Treatment of Complex Aneurysmal Disease with Fenestrated and Branched Stent Grafts

C.D. Bicknell a,*, N.J.W. Cheshire a, C.V. Riga a, P. Bourke a, J.H.N. Wolfe a, R.G.J. Gibbs a, M.P. Jenkins a, M. Hamady b

a St Mary’s Regional Vascular Unit, Imperial College Healthcare NHS Trust, London, United Kingdom
b Department of Interventional Radiology, St Mary’s Hospital, Imperial College Healthcare NHS Trust, London, United Kingdom

Submitted 31 July 2008; accepted 6 November 2008
Available online 1 December 2008

KEYWORDS
Aneurysm; Fenestrated stent graft; Thoracoabdominal aneurysm; Juxtarenal aneurysm

Abstract
Objectives: To describe our experience of treating juxtarenal (JRAAA’s <4 mm neck) and thoracoabdominal aortic aneurysms (TAAA’s) using fenestrated and branched stent graft technology.

Design: Prospective single centre experience.

Methods: Since 2005, 29 fenestrated/branched procedures have been performed. 15 patients are studied with JRAAAs (n = 7; median neck length 0 mm (IQR 0–3.8)) or TAAAs (type I (n = 2), III (n = 2), IV (n = 4)). ASA grade III in 12/15. Maximum diameter of aneurysm 64 mm (56–74 mm). Aneurysms were excluded using covered stents or branches from the main body to patent visceral vessels (40 target vessels total). Pre-operative and follow-up CT scans (1, 3, and 12 months) were analysed by a single Vascular Interventional Radiologist.

Results: Technical success for cannulation and stenting of target vessels was 98%. In-hospital mortality was 0%. One patient underwent conversion to open repair. Five had major complications including one paraplegia (type III TAAA) with subsequent recovery. Median length of stay was 9 days (IQR 7–18.75).

At a median follow-up of 12 months (9–14), CT confirmed 36/37 (97%) target vessels remain patent. Sac size increased >5 mm in one patient only. There were no type I endoleaks, three type II endoleaks (one embolised, two under surveillance) and three type III endoleaks (two successfully treated percutaneously, one aneurysm ruptured 18 months after endografting and died).

Conclusion: In selected patients, fenestrated and branched stents appear to be a safe and effective alternative to surgery for juxtarenal and thoracoabdominal aneurysms. The complication and mortality rates are low. The long-term durability of this procedure, however, needs to be proven.

Crown Copyright © 2008 Published by Elsevier Ltd on behalf of European Society for Vascular Surgery. All rights reserved.
Introduction

With recent advances in endovascular technology, endovascular aneurysm repair (EVAR) has become an attractive alternative to open surgery for infrarenal aortic aneurysms with significantly reduced 30-day mortality and comparable long-term outcomes. Approximately 55% of infrarenal aneurysms are treatable by EVAR with newer devices.

Further development of this technology has led to the production of fenestrated and branched stents to treat aneurysms previously unsuitable for standard EVAR. The Zenith stent (Cook Medical Inc, USA) is CE marked for aneurysms with an infrarenal neck of between 4 and 11 mm. The efficacy of these custom-made fenestrated stents for the treatment of short-necked infrarenal abdominal aortic aneurysms has been well described. This procedure may benefit in those patients selected to undergo fenestrated grafting compared to open repair candidates. These stents can also be used to treat juxtarenal aneurysms (JRAAA’s) and thoracoabdominal aortic aneurysms (TAAA’s) involving the visceral segments. Although the procedure may be more complex, involving fenestrated stenting of three or more vessels, the advantages for patients who would otherwise require a suprarenal or supraceliac repair may be important. The procedure is currently developing and gaining acceptance. We describe our early experience treating these more complex aneurysm configurations by our experience with fenestrated devices for juxtarenal and thoracoabdominal aneurysms.

Definitions

Thoracoabdominal aneurysms were classified using the Crawford classification (Fig. 1). All aneurysms that originated at or less than 4 mm below the lowest renal artery were described as juxtarenal.

Procedure

All patients with complex aneurysmal disease that were present to St Mary’s Hospital are considered for fenestrated stent grafting in a multidisciplinary forum. Pre-procedure planning is conducted using a CT angiogram carried out on a 64 slice Philips Brilliance Scanner (using bolus tracking, 100 mls contrast, 2 mm slice thickness with 1 mm reconstructions. Rotation time 0.65 s) Complicating factors in fenestrated stent grafting include small, tortuous iliac arteries, which cause significant problems with control of catheters and rotation of the graft; thrombus around the visceral vessel origin; severe stenosis of visceral arteries; multiple renal vessels and tortuosity/angulation of the aorta above or at the level of the fenestrated segment, which can lead to significant misalignment of fenestrations with target vessels. The presence of a previous aortic graft does not exclude patients from aneurysm repair but the graft may be tortuous, which makes the procedure difficult, as mentioned above. Patients are excluded from fenestrated stent grafting if complicating factors are present and an operative approach is suitable. Conversely, in those with a proposed open procedure that is high risk may be planned for stenting despite these difficulties. For those that are suitable, custom-made fenestrated devices based on the Zenith platform (Cook Medical Inc, USA) are produced from computerised tomographic data with bespoke fenestrations at the level of the target vessels. This stent needs to be carefully planned before construction and both these processes add to the length of time required before stenting. At our institution we plan the fenestrated stents in principal and request.

Procedures were performed in an angiography suite (Philips Integris) that is suitable for open operative procedures. This ensures the best image quality, which is of paramount importance in these complex interventions.

The technique of fenestrated stent graft placement is well described in previous publications and is shown in Fig. 2(a–e). In thoracoabdominal aneurysms, there are usually 3 or 4 fenestrations that require covered stent placement. If the anatomy is suitable then we incorporate a branch into the device for the coeliac or SMA vessels. This short, downward cuff from the main body is accessed with a wire via the arm and extended using a covered stent. For fenestrated stent grafting of juxtarenal aneurysms we use covered stents if the aorta is parallel walled for less than 4 mm below the vessel, so that the lowest renal artery stent is always covered, but the higher may be uncovered.

For thoracoabdominal aneurysms, spinal cord drainage is routine except when contraindicated. We place spinal drains before surgery and maintain the cerebrospinal fluid pressure at 10 mmHg with the patient lying flat and drainage into a reservoir 13 cm above the cord.

Patients and Methods

Data was collected from 2005 to date by means of a prospectively collected database. All patients undergoing fenestrated and/or branched stent grafting at St Mary’s hospital were included into the database. Patient comorbidity, technical stent data, in-hospital mortality and complications were all recorded. Details of follow up and subsequent procedures were also collected. Patients with fenestrated grafts introduced for juxtarenal and thoracoabdominal aneurysms were studied from this database.

Computerised tomography (CT) scans were analysed by a Consultant interventional radiologist. The aneurysm morphology was determined from pre-operative scans. Neck length, angulation and presence of thrombus were determined for each of the infrarenal aneurysms. Follow-up scans were reviewed and reported for sac expansion, endoleak and patency of target vessels.

Over the study period 29 procedures were performed. Of these, 15 patients had juxtarenal (n = 7) or thoracoabdominal aneurysms (two type I, two type III and four type IV TAAAs) and were included in the study group. Patient demographics are listed in Table 1. The aneurysm morphology assessed by a single consultant interventional radiologist with an interest in endovascular aneurysm repair is recorded in Table 2.

In these 15 grafts, 39 fenestrations and one branch were utilized in an attempt to revascularise 40 target vessels. Thirty-three covered (Advanta V12 (Atrium, USA)) and 6 uncovered (Primus™ GPS™, ev3 Europe SAS) stents were
used (we failed to revascularise one target vessel). Precise details of vessels stented are included in Table 3.

**Results**

**Technical success**

This procedure was a technical success in 14 of 15 patients (93%). Thirty-nine out of 40 target vessels (98%) were successfully stented through the femoral (37 stents) or brachial (2 stents) routes. Completion of angiograms following the successful procedures showed no evidence of endoleak after any of the procedures.

The median procedure time was 375 min (interquartile range 300–395 min) and median screening time was 111 min (83.5–145). The median volume of contrast injected was 136 mls (100–200). Median peak plasma creatinine after the procedure was 116 Umol/L (108–179). Plasma creatinine on discharge was a median of 103 Umol/L (89–163).

One patient with a 10 cm juxtarenal aneurysm with severe angulation of the aorta at the renal level and associated significant coronary artery disease underwent fenestrated stent grafting prior to coronary artery revascularization. During the procedure the right renal artery could not be cannulated (believed to be as a result of orientation issues between the graft and target vessel). After a lengthy procedure the graft was deployed without cannulation of this vessel and a covered stent was placed into the left renal artery and an uncovered stent into the SMA. The patient was transferred to intensive care with a view to subsequently attempting cannulation via the brachial route. Before this was able to take place, on day two following the original procedure, the aneurysm ruptured and the patient underwent open tube graft repair. The aortic clamp was placed in a supraceliac position for endograft explantation and an infrarenal anastomosis was fashioned. He was discharged home after a protracted intensive care stay during which he required haemofiltration and had a prolonged respiratory wean. This was our only conversion to open surgery.

In one subsequent patient a similar situation has arisen, with failure to cannulate and stent the right renal orifice. This patient underwent CT scanning, following deployment of covered stents to the other renal artery and SMA, to further delineate the anatomy. The patient subsequently returned to the angiography suite 12 h later and underwent successful stenting of the renal vessel via the brachial approach. Of note, this patient had a significantly tortuous infrarenal tube graft that was thought to have restricted control of the catheters whilst attempting to cannulate the target vessel. Aside from these orientation issues, only minor difficulties were experienced with graft orientation in relation to the target vessels, requiring small rotational adjustments of the graft during vessel cannulation.

**Morbidity and mortality**

There was no 30-day or in-hospital mortality in this group. Median hospital stay was 9 days (7–19). One patient, after a prolonged type IV TAAA stent graft placement, required fasciotomies for an acute compartment syndrome the same day as stent grafting and underwent a Hartmann’s operation for colonic ischaemia 2 days after the procedure. He went on to develop multiorgan failure requiring respiratory support and haemofiltration on a temporary basis. He then made good recovery. One patient after endovascular repair of her type III TAAA developed paraplegia which partially recovered over the subsequent six months. This patient developed paraplegia late after surgery despite the use of cerebrospinal fluid drainage. Another developed significant line sepsis requiring high dependency care and intravenous antibiotic therapy. One patient thrombosed the left limb of a bifurcated graft and developed short distance claudication, requiring femoro-femoral cross over bypass grafting. This thrombosis was thought to be secondary to a kink in the stent.

**Figure 1** The Crawford classification for thoracoabdominal aneurysms and juxtarenal aneurysms (as defined in this paper by a neck length of less than 4 mm).
In the juxtarenal aneurysm group, one patient with significant coronary disease deemed unsuitable for percutaneous coronary intervention and too high risk for coronary bypass had a myocardial infarction following aortic stenting with no significant sequelae.

Follow up

The median follow up for this group is 12 months (interquartile range 9–14 months). Thirty-six of the 37 (97%) vessels in the successfully stented group remain patent on follow-up CT scanning. One coeliac stent was occluded with an Amplatz occluder after dislocation of the stent leading to a type III endoleak (discussed below). The maximum sac size has decreased in size by more than 5 mm in 5 of 11 patients who have had follow up scans after 3 months. Only one patient has had an increase in sac size greater than 5 mm. This was discovered when he presented with a ruptured aneurysm (discussed below). The median change in sac size was $-2 \text{ mm} (-5 \text{ to } +2 \text{ mm})$.

Over the follow-up period no patients developed a type I endoleak. Three patients developed type II endoleaks, two of which are under surveillance with a decreasing aneurysm sac size on follow-up CT examination. One patient with a type I TAAA had a type II endoleak from a significant branch of the right subclavian artery, filling the proximal sac. This branch was identified by angiography, catheterized selectively and embolized successfully.

Three patients developed type III endoleaks. In one patient this was secondary to the dislocation of the coeliac stent from the target vessel, with free flow of contrast into the aneurysm sac. This was recognised on the first surveillance CT scan and was most probably due to the coeliac stent not extending far enough into the target vessel. This was treated by Amplatz occlusion of the celiac stent and sacrifice of the celiac arterial supply. The patient tolerated this well and suffered no sequelae as a result. Another patient with a type IV TAAA developed a type III endoleak at the join between the covered renal stent and fenestration. This required a further covered renal stent to be placed to seal this leak with an excellent angiographic result. The final patient presented 18 months after an uncomplicated juxtarenal AAA fenestrated graft with an acutely ruptured aneurysm.

Figure 2  (a) The device is placed at the level of the visceral vessels under fluoroscopic imaging with the markers on the graft demonstrating the correct orientation and alignment of the fenestrations with the visceral vessels (which have been previously identified with fluoroscopic imaging). This case of a type III thoracoabdominal aneurysm used three stents into the renal vessels and superior mesenteric artery (SMA) as the celiac trunk was occluded. (b) The fenestration/ostial interfaces are bridged with extra stiff wires allowing guide catheters to be placed into the vessels. This allows easy passage of covered stents into the vessels. This figure shows guiding catheters and stiff wires in the renal vessels and a cobra catheter cannulating the SMA through the appropriate fenestration. (c) Through the guide catheters, stents (PTFE covered in the case of TAAAs) are placed, which are deployed to secure the main body of the aortic side wall to the visceral ostium and bridge the aneurysm sac. This image shows contrast in the SMA stent and SMA and both renal stents in place. (d) After all the target vessels have been stented, the distal sections of this composite device are finally placed and deployed (bifurcated for iliac fixation and tubular in aneurysms with a distal landing zone in the aorta or in a previous aortic tube graft). This image shows a completion angiogram. All vessels have been successfully stented and there is exclusion of the aneurysm. (e) CT reconstruction of the same patient during follow up assessment.
secondary to a type III endoleak from dislocation of the iliac limb of the graft. This rupture occurred 4 months after a routine surveillance scan that had shown a decreasing sac size and no evidence of endoleak, with no evidence of insufficient overlap between components. Expedient treatment was mandatory; we were not able to arrange the facilities for immediate endovascular iliac extension grafting, and so the patient underwent open repair of the aneurysm with a suprarenal clamp, explantation of the device and tube graft repair. This patient died in intensive care.

There was one further death in this group of patients during the follow-up period. One patient after juxtarenal fenestrated repair presented 4 months later with an acute type A dissection of the aortic arch and died following cardiac surgery. The origin of the dissection was far removed from the stent graft landing zone and was not considered to be related.

**Discussion**

Open treatment of juxtarenal and thoracoabdominal aortic aneurysms involving major abdominal branches of the aorta is significantly more challenging compared to infrarenal surgery, with a large increase in mortality and complications. At St Mary’s, we repair the majority of juxtarenal and type IV TAAAs via an open approach utilising a suprarenal or supracoeliac clamp and subsequent tube graft repair. For those more complex aneurysms (types I, II and III) we have pioneered a hybrid approach to repairing these complex aneurysms. This utilizes both open and endovascular procedures with retrograde revascularisation of the visceral vessels and endovascular exclusion of the aortic aneurysmal site. This procedure has subsequently decreased mortality rates, but is still a major surgical insult and patients still require long ITU and hospital stays. A total endovascular approach to the treatment of these aneurysms is attractive and may have significant benefits in terms of mortality, morbidity and hospital stay when compared to the open operation. Our series demonstrates that it is possible to achieve a low mortality rate and minor complication rate when compared to standard open surgery results. Clearly, however, this group of patients is highly selected has more favourable anatomy than those that undergo open surgery and this needs to be taken into account. On the contrary, these patients are sometime selected for fenestrated stenting based on significant co-morbidity that precludes open repair. In this situation the anatomy may be less than favourable for stenting but stenting may be the favoured approach.

Other significant series of fenestrated and branched stent grafts have shown similar results with respect to mortality and complications. Roselli et al. have recently reported a series of seventy-three patients who underwent endovascular repair of thoracoabdominal aortic aneurysms with fenestrated stent grafts. Just over 60% of these aneurysms were type IV TAAAs. This group achieved technical success in over 90% of cases with a mortality rate of 5.5%. The complication rate was low, occurring in 14% of patients, with two patients developing paraplegia. Chuter has reported 22 cases of thoracoabdominal aneurysms using self-expanding covered stents to connect the aortoiliac limb of the stent graft (branched grafts) with the visceral branches of a TAAA. The covered stents are all inserted via the brachial route. This method appears equally effective in producing low mortality rates as only two patients died perioperatively in this series. An added

---

**Table 1** Patient demographics for juxtarenal and thoracoabdominal aneurysm stent grafts ($n = 14$). Median values are shown with interquartile ranges in parentheses or number of patients with percentage of entire study group where appropriate

<table>
<thead>
<tr>
<th>Variable</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>70 years</td>
<td>(67–73 years)</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td>12 men</td>
<td>(80%)</td>
</tr>
<tr>
<td><strong>Presentation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asymptomatic presentation</td>
<td>15 (100%)</td>
<td></td>
</tr>
<tr>
<td><strong>Risk factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>13 (87%)</td>
<td></td>
</tr>
<tr>
<td>Diabetes</td>
<td>2 (13%)</td>
<td></td>
</tr>
<tr>
<td>Smoking</td>
<td>11 (73%)</td>
<td></td>
</tr>
<tr>
<td>Statin therapy</td>
<td>13 (87%)</td>
<td></td>
</tr>
<tr>
<td><strong>Co-morbidity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASA grade &gt; 3</td>
<td>12 (80%)</td>
<td></td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>2 (13%)</td>
<td></td>
</tr>
<tr>
<td>Previous aneurysm surgery</td>
<td>3 (20%)</td>
<td></td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>7 (47%)</td>
<td></td>
</tr>
<tr>
<td>Coronary intervention</td>
<td>5 (33%)</td>
<td></td>
</tr>
<tr>
<td>(PCI or CABG)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creatinine</td>
<td>109 Umol/L (93–120 Umol/L)</td>
<td></td>
</tr>
<tr>
<td>Abnormal renal function</td>
<td>3 (20%)</td>
<td></td>
</tr>
<tr>
<td>ICA stenosis &gt; 70%</td>
<td>0 (0%)</td>
<td></td>
</tr>
</tbody>
</table>

---

**Table 2** Aneurysm CT data for juxtarenal and thoracoabdominal aneurysm stent grafts ($n = 14$). Median values are shown with interquartile ranges in parentheses or number of patients with percentage of entire study group where appropriate

<table>
<thead>
<tr>
<th>Aneurysm type</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juxtarenal aneurysm</td>
<td>7 (50%)</td>
<td></td>
</tr>
<tr>
<td>Neck length</td>
<td>0 mm</td>
<td>(0–3.8 mm)</td>
</tr>
<tr>
<td>Type I TAAA</td>
<td>2 (14%)</td>
<td></td>
</tr>
<tr>
<td>Type III TAAA</td>
<td>2 (14%)</td>
<td></td>
</tr>
<tr>
<td>Type IV TAAA</td>
<td>4 (27%)</td>
<td></td>
</tr>
<tr>
<td><strong>Morphology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum diameter</td>
<td>64 mm</td>
<td>(56–74 mm)</td>
</tr>
<tr>
<td>Thrombus at neck</td>
<td>5 (33%)</td>
<td></td>
</tr>
<tr>
<td>Angulation</td>
<td>15 (8.75–23.5°)</td>
<td></td>
</tr>
<tr>
<td><strong>Iliac vessels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left iliac diameter</td>
<td>17 mm</td>
<td>(13.7–22.8 mm)</td>
</tr>
<tr>
<td>Right iliac diameter</td>
<td>15 mm</td>
<td>(11.7–18.3 mm)</td>
</tr>
</tbody>
</table>

---

*a One patient with a type III TAAA had previous arch replacement, two patient with type IV TAAAs had previous open infrarenal tube and open aorto bi-iliac grafts.

*b Percutaneous coronary intervention.

*c Coronary artery bypass grafts.
advantage of endovascular methods of aneurysm repair is that previous open repair does not seem to increase the risk. Of a series of 9 para anastomotic aneurysms of the aorta, technical success was achieved in all cases, with no mortality. 11

We experienced no type I endoleaks, presumably due to the enhanced landing zone created by utilising the aorta around the level of the visceral arteries or in the thorax as well as fixation by means of stents through the fenestrations. This configuration has been shown experimentally to increase the stability of the proximal graft 12 and seems to be effective. Unsurprisingly the majority of our significant endoleaks were type III in nature. This must be expected due to the multi-modular nature of these grafts. Most of these endoleaks, however, can be dealt with by a relatively simple percutaneous technique. Unfortunately one patient ruptured after a type III endoleak from an iliac limb dislocation. Clearly, whilst type I endoleaks may not be so prevalent in fenestrated grafts, attention must be paid to overlap between the modular components of this graft to ensure maximal stability in the mid portion of the graft.

Although the follow-up period of our series was a median of 12 months we experienced no unintentional loss of any of the 37 target vessels stented. Although the stents are placed into relatively small visceral branches, the patency rates seems to be good, certainly in the medium term. Others have observed similar patency rates when thoracoabdominal aneurysms are stented either using a fenestrated or branched graft method. 9,10 This is encouraging, but further observation is mandatory, as the morphology of the excluded aneurysm changes over many years. In addition to this positive observation, all aneurysm sacs have remained stable or decreased in size after stenting, bar the patient who quickly dilated following occurrence of a type III endoleak. This can also be observed in larger series where no stent migration or aneurysm growth was seen, 9,10

Whilst this technique to extend the role of stent grafting for aneurysms to include juxtarenal and thoracoabdominal aneurysms is attractive, it does have its limitations. The bespoke nature of these grafts means that there are inherent time delays in manufacture and they are therefore unsuitable for urgent and emergency cases. In complex aortic aneurysms, the strategy for fenestrated and branched endograft planning is difficult and often requires close discussion between the clinical team and manufacturing partner. A lack of experience can add to the planning and manufacture time significantly.

Further development of the technique may need to include methods to perform “in situ” fenestration of grafts (puncturing the graft at the desired level and stenting of the target vessel) but the development of the technology for this is at an early stage. 13–15 Another prohibitive consideration is that of cost. The custom-made nature of these grafts is expensive which may hinder its widespread applicability. Lastly, this is a very labour intensive process that requires a great deal of expertise. Procedure times are long and cases can be very demanding, especially when all visceral vessels need stenting. Also anatomical difficulties such as iliac tortuosity can hinder the operator further, causing major problems with “torquing” catheters. Suitable training for these new and complex techniques will also be time consuming. We performed seven cases with the help of a proctor to learn the techniques associated with fenestrated stent grafting including implantation and planning techniques. Recommendations are hard to give for all clinicians when considering how to learn the techniques associated with fenestrated stent grafting. A detailed knowledge of thoracoabdominal aneurysm disease, endovascular treatment and experience with open surgical techniques is essential when deciding between an open surgical and totally endovascular approach to treat the individual patient.

### Conclusions

In selected patients, fenestrated and branched stent grafts appear to be a safe and effective alternative to surgery for true juxtarenal and thoracoabdominal aneurysms. The complication and mortality rates after surgery are low. The long-term durability of this procedure, however, needs to be proven.

### Conflict of Interest

None.

### Funding

The authors acknowledge funding support from the Imperial College Healthcare Biomedical Research Centre.

### References


