be secondary to penetrating or blunt trauma. In case of penetrating trauma, immediate death usually occurs, and it is rarely possible to intervene. Blunt aortic trauma generally results from acute deceleration trauma, such as high-speed motor vehicle accidents or falls from great heights. Some series report immediate death rates ranging from 75% to 90%.²⁻⁵

Moreover, the prognosis for patients who do survive the initial injury remains poor: approximately 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

The classic injury mechanism of blunt thoracic aortic trauma 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. Seventy to ninety percent of traumatic aortic ruptures are located at the isthmus site.⁴⁻⁷

The lesion affects the 3 layers of the arterial wall in different ways, causing distinct patterns ranging from subintimal hematoma to complete aortic transection. Patient survival primarily depends on adventitia integrity and hematoma formation that permit the tamponment of the lesion. When the lesion affects the adventitia, death is instantaneous at the accident site. The majority of patients who arrive at the hospital alive present a subadventitial rupture, partial or circumferential, that can later evolve toward rupture or pseudoaneurysm formation.

Unlike ascending thoracic aortic lesions, in case of isthmus or descending thoracic aortic injuries, there is not a general consensus on an immediate surgical treatment. Patients with blunt trauma to the thoracic aorta typically have multiple associated injuries that not only compound therapeutic

From the Vascular Surgery Division of the Thorax Institute, Hospital Clinic, Barcelona, Spain.

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Address for reprints: Francesca Urgnani, MD, Hospital Clinic, Vascular Surgery Division, Carrer Villarroel, Barcelona, Spain 08036 (E-mail: franci_u@yahoo.it).

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Abbreviations and Acronyms

CT	= computed tomography
CTA	= computed tomographic angiography
LSA	= left subclavian artery
TAI	= traumatic aortic injury
TEVAR	= thoracic endovascular aortic repair

challenges in their surgical management but also increase their overall morbidity and mortality.

Despite significant advances in critical care medicine and refinement in surgical techniques, morbidity and mortality from immediate open surgical repair of traumatic lesions of the thoracic aorta are still high, with paraplegia ranging from 2.3% to 25%^{8,9} and 30-day mortality ranging from 8% to 30%.¹⁰⁻¹² Some authors¹³ have advocated a delay of the operative intervention in hemodynamically stable patients to permit stabilization of other serious concomitant injuries and medical optimization to improve the outcome and decrease perioperative and postoperative complications.

Nonetheless, this therapeutic conduct is not unanimously accepted; even with careful blood pressure monitoring, some patients (2%–5%) experience a total aortic rupture while awaiting stabilization and repair.¹⁴⁻¹⁶ As a result, endovascular therapy, because of its minor invasiveness, has emerged as a valuable therapeutic alternative in the treatment of these lesions, generally affecting patients with multi-trauma with severe comorbidities.

Since the first report on endovascular treatment of traumatic aortic ruptures in 1997,¹⁷ several small series have demonstrated endovascular repair to be an effective new treatment strategy with promising results.¹⁸⁻³⁵ The aim of this study is to report a 10-year experience in the endovascular treatment of 20 patients with acute traumatic thoracic aorta rupture at the Hospital Clinic and to evaluate whether endovascular treatment is a valuable or better alternative to open surgical repair in emergency settings.

MATERIALS AND METHODS**Patients**

We retrospectively reviewed 20 consecutive patients with an acute blunt traumatic thoracic aortic rupture treated with an endovascular graft between August 1997 and July 2007 at the Hospital Clinic. The demographic characteristics of the patients treated, type and site of lesion, and associated injuries are summarized in Table 1. Seventy percent were male, and 60% presented an American Society of Anesthesiologists score of 3 or more. The mean age was 29 years (range, 18–45 years). All were patients with multi-trauma resulting from high-velocity or great impact accidents. Sixteen patients had been traffic accidents (6 car accidents and 10 motorbike accidents), and 4 patients had fallen from great heights.

An injury severity score was calculated for each patient.³⁶ The mean injury severity score was 46, with values ranging from 29 to 66; 50% of the patients had an injury severity score of 50 or more. The Revised Trauma Score³⁷ was not calculated because of the lack of respiratory frequency rate data in many patients' records. However, we did value the Glasgow

TABLE 1. Demographic characteristics of the patients treated, type and site of lesion, and associated injuries

	No.	%
Age of patients, y	29 (range, 18–45)	
Male	14	70
Female	6	30
ASA $\geq$ 3	12	60
Type of lesion		
Partial and contained ruptures	13	65
Intramural hematoma	2	10
Dissection	1	5
Pseudoaneurysm	4 (mean diameter, 3.5 mm)	20
Site of lesion		
Isthmus, affecting LSA	8	40
Isthmus, not affecting LSA	10	50
Median descending thoracic aorta	2	10
Associated injuries		
Lung injury (hemothorax or pneumothorax)	18	90
Head injury	3	15
Pelvic fracture	6	30
Long bone fracture	6	30
Rib fracture	16	80
Scapula fracture	2	10
Clavicle fracture	6	30
Sternum fracture	2	10
Facial bones fracture	6	30
Vertebral fracture	10	50
Stable	7	35
Unstable	3	15
Abdomen	9	45
Hemoperitonea	2	10
Hepatic, splenic, renal or pancreatic contusion	5	25
Diaphragmatic hernia	2	10

ASA, American Society of Anesthesiologists; LSA, left subclavian artery.

Coma Scale and hemodynamic stability. The mean Glasgow Coma Scale was 11.5, with values ranging from 3 to 15, and 6 patients were hemodynamically unstable.

In all patients, the diagnosis of aortic injury was suggested by the presence of hemothorax or by radiographic finding of a mediastinal enlargement and confirmed by computed tomographic angiography (CTA), according to the Advanced Trauma Life Support guidelines.³⁸

The majority of lesions were partial aortic ruptures at the isthmus level, contained and frequently associated with a pseudoaneurysm. In 6 patients, immediate intervention was required because of voluminous hemothorax, hemodynamic instability, or quick growth of the mediastinal hematoma. All other patients were treated after medical optimization and, in some cases, after the stabilization of other life-threatening concomitant injuries (chest drain insertion, intracranial pressure bolt insertion, laparotomy, and orthopedic intervention). The mean time between hospital admission and endovascular treatment of the aortic lesion was 2 days (range: 1 hour to 5 days).

Preoperative Imaging

All patients underwent preoperative spiral thin-cut computed tomography (CT) scans of the chest (Figures 1 and 2) with 3-dimensional reconstructions to determine the location and type of lesion and the length and

FIGURE 1. Preoperative CTA of thoracic aortic rupture at the isthmus site.

diameter of landing zones, and to evaluate the suitability of the iliac and femoral arteries for vascular access. An aortogram with calibrated catheters was performed in all patients before the release of the graft to obtain more precise measurements of the aorta's diameter and length and its relationship with supra-aortic vessels (Figures 3 and 4).

Procedures

All procedures were performed in an endovascular suite equipped for the eventual conversion to open surgery, with a radiotransparent surgery table and a fixed digital C-arm image intensifier with subtraction and road-mapping capabilities.

All intravascular devices used were covered stent grafts chosen on a commercial availability basis. Six different self-expanding, commercially available endovascular stent grafts were used: Talent and Valiant (Medtronic AVE Inc, Santa Rosa, Calif), Gore TAG (WL Gore and Associates, Flagstaff, Ariz), Relay (Bolton Medical, Sunrise, Fla), Endofit (LeMaitre Vascular Inc., Burlington, Mass), and Zenith TX2 (Cook Medical Inc, Bloomington, Ind).

The dimensions of the stent graft used were determined by the anatomic contour of the aorta, as demonstrated on contrast-enhanced helical CT images. For optimal fixation, all stent grafts were oversized by 15% to 20% compared with the landing zones. The mean graft diameter was 28 mm (range, 22–32 mm), for a mean aortic diameter of 24 mm (range, 18–26 mm).

FIGURE 2. Preoperative CTA of thoracic aortic rupture at the isthmus site.

FIGURE 3. Preoperative aortogram showing thoracic aortic rupture at isthmus site.

Because of the focal nature of the lesion, the use of a single graft was sufficient in all patients. Because of the frequent localization at the isthmus site, 8 patients (40%) required coverage of the left subclavian artery (LSA) to obtain a neck of suitable length. Subclavian revascularization was not performed in any of these patients.

The majority of patients (18/20) were treated with general anesthesia, which permits multiple access sites (femoral, subclavian and iliac) and ensures the patients' compliance during the entire procedure.

The common femoral artery was used for device insertion in 14 patients (70%), and a left retroperitoneal iliac approach was used in 6 patients, with the anastomosis of a temporary conduit (10-mm Dacron graft) to the

FIGURE 4. Preoperative aortogram showing thoracic pseudoaneurysm partially involving the origin of the LSA.

TABLE 2. Characteristics of the procedure and the grafts used

Access	
Femoral	14
Iliac	6
General anesthesia	18
Locoregional anesthesia	2
Procedure's mean time	74 min (range, 55–130 min)
No. of grafts	20
Type of graft	
Talent (Medtronic AVE Inc)	5
Bolton Relay (Bolton Medical)	6
Endofit (LeMaitre Vascular Inc)	2
Gore-TAG (WL Gore and Associates)	3
Valiant (Medtronic AVE Inc)	2
TX2 (Cook Medical Inc)	2
Mean diameter of the graft	28 mm (range, 22–32 mm)
Mean length of the graft	117 mm (range, 90–170 mm)
Mean length of the covered aorta	116.8 mm (range, 90–170 mm)
Coverage of the LSA	8
LSA revascularization	0

LSA, Left subclavian artery.

common iliac artery. The procedure characteristics and type, diameter, and length of grafts are described in Table 2.

Technical Details

Patients were placed in the dorsal decubitus position, and the operative field was prepared and draped permitting emergency laparotomy or thoracotomy. All patients received prophylactic antibiotic therapy perioperatively. The main access artery (femoral or iliac) was exposed surgically. A bolus of heparin was administered to all patients who did not present head injury or bleeding diathesis. When systemic heparinization was contraindicated, local heparin saline flushes of the access arteries were performed to prevent local thromboses.

A standard angiographic pigtail catheter was inserted through a percutaneous puncture (5F) into the contralateral common femoral artery or left brachial artery to permit angiographic control throughout the procedure. When angiographic information was insufficient to identify the exact tear point, transesophageal echocardiography was used.

At the cut-down site, a stiff 260-cm long, 0.035-inch stiff guide wire (Lunderquist, Cook Medical Inc; Backup Meier, Boston Scientific, Natick, Mass; Amplatz super-stiff, Boston Scientific) was advanced up to the aortic arch under fluoroscopic guidance. The endovascular stent-graft system was then inserted under fluoroscopic guidance and positioned properly according to prior imaging. A pre-deployment arteriography was performed through the catheter from the percutaneous side to verify the exact localization of the stent graft in relation to the main arterial branches and the diseased aortic segment. A left anterior oblique sequence usually visualized the aortic arch. The stent was then deployed under fluoroscopic guidance (Figure 5). During deployment, a mild systemic hypotension (mean arterial pressure < 65 mm Hg) was induced pharmacologically by the anesthesiologist with a bolus of fast-acting vasodilators. To obtain an optimal fixation to the aortic wall, only in case of type I endoleak, we used ballooning of proximal and distal ends of the stent graft. A conclusion arteriography was performed to verify the sealing of the stent graft and exclusion of the lesion (Figure 6). Finally, the introducer was removed from the groin, and the arteriotomy was sutured.

Follow-up

All patients underwent standard chest radiography before discharge; clinical and imaging follow-ups (chest x-ray and CT scan or magnetic resonance imaging) were performed at 3, 6, and 12 months (Figures 7, 8, and 9)

FIGURE 5. Intraoperative aortogram showing partial deployment of the graft.

and every subsequent year. The mean follow-up was 58 months (range, 2–119 months).

Definitions

Primary technical success was the complete cure of the injury at the end of the primary procedure in the absence of any immediate complication. *Assisted technical success* was the complete cure of the injury after the correction of immediate complications during the primary procedure. *Secondary technical success* was the complete cure of the lesion after an additional secondary endovascular procedure or after spontaneous thrombosis of primary endoleak within the first month.

Endoleak was defined as an angiographic or tomodensitometric description of blood flow apart from the stent and was classified according to the literature.^{39,40}

FIGURE 6. Image post-TEVAR. Note the partial coverage of the LSA.

FIGURE 7. Three-month follow-up CTA.

Complications were defined as *immediate* when diagnosed intraoperatively, *perioperative* when diagnosed during the hospitalization period or within 30 days from the intervention, and *late* when diagnosed after a patient’s discharge or after 30 days from intervention.

We used the same timing definition for mortality. *Immediate mortality* referred to intraoperative deaths, *perioperative mortality* referred to deaths during the hospitalization period or within 30 days from intervention, *late mortality* referred to deaths after a discharge or 30 days after intervention, and *graft/procedure-related mortality* referred to deaths resulting from procedural or graft-related complications.

Statistical Analysis

We evaluated the actual survival, freedom from graft/procedure-related mortality, and freedom from reintervention curves at 1, 3, and 5 years, according to the Kaplan–Meier method.

RESULTS

The endovascular procedure was performed in all patients, without any conversion to open surgery. We obtained a primary technical success in 19 patients (95%) and an assisted technical success in 20 patients (100%). An external

FIGURE 8. Six-month follow-up.

FIGURE 9. Twelve-month follow-up.

iliac lesion was recorded as an immediate complication, which was corrected intraprocedurally by the introduction of a proximal occlusion balloon via the femoral artery and the performance of an iliofemoral bypass.

The mean intensive care unit stay was 10.3 days (range, 2–20 days), with a mean hospital stay of 24.6 days (range, 4–50 days). Postoperative fever, leucocytosis, and elevated C-reactive protein occurred in 17 patients and were resolved in a mean of 2.5 days (“transient postimplantation syndrome”).

All perioperative complications recorded were related to the trauma, and none were related to the endovascular intervention (Table 3). None of the patients with intentional coverage of the subclavian artery experienced vertebrobasilar or left arm ischemia.

The only perioperative death (perioperative mortality rate of 5%) was unrelated to the aortic rupture or stent placement, resulting in multiorgan failure in a patient with lung, renal, and liver lesions. There was no *late mortality* during the follow-up.

TABLE 3. Results

	No.	%
Primary technical success	19	95
Immediate complications	1	5
Endoleak	0	0
Arterial lesion	1	5
Perioperative complications		
Systemic		
Pulmonary problems (12)		65
Pancreatitis (1)		
Urinary tract infection (1)		
Procedure related	0	0
Perioperative mortality	1 MOF	5
Late complications	2 stent fractures	10
Late mortality	0	0

MOF, Multiorgan failure.

During the follow-up period, we did not record any severe endovascular graft or procedure-related morbidity. We observed 2 cases of stent fracture, diagnosed by chest radiography and CTA, without clinical impact or signs of endoleak.

The survival recorded at 1 and 5 years after the intervention was 95%, as well as the freedom from graft/procedure-related death. The freedom from reintervention rate was 100%.

DISCUSSION

Patients affected by traumatic lesion of the thoracic aorta typically present with multiple concomitant injuries that complicate the traditional surgical treatment. Traditional open repair requires thoracotomy, aortic crossclamping, and, in some cases, left-sided heart bypass. Respiratory compromise from lung and chest wall injuries is compounded by thoracotomy and single-lung ventilation, resulting in prolonged respiratory insufficiency and infectious complications. Aortic crossclamping and unclamping can complicate preexisting hemodynamic and cardiac instability in these critically ill patients and increases the paraplegia risk. Finally, the need for a high level of systemic heparinization increases the risk of bleeding in patients with multiple concomitant injuries.

A variety of technical improvements, including the use of shunts for distal perfusion and cardiopulmonary bypass, seem to have decreased the mortality rate of the open intervention, but overall, open thoracic aortic surgery in patients with trauma remains a challenge.

Delaying aortic repair in those patients who otherwise would not tolerate immediate surgery is often an alternative;

this delay, of course, comes at a cost: Some patients with untreated aortic injury may progress to aortic rupture before undergoing repair.

The advent of thoracic endovascular aortic repair (TEVAR) to treat traumatic aortic injury (TAI) promises to avoid many of the complications associated with open repair, allows surgeons to offer this treatment to more critically ill patients with aortic transection who previously may not have tolerated open repair, and invalidates all the reasons to postpone treatment.

Experience with the endovascular treatment of TAI is still limited. Nonetheless, the majority of the series report a technical success ranging from 81.1% to 100%, with a paraplegia rate of 0% and low mortality and morbidity rates, with accompanying injuries as primary causes of mortality and morbidity (Table 4).⁴¹⁻⁴⁵

These results seem promising, especially when compared with the results of open treatment.⁴⁶⁻⁴⁸ In a recent retrospective review, Riesenman and colleagues⁴⁸ compared the results of the 2 techniques in the treatment of TAI and observed that endovascular repair was associated with a significant reduction in operative time, estimated blood loss, and mortality (0% with endovascular repair and 23% with open repair). These benefits occurred despite similar patient characteristics between the 2 groups. Their experience and other single-institution studies that report parallel outcomes for both open surgical and endovascular treatment of acute TAI are reported in Table 5.

Although these studies are heterogeneous with respect to the type of endovascular graft and the timing of intervention, all report a better early outcome after endovascular repair, including decreased mortality (open mortality rate, 8%–50%; TEVAR mortality, 0%–20%).

TABLE 4. Series reported in the literature concerning the thoracic endovascular aortic repair of traumatic aortic injury

Author	No.	Time until repair	Technical success (%)	Procedure-related mortality (%)	Comorbid mortality (%)	Follow-up (mo)	Paraplegia
Thompson and colleagues ²⁷	5	14 h to 5 d	100	0	0	20.2	0
Lachat and colleagues ²³	12	24 h to 3 wk	100	8.3	0	17	0
Czermak and colleagues ¹⁹	6	NS	83.3	0	0	19.5	0
Orend and colleagues ²⁶	11	3–36 h	100	0	9.1	14	0
Daenen and colleagues ²⁰	7	Few hours to 17 mo	100	0	14.3	9	0
Marty-Ane and colleagues ²⁴	9	12 h to 5 d	100	0	0	4–20	0
Karmy-Jones and colleagues ²²	11	8–72 h	81.1	0	27.3	2–24	0
Melnitchouk and colleagues ²⁵	15	Median 2 d	100	0	13.4	31.9	0
Dunham and colleagues ²¹	16	<24 h to 25 d	100	0	6.3	10.7	0
Amabile and colleagues ¹⁸	9	<24 h to 21 d	100	0	0	51.1	0
Wellons ²	9	NS	100	0	11.1	NS	0
Neuhauser and colleagues ⁴¹	10	<24 h	100	0	0	26.4	0
Rousseau and colleagues ⁴²	8	<14 d	100	0	0	NS	0
Hoonweg and colleagues ³⁴	28	NS	100	0	14.3	25.6	0
Go and colleagues ⁴³	10	>24 h to 2 mo	90	0	0	20	0
Midgley and colleagues ⁴⁴	12	3.6 h to 15 d	100	0	0	15.3	0
Bent and colleagues ⁴⁵	13	Mean 18.5 h	85	0	0	29	0

NS, Not specified.

TABLE 5. Open surgical versus endovascular repair: Summary of the literature

Author	Year	No.	Intraoperative mortality	Hospital mortality	Paraplegia/paraparesis
Kasirajan and colleagues ³²	2003	10	NR	50%	0%
Open EV repair		5	NR	20%	0%
Ott and colleagues ³⁰	2004	12	NR	17%	17%
Open EV repair		6	NR	0%	0%
Amabile and colleagues ¹⁸	2004	11	9%	9%	0%
Open EV repair		9	0%	0%	0%
Rousseau and colleagues ⁴²	2005	35	11%	17%	9%
Open EV repair		29	0%	0%	0%
Pacini and colleagues ⁴⁶	2005	51	6%	8%	8%
Open EV repair		15	0%	0%	0%
Broux and colleagues ⁴⁷	2006	17	0%	23%	18%
Open EV repair		3	0%	15%	0%
Riesenman and colleagues ⁴⁸	2006	48	23%	40%	0%
Open EV repair		14	0%	14%	0%
Midgley and colleagues ⁴⁴	2007	16	18.7%	15%	6.25%
Open EV repair		12	0%	0%	0%

EV, Endovascular; NR, not reported.

Our series demonstrated a high immediate technical success rate, with only 1 procedure-related complication and a low mortality rate. As often occurs in these patients, the only perioperative death recorded was due to concomitant injuries.

None of the perioperative complications we reported were graft or procedure related. Injuries of the lung and chest wall are responsible for the high rate of pneumonia and respiratory insufficiency recorded in the immediate postoperative period in these patients.

The only immediate complication was an iliac artery lesion in 1 female patient (5%). The delivery devices used for introduction of aortic stent grafts are large-profile types; therefore, pre-procedural assessment of the iliac arteries is mandatory to ensure the vessel caliber was sufficient (minimum 7.5 mm) to accommodate the delivery system. When the femoral and external iliac arteries are less than 7.5 mm, the use of an iliac or aortic conduit may be considered. For this reason, we resorted to an iliac approach in 6 patients, with the anastomosis of a temporary conduit.

One possible explanation for such a complication may involve spasm secondary to irritation of the vessel wall during guide wire and catheter manipulation. This complication is more often observed in young female patients, in whom the vessel wall is more soft and compliant to the longitudinal pulling forces, resulting in an increased risk of rupture.

Coverage of the LSA did not result in any complications or need for intervention in our series, equivalent to other reports.^{18,25,49,50} Although coverage of the LSA is generally well tolerated, cerebral problems and upper extremity claudication have been described.²⁶ Consequently, if time permits, optimal pre-procedural workup should include duplex assessment of the extracranial circulation to ensure antegrade blood flow in the right vertebral artery. In the

presence of retrograde flow, it would be prudent to perform left carotid-subclavian bypass before stent grafting. Obviously, the presence of a left-sided thoracic arterial bypass requires subclavian revascularization.

No thromboembolic complications were observed in our study. To prevent local thrombosis because of the large diameter of the deployment sheaths, in the absence of head injury or bleeding diathesis, all patients underwent systemic administration of heparin before stent-graft insertion. In 5 patients with severe associated head injuries or hemorrhagic diathesis, TEVAR was performed with local heparin saline flushes of the access arteries. None of these patients had thromboembolic complications. By avoiding systemic anticoagulation, there is no need to postpone the repair of TAI to avoid increased bleeding risk from concomitant injuries.

We did not record any case of paraplegia, representing the most devastating complication associated with open surgical repair of TAI. Although the use of retrograde femoral perfusion has reduced the incidence of paraplegia in open repair, this complication still occurs (6.25%–18%) (Table 5). Although this severe neurologic complication has been observed after elective endovascular treatment of degenerative thoracic aneurysms, to our knowledge there has never been a reported case of paraplegia after endovascular repair of blunt TAI. The relative short lengths of the endovascular grafts used for this specific lesion, along with no need for aortic crossclamping, could explain these good results.

We did not observe any case of stroke, similar to other reports in the literature.^{18,30,32,44,47} This neurologic complication has been recorded in the endovascular treatment of other pathologies of the thoracic aorta.⁵¹⁻⁵⁴ Its absence in the treatment of TAI can be explained by the young mean age of patients with trauma accompanied by the absence

of atherosclerosis at the level of the aortic arch and origins of the carotid arteries. This absence decreases the risk of embolization during the manipulation of the arch with guide wires and catheters. The 2 cases of stent fracture, which caused neither clinical problems nor endoleak, during the follow-up were not registered as stent-related complications.

However, potential complications unique to stent grafting must be taken into consideration when applying this technique to repair TAI. Type 1 and 2 endoleaks associated with LSA are well documented in the literature, as well as the incidence of stent-graft collapse and migration.^{35,51,55,56} The smaller caliber of the aorta of young patients with trauma and the tighter curvature of their aortic arch present significant challenges to current stent-graft devices, which were designed for a chronically diseased aorta.

The mismatch existing between the aortic diameters of trauma victims and the relatively big diameter of many thoracic grafts often leads to an excessive oversizing of the graft. This is clearly apparent if we consider that the smallest diameter of the Gore TAG, the only graft that has received Food and Drug Administration approval, is 26 mm and that the diameter of the thoracic aorta of a young patient could measure 19 to 20 mm.

The tighter curvature of the distal arch can cause a lack of good graft apposition at the inner curve. This, together with the excessive oversizing, can lead to graft collapse.⁵⁷⁻⁵⁹ For this reason, some authors² are proposing the use of aortic cuffs with a mean stent-graft diameter of 25 mm (range 20–28 mm) in the treatment of traumatic aortic lesions. The more appropriate diameter of these cuffs, however, is counterbalanced by the fact that the delivery systems lack sufficient length to reach the level of the subclavian artery in tall patients. Therefore, they could be used to treat only a part of the European population. Apart from the delivery system length, the maximal aortic cuff length (30–58 mm) is insufficient to obtain an adequate sealing zone. This would result in the need of multiple cuffs with significant risk of disconnection and type 3 endoleak.

In addition, the acute angle of the transverse arch, combined with poor conformability of many grafts, increases the risk of an inadequate proximal sealing. Such inability to gain optimal apposition of the graft to the vessel wall may lead to the development of an endoleak or “wind sock”/“bird’s beak” effect. This is due to an elevation of the proximal portion of the graft at the lesser curvature of the aorta and its hemodynamic features. Vector forces exerted onto this area may promote collapse or migration of the graft.

To size the endograft, we measured the aortic diameter between the LSA and the left carotid artery origins and never oversized the graft more than 20%. This was possible because of the availability of a wide range of stent-graft sizes and models to allow us to choose the more suitable graft for each patient and each anatomy.

The availability of different endovascular equipment, along with a wide range of stent grafts, is essential to offer endovascular treatment in the emergency setting, as well as the availability of a vascular surgeon able to perform endovascular thoracic aortic procedures in appropriate interventional suite or operating room settings.

The total absence of device-related complications that we observed can also be explained by the fact that we never deployed the graft in the most acute angled aortic segments. We avoided these zones by extending the proximal landing zone to the more horizontal segment of the aortic arch, without fear of covering the subclavian artery.

Another point of concern in the endovascular treatment of traumatic aortic injuries is the follow-up. The patient population with TAI is relatively young, and life expectancy is considerable, exceeding the current experience with endovascular graft. Consequently, lifelong follow-up surveillance is indicated for these patients to monitor for any potential device-related complication. Current recommendations involve annual plain chest radiography with interval CT scanning; consequently, cumulative radiation exposure is potentially hazardous.

CONCLUSIONS

Endovascular treatment of traumatic thoracic aorta injuries offers various advantages compared with open treatment: no need for thoracotomy or single-lung ventilation, decreased use of systemic anticoagulation, avoidance of aortic crossclamping, less blood loss, less postoperative pain, and lower paraplegia rate.

Although endovascular treatment has its limitations due to its retrospective nature and relatively small numbers, this study shows that the short- and mid-term results of endovascular repair of acute traumatic aortic injuries are promising. Thus, endovascular therapy may be preferable in patients with multi-trauma and traumatic ruptures of the thoracic aorta. Nevertheless, we have to consider the young age of patients with trauma.

Only long-term follow-up results will determine whether endovascular treatment should completely replace open surgery as first-line therapy in thoracic aortic injuries or should be considered as a bridge procedure, an intermediate measure until the patient is sufficiently stable to undergo open repair. With a younger population involved in trauma, follow-up protocols may need refinement to minimize the risk of radiation exposure. Stent grafts with smaller sizes and lower profiles, and that generate fewer artefacts during magnetic resonance imaging assessment also would be beneficial to apply this technique to a young population.

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