Endovascular Therapy for the Treatment of Arterial Trauma

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Abstract

Several factors may limit the success of conventional operative therapy for traumatic arterial injuries. In particular, the inaccessibility of the vascular lesion, anatomic distortion, and the inherent problems associated with operating in a traumatized and often contaminated field are among these limiting factors. As a result, endovascular therapy has emerged as an important potential alternative.

This paper focuses on the application of endovascular therapy to the trauma patient, based on our experience and those previously published by other groups. Injuries to the carotid, femoral, axillary/subclavian and iliac arteries, as well as to the abdominal and thoracic aorta, have been successfully managed by stent-grafting.

Despite the potential benefits of this mode of therapy, its long-term utility will depend on our ability to overcome certain limitations associated with the technique, and on careful patient selection.
Key Words: Endovascular treatment, arterial trauma, stent-grafting.

Introduction

ARTERIAL INJURY, including dissection, occlusion, pseudoaneurysm and arteriovenous fistula (AVF) formation, may result from both penetrating and blunt trauma. The success of current operative therapy for traumatic arterial injuries may be limited by several factors. The inaccessibility of the vascular lesion (e.g., due to central vessel involvement), anatomic distortion that results in venous hypertension with excessive bleeding, and inherent problems with operating in a traumatized and often contaminated field, are among these limiting factors. Furthermore, the presence of multiple trauma or severe medical co-morbidities may increase the incidence of surgical complications and mortality (1).

The use of endovascular stent-grafts to address these limitations was first introduced by Dotter in 1969 (2). Over the past 12 years, endovascular grafting has been evaluated as an alternative to conventional surgical repair in the management of aneurysms and other vascular lesions. The application of this form of therapy as well as other endovascular techniques for the management of vascular trauma offers many potential advantages. Angiography assists with the diagnosis of traumatic lesions such as intimal dissections and AVFs (3). Embolization techniques for hemostasis have been well studied and are the standard for the management of bleeding from pelvic fractures (3). In addition, endovascular techniques can be utilized to help with vascular control, as an adjunct to surgery in regions where obtaining proximal or distal control is technically difficult. The use of endovascular stent-grafting for the definitive repair of traumatic lesions has been shown to be associated with a decrease in anesthetic requirement, blood loss, and extent of dissection (4). High-velocity missiles can produce a significant amount of tissue damage, even if not suspected on initial examination due to the classically small size of the entrance and exit wounds (5). The inherent problems of graft placement in the setting of severe tissue damage, gross contamination and scar tissue formation make

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the use of a remote insertion site particularly advantageous in the trauma patient (6, 7).

At present, the largest experience with endovascular graft therapy for the management of vascular trauma has been with the treatment of arterial pseudoaneurysms and AVFs (4, 6, 8–13). Although the optimal timing of repair is still controversial (14, 15), this method is limited to the stable patient. In the setting of severe ischemia or active hemorrhage, urgent conventional operative repair is still recommended (9). Similarly, the patient with an expanding hematoma or multiple traumatic injuries may not be a suitable candidate for endovascular graft therapy. Stented grafts have been extensively studied and have demonstrated excellent technical success rates (16). In its use for arterial trauma, endovascular stent-grafting has proven safe and effective in preliminary investigations (4). This paper focuses on the specific application of this technology to the trauma patient. The discussion presents the potential benefits and disadvantages of the specific methods, reviews the current status of the field and available data, and addresses the technology's future role within the field of trauma surgery.

Techniques

Clinical experience has demonstrated a wide variety of options for device use in the treatment of traumatic lesions (4, 10, 16, 17). In their current design, stented grafts for treating traumatic arterial injuries are composed of a stent rendered nonporous by an outer covering. The covering, whether polytetrafluoroethylene (PTFE), Dacron, polyester or other material, does not appear to influence outcome (9). Some have used radially expandable, thin-walled Dacron grafts (16); others have used autogenous vein (jugular or saphenous) sutured to a Palmaz stent (16, 18). At our institution, we have used Palmaz balloon-expandable metallic stents in conjunction with thin-walled PTFE graft material to perform arterial repair of pseudoaneurysm and AVFs. Precise delivery to the site of injury is performed under fluoroscopic guidance. Heparin is used during insertion, but long-term anticoagulation has not been necessary.

An alternative device is the Corvita stent (Corvita, Inc./Schneider Corp./Boston Scientific Corp., Natick, MA) graft, which is fabricated from a self-expanding stent of braided wire. The Corvita stent-graft was the first commercially available endograft to enter into clinical trials. It has the distinct advantage of being able to be cut to the desired length in the operating room prior to loading into a special delivery sheath. The sheath has a special pusher catheter which is used for maintaining the graft in position while the outer sheath is being retrieved. The Wallgraft (Schneider-Pfizer, Minneapolis, MN) has a similar design and a polyester outer covering. Another system, the Passager Endograft System (Boston Scientific, Watertown, MA), uses a nitinol thermal-expanding stent covered with an ultrathin woven polyester fabric.

Another endograft device which has been successfully used for traumatic lesions is the Hemobahn™ graft, produced by W.L. Gore and associates (Flagstaff, AZ). This device is also fabricated from an ultra-thin ePTFE tube externally supported by nitinol wire arranged in a helical coil fashion.

Carotid Injuries

Internal carotid artery (ICA) pseudoaneurysms are often the result of a previous dissection occurring either spontaneously or in association with an identifiable traumatic episode (19). The significant risk of life-threatening stroke or hemorrhage warrants strong consideration for treatment of these lesions, even if asymptomatic (19). Although standard treatment has been open surgical management, endovascular techniques have been utilized recently to address the problem (8, 19). Conventional open repair is often technically difficult or impossible when exposure at the skull base requires mandibular disarticulation (5, 8, 19). In such a situation, endovascular repair provides a potential alternative. Several centers have reported the use of bare stents to treat such aneurysms (19–22). However, in the case of larger, wide-mouthed aneurysms (22), the aneurysms were not totally excluded by the Palmaz stents alone and continued to be at risk for rupture and embolization. Complete aneurysm exclusion with an endovascular graft may be a more reasonable option in the case of large ICA aneurysms.

Our colleagues recently described the successful use of an endovascular stented graft composed of a Palmaz balloon-expandable stent covered with a PTFE thin-wall vascular graft (Impra, Tempe, AZ), for the treatment of a 2 cm ICA pseudoaneurysm located at the skull base (8). Access may be obtained by either a femoral approach or direct operative exposure of the common carotid artery at the base of the neck. Open exposure of the proximal carotid artery allows blood flow to be arrested, thereby reducing the risk of embolization secondary to luminal manipulations. The patient remains asymptomatic on oral anticoagulation, and the aneurysm remains fully excluded.

In addition to pseudoaneurysm formation, blunt carotid injury may result in intimal dissection, for which standard therapy has been systemic anticoagulation (23). In 1997, Duke et al. reported a series of six cases of progressive dissection or pseudoaneurysm formation following blunt carotid injury (24). All six patients were successfully treated with covered stents without the use of anticoagulation.

Parodi et al. reported 8 cases of traumatic internal or common carotid artery pseudoaneurysms or AVFs treated with autogenous-vein-covered stents, the Corvita endograft, or the Wallgraft (25, 26). Parodi reported one failure related to external compression of the Palmaz stent at the level of the base of the skull (25). Determination of the potential benefit of using autogenous vein vs. a synthetic-covered stented graft in such patients needs to be addressed in a controlled study. Whether exclusion of the aneurysm will prevent future expansion and potential rupture of the pseudoaneurysm will require long-term evaluation.

Femoral Artery Trauma

With the rapid expansion in the use of interventional procedures and the rising incidence of civilian-based (noncombatant) trauma, AVFs and pseudoaneurysms of the femoral arteries have become common vascular complications. Small AVFs may resolve spontaneously, but larger fistulas do not generally have the same benign prognosis (27, 28). Currently, surgical treatment is recommended for the prevention of complications, including hemorrhage, thrombosis, compression of local neurovascular structures, venous hypertension and congestive heart failure (6). Yet, surgical repair is often technically difficult, due to bleeding secondary to venous hypertension associated with the arterialized vascular bed (6). We reported the first successful repair, in an 18-year-old youth, of a traumatic AVF caused by a bullet wound to the superficial femoral artery and vein, using a balloon-expandable, stented, PTFE-covered Palmaz stent-graft (6). At 5 months follow-up, the graft was still patent.

Subsequently, a number of groups have reported on the treatment of traumatic femoral pseudoaneurysms and AVFs, with technical success rates of 90 – 100% and one-year patency rates of 83 – 100% (4, 16, 26, 29). Although the use of covered stent-grafts has been reported for the treatment of popliteal pseudoaneurysms and AVFs (3, 26, 30), the long-term patency of the grafts and adjacent vein has not been evaluated.

Axillary/Subclavian Trauma

Penetrating axillary and subclavian artery trauma may result in the formation of a dissection, pseudoaneurysm or AVF. Post-traumatic pseudoaneurysms of the subclavian and axillary arteries are rare, and like aneurysms of other arteries, can rupture, thrombose or embolize (31, 32). Other mechanisms of injury include compression with contusion, avulsion, and traction from stretch or rotational stress (33). The surgical approaches developed to repair such lesions include clavicular resection, median sternotomy and thoracotomy, but these are each associated with significant potential for morbidity (34). The approaches require extensive dissection, often with large volume of blood loss and prolonged hospital stay.

Although the optimal management of such injuries is unclear, the role of endovascular stent-grafting for such lesions has expanded over the past decade (4, 11, 16, 26, 35 – 38). Parodi reported on 12 patients who underwent endovascular grafting for the treatment of axillary or subclavian AVFs or pseudoaneurysms (26). In that series, one partial failure of the main stent occurred due to an additional AVF located in a branch of the subclavian artery. The AVF was closed successfully with a detachable balloon placed into the scapular branch of the thyrocervical trunk. All cases of longstanding AVF were associated with a significant stenosis at the site of injury that required dilation prior to graft implantation. In a collective review of 18 recent cases of axillary or subclavian artery trauma managed with endovascular stent-graft therapy, a technical success rate of 94% was reported (10). Primary patency in these patients was 85% at a mean follow-up period of 18 months. Associated complication rate was 6%. Mean length of hospital stay was 3.3 days. Another group recently reported its experience with one patient with an embolizing traumatic subclavian artery aneurysm. The aneurysm was repaired with a polyester-covered nitinol stent with concomitant vein bypass of embolic brachial artery occlusion. At 24 months follow-up, both bypasses were patent (37).

Aorta or Iliac Artery Trauma

Patients sustaining blunt trauma to the abdominal aorta often do not survive, due to the impact of the direct compressive force and associated injuries. In a recent review, the mortality rate associated with blunt abdominal aortic injury was 24% (39). Injuries may include intimal disruption with dissection, intramural hematoma, pseudoaneurysms, as well as simple contusion to frank rupture (40, 41). Endovascular stent-graft repair of such injuries has emerged as a therapeutic option in the case of stable aortoiliac injuries. Most experience has been with penetrating injuries of these vessels, either iatrogenic (related to surgery or catheterization procedures), or bullet injuries (10, 12, 42). In the presence of associated injuries or hemodynamic instability, conventional open repair should be undertaken. Fifteen patients in recent reports underwent endovascular stent-graft repair of traumatic injuries to the abdominal aorta or iliac arteries — injuries that were either AVFs or pseudoaneurysms (4, 13, 16, 35). Technical success of the procedures was 100%, with primary patencies of 100% at a mean follow-up period of 10.5 months (10).

Isolated injuries to the iliac vessels have also been successfully treated with endovascular grafting (43, 44). Rupture of the iliac artery occurs in one of every 200 angioplasty procedures (45, 46). In these cases, emergent repair of an acute rupture of the external iliac artery during angioplasty by endovascular stent-graft is likely to be necessary, as reported by Formichi et al. (43). The authors obtained temporary hemostasis using balloon tamponade followed by exchange for a Cragg-Endopro-System-covered endoprosthesis to seal the injury. At follow-up more than 18 month later, the graft was still patent without endoleak.

Thoracic Aortic Trauma

Most blunt thoracic aortic injuries are caused by deceleration injuries, most often related to motor vehicle accidents (47, 48). Patients who sustain trauma to the thoracic aorta, whether blunt or penetrating, usually do not survive (49). The few patients who survive the immediate injury often develop a chronic aortic aneurysm (50, 51). Open thoracic surgery for repair of a chronic traumatic aneurysm is associated with a mortality rate of 5–18%, due mainly to bleeding, heart failure or renal failure, with associated morbidity rates as high as 50% (51, 52). In the case of acute aortic injury, the frequency of multiple traumatic injuries further increases the mortality rate (53–55). The presence of medical co-morbidities also contributes to a poorer prognosis (56).

Due to the lack of prospective data regarding the optimal management of these injuries, controversy exists as to the indications for operative therapy. Minor injuries, including mural hematoma or intimal flap, usually resolve on their own (57). Pseudoaneurysms, even small ones, rarely remain stable over time, and have a high risk of rupture, embolization, fistulization or compression of adjacent structures (57, 58). Nonoperative management can be considered only for simple lesions, for some patients with severe neurologic deficits, or for arterial injuries not actively bleeding (57, 59, 60). For these patients, antihypertensive therapy with nitroprusside or labetalol is recommended until a decision on aortic repair is reached (61). Nevertheless, Finkelmeier et al. reported that 33% of his patients with untreated chronic aortic aneurysm died of complications attributed to the aortic lesion, with 75% of deaths secondary to aneurysm rupture (51).

Endovascular stent-grafting of traumatic thoracic injuries has begun to assume a role in the management of these injuries (62–65). Using this technique, the need for aortic clamping is obviated. This could potentially decrease the incidence of paraplegia, which has been reported to occur in 4–32% of cases after surgery for thoracoabdominal aortic aneurysm (66). Although several factors have been implicated in the pathophysiology of paraplegia in thoracic aortic surgery (66), duration of spinal cord ischemia is undoubtedly a major factor (67). The endovascular approach does not allow for the reimplantation of intercostal arteries. However, in the case of nonpenetrating thoracic aortic injury, the location of the lesion is at the isthmus approximately 90% of the time (48, 68); therefore, the area of repair usually does not involve segments with branches to the spinal cord (62).

Respiratory failure is the most common complication following surgery for thoracic aortic aneurysms (69). The elimination of thoracotomy, especially in patients with existing pulmonary disease, will probably decrease the incidence of this complication, with an additional benefit in hospital cost reduction. We will probably also see a decrease in other complications, related to the decrease in operative blood loss, the minimal invasiveness of this form of therapy, and the reduced need for general anesthesia, (particularly in patients with serious risk factors for open repair).

Several limitations must be addressed. With most of these injuries occurring at the isthmus just beyond the origin of the subclavian artery, the length of the proximal neck may be insufficient for adequate fixation of the stented graft if precise deployment is not achieved. This may result in either endoleak (incomplete aneurysm exclusion) or occlusion of the upper extremity inflow. Preprocedural left-subclavian-to-carotid transposition has been useful in increasing the proximal endograft landing zone. In addition, the relative rigidity of the stent-grafts currently used limits their ability to conform to the curved aortic contour of the distal arch or proximal descending aorta (62).

Another problem that could limit benefits of a minimally invasive procedure may arise in the case of a large traumatic aneurysm, when compression of adjacent structures (e.g., mainstem bronchus) is unrelieved by simple surgical graft interposition. In such a case, removal of large amounts of intramural thrombus around a mainstem bronchus is necessary to relieve lung atelectasis (70). Furthermore, heparin is required to prevent thrombosis caused by the obstruction of blood flow related to the large delivery sheath. In the acute trauma patient with coexisting injuries, this is potentially hazardous.

To date, a number of groups have reported on their experience with endovascular stent-graft repair of thoracic aortic trauma. One group reported a single case of a previously paralyzed patient who had sustained a bullet wound injury to the descending thoracic aorta at the level of T11. The pseudoaneurysm was discovered 3 months after the injury, and was repaired using a Dacron-covered (Dupont, Wilmington, DE) nitinol stent inserted via a retroperitoneal approach to the iliac artery. Follow-up studies failed to demonstrate the presence of an endoleak or pseudoaneurysm (64). A second group reported on 10 patients who underwent repair of a traumatic thoracic aortic aneurysm (62). In their study, modified Z-stents covered with either woven polyester or expanded PTFE graft material were used to treat 10 aneurysms, 9 of them located at the level of the isthmus. In this report, three major complications were noted. One patient developed an endoleak, which was successfully treated with coil embolization. The second patient developed thrombosis of the subclavian artery, which was treated by subclavian-carotid bypass. The last patient required stenting of the left mainstem bronchus to relieve left lung atelectasis. There were no other major or minor complications, including paraplegia, embolization, respiratory failure, renal failure or myocardial infarction. Another group reported two patients with distal descending thoracic aortic pseudoaneurysms which received successful stent-graft repair (in which only the T11 intercostal artery was sacrificed by endoluminal exclusion) (65). One recent study of endovascular graft treatment of acute bleeding from traumatic aortic rupture or aortobronchial fistula in 6 patients reported a 100% success rate, with no major complications (71).

Our own recent series of thoracic aortic stent-grafting using balloon-expandable and self-expandable endovascular grafts in 14 patients included 5 traumatic injuries (72). In this series, graft insertion was technically successful in 11 of 14 patients (78%), with procedural failures related to graft migration and endoleaks. Self-expanding devices were found to be associated with greater success, most likely related to the avoidance of asystole in obtaining precise device position. There were 2 deaths, as a result of microembolization and multiorgan system failure. Average length of hospital stay was 2.9 days. The use of endovascular stent graft-repair for traumatic thoracic aortic injuries, despite significant limitations to its application, will probably be shown to be of great benefit for selected patients in future studies.

Discussion

Since Parodi's first report of the use of endovascular stent-grafting for the treatment of aneurysms (73), the use of endovascular surgery has broadened to include the treatment of arterial trauma, although experience is limited. Endoluminal grafts have been used to treat occlusive and aneurysmal arterial disease, with variable success (74). In comparison with standard operative repair of traumatic injuries, this new, less invasive method appears to be associated with less blood loss and a reduced requirement for anesthesia. Less dissection in a traumatized field is of particular advantage in the case of arteriovenous fistulas with venous hypertension, where standard surgical repair is notoriously difficult and associated with large operative blood losses in the setting of either acute or chronic traumatic injury. When successfully applied, the procedure also has the advantage of greater simplicity and decreased operative time. Vascular surgeons are increasingly faced with older patients who have severe comorbid illnesses that can increase operative morbidity and mortality; thus, the use of a minimally invasive approach becomes increasingly necessary.

Despite the potential benefits, eventual long-term utility will depend on our ability to overcome the limitations associated with this mode of therapy (75). It is assumed that the full exclusion of aneurysms will lead to the elimination of rupture potential. However, it is possible that arterial pressure that is transmitted to the thrombosed, excluded circulation will lead to eventual aneurysm expansion and rupture. The fact that a decrease in the excluded aneurysm size has been observed is encouraging (12, 16); however, rupture has been observed following stent-graft repair of an aneurysm and a demonstrated decrease in aneurysm size (76). The effects of a stent embedded in the wall of a vessel in preventing future expansion is not known (25). Long-term follow-up is necessary to determine this risk.

Another possible problem in the use of this technology is the potential for development of intimal hyperplasia at the junction of the artery and the stent-graft. The Palmaz stent has been shown to be associated with only minimal intimal hyperplasia in experimental studies evaluating stenting of occlusive or stenotic iliac lesions (77).

Difficulty in obtaining access accounts for occasional problems (25). Extending incisions and prolonging procedures or resorting to more invasive approaches often result in complications ordinarily not associated with the usual procedure.

Microembolization is a serious problem encountered with endovascular surgery. In Parodi's study (25), 3 of 4 patients who developed embolic complications died as a result. These procedures all involved technical difficulties in patients with large aneurysms. Possible reasons for the increased potential for embolization in larger aneurysms were suggested by Parodi (25). These include both negotiation of the guidewire inside a large chamber with embolic material within it, and multiple manipulations resulting from miscalculation of aneurysm length.

In addition, device limitations exist and are the focus of current investigative work. Stent compression has been reported in the case of stent-graft repair of axillary-subclavian injury (10) due to compression between the clavicle and first rib. In these situations, the use of less rigid self-expanding devices has been advocated.

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