VASCULAR PAPERS

Endovascular repair of abdominal aortic aneurysm: Getting out of trouble

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The standard techniques of endovascular aneurysm repair sometimes fail to produce atraumatic stent-graft delivery of hemostatic implantation, and additional maneuvers are required to avoid conversion to open repair. Between June 1996 and May 1997 elective endovascular aneurysm repair was performed in 33 high risk patients, using a Z-stent-based prosthesis. Challenging anatomic features included: short neck (< 15 mm) in four cases, angulated neck (> 60°) in seven, iliac aneurysm in six, and iliac tortuosity (> 80°) in 24. There were no deaths, no renal failure, no pulmonary failure, no graft thrombosis, no migration, and no conversions to open surgery. Deviations from standard technique were required to treat iliac artery dissection, iliac artery stenosis, and leaks resulting from proximal stent malalignment, proximal stent malposition, and distal stent malposition. The necessary adjunctive maneuvers included: additional stent placement, additional stent-graft placement, and balloon dilatation.

Mean operating time was 191 ± 72 min, mean contrast volume was 148 ± 76 ml, and mean blood loss was 314 ± 427 ml. Mean time from operation to discharge from the hospital was 3.5 ± 1.67 days. These short-term results demonstrate that endovascular aneurysm repair is safe and effective in high risk patients, only if adjunctive maneuvers are available to supplement standard technique.

Keywords: aorta, aneurysm, treatment, endovascular, transfemoral

Endovascular aneurysm repair is neither as flexible nor as versatile as conventional surgical aneurysm repair. Although patients undergo endovascular repair only if their arterial anatomy appears to meet the requirements of the technique, the intraoperative findings sometimes include an unpleasant surprise. If conversion to open repair is to be avoided, these surprises must be accommodated by deviations from the usual technique.

This report describes our standard approach to endovascular aneurysm repair in a series of 33 cases performed over the past year, and the various ways in which these procedures were customized by the use of additional maneuvers. The focus here is not on the results themselves, but on the way those results were achieved, and on operative technique in particular. The majority of these cases employed tapered aorto-uni-iliac stent-grafts in combination with femoro-femoral bypass and contralateral common iliac artery occlusion, an approach developed by Parodi [1], May et al. [2], Yusuf et al. [3], Marin et al. [4] and others.

The problems encountered in endovascular aneurysm repair can be categorized into two groups, difficult access and leak (endoleak). The consequences of difficult access are clear; if the stent-graft cannot be inserted, the aneurysm cannot be treated by endovascular means. The consequences of perigraft leak are less well defined [5]. We have taken the position that perigraft leak represents a failure of endovascular repair [6, 7], at least until the leak ceases or is
treated by endovascular means; hence, the inclusion here of a wide variety of maneuvers designed to eliminate perigraft leak.

Method

Preoperative

Inclusion criteria for our FDA approved IDE (Investigational Device Exemption) were: ‘high risk’ for conventional surgical aneurysm repair, greater than 20% risk of rupture if left untreated, and life-expectancy longer than 2 years. The main factors in determining that a patient was high risk were: hostile abdomen, obesity, age greater than 80 years, and most importantly cardiopulmonary disease. Significant coronary artery disease was defined as unstable angina, the presence of delayed reperfusion on thallium scanning, or ST changes on electrocardiogram. The threshold for inclusion as high risk was adjusted downwards after review of the first 20 patients. Nevertheless, all 33 patients in this study had previously been refused conventional aneurysm repair. Only elective repairs are reported here. The four patients who underwent urgent endovascular aneurysm repair for acute symptoms or contained leak are not included.

Patient selection and graft sizing were based on preoperative imaging. One patient was evaluated by MRA (Magnetic Resonance Angiography) alone, and another by computed tomography (CT) alone, but all the others had some form of sectional imaging combined with catheter angiography.

The prosthesis was constructed from conventional fabric (Cooley Verisoft, Meadox Medicals, Inc., Oakland, NJ) and Gianturco Z-stents (Cook, Inc., Bloomington, IN). The delivery system comprised a central carrier, which consisted of several co-axial catheters, and a sheath with an outer diameter of 20.3 Fr. Both have been described elsewhere [8]. Aorto-aortic tube grafts were used in seven patients, one of whom also received a common iliac to external iliac stent-graft. The remainder were treated with aorto-iliac tapered stent-grafts, combined with conventional femoro-femoral bypass and contralateral common iliac artery occlusion.

No bifurcated aorto-bi-iliac stent-grafts were used in this series, because of the constraints of our FDA protocol, which specified the fabric (Cooley Verisoft). Although this is the thinnest approved vascular graft, it is too thick-walled to be the substrate for our bifurcated graft, which requires specially woven thin-walled fabric for graft limbs larger than 8 mm in diameter. Composite grafts and grafts made entirely from thin-walled fabric were the basis for our earlier bifurcated stent-grafts experience, which was conducted mainly in Europe [8]. Thin-walled bifurcated grafts will eventually be available in the United States, but not now and not under this protocol.

The occluder was a short Z-stent based stent-graft, with one or both ends of the graft sewn shut to form a bag. Similar occluders have been used by Yusuf et al. [3], Ivancev et al. [9] and Kato et al. [10].

Standard operative technique

Preliminary procedures in the angiography suite included: internal iliac artery embolization in five patients, lumbar artery embolization in one, accessory renal artery embolization in one, and iliac artery balloon dilatation with stent implantation in one. Embolization was performed by transcatheter insertion of Gianturco coils. In these cases the internal iliac arteries were embolized to prevent retrograde perfusion through a common iliac artery aneurysm into the aortic aneurysm. The sole instance of lumbar artery embolization was also intended to prevent collateral perfusion of the aneurysm following stent-graft implantation. In this case the aneurysm was entirely devoid of mural thrombus and the lumbar artery led directly into a large arteriovenous malformation, which was fed by many other pelvic arteries.

Stent-graft placement was performed in the operating room using a mobile C-arm fluoroscopy unit. Our current version is equipped with a 12-inch field and the usual angiographic package of road-mapping, digital subtraction and cine-loop. All fluoroscopy was recorded on tape for educational purposes.

Arterial access for delivery system insertion was through the surgically exposed common femoral artery in all but one case. The preferred approach was an oblique incision over the inguinal ligament. The proximal common femoral, distal external iliac, circumflex iliac and inferior epigastric arteries were isolated with hemostatic loops. Aorto-uniliac stent-graft insertion and femoro-femoral bypass required bilateral femoral arterial exposure. Aorto-aortic stent-graft insertion required only unilateral femoral artery exposure. Contralateral access for an angiographic catheter was obtained through a percutaneously inserted 5 Fr sheath. All preliminary catheter manipulations were performed through sheaths to minimize ischemia times and minimize the risk of arterial dissection, which can otherwise occur when catheters are inserted unguided into the open arterial lumen. These catheter manipulations included the placement of a stiff guidewire (Amplatz Extra Stiff, Cook, Inc.) from the femoral artery on the side of delivery system insertion to the descending thoracic aorta, and placement of a straight-tipped, multi-side-hole catheter from the contralateral femoral artery into the proximal abdominal aorta.

Aorto-aortic stent-grafts were inserted through transverse arteriotomies. All aorto-iliac stent-grafts were inserted through longitudinal arteriotomies, which were later connected by the femoro-femoral bypass. All patients were anticoagulated with
100 units/kg of heparin prior to the application of distal clamps and proximal hemostatic loops. During the initial stages of stent-graft delivery system insertion the hemostatic loops were released and proximal control maintained by finger pressure.

The proximal end of the delivery system was followed on fluoroscopy as it was advanced over the stiff guidewire from the femoral artery to the proximal abdominal aorta. The first angiograms were performed by injection of contrast through contralateral angiographic catheter when the delivery system was already in position. The usual contrast load for each aortic injection was approximately 15–20 ml. When the neck of the aneurysm was thought to be tortuous, based on preoperative imaging, the position of the C-arm was adjusted so that the X-ray beam would be at right-angles to the long axis of the neck. Renal artery localization was also enhanced by positioning the renal arteries in the center of a small field (4” diameter).

The radio-opaque metal of the stent was easily seen, and the position of the delivery system adjusted to bring the stent into its desired location relative to the renal arteries. Our policy was to implant the proximal stent as close to the renal arteries as possible. In cases where the neck was shorter than 15 mm, an uncovered portion of the proximal stent was placed over renal arteries. Proximal stent position was then maintained as the sheath was withdrawn and the stent deployed. The usual practice was to start stent-graft deployment 3–5 mm too high and pull the stent down to its final position as it opened. Angiographic localization of the renal arteries was repeated at least once during proximal stent deployment. Only when the stent-graft was fully deployed was the angiographic catheter removed. In cases where the distal implantation site was short, and there was some concern over the accuracy of distal stent deployment, the field of view was expanded to include the entire infrarenal aorta as soon as proximal stent deployment was complete. However, in the majority of cases attention remained focused on the proximal stent throughout stent-graft insertion. Once the stent-graft was in position, the central carrier would be released and the delivery system removed, taking care to leave a guidewire within the lumen of the stent-graft.

The contralateral angiographic catheter could not be used for completion assessment, because it was outside the stent-graft and would give a false impression of perigraft leak by injecting contrast directly into the aneurysm. But this catheter was still useful as a means of inserting a guidewire through the contralateral iliac artery into the aneurysm. The angiographic catheter could then be exchanged over this wire for the 14 Fr sheath used to insert the common iliac artery occluder.

Aorto-iliac stent-grafts were routinely reinforced by the insertion of a Wallstent into the narrower iliac segment of the graft. Wallstent insertion was followed by completion angiography to assess stent-graft position and to look for kinking, stenosis or perigraft leakage. Femoro-femoral bypass was performed using standard surgical technique and 8 mm ePTFE to connect the two femoral arteries through a subcutaneous tunnel.

**Postoperative assessment**

Routine follow-up included contrast-enhanced CT and AXR (Abdominal X-ray) within the first week after stent-graft implantation, and at 3, 6, 12 and 24 months.

**Intraoperative problems and additional techniques**

**Bleeding**

Hemostasis was seldom a problem during the initial catheter manipulations, because the wall of the artery was stretched tightly around the sheath at the site of arterial puncture. Minor leakage through the sheath valve was treated by temporarily advancing a dilator or catheter over the guidewire and into the valve orifice to enhance the seal. After arteriotomy, the critical point of hemostatic control became the proximal hemostatic loops. In cases where the external iliac arteries were rigid or irregular, blood leaked between the catheter and the arterial wall to emerge through the arteriotomy. Maneuvers to improve proximal hemostatic control included: forcible tightening of the hemostatic loops, the use of additional (more proximal) loops, and the insertion of a large valved sheath to fill more of the arterial lumen. The large sheath had the added advantage of minimizing trauma to the external iliac artery, which was sometimes a problem following forcible tightening of hemostatic loops.

**Iliac dissection**

Iliac arterial dissection occurred twice in this series, producing typical signs such as resistance during wire insertion, wider than expected loops in the guidewire, and persistence of contrast enhancement long after injection. In both cases the dissection was of little importance because it affected the iliac artery on the side opposite the stent-graft outflow. Otherwise, treatment would have been Wallstent insertion, after first gaining access to the true lumen of the artery using angulated catheters and guidewires under road-mapped fluoroscopic control. We found that the creation of an iliac artery dissection was best avoided by performing arterial puncture and guide wire insertion before arteriotomy. The guidewire was then advanced gently through the distal arterial tree in advance of any rigid, sharp-ended instruments.
Difficult delivery system insertion

Iliac artery tortuosity was the primary impediment to delivery system insertion. Fortunately, the iliac arteries were usually mobile, and the presence of a stiff guidewire induced sufficient straightening for delivery system insertion. Problems occurred when the arteries were very tortuous and arterial mobility was limited by calcification, retroperitoneal inflammation [11], or retroperitoneal scarring from previous operations. The full extent of arterial tortuosity was seldom apparent on AP (Anteroposterior) films. The arterial course was better seen on oblique or lateral views.

External iliac artery tortuosity was the easiest to deal with, since the external iliac artery was accessible through a limited retroperitoneal exposure beneath the inguinal ligament. The frequent need to mobilize the inguinal ligament was one of the reasons we preferred an oblique incision. A finger was introduced over the anterior surface of the artery into the retroperitoneum. Gentle pressure on the apex of the loop usually induced sufficient straightening for delivery system insertion. Alternatively, the external iliac artery was dissected free from surrounding structures and mobilized into the groin wound (Figure 1), thereby eliminating the redundant loop, as described by Parodi [1].

Severe tortuosity of the common iliac artery was less frequent, but less accessible and more difficult to deal with. In such cases, delivery system insertion was sometimes achieved by pushing the aortic bifurcation gently towards the ipsilateral shoulder using a hand on the abdominal wall. The abdominal aorta in these patients is often frighteningly mobile. The above maneuvers were successful in all cases. Otherwise, an alternative would have been to use an axillo-femoral guidewire [1], [12]. Traction on both ends of an axillo-femoral guidewire generates tension that effectively makes the wire stiffer. It should be remembered that the force applied to the ends of the guidewire is transmitted to any acute angulations along its course, particularly the lateral margin of the left subclavian origin. The possibility of a cheese-wire injury should be minimized by covering the wire with a catheter.

The other main impediment to delivery system insertion was iliac artery stenosis. Balloon dilatation of an iliac artery was performed in one case preoperatively and one case intraoperatively. In both cases a wallstent was implanted to support, straighten and smooth the inner surface of the iliac artery, and in both cases the delivery system traversed the stented artery very smoothly. Another patient had diffusely narrowed external iliac arteries with common iliac artery aneurysms bilaterally. In this case we performed conventional surgical reconstruction of the iliac arteries using an ileo-bifemoral graft, which then served as a route for stent-graft insertion, and as the stent-graft’s distal implantation site [13]. One alternative would have been to perform the endovascular repair first, using a side-arm to the common iliac arteries for access, and then distributing the outflow from the stent-graft to the femoral arteries by conventional surgical bypass [2]. We preferred to perform the conventional iliac artery reconstruction before the endovascular repair to minimize ischemic times. Another alternative would have been to perform an entirely open surgical aneurysm repair. However, it is doubtful whether open repair could have been performed without general anesthesia, as it was in this case. It is also doubtful whether the patient would have been able to resume his usual diet on the first postoperative day, as he was in this case.

Intraoperative proximal perigraft leak (endoleak)

Most cases of proximal perigraft leak were detected by intraoperative angiography and treated while open arterial access was still available. The commonest cause was misalignment of the proximal stent relative to the axis of the neck, due to neck angulation. Inflation of a large balloon within the stent induced a re-alignment (Figure 2), which persisted after balloon deflation and stopped the leak.

In two cases the proximal stent was initially located too low for an optimal seal. At the same operation, a second stent-graft was inserted inside the first to act as a proximal extension, to enhance the proximal seal and to close the leak. Others have reported using proximal extensions [14] to treat proximal perigraft leak. The additional stent-graft can seal the leak and help secure the position of the
original stent-graft, if it is well placed, and if it is long enough.

**Intraoperative distal perigraft leak (endoleak)**

On two occasions the aorto-iliac stent-graft did not reach the iliac artery implantation site. One resulted from undersizing, and the other from distal stent malposition. In both cases the common iliacs were very short. Now that we have an imaging system with a 12-inch field, we perform distal stent placement under fluoroscopic guidance. We used to place the proximal stent accurately and just hope that the graft length would be such that distal stent placement would be optimal.

Implantation of a second stent-graft within the distal end of the first stent-graft was used to extend the conduit down to the correct level, thereby abolishing the leak. Similar maneuvers have been described by others [1], [14], [15]. The Sydney group [15] have gone on to incorporate this approach into their routine technique as a means of achieving *in situ* stent-graft sizing (see below).

In our experience the introduction of the second delivery system was sometimes difficult. We found that even with a guidewire in place, the end of the large stent-graft delivery system tended to impinge on the end of the first stent-graft, pushing it still further from the iliac artery orifice. The solution was to insert a wallstent between the iliac artery and the distal end of the first stent-graft to hold the stent-graft in position, help to straighten the pathway, and protect the distal orifice of the stent-graft from the leading end of the delivery system.

Distal stent-graft extension was also performed in three of the aorto-aortic procedures (Figure 3). However, in these cases it was used as a planned approach to overcome the problems of sizing a stent-graft for insertion between two short implantation sites. This 'trombone technique' [15] allowed the first stent-graft to be implanted in the correct position relative to the proximal implantation site, and the second stent-graft to be implanted in the correct position relative to the distal implantation site. The variable degree of overlap between the two permitted intraoperative adjustment in the length of the combined conduit.

**Late perigraft leak (endoleak)**

We believe that a patient with perigraft leak on CT is still at risk of rupture, and should be treated. The first CT following endovascular repair showed perigraft leak in 4/33 patients, two of whom required additional endovascular procedures. The first step in management of leakage was to locate the perigraft tract by angiography or three-dimensional reconstruction of spiral CT. Persistent leakage often has both an inflow around the end of the graft and an outflow through a patent aortic branch such as a lumbar or inferior mesenteric artery (Figure 4).

The inflow was treated by additional stent-graft implantation and balloon driven proximal stent re-orientation, as described above. Implantation of an additional stent-graft was performed through a separate longitudinal groin incision and a distal com-
mon femoral arteriotomy to avoid re-exploring the previously operated area.

The lumbar arterial outflow was treated by transcatheter coil embolization (Figure 5). A large curved (Simmons) catheter was inserted from a femoral puncture, reformed in the thoracic aorta, and brought down over a movable core guidewire until its tip entered the space between the proximal margin of the stent graft and the aorta. A co-axial microcatheter was then inserted through the Simmons catheter, into the aneurysm, and across the leakage tract to the outflow vessel. Small Gianturco coils were inserted through the microcatheter to impede perigraft flow and act as a nidus for thrombus formation. Dake et al. [16] have used a similar approach to treat perigraft leak following stent-graft repair of thoracic aneurysms.

This method of obtaining access to the perigraft space was feasible in the early postoperative period for two reasons. First, the graft had not yet become incorporated into the vessel wall. Second, the self-expanding proximal stent was compliant enough to allow the catheter to pass, and elastic enough to fill the space where the catheter had been as soon as the catheter was removed.

**Results**

Between June of 1996 and June of 1997 we designated 72% of all high risk referrals as suitable for endovascular repair based on angiography and CT. During the same period we performed elective endovascular aneurysm repair in 33 patients. All 33 aneurysms were successfully excluded from the circulation. There were no deaths, no renal failure, no pulmonary failure, no graft thrombosis, no migration and no conversions to open surgery. Mean follow-up was 6 months at the time of writing (May 1997).

Co-morbidities included: significant coronary artery disease in 26 patients (see the definition in methods), chronic obstructive pulmonary disease in 11, obesity in 6 and hostile abdomen in 11. The patients age was 71.6 ± 14.5 years (mean ± standard deviation). Mean AAA (Abdominal Aortic Aneurysm) diameter was 6.4 ± 1.2 cm. Iliac aneurysms ( > 3 cm diameter) were present in six patients. The neck was shorter than 15 mm in four cases, and angulated (relative to the aneurysm) by more than 60° in seven cases. In 24 patients, at least one of the iliac arteries (external, common, right or left) contained an angulation of more than 80°.

Mean operating time was 191 ± 72 min, mean contrast volume was 148 ± 76 ml and mean blood loss was 314 ± 427 ml. Mean time to resumption of a normal diet was 0.66 ± 0.66 days, and mean time to discharge was 3.5 ± 1.67 days.

The complications are listed in Table 1. One patient experienced a non-Q-wave myocardial infarction on the third postoperative day. Another
femoro-femoral grafts are not high. Moreover, the reported patency rates of femoro-femoral graft infection or occlusion, but we need for a femoro-femoral graft. We had no cases of distal aortic blood flow into one iliac system and the weaknesses of this approach are: the diversion of all tility of the aorto-uni-iliac stent-graft [1–4]. The vascular repair to 72% of the cases evaluated. Not all the potential problems can be anticipated based on preoperative imaging. One needs to start every case armed with a variety of multi-purpose components, which Parodi calls his ‘endovascular toolbox’. In many of the cases in this series, endovascular repair would have failed had it not been for the use of adjunctive maneuvers to get us ‘out of trouble’. Alternatively, we would have had to exclude patients that were thought likely, based on preoperative imaging, to run into trouble. Under such circumstances we could not have included cases with severely angulated iliac arteries or short angulated implantation sites, nor would we have been able to offer endovascular repair to 72% of the cases evaluated.

The high inclusion rate may also reflect the versatility of the aorto-uni-iliac stent-graft [1–4]. The weaknesses of this approach are: the diversion of all distal aortic blood flow into one iliac system and the need for a femoro-femoral graft. We had no cases of femoro-femoral graft infection or occlusion, but we may just have been lucky. Graft infection could easily have resulted from wound necrosis, wound infection and lymph fistula, all of which occurred in this series. Moreover, the reported patency rates of femoro-femoral grafts are not high.

It is still too early for us to assess the effects of placing an uncovered stent over the renal arteries. We restricted this practice to patients for whom there was little alternative, because we were concerned that the stent might induce hyperplasia or serve as a nidus for thrombus formation. Other groups have taken a more liberal approach [17].

A few common complications of endovascular repair, which we did not encounter in this series, have well-described endovascular solutions. Perigraft leak through a patent lumbar or inferior mesenteric artery, is an example. The patent lumbar artery can be catheterized and coil embolized through collaterals from the internal iliac artery [18], while the patent inferior mesenteric artery can be catheterized through collaterals from the superior mesenteric artery.

All 33 of the patients in this series had already been refused conventional aneurysm repair due to high risk. Conversion to open operation would have likely resulted in serious cardiopulmonary complications and deaths; hence, our determination to find endovascular solutions. But these techniques offer more than just a way to rescue an otherwise failed procedure. They can be used to enhance the versatility and flexibility of the planned operation. The incorporation of additional maneuvers into routine technique is seen in the evolution of the ‘trombone technique’ [15], and the ‘modular’ approach to endovascular aneurysm repair, in which multiple stent-graft extensions are added to the primary stent-graft to create an individualized endovascular conduit in situ [19].

Discussion

For endovascular aneurysm repair to be successful, the stent-graft delivery system needs to traverse the often tortuous, atherosclerotic iliac arteries without causing injury. In addition, the ends of the stent-graft must be implanted accurately and securely in the non-dilated arteries proximal and distal to the aneurysm, so that the aneurysm is isolated from the circulation without occluding vital branches, such as the renal arteries. Additional maneuvers are needed when the standard approach fails short of these goals. Not all the potential problems can be anticipated based on preoperative imaging. One needs to start every case armed with a variety of multi-purpose components, which Parodi calls his ‘endovascular toolbox’.

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References

experience with a system for bifurcated stent-graft insertion.  


Paper accepted 19 November 1997