Endovascular Treatment of Penetrating Thoracic Outlet Arterial Injuries

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Objectives: to establish the feasibility of stent-graft treatment of penetrating thoracic outlet arterial injuries.

Design: prospective study.

Materials and methods: forty-one patients with penetrating injuries to the carotid, subclavian and proximal axillary arteries admitted between August 1998 and May 1999 were studied. Patients requiring urgent surgical exploration for active bleeding (n = 26) were excluded. Remaining patients underwent arteriography to assess suitability for stent-graft placement. After successful stent-graft treatment clinical and sonographic follow-up were done at 1 month and thereafter 3-monthly.

Results: of the 15 patients considered, 10 patients qualified for stent-graft treatment (seven male, three female, mean age 27 years). The vessels involved were subclavian artery (seven), carotid artery (two) and axillary artery (one). Seven had arteriovenous fistulae and three, pseudoaneurysms. Stent-graft treatment was successful in all 10 patients with no procedure-related complications. On mean follow-up of 7 months no complications were encountered.

Conclusion: endovascular treatment shows promise as a treatment modality for thoracic outlet arterial injuries. Long-term follow-up is required for comparison to the results of standard surgical repair.

Key Words: Thoracic outlet; Penetrating arterial injury; Endovascular; Stent graft.

Introduction

Injuries to arteries of the thoracic outlet constitute 5–10% of arterial trauma.1 Due to inaccessibility and extensive dissection to achieve control, attempts to treat these lesions often end in exsanguination and death. Reported morbidity and mortality rates range from 5–30%.2 Surgical exposures that are used to achieve control include supra- and infraclavicular dissection, clavicular transection, thoracotomy and median sternotomy.3 This major dissection contributes significantly to the high morbidity when treating these injuries. Concomitant injuries might render these patients a high risk for general anesthetic and open surgery.

In 1964, Charles Dotter described the first angioplasty4 and in 1969 reported the first stent graft used in a canine popliteal artery.5 These reports initiated the era of modern endovascular therapy. The use of stents in humans was first reported in 1987.6 In 1990 Juan Parodi and colleagues were the first to use stent grafts for the treatment of abdominal aortic aneurysms in humans.7 Since then, rapid improvement of endovascular techniques and graft technology have led to wide application of this treatment method. Several investigators have reported applications in vascular trauma.8–11

The inaccessibility of arteries of the thoracic outlet makes stent-graft treatment of injuries to these vessels particularly attractive. The stable patient with a pseudoaneurysm or an arteriovenous fistula seems to be the ideal candidate to treat in this way. This report describes the experience of a single trauma unit with stent-graft treatment of arterial pseudoaneurysms and arteriovenous fistulae of the thoracic outlet.

Patients and Methods

During a 10-month period from August 1998 to May 1999, all patients with injuries of the carotid, subclavian and proximal axillary artery were considered for endovascular management. Patients requiring urgent surgical exploration for active bleeding or acute occlusion were excluded. Remaining patients underwent arteriography to assess their suitability for stent-graft placement.
This was performed in the operating suite with both a vascular surgeon and interventional radiologist in attendance. Facilities were available for immediate conversion to open repair if necessary. Routine preprocedural heparin (50 units/kg) and prophylactic cefazolin were given and continued for 24 hours.

Transfemoral arterial access was gained under local anaesthetic. Anatomical location of lesions and proximal and distal vessel diameter were determined with routine angiography. A final decision regarding stent-graft treatment was then taken with inability to traverse the lesion by guidewire and large proximal/distal lumen discrepancy representing exclusion criteria for stent-graft placement.

The stent graft used was the Hemobahn endovascular prosthesis (W.L. Gore). It consists of a self-expanding nitinol stent with a thin expanded polytetrafluoroethylene (ePTFE) inner lining. It was available in different lengths and sizes (6–10 mm diameter) with an introducer sheath 1 French bigger than the deployed stent diameter in millimetres. The delivery catheter length (110 cm) makes it possible to reach the cervicothoracic vessels via a femoral puncture.

Exact proximal and distal lumen diameter measurements were used to choose the right size stent. Measurements were made on precalibrated computer-generated digital subtraction angiography images. The proximal diameter was oversized 1–1.5 mm and the lesion overlapped with at least 1 cm at both ends. To prevent endoleak formation, all arterial branches that could participate in complex lesions, especially arteriovenous fistulae of the subclavian vessels, were embolised liberally before stent deployment. To avoid neurological complications, vertebral artery cross-flow was checked angiographically before embolisation.

With the guidewire traversing the lesion, the stent graft was introduced through a femoral introducer sheath and advanced under fluoroscopic guidance to overlap the injury. Initially, image masking (roadmapping) and bony landmarks were used to position the stent graft, but later replaced by localisation under angiographic control using a contralateral transfemoral catheter. The stent graft was then deployed, seated by balloon dilatation, and a routine completion angiogram was obtained.

Angiographic examples of the above procedures for a right common carotid arteriovenous fistula, a left subclavian arteriovenous fistula and a left subclavian pseudoaneurysm can be seen in Figures 1–3.

All data were collected prospectively from time of admission. Immediate postoperative evaluation was followed up by clinical and sonographic evaluation after 1 month and thereafter 3-monthly. Evaluation criteria were graft patency, limb loss, the presence or absence of other complications, and death.

**Results**

During the study period a total of 41 patients with thoracic outlet arterial injury were seen. Twenty-six required urgent open surgery for active bleeding or acute occlusion. The remaining 15 patients were evaluated for stent-graft treatment. All were haemodynamically stable and underwent angiography. Five were excluded due to inability to traverse the lesion with a guidewire \((n = 4)\) or too large a proximal/distal lumen discrepancy \((n = 1)\).

Ten patients (seven male, three female) with a mean age of 27 years \((range 18–40 years)\) were considered suitable for stent-graft placement (Table 1). Nine injuries were the result of stab wounds and one was a gunshot wound. Three lesions were arteriovenous fistulae, three were false aneurysms and four patients had both a false aneurysm and an arteriovenous fistula. The vessels involved were subclavian artery (seven), carotid artery (two) and axillary artery (one). Subclavian artery sidebranches that were embolised were thyrocervical trunks (three), internal mammary arteries (three) and vertebral arteries (four). Four patients had associated pathology with two haemothoraces and two brachial plexus injuries. Duration between injury and presentation varied from 24 h to more than 2 years. The mean duration of the procedure was 123 min \((range: 77\ min–179\ min)\) (Table 1).

Stent-graft treatment was ultimately successful in all 10 patients. Success was defined as complete exclusion of the lesion with no endoleaks, as confirmed by completion angiography. No deaths, limb loss or procedure-related complications were encountered and no conversion to open repair was necessary. Two patients required a second stent to exclude endoleaks caused by incorrect positioning of the first stent not overlapping the lesion.

Careful perioperative neurological observations were done in patients with carotid artery lesions and all patients who needed vertebral artery embolisation. None of these patients experienced any neurological signs or symptoms. All patients were discharged within 24 h after the procedure.

On mean follow-up of 7 months \((range 6–10 months)\), no evaluable patient had clinical or sonographic evidence of graft stenoses or occlusion. No
Fig. 1. Treatment of an arteriovenous fistula between the right common carotid artery and the brachiocephalic vein. (a) Initial aortogram via the transfemoral catheter; (b) selective common carotid arteriogram demonstrating the fistula; (c) completion arteriogram showing exclusion of the arteriovenous fistula.
The average mortality associated with carotid artery injury is 17%, ranging from 6.6% to 33%. Even in the elective setting, achievement of surgical exposure may require a sternotomy, thoracotomy or clavicular transection with substantial surgical morbidity and blood loss. This is the group of trauma patients thought most likely to benefit from stent-graft treatment.

Fig. 2. Treatment of an arteriovenous fistula between the artery and vein. (a) Selective left subclavian arteriogram demonstrating the fistula; (b) coil embolisation of subclavian artery branches; (c) stent graft before deployment; (d) complete exclusion of lesion after deployment.

neurological or upper-limb symptoms due to embolisation or progressive ischaemia were encountered. Two patients were lost to follow-up.

Discussion

Arterial injuries of the thoracic outlet present a challenge even to the experienced surgeon. Reported mortality for axillary/subclavian artery injury ranges from 3% to 33%. The average mortality associated with carotid artery injury is 17%, ranging from 6.6% to 33%. Even in the elective setting, achievement of surgical exposure may require a sternotomy, thoracotomy or clavicular transection with substantial surgical morbidity and blood loss. This is the group of trauma patients thought most likely to benefit from stent-graft treatment.
Fig. 3. Treatment of a pseudoaneurysm of the left subclavian artery. (a) Selective left subclavian artery arteriogram demonstrating the pseudoaneurysm; (b) complete exclusion of the lesion after stent-graft deployment.

Table 1. Patients, pathology and procedure duration.

<table>
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<tr>
<th>Sex/age</th>
<th>Mechanism of injury</th>
<th>Pathology</th>
<th>Vessel/s involved</th>
<th>Associated injuries</th>
<th>Duration injury to procedure (days)</th>
<th>Duration of procedure (minutes)</th>
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<td>M 20</td>
<td>GSW</td>
<td>AVF</td>
<td>L SCA/L BCV</td>
<td>Left haemothorax</td>
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<td>AVF</td>
<td>L CCA/L IJV</td>
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<td>91</td>
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<tr>
<td>F 21</td>
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<td>PA + AVF</td>
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<td>M 28</td>
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<td>PA</td>
<td>L SCA</td>
<td>Left haemothorax</td>
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<td>115</td>
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PA = pseudoaneurysm; AVF = arteriovenous fistula; SCA = subclavian artery; AXA = axillary artery; CCA = common carotid artery; BCV = brachiocephalic vein; IJV = int. jugular vein; SCV = subclavian vein; AXV = axillary vein.

All the patients treated in this series presented with established false aneurysms or arteriovenous fistulae. If left untreated, these lesions can enlarge and present with numerous complications, such as pressure effects, erosion of adjacent organs and rupture in the pleural cavity or extravasation into soft tissue. Thrombosis or distal embolisation can lead to upper limb or cerebrovascular ischaemic incidents. In the case of arteriovenous fistulae, additional problems of venous hypertension, ulceration and high-output cardiac failure can add to the long-term morbidity and mortality.

Stent-graft treatment of arterial injuries has been reported since 1991 with good short- and medium-term results. Patients treated in these series were mostly haemodynamically stable and able to undergo routine angiography. Completing the patient’s treatment during angiography makes excellent economic and medical sense. Not only is extensive surgery avoided, but also prolonged hospital stay. If long-term results of stent-graft treatment can be demonstrated to be comparable to the standard surgical approach, it might replace open repair as method of choice for treating these selected lesions.

The success of stent-graft treatment for traumatic lesions depends to a great extent on patient selection. Patients have to be haemodynamically stable and it must be possible to traverse the lesion by guidewire. To avoid endoleaks with this technique, the proximal-distal lumen discrepancy must not be too large. This becomes a problem with time as the distal vessel becomes small and atrophic. Attempted stent place-
ment in this situation can lead to either a proximal endoleak or distal oversizing to the extent of vessel rupture. These lesions are probably best excluded from stent-graft treatment. If the lumen discrepancy is not a problem, the stent should still be oversized by 1 millimetre (relative to proximal vessel diameter) to achieve a tight seal.

Another reason for endoleaks is side-branch involvement. In false aneurysms, as in abdominal aortic aneurysm repair, most might seal off, but in arteriovenous fistulae even small branches might maintain the lesion and eventually return it to its original size. This is particularly true of the subclavian artery, where numerous sizeable branches might be involved in the injury and participate in the lesion. To avoid endoleaks in this location, we believe that all side-branches which potentially participate must be embolised before stenting.

Contralateral vertebral artery patency and flow should be confirmed before embolisation. Endoleaks can also develop when the lesion is not overlapped at both ends by at least 1 cm. To achieve this accurate deployment we now favour fluoroscopic guidance with a second contralateral femoral catheter. We believe that by adhering to these principles endoleaks, as reported by Reber et al., can be prevented.

One advantage of stent-graft use in trauma is the option of approaching the lesion from an anatomical site unaffected by injury. The graft used in our series made it possible to deliver the stent via a femoral puncture under local anaesthetic. With the low-profile introducer sheath (only 1-F bigger than the diameter in millimetres of the deployed stent) percutaneous puncture without cutdown was possible. The small introducer sheath and larger artery minimises the risk of arterial injury at the delivery site, as reported by others.10

ePTFE-covered stents in trauma raise the old controversy of potential septic complications. The extent of most of the lesions treated would, however, have generally required surgical grafting rather than primary repair. In this location, availability and size will lead in most cases to the use of ePTFE grafts, which have proved their reliability in the trauma setting.15

Graft kinking or fracture, especially in the subclavian artery, where shoulder movement causes compression between the first rib and the clavicle, has been reported11 and remains a potential long-term complication.

When repairing arteriovenous fistulae it is advisable to try to preserve patency of the involved veins rather than resorting to ligation. This restricts long-term complications of venous hypertension.26,27 Achieving this goal is easier with arterial stent-graft treatment than with standard surgical repair as no periarterial dissection is required. Postoperative arm-swelling was minimised and all involved veins were patent on follow-up Doppler studies.

The need for covered stents in the treatment of pseudoaneurysms has been questioned by reports of successful treatment with non-covered stents16,17 and the adjunct use of endovascular coil placement.18 Even arteriovenous fistulae have been treated with non-covered stents in the experimental setting with reasonable results.19 Despite these reports a well-designed covered stent seems to be the logical choice for endovascular treatment of these lesions.

Potential disadvantages of stent-graft repair are early thromboembolic events, late stenosis and occlusion caused by neointimal hyperplasia.16 These are well-known complications of uncovered stenting for occlusive disease, with late re-stenosis rates of 4.3 to 6.5% for iliac20 and 15 to 30% for coronary artery stents.21 The results of carotid artery stents for stenotic disease have been promising, with preliminary re-stenosis rates of less than 5%.22 Other authors have been less enthusiastic, reporting total stroke and death rates ten times higher in carotid stenting than with endarterectomy.23 These neurological complications were the result of perioperative embolic events and the results of potential long-term re-stenosis were not taken into account. In trauma cases, predominantly young patients with healthy vessels are treated, and with short-term follow-up no symptomatic stenosis or occlusions have been reported due to neointimal hyperplasia.10,11 Parodi et al.24 reported one stenosis and three occlusions with long-term follow-up. None of these were symptomatic and they included one internal carotid stent graft. Our early results are also promising, but long-term follow-up is necessary to resolve this issue. If stenosis occurs it should be relatively easy to treat with redilatation or deployment of another stent. Identifying a failing stent graft in the trauma patient might not be that easy, as compliance with respect to follow-up is generally poor (two of 10 patients in this study were lost to follow-up). This could lead to late presentation with irreversible cerebral or upper-limb ischaemia.

The potential occurrence of thromboembolism during or after stent deployment, especially in the carotid artery, is also a cause of concern. Some pseudoaneurysms and arteriovenous fistulae can contain luminal clot that might embolise, but no cases have been recorded in numerous reports, although individually small in patient numbers.16,24,25

In summary, early results of endovascular treatment
of selected patients with traumatic thoracic outlet arterial injuries suggest it to be an effective, minimally invasive and safe method of treatment. Although this early experience is encouraging, long-term follow-up of larger numbers is required for comparison to the results of standard surgical repair.

References


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