Delayed Treatment of Traumatic Rupture of the Thoracic Aorta With Endoluminal Covered Stent

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Methods and Results—Nine patients (14 to 76 years old; mean, 37 years; male/female ratio, 8/1) underwent stent grafting of the aortic isthmus in subacute (n=5) or chronic (n=4) aortic traumatic rupture after a motor accident. In subacute ruptures, this treatment was delayed (1 to 8 months; mean, 5.4 months) because of the severity of other associated injuries. Stent grafting was technically successful (defined as complete exclusion of the pseudoaneurysmal sac) in all patients. Short-term fever and biological inflammatory syndrome occurred in 3 patients. Two major complications occurred: in 1 patient, an early occlusion of the left subclavian artery was treated by placement of 2 Palmaz stents. In another patient, an atelectasis related to an increase of preexisting compression of the left main bronchus by the pseudoaneurysmal sac was successfully treated by temporary placement of an endobronchial silicone stent. Mean follow-up was 11.6 months (range, 3 to 21 months). Thrombosis of the pseudoaneurysmal sac was found in all patients.

Conclusions—In the absence of available extended follow-up about the safety and effectiveness of endovascular grafting, this approach seems to be a viable therapeutic option for traumatic rupture of the aortic isthmus, but appropriately controlled prospective studies are needed before we can recommend its widespread use. (Circulation. 1999;99:498-504.)

Key Words: aorta ■ prosthesis ■ stents ■ grafting ■ surgery

Rupture of the thoracic aorta due to blunt chest trauma leads to immediate death in 75% to 90% of cases1,2 and accounts for up to 18% of deaths in motor vehicle accidents.3 Approximately 15% to 20% of the victims reach the hospital alive.4 In survivors, blood flow is precariously maintained within the vascular lumen by the adventitia and mediastinal surrounding tissues only. Very few aneurysms remain stable over time; the majority tend to expand and rupture. Finkelmeier et al5 reported that 20 of 60 patients with untreated chronic aortic aneurysm died of aortic complications. Other complications, such as distal embolization, compression, or fistulization to adjacent organs, can be observed.6-7 For all these reasons, early surgical repair is the standard method of treatment for any aortic injury. Nevertheless, some investigators advocate delaying repair by a few weeks for patients in stable condition, particularly when severe neurological lesions are present.6-15

Since the pioneering publication by Parodi et al in 1991,16 the safety and efficacy of transfemoral intraluminal stent-graft implantation for the treatment of peripheral and aortic aneurysms seems to be confirmed by many authors.17-21 Although most investigation is currently focused on abdominal aortic aneurysm, there is sometimes an even greater need for this technique in thoracic aortic diseases.

The purpose of this study was to demonstrate the feasibility and safety of delayed treatment of thoracic aortic injury by transluminal placement of endovascular covered stents.

Methods

We prospectively studied 9 patients (8 men and 1 woman) whose age ranged from 14 to 76 years at the time of the procedure (mean, 37 years) (Table). The indication for stent grafting of the thoracic aorta was subacute or chronic traumatic subadventitial rupture of the aortic isthmus sustained after a motorbike or car accident. In the subacute group (n=5), the delay between initial trauma and stent-grafting procedure ranged from 1 to 8 months (mean, 5.4 months), and no calcification was found on the wall of the pseudoaneurysm. Delay of the endoluminal aortic intervention in our 5 subacute patients was always warranted by the patient’s hemodynamic stability and the severity and number of other associated injuries and by the presence of additional sepsis in 1 of them. Moreover, the risk of intrathoracic exsanguination was thought to be rather low in the absence of clinical evidence of active, ongoing hemorrhage.

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Preprocedural Imaging Studies

Thoracic spiral CT and digital subtraction angiography of the thoracic aorta with a calibrated catheter were performed for measuring and localizing purposes. The graft diameter was oversized by 10% to achieve a tight friction seal, and the length was 2 cm longer than the lesion treated.

### Patient Data

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age</th>
<th>Trauma-to-Treatment Interval</th>
<th>Calcification</th>
<th>Risk Factors Other Than Polytrauma</th>
<th>Device</th>
<th>Approach</th>
<th>Complications</th>
<th>Follow-Up, mo</th>
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<tr>
<td>M</td>
<td>34</td>
<td>5 mo</td>
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<td>Talent</td>
<td>Right femoral</td>
<td>Fever</td>
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<tr>
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<td>Yes</td>
<td>Posttransfusion chronic active hepatitis, chronic C, splenectomy</td>
<td>Talent</td>
<td>Right femoral</td>
<td>Early occlusion of left subclavian artery (2 Palmaz); local thrombos of superficial brachial artery (medical treatment)</td>
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<td>Left external iliac</td>
<td>Fever</td>
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<tr>
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<td>8 mo</td>
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<td>Fever</td>
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</tr>
<tr>
<td>M</td>
<td>18</td>
<td>7 mo</td>
<td>No</td>
<td>Asymptomatic compression of left main bronchus by pseudoaneurysm</td>
<td>Talent</td>
<td>Right femoral</td>
<td>Fever</td>
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<tr>
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<td>6 mo</td>
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<td></td>
<td>Min Tec</td>
<td>Right femoral</td>
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<td>Fever</td>
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<td>Tobacco</td>
<td>Talent</td>
<td>Left femoral</td>
<td>Fever</td>
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</tbody>
</table>

*Proximal indentation of the covered portion to spare the left subclavian artery ostium.

### Stent-Graft Device

The endovascular devices used in our first 2 patients were straight stent grafts (MinTec, 22×80 and 26×90 mm, respectively, both with a 12-mm bare portion at the proximal end and an outer polyester covering. The introduction caliber of the compressed stent grafts was 18F (ie, 6 mm in diameter). Another type of device was used in the last 7 patients (Talent, World Medical Manufacturing Corp), whose diameter ranged from 24 to 34 mm (mean, 27.7 mm) and length from 80 to 100 mm, with 15 mm bare at the proximal end. It has 2 V-shaped radiopaque markers at both ends of the polyester outer covering that allow a more precise placement. No depressive stent graft was used. The introduction caliber of these last 7 stent grafts ranged from 22F to 27F (ie, up to 9 mm in diameter). In 1 patient, stent-graft design was customized to include a 17×21-mm proximal indentation in the covered portion, centered on the external curvature connecting bar, to avoid covering the left subclavian artery ostium with the polyester tube. This modification was dictated by the particular configuration of the aortic rupture, with a nearly nonexistent neck between the left subclavian artery ostium and the upper limit of the pseudoaneurysmal neck.

### Stent-Grafting Procedure

Prior informed consent was obtained from all patients, and a team of interventional radiologists and vascular surgeons performed the endovascular procedure under general anesthesia, with tracheal intubation and mechanical ventilation. The procedure was conducted in a sterile radiological vascular interventional suite (in accordance with the World Health Organization’s recommendations on air handling in surgical suites). The patient was positioned in the dorsal decubitus position, and the operative field was prepared and draped for thoracotomy in the event that the endovascular device could not be deployed or a major complication occurred. Cardiopulmonary bypass equipment was readily available, should such a complication occur.

In all patients, arterial access for introducing the stent graft was the right (n=7) or left (n=1) femoral artery and the left external iliac artery (n=1). The artery was surgically isolated, and a transverse arteriotomy was performed after an intravenous bolus of 5000 IU heparin. We did not have to use any side-limb graft attached to the lower aorta or the common iliac artery to allow stent-graft insertion. Additional axillary arterial accesses were gained to allow (1) easy...
completion of control angiograms during procedures, (2) straightforward marking off of the left subclavian artery ostium just before stent-graft deployment, and (3) in some cases, direct invasive arterial pressure monitoring. Periprocedural transesophageal echocardiography (TEE) was performed to guide the stent-grafting procedure before and during deployment of the device. An initial aortogram with a 5F pigtail catheter introduced through the axillary access helped to obtain the best incidence. A 260-cm-long, 0.035-in stiff guidewire (Amplatz, Meditech) was advanced up to the aortic arch under fluoroscopic and TEE guidance. The delivery system was positioned at the preestablished level in front of the aortic tear. A mean arterial pressure, 70 mm Hg was maintained during implantation, and the outer sheath was slowly withdrawn to fully deploy the implant. Thereafter, the compliant balloon included with the stent-graft package was inflated with sterile hot saline solution to fully anchor the stent into the nonaneurysmal wall of the aorta.

In 2 patients, the proximal part of the stent graft was 1 cm below the ostium of the left subclavian artery and the distal end a few centimeters below the aortic rupture (Figure 1). In 6 patients, the stent graft was deployed with the first proximal noncovered end on the left subclavian artery ostium because of the close proximity of the pseudoaneurysmal sac. As long as only the bare portion of the stent graft covered the ostium of the left subclavian artery, this artery remained patent, with good opacification in all cases (Figure 2).

In 1 patient, we had to cover the left subclavian artery ostium by the polyester tube to exclude the pseudoaneurysm, and the patency of the left subclavian artery was obtained by placement of 2 Palmaz stents (Figure 3).

Finally, the introducer delivery system was removed, and the arteriotomy was repaired after arteriographic and TEE controls. Anticoagulation was maintained for 48 hours and then followed by aspirin 250 mg/d.

Follow-Up
Further imaging follow-up consisted of TEE (at 3, 6, 12, and 18 months) and spiral CT (before discharge and at 3, 6, 12, and 18 months) after the intervention, except for 3 patients who were followed only by CT. Mean follow-up was 11.6 months (3 to 21 months).

Results
Primary Technical Results
Digital subtraction angiography and perioperative TEE revealed complete exclusion of the pseudoaneurysm in all 9 patients (100%), without any immediate leak. Only 1 stent graft was needed in each patient. In 1 patient, arteriotomy had to be extended up to the left external iliac artery because of insufficient length of the standard stent-graft delivery system (MinTec).

Hospital Stay Duration After Procedure
Seven patients could be discharged in good condition between postoperative days 3 and 10, after performance of a spiral CT examination. The 2 remaining patients had to stay in hospital for several weeks because of coexisting diseases.

Figure 1. A and B, Spiral CT and angiography show aortic injury of isthmus before and after positioning of stent graft. Proximal extremity of device starts soon after left subclavian artery ostium. C, At 6 months, reconstructions after spiral CT demonstrate complete exclusion of pseudoaneurysm and stent-graft relationship with aortic arch vessels.
Pseudoaneurysmal lumen thrombosis was found in all cases on follow-up TEE and CT control examinations.

Complications and Management

No death, neurological complication, or infection was observed, but early after intervention, fever, neutrophilic leukocytosis, and biological inflammatory syndrome for 1 to 5 days (mean, 2.7 days) were observed in 3 patients; no causal infectious agent could be identified. Blind broad-spectrum antibiotics were given to 2 patients to cover an eventual stent-graft infection. The significance of these features is uncertain, but they could be related to the “postimplantation syndrome” described in stent grafting for abdominal aortic aneurysms.21

No significant kinking, twisting, stenosis, intragraft thrombosis, migration, perigraft leak, pseudoaneurysmal expansion, or rupture was observed. Three patients showed minimal deformity of the inner face of the stent graft in front of the aortic rupture due to the complete expansion of the graft, without significant stenosis either at end of procedure or on follow-up imaging controls.

Two major complications were observed. (1) In 1 patient, the covered part of the stent graft encroached on the left subclavian artery aortic ostium, necessitating further placement of 2 Palmaz stents to open the Dacron at this level; patency was later shown on arteriographic and CT controls. In the same patient, occlusion of the left superficial brachial artery occurred at the puncture site and was treated only

Figure 2. A, 3D surface shaded display reconstructions after spiral CT show typical aortic injury. Arteriography shows initial noncovered portion of stent graft over left subclavian artery ostium, which stays patent. C and D, Complete involution of pseudoaneurysm and good apposition of endoprosthesis to aortic wall are seen after repair on imaging controls. LSA indicates left subclavian artery ostium; LCA, left carotid artery.
medically. Follow-up clinical examinations and color Doppler ultrasounds (up to 15 months later) showed downstream reentry, weak but present radial and cubital pulses, and moderately asymmetrical systolic pressures (150 mm Hg in the right arm versus 120 mm Hg in the left). (2) In 1 patient with a past history of severe septic context and neurological impairment, acute compression of the left main bronchus and homolateral pulmonary atelectasis occurred soon after the procedure; it was believed to be related to a sudden rise in pressure inside the freshly thrombosed pseudoaneurysmal sac. A Dumon endobronchial silicone stent was placed with good clinical and bronchoscopic results; it was retrieved 3 months later.

Discussion
The timing of repair of traumatic injury of the aorta is still controversial. For many decades, standard surgical practice has dictated that traumatic rupture of the thoracic aorta must be diagnosed quickly and managed aggressively by immediate surgical repair. More recently, the concept of deliberately delayed surgical repair has been reported in the literature.6–15 It stands to reason that immediate surgical repair of aortic injury is mandatory if a significant hemothorax or a pseudocoarctation syndrome indicates impending free rupture. However, in the majority of patients who reach the hospital alive, the adventitia and surrounding mediastinal structures remain more or less intact, thus partially preserving the integrity of the disrupted aorta and preventing acute exsanguination into the thorax. In fact, provided that adequate antihypertensive treatment is given, exsanguination due to delayed free rupture of an initially stable aortic tear may be less frequent than previously assumed. Supporting this hypothesis is a retrospective analysis of 5752 autopsies in which 166 of them died within 2 hours of the accident, precluding surgery, but only 1 patient died of delayed rupture of a periaortic hematoma. In a review of the American literature, Walker and Pate25 found 64 patients with thoracic aortic trauma treated initially by conservative therapy; free rupture of the periaortic hematoma did not occur in any of them. Maggisano et al15 demonstrated an operative mortality of 9% when using a more selective approach consisting of immediate repair for unstable patients and for stable patients with no contraindications to this early repair, and deliberately delayed repair for patients with concomitant injuries or sepsis. This compares favorably with the operative mortality of 21.3% in a 20-year meta-analysis.26

Pate et al10 found that the risk of developing free rupture after arrival at the hospital with the periaortic hematoma contained in the mediastinum appeared to be considerably lower than the risk involved in emergency aortic repair in patients with serious associated injuries. Moreover, they
showed that no patient whose systolic arterial pressure was maintained at <140 mm Hg by drug therapy developed free rupture. They remind us that 1 of the major determinants of rupture of the pseudoaneurysm is the left ventricular systolic ejection dynamics, which suggests that the use of β-blockers is even more essential than simple antihypertensive therapy. All our patients were closely monitored for any rise in blood pressure. The goal was to maintain a mean arterial pressure <80 mm Hg. This was achieved with a combination of a β-blocker and vasodilators.

Moreover, controversy remains regarding the best method of intraoperative management. A meta-analysis of articles concerning the surgical management of acute traumatic rupture of the descending thoracic aorta has been reported. It showed that the risk of paraplegia complicating surgery on hemodynamically stable patients with acute rupture of the thoracic aorta is ≥2.3%, even if active distal perfusion is provided. With either passive shunting or simple aortic cross-clamping, the risks of paraplegia are 11.1% and 19.2%, respectively. However, full systemic heparinization, needed for active distal perfusion, is very risky in patients with acute traumatic rupture of the aorta because of the high incidence of associated cerebral and visceral injuries. Heparinization has been suggested to contribute to morbidity by aggravating neurological injuries, causing intrapulmonary hemorrhage, and increasing surgical mortality. Data from this meta-analysis documented a higher mortality in patients treated with systemic heparinization (18.2%) as opposed to those who did not receive heparin (11.9%). Thus, patients with multisystem lesions have to be carefully evaluated to establish a plan of therapy for each injury.

In combination with aggressive medical management by reducing cardiac shear forces, standard therapy involves surgical placement of an interposition graft through a thoracotomy. Currently, less invasive strategies are being investigated for elective therapy of thoracic aortic lesions with use of endovascular stent grafts. The theoretical advantages of endovascular treatment of acute rupture of the thoracic aorta are multiple: a simple arteriotomy is performed without thoracotomy or aortic clamping, and the length of the covered aorta is limited to the diseased segment, which theoretically lessens the risk of medullar ischemia. Furthermore, severe head injury and pulmonary contusions pose fewer problems with this approach because, for the former, the absence of aortic cross-clamping prevents an intracranial pressure rise, and for the latter, there is no need for intraoperative 1-lung ventilation. And finally, because stent-graft insertion can be done with mild anticoagulation, the major bleeding complications observed with a surgical full heparinization could theoretically be avoided.

A Stanford team recently reported a series of 82 selected patients with descending thoracic aortic aneurysms treated by transluminal stent-graft placement. They observed a mortality rate of 8.5% and a paraplegia rate of 3.6%. In our study, we did not experience any major coexisting morbidity, including such complications as heart failure, renal failure, neurological complications, or distal embolization or infection. Every pseudoaneurysm was treated in 1 step with only 1 stent graft, and no leak was observed. The precise sizing of the device is certainly the most critical point of these endovascular procedures. We use data from the digital subtraction angiogram with a calibrated catheter and spiral CT with multiple angles of view provided by 3D reconstructions to thoroughly evaluate neck lengths, topography of the pseudoaneurysm in relation to branch vessels, and aortic diameters.

Because the isthmus is involved in >85% of traumatic aortic injuries, it may be difficult to treat these lesions by stent grafts, for different reasons. A relatively rigid device could be difficult or dangerous to cross in a very angulated aortic arch. The aneurysm frequently originates just beyond the left subclavian artery with an insufficient proximal anchoring length to have a safe support of the stent graft on healthy aortic wall. This was observed 7 times in this series, and it was resolved by different means: (1) the noncovered part of the stent graft was intentionally placed over the ostium of the left subclavian artery in all but 2 patients, leaving the polyester covering starting just after this ostium; (2) a small preimplant window was created in the polyester in front of this ostium at manufacturing; and (3) a hole was made inside the polyester after graft insertion, and this channel was calibrated by dilatation and stenting. By these techniques, no arm ischemia or neurological complication was observed, and it was not necessary to create a carotid-to-subclavian arterial bypass graft before or after stent-graft insertion.

The rigidity of the stent graft could be also a problem, because an inability to hug the aortic arch securely might cause a perigraft leak. We did not observe this complication. We used 2 different devices for this study, and in our opinion, it seems that the Talent device, with a conical shape of the proximal part of the stent, is more appropriate for this indication, allowing a better proximal fixation and avoiding partial protrusion of the polyester inside the aortic lumen as encountered with straight devices. Some homemade devices have been illustrated in isolated case reports; their reproducibility is limited on a large scale. Other available devices are manufactured but seem to be less adapted to endovascular techniques, as a result of their rigidity and the size of their introducing system.

Our preliminary experience demonstrates the feasibility and safety of this method, but the durability of stent-graft material and the fixation system, which is crucial to the success of this technique, are a subject of concern. So far, it seems that this technique may be of practical value for elderly patients or patients with coexisting conditions that would increase the risk in conventional operative treatment.

Moreover, the effect of endoluminal grafting on paraplegia rates is unknown. If we compare stent graft with surgery, it is true that stent graft eliminates the opportunity to reimplant intercostal arteries, so stent grafts may expose the patient to a higher risk of paraplegia. But for aortic lesions located at the isthmus, this risk is relatively low because branches to the spinal cord are rarely involved by this segment. This hypothesis seems to be confirmed by our series and by Kato et al. For all these reasons, that new therapeutic strategy seems to be very appealing. However, a few drawbacks are worth mentioning. (1) The covered stents currently in use can treat only aortas with a diameter <40 mm. (2) The caliber of the delivery system is quite important (18F to 24F), which can
potentially be problematic with the small and spastic arteries of young people and the tortuous and rigid arteries of older people. In these cases, iliac or aortic access could be necessary. We hope that future technical developments will yield improved stent-graft design, particularly for the flexibility and size of the introducer. (3) Currently, these devices are not available in the angiography suite in the emergency department, because each device must be individually designed according to the measurements obtained by specific preprocedure imaging. But in the near future, we can expect to have a sufficient inventory of devices available for emergency cases.

This raises the question of whether it is justified to use this new approach to replace standard treatment in patients who have the usual indications for surgery with no major systemic or local factors that increase risk and contraindicate standard therapy. It is well known that surgical repair of a chronic aneurysm, particularly in young patients, has excellent long-term results. Nevertheless, the postoperative mortality rate of 5% to 18% and a morbidity rate associated with minor complications, including Horner syndrome and vocal cord paralysis, 5,32 as high as 52.9% can justify the trial of a less invasive and potentially safer treatment.

The minimally invasive nature of endovascular prostheses makes them very attractive in accordance with the new trend in surgery to develop less invasive procedures to achieve treatment goals with reduced operative risk and complications. In this condition, a stent-graft procedure may lead to a reduction of the cost of hospitalization. However, because the devices and techniques for inserting endovascular grafts are still in the early stages of development, we should follow reasonable guidelines that have been created to direct the development of the technique and to prevent unjustified overuse. 33

References
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