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# Fenestrated Stent Grafting for Short-necked and Juxtarenal Abdominal Aortic Aneurysm: An 8-Year Single-centre Experience

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**Abstract** *Objectives:* To present an 8-year clinical experience in the endovascular treatment of short-necked and juxtarenal abdominal aortic aneurysm (AAA) with fenestrated stent grafts.
*Methods:* At our tertiary referral centre, all patients treated with fenestrated and branched stent grafts have been enrolled in an investigational device protocol database. Patients with short-necked or juxtarenal AAA managed with fenestrated endovascular aneurysm repair (F-EVAR) between November 2001 and April 2009 were retrospectively reviewed. Patients treated at other hospitals under the supervision of the main author were excluded from the study. Patients treated for suprarenal or thoraco-abdominal aneurysms were also excluded. All stent grafts used were customised based on the Zenith system. Indications for repair, operative and postoperative mortality and morbidity were evaluated. Differences between groups were determined using analysis of variance with $P < 0.05$ considered significant.
*Results:* One hundred patients (87 males/13 females) with a median age of 73 years (range, 50—91 years) were treated during the study period; this included 16 patients after previous open surgery or EVAR. Thirty-day mortality was 1%. Intra-operative conversion to open repair was needed in one patient. Operative visceral vessel perfusion rate was 98.9% (272/275). Median follow-up was 24 months (range, 1—87 months). Twenty-two patients died during follow-up, all aneurysm unrelated. No aneurysm ruptured. Estimated survival rates at 1, 2 and 5 years were $90.3 \pm 3.1\%$, $84.4 \pm 4.0\%$ and $58.5 \pm 8.1\%$, respectively. Cumulative visceral branch patency was $93.3 \pm 1.9\%$ at 5 years. Visceral artery stent occlusions all occurred within the first 2 postoperative years. Four renal artery stent fractures were observed, of which three were associated with occlusion. Twenty-five patients had an increase of serum creatinine of

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more than 30%; two of them required dialysis. In general, mean aneurysm sac size decreased significantly during follow-up ($P < 0.05$).
*Conclusions:* Fenestrated stent grafting for short-necked and juxtarenal abdominal aortic aneurysm appears safe and effective on the longer term. Renal function deterioration, however, is a major concern.


Since the first report of a juxtarenal abdominal aortic aneurysm (AAA) endovascularly treated with a fenestrated stent graft in 1999,[1] a number of published series have demonstrated excellent early and mid-term results of the technique.[2–7] A recently published systematic review confirms the potential lower perioperative mortality of the technique in comparison with open repair, but acknowledges the lack of longer-term data.[8] Fenestrated stent grafts are now commercially available and provide an alternative to open surgery, especially in patients who are at increased risk for open repair.

In our institution, the fenestrated technique was initially used for patients refused for open surgery. With increasing experience, however, surgical candidates were also considered for fenestrated stent grafting. Patients with proximal anastomotic aneurysms after open surgery or type I endoleaks after endovascular aneurysm repair (EVAR) were also successfully treated with fenestrated stent grafts.[9,10]

In this article, we present our 8-years' experience with the technique in the first 100 patients treated at our institution.

## Materials and Methods

### Subjects

All patients treated with fenestrated and branched stent grafts at our tertiary referral centre or elsewhere under the supervision of the first author have been enrolled in an investigational device protocol database. Patients with short-necked or juxtarenal AAA, treated between November 2001 and April 2009, were retrospectively analysed. A short-necked aneurysm was defined as having a proximal neck length below the lowest renal artery of 4–12 mm. A juxtarenal aneurysm was defined as having a neck length of less than 4 mm. Patients with a suprarenal AAA or a thoraco-abdominal aortic aneurysm treated with fenestrated and branched techniques were excluded from this report. Patients who were treated elsewhere under the direct supervision of the main author were also excluded. The research protocol was reviewed and approved by the Institutional Review Board. Informed consent was obtained for all patients. All patients were classified using guidelines from the American Society of Anaesthesiologists (ASA). Main indication for F-EVAR included a proximal neck too short for standard EVAR, but otherwise suitable anatomy for EVAR in an AAA of at least 55 mm in diameter (or an AAA smaller than 55 mm but in conjunction with iliac aneurysm larger than 35 mm).

### Preoperative assessment and devices

Aneurysm morphology was assessed by thin-cut (1.5 mm) spiral computerised tomography angiography (CTA) with axial and coronal reconstructions. Customised fenestrated devices based on the Cook Zenith system (William A. Cook Australia, Ltd., Brisbane, Australia) were designed based on the multiplanar reconstructions to define the exact relative position of visceral vessels. A three-part composite system including a proximal tubular body containing the fenestrations, a distal bifurcated graft and a contralateral limb was used in most cases. The composite system simplifies the deployment and repositioning of the first tubular graft to facilitate catheterisation of the target vessels. In addition, direct migration forces on the tube graft are lower than on a bifurcated graft. The term 'fenestration' includes small fenestrations (holes at some distance of the top of the graft, mostly used for the renal arteries) and scallops (opening in the top of the fabric, used for the top target vessel, usually the superior mesenteric artery (SMA)).

Delivery of an ordered fenestrated graft nowadays takes 4–6 weeks.

### Procedures

Detailed reports of the fenestrated technique have been published before.[3,5,11] In brief, the technique involves catheterisation of small fenestration target vessels and stenting with either uncovered stents (in short-necked aneurysms) or covered stents (in juxtarenal aneurysms). Stents are flared inside the main body of the stent graft to improve fixation. After stenting of each target vessel, a selective angiography is performed to demonstrate patency and outflow. Completion angiography at the end of the procedure is performed to confirm target vessel perfusion, correct stent-graft placement and absence of endoleak.

### Follow-up

Postoperatively, patients were usually prescribed double anti-platelet therapy (aspirin lifelong and clopidogrel for 2 months). Prior to discharge, patients were evaluated with clinical examination and renal function laboratory examination and abdominal radiography. CTA was performed 1 month after the procedure, at 1 year and yearly thereafter. Abdominal X-rays were analysed specifically to detect stent fractures, disconnections and components separation or migration. Pre- and postoperative renal function was monitored by serum creatinine measurements. Elevation of serum creatinine was considered significant in presence of a rise of serum creatinine of more than 30% from preoperative levels. In case of suspicion of a significant endoleak or branch vessel malperfusion, angiography was performed for further evaluation.

### Data analysis

SPSS (SPSS Inc., Chicago, IL, USA) for Windows version 16.0, was used for statistical analysis. Differences between groups were determined using analysis of variance with $P < 0.05$ considered significant. Variables are expressed as mean ± standard deviation (SD) in case of normal distribution, and median plus range if data had a skewed distribution. Endovascular outcomes, including technical success, mortality and morbidity and late procedure-related events with regard to target vessel patency, endoleak, renal function and re-intervention were analysed. Technical success was defined as an endovascularly completed procedure with absence of endoleak type I or III, and patent target vessels.

## Results

### Patients

A total of 160 patients with short-necked and juxtarenal aneurysms were treated with fenestrated stent grafts during the study period. Sixty patients were treated in other hospitals under the supervision of the first author, leaving 100 patients (juxtarenal, $n = 53$; short-necked, $n = 47$) for analysis. There were 87 men and 13 women with a mean age of 72.6 ± 7.4 years (range, 50–91 years). Preoperative co-morbidity and risk factors of the patients are listed in Table 1. Eight patients had previous open AAA repair and another eight patients had undergone previous standard EVAR.

### Aneurysms

Median maximal AAA diameter was 60 mm (range, 43–88 mm). Four patients with an AAA smaller than 55 mm had iliac aneurysms of more than 35 mm in diameter. Mean proximal neck length was 3.6 ± 3.5 mm, ranging from 0 to 10 mm.

**Table 1** Preoperative patient characteristics.

| | Patients (%) |
|---|---|
| Coronary artery disease/CABG/stenting/ MI > 6 months | 39 |
| Congestive heart failure/MI < 6 months | 19 |
| Arterial hypertension | 75 |
| COPD | 26 |
| Diabetes mellitus | 18 |
| Hypercholesterolemia | 76 |
| Serum creatinine > 100 μmol/l | 46 |
| Previous stroke/TIA | 9 |
| Smoking (active/past) | 25/42 |
| Previous abdominal operation | 34 |
| ASA III/IV | 83/3 |

CABG, coronary artery bypass graft; MI, myocardial infarction; COPD, chronic obstructive pulmonary disease; ASA, American Society of Anaesthesiologists.

### Devices

Three-part composite systems were used in 95 patients. In the first patient of this series, a bifurcated graft was used; this was also the case in four additional patients, all after previous open surgery ($n = 2$) or EVAR ($n = 2$) with a working length too short for the composite system. The total number of fenestrations was 275, including 192 renal arteries fenestrations, 78 SMA fenestrations and five coeliac artery fenestrations (Table 2). The most common combination included two small fenestrations for the renal arteries and a scallop for the SMA. This type of graft was used in 70 patients. Stent grafts with two fenestrations only were used in 20 patients, and stent grafts with one fenestration in five patients. In the remaining five patients, stent grafts with four fenestrations were used. Four patients had three fenestrations for the renal arteries and the SMA, and a scallop for the coeliac artery. The last patient had three renal artery fenestrations and a scallop for the SMA.

### Operative details

Local anaesthesia was used in 13 patients, regional anaesthesia in 37 patients and general anaesthesia in 48 patients. In two patients, conversion from local to general anaesthesia was required.

The median procedure time was 180 min (range, 110–540 min). Median blood loss was 200 ml (range, 50–3000 ml). Median fluoroscopy time was 26 min (range, 5–90 min) and mean volume of iodinated contrast material used was 193 ± 50 ml.

### Intra-operative complications and technical success

Intra-operative complications occurred in 13 patients. An overview with intra-operative management and outcome is shown in Table 3. Six endovascular procedures were unsuccessful or required open surgery to solve intra-operative complications. One patient required an open

**Table 2** Distribution of vessels incorporated into the fenestrated stent graft and type of fenestration.

| Target vessel | Type of fenestration | | | |
|---|---|---|---|---|
| | Scallop | Small fenestration | Large fenestration | Total |
| Right renal artery | 17 | 80 | | 97 |
| Left renal artery | 10 | 84 | 1 | 95 |
| SMA | 74 | 4 | | 78 |
| Coeliac artery | 5 | | | 5 |
| Total | 106 | 168 | 1 | 275 |

SMA, superior mesenteric artery.

**Table 3** Intra-operative complications, management and outcome.

| Intra-operative complications | *N* | Intra-operative management | Technical success | Late follow-up |
|---|---|---|---|---|
| Top cap not retrievable | 1 | Open conversion | Unsuccessful | Visceral vessels patent |
| Stenosis RRA + LRA | 1 | Bypass RRA + pull-down device | Unsuccessful | Visceral vessels patent |
| Small type I endoleak | 2 | Ballooning | ? | Endoleak resolved |
| Overlap too short | 1 | Tube graft extension | Successful | No endoleak |
| *Renal artery events* | | | | |
| Failed Catheterisation | 2 | – | Unsuccessful | Occlusion |
| Perforation | 1 | Renal artery embolisation | Unsuccessful | Occlusion |
| Occlusion of stent | 1 | Retrograde catheterisation | Unsuccessful | Renal artery patent |
| Dissection RRA | 1 | Stenting | Successful | Renal artery patent |
| Dislocation of stent | 1 | Re-stenting | Successful | Renal artery patent |
| *Iliac events* | | | | |
| Limb disconnection | 1 | Bridging stent graft | Successful | Limb occlusion at 3 years |
| Kinking iliac limb | 1 | Self-expandable stent | Successful | Patent |

conversion during repair of a juxtarenal aneurysm after previous stent grafting with a Talent graft. A bifurcated fenestrated graft with an inner contralateral limb was used. Due to twisting of the ipsilateral limb during repositioning of the stent graft, the top cap could not be retrieved. Further attempts resulted in crushing of the already positioned renal stents, which required an immediate conversion. The patient had a prolonged recovery in hospital of 22 days, including intensive care stay of 8 days, but ultimately was discharged in good condition. In the second patient, where only the right renal artery was targeted, the graft deployed slightly higher than intended, creating a severe stenosis of the right renal artery with impossible access for stenting, but also a stenosis of the left renal artery due to the higher position of the graft. On postoperative day 1, the patient underwent open repositioning of the fenestrated stent graft and a bypass from the right iliac artery to the right renal artery. The repositioning consisted of opening the aorta and pulling the endograft downwards carefully. This resulted in a widely patent left renal artery. Serum creatinine level at 1 year is 123 $\mu$mol $l^{-1}$ (preoperative 70 $\mu$mol $l^{-1}$) with both renal arteries patent. In the third patient, completion angiography after an uncomplicated procedure demonstrated an occlusion of the left renal artery. This was judged to be caused by crushing the stent during flaring and ballooning of the contralateral renal artery stent. A retroperitoneal surgical approach was carried out to catheterise the left renal artery in a retrograde manner. A wire easily passed through the crushed stent, which was re-opened by balloon angioplasty, and flared with a larger balloon. After 6 months, the left renal artery is still patent. In a fourth patient, a renal artery perforation occurred, which needed embolisation with a plug (Amplatzer, Boston Scientific, Natick, MA, USA) and resulted in loss of the kidney. Finally, in two patients a renal artery could not be catheterised, which resulted in occlusion of the renal artery and loss of the kidney.

In five patients, intra-operative complications were successfully managed with endovascular techniques. Additional stenting of a renal artery was required in two patients, the first to repair a dissection, the second because the initial stent dislocated. The dislocated stent was parked in the aneurysm sac. In two further patients, iliac problems were successfully managed. In the fifth patient, where a fenestrated tube only was implanted to seal a type I endoleak, the distal landing zone became too short due to crimping of the distal two sealing stents during downward repositioning. This was solved with additional tube graft extension.

Finally, in two patients a small type I proximal endoleak persisted even after ballooning. This was accepted. Computed tomography (CT) at 1 month showed no evidence of endoleak, and follow-up in both patients was uneventful regarding proximal endoleak, with aneurysm shrinkage.

## Target vessel patency

The total number of stents used to secure the fenestrations was 169, including 93 covered stents and 76 uncovered stents. Small fenestrations were routinely stented except in a few patients in the beginning of our experience. Scallops were generally not stented. The overall operative target vessel perfusion success rate was 98.9% (272/275). Three renal artery small fenestrations were not successfully catheterised and/or stented, as previously mentioned.

## Postoperative mortality and morbidity

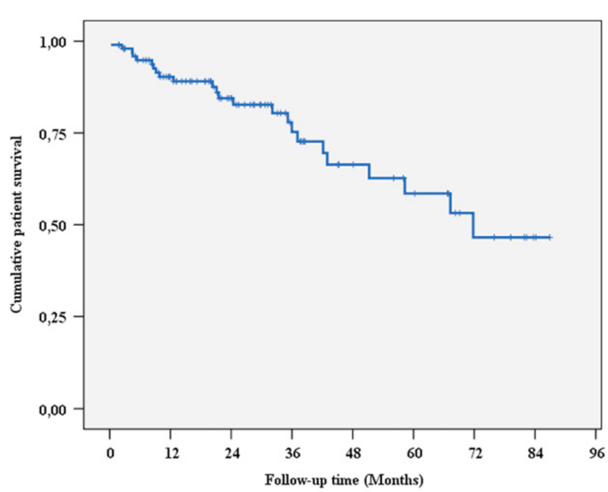
Surgical mortality was 1% ($n = 1$). This patient, with a preoperative left ventricular ejection fraction of 23%, was re-admitted on postoperative day 6 and died 2 days later due to mesenteric ischaemia. Laparotomy at re-admission showed a pale left colon but no localised ischaemia. Therefore, it was decided not to perform a resection of the colon. Intra-operatively, a stent graft with two renal artery fenestrations and an SMA scallop was inserted without technical difficulties, with SMA patency confirmed on completion angiogram. At autopsy the SMA was patent. Colon ischaemia may have been induced by occlusion of the internal iliac arteries due to the introduction sheaths. Nonfatal postoperative complications were seen in 14 patients, and included two retroperitoneal haematomas, which were treated conservatively, two cardiac events (myocardial infarction and arrhythmia), two surgical access site infections that were treated with antibiotics and wound dressing, two urinary tract infections, two pulmonary infections and four cases of urinary retention. Median hospital stay was 4 days (range, 2–64 days), including the preoperative admission day.

## Late follow-up

Median follow-up was 24 months (range, 1–87 months). Eight patients refused follow-up after a mean of 32 months because of old age and co-morbidity, but are still alive without re-intervention or complication. All-cause late mortality was 22, all aneurysm unrelated (Fig. 1). Estimated survival rates at 1, 2 and 5 years were 90.3 ± 3.1%, 84.4 ± 4.0% and 58.5 ± 8.1%, respectively. Ten target vessels in nine patients (renal arteries, $n = 9$; SMA, $n = 1$) were lost during follow-up. Cumulative visceral branch patency was 93.3 ± 1.9% at five years (Fig. 2). Postoperative stent occlusions all occurred during the first 2 postoperative years (Table 4).

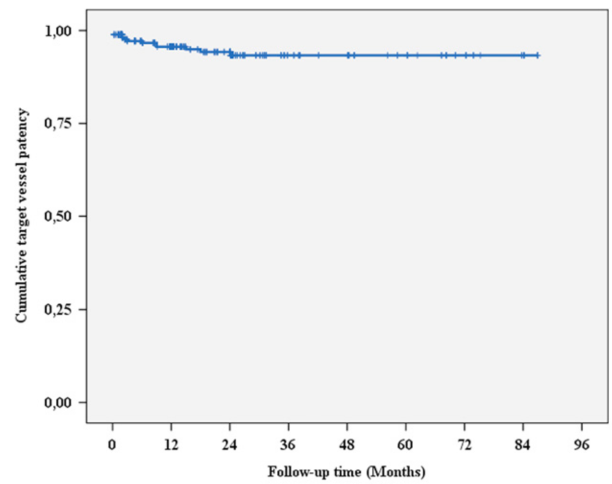
Twenty-five patients had an increase of serum creatinine of more than 30% during follow-up, with two patients requiring dialysis. One patient developed acute renal insufficiency due to simultaneous bilateral renal artery stent occlusion 9 months postoperatively. The second patient (preoperative serum creatinine of 206 $\mu$mol $l^{-1}$) had progressive renal function deterioration with two patent renal arteries, and required dialysis at 3 months postoperatively. Elevation of serum creatinine level of more than 30% was not related to preoperative renal function (for instance, 13 out of 54 patients with preoperative normal renal function, 12 out of 46 patients with preoperative impaired renal function, Pearson chi squared 0.817) During follow-up, four stent fractures were diagnosed on abdominal X-ray. In three of them, this resulted in occlusion of the renal artery (Table 4).

Aneurysm sac size decreased significantly from 63 mm to 56 mm ($P < 0.001$) during follow-up. In five patients, aneurysm sac diameter increased more than 5 mm, two with lumbar artery retrograde endoleak, and one with inferior mesenteric artery (IMA) retrograde endoleak. In the other two patients, no reason was found for the aneurysm sac increase. No type I endoleak was diagnosed during follow-up. Migration less than 5 mm was suspected in three cases and probably resulted in occlusion of a renal artery stent in two patients.




| Time (months) | 12 | 24 | 36 | 48 | 60 | 72 |
|---|---|---|---|---|---|---|
| Number at risk | 73 | 50 | 29 | 19 | 14 | 7 |
| Standard Error | 0.031 | 0.040 | 0.057 | 0.070 | 0.081 | 0.100 |

**Fig. 1** Kaplan–Meier estimate of the cumulative overall patient survival for all-cause mortality during follow-up.




| Time (months) | 12 | 24 | 36 | 48 | 60 | 72 | 84 |
|---|---|---|---|---|---|---|---|
| Number at risk | 170 | 115 | 47 | 39 | 28 | 14 | 6 |
| StandardError | 0.014 | 0.017 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 |

**Fig. 2** Kaplan–Meier estimate of the cumulative overall visceral branch patency.

## Re-interventions

In total, there were 11 re-interventions in nine (9%) patients. Besides the two already mentioned early re-interventions (laparotomy at day 6 for suspected mesenteric ischaemia, laparotomy at day 1 for bypass RRA and pull-down of the stent graft), a third patient underwent stenting of iliac stenoses within 30 days. Late re-interventions ($n = 8$) were performed in six patients. In two patients, catheterisation of severe renal artery stenosis at 2 and 18 months, respectively, proved impossible, finally resulting in occlusion. A third patient underwent coil embolisation of a persistent IMA at 3 months. A fourth patient underwent a laparotomy at 4 months to clip persistent lumbar arteries, and subsequently underwent a (failed) renal artery catheterisation at 13 months. The fifth patient also underwent two re-interventions; the first at 5 months for iliac limb occlusion (treatment: cross-over bypass), the second at 20 months to correct a disconnection between tube and bifurcation (treatment: thoracic stent graft used to bridge the gap). Finally, a sixth patient underwent a cross-over bypass at 5 months for iliac limb occlusion.

**Table 4** Occlusion of target vessel, with time of event and outcome.

| Patients | Occluded vessel | Type of fenestration | Use of stent | Time of occlusion postoperatively (months) | Cause/possible cause | Outcome |
|---|---|---|---|---|---|---|
| 1 | LRA | Fenestration | No | 2.5 | Malpositioning | ESC < 30% |
| 2 | LRA | Scallop | No | 6 | Malpositioning | ESC < 30% |
| 3 | RRA | Scallop | No | 2 | Malpositioning | ESC > 30% |
| 4 | RRA | Fenestration | No | 0 | Failed catheterisation | ESC < 30% |
| 5 | RRA | Fenestration | Uncovered[a] 6 mm | 15 | Fracture | ESC > 30% |
| 6 | RRA | Fenestration | Uncovered[a] 7 mm | 3.5 | Fracture | ESC > 30% |
| 7 | SMA | Scallop | No | 2 | Malpositioning | Asymptomatic |
| 8 | LRA | Fenestration | Covered[b] 7 mm | 0 | RA perforation | ESC < 30% |
| 9 | LRA | Fenestration | Covered[b] 7 mm | 24 | Migration | ESC > 30% |
| 10 | LRA | Fenestration | Covered[b] 7 mm | 18 | Fracture | ESC > 30% |
| 11 | RRA | Fenestration | Covered[c] 7 mm | 9 | Extreme dehydration | Dialysis |
| | LRA | Fenestration | Covered[c] 7 mm | 9 | | |
| 12 | RRA | Fenestration | No | 0 | Failed catheterisation | ESC > 30% |

LRA, left renal artery; RRA, right renal artery; RA, renal artery; ESC, elevation of serum creatinine.
[a] Genesis.
[b] Advanta V12.
[c] Jostent.

## Discussion

Fenestrated stent grafting for short-necked and juxtarenal aneurysms is entering its second decade. In the beginning, the technique was reserved to a few Australian and European centres, and one American centre. It is becoming widespread in Europe, and an American prospective multi-centre trial was recently published.[12] Published results of expert centres have demonstrated excellent short- and mid-term results.[2–7] A recently published systematic review confirms the reduction of perioperative mortality in comparison to open treatment.[8] Although caution has to be exerted in view of selectivity within the study groups and the lack of rigorous classification, the fenestrated technique has shown to be safe in experienced hands. Further development of the fenestrated techniques also opened the way for endovascular treatment of supra-renal and even thoraco-abdominal aneurysms.[13,14]

This series represents one of the largest worldwide single-centre studies with a 7-year follow-up. Results are in range with published series from other expert centres. One percent mortality is remarkably low in view of the percentage of high-risk patients, including 16 patients having undergone previous aortic surgery, and the high proportion of juxtarenal aneurysms (53%). Intra-operative technical success was equally high with only three out of 275 vessels lost due to technical problems. However, technical complications (13% in this series) can occur and do underline the need of both endovascular and open expertise to rescue the situation. Availability of back-up materials is equally a priority.

The fenestrated technique is clearly more complex than standard EVAR. Over time, however, the technique has reached maturity. Software allowing for CTA multiplanar reconstructions facilitates preoperative measurement, and standard order forms are available to allow for quick ordering of the grafts, with a delivery between 4 and 6 weeks. Procedure planning is crucial to achieve success. This is also reflected in the training programme, which includes the active presence of an expert for the first three to five cases only, but persisting additional control of graft planning. Materials have improved, technical refinements have been added, both of which result in an overall easier procedure. Guiding sheaths are nowadays routinely used to facilitate introduction of stents. Separate puncture of valve leafs of the sheath in the contralateral femoral artery is the solution to avoid continuous blood loss induced by multiple wires through the central lumen of a valve. The use of a composite system facilitates the repositioning of the graft for easier catheterisation of the target vessels. Experience has taught us to position the fenestrations at the highest possible level during the procedure (i.e., to push up the graft against the guiding sheaths just before final deployment): this allows for maximal apposition and even for some minimal migration downwards (~2 mm) until the hooks and barbs encroach on the aortic wall to prevent further migration.[15] Stent fractures observed in our series were all related to less than optimal apposition between fenestration and target vessel ostium. The fact that all target vessel occlusions occurred in the first 2 years also seems to indicate an intra-operative technical imperfection rather than an inherent stent problem. A learning curve has to be taken into account as half of the occlusions occurred in non-stented fenestrations or scallops in the early stages of our experience. Nowadays, stenting of a fenestration is mandatory. Scallops underwent an important modification with the introduction of a double ring reinforcement, which prevents them from narrowing down. Indeed, the non-reinforced scallop being the weakest link in the oversized top stent sometimes resulted in folding and narrowing of the opening (Fig. 3).

Late renal events are a concern and have been reported before.[16] In this series, similarly, 25 patients had a significant deterioration of renal function. This is not explained by occlusions only. Two patients required dialysis, the first of which had an acute onset of bilateral renal artery occlusion during a summer holiday 9 months after the procedure. This might have been explained by dehydration during physical activity in the heat. The second patient with a preoperative impaired renal function, was diagnosed to have cholesterol emboli and required dialysis at 3 months. Other patients experienced decrease of renal function without occlusion of renal arteries. This was not related to preoperative renal function. Repeated examinations with iodated contrast postoperatively may have played a role in this decrease of renal function. This was also suggested by Mills et al. in their comparison of open repair versus standard EVAR, and raises the question whether we should reduce the number of postoperative contrast-enhanced CT scans.[17]

A comparison with open surgery is difficult. A clear publication bias needs to be acknowledged. Selection bias is probably less important as many patients were high risk for open surgery. A recent report of open surgery for short-necked and juxtarenal aneurysms from the Mayo clinic seems to demonstrate comparable results to fenestrated EVAR.[18] However, other reports do underline the risk of open surgery in more complex AAA, especially in the presence of preoperative impaired renal function.[19,20] A randomised trial could answer a number of questions but may be difficult to achieve in view of lower number of patients presenting with these more complex aneurysms, and the fact that only a few centres have acquired enough experience to conduct such a trial. We may need such a trial to convince health-care providers to support these techniques.[8] Another important question is who should be offered the technique as more than 40% of patients died of another cause within 5 years after the procedure. However, not a single patient experienced or died from aneurysm rupture.

Finally, at this moment fenestrated grafts still require 4–6 weeks' planning and delivery and are therefore not applicable in cases requiring more urgent treatment.

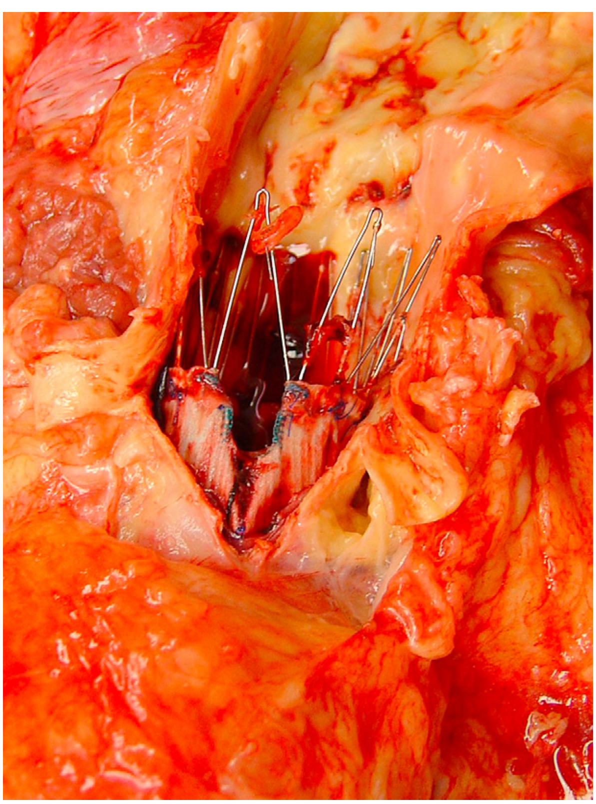


**Figure 3** Autopsy image of an original non-reinforced SMA scallop of a fenestrated graft. Please note the narrowing due to over sizing of the graft versus the aortic wall diameter.

## Conclusions

Fenestrated stent grafting for short-necked and juxtarenal aortic aneurysms demonstrates promising results in the short and mid-term, and is safe and effective in the prevention of aneurysm rupture. Renal function deterioration is a concern in a substantial number of patients. To allow widespread application of the technique, continuous efforts must be placed in training new centres on patient selection, device measurement and the development of new materials and techniques.

## Conflicts of Interest

Eric Verhoeven has received educational grants and is a consultant for Cook Inc. and W.L. Gore & Associates, and has received Royalties from Cook Inc.

## References


1 Browne TF, Hartley D, Purchas S, Rosenberg M, van Schie G, Lawrence-Brown M. A fenestrated covered suprarenal aortic stent. *Eur J Vasc Endovasc Surg* 1999;**18**(5):445–9.
2 Greenberg RK, Haulon S, Lyden SP, Srivasta SD, Turc A, Eagleton MJ, et al. Endovascular management of juxtarenal aneurysms with fenestrated endovascular grafting. *J Vasc Surg* 2004;**39**(2):279–87.
3 Verhoeven EL, Prins TR, Tielliu IF, van den Dungen JJ, Zeebregts CJ, Hulsebos RG, et al. Treatment of short-necked infrarenal aortic aneurysms with fenestrated stent-grafts: short-term results. *Eur J Vasc Endovasc Surg* 2004;**27**(5): 477–83.
4 O'Neill S, Greenberg RK, Haddad F, Resch T, Sereica J, Katz E. A prospective analysis of fenestrated endovascular grafting: intermediate-term outcomes. *Eur J Vasc Endovasc Surg* 2006; **32**(2):115–23.
5 Muhs BE, Verhoeven EL, Zeebregts CJ, Tielliu IF, Prins TR, Verhagen HJ, et al. Mid-term results of endovascular aneurysm repair with branched and fenestrated endografts. *J Vasc Surg* 2006;**44**(1):9–15.
6 Ziegler P, Avgerinos ED, Umscheid T, Perdikides T, Stelter WJ. Fenestrated endografting for aortic aneurysm repair: a 7-year experience. *J Endovasc Ther* 2007;**14**(5):609–18.
7 Kristmundsson T, Sonesson B, Malina M, Björses K, Dias N, Resch T. Fenestrated endovascular repair for juxtarenal aortic pathology. *J Vasc Surg* 2009;**49**(3):568–74.
8 Nordon IM, Hinchliffe RJ, Holt PJ, Loftus IM, Thompson MM. Modern treatment of juxtarenal abdominal aortic aneurysms with fenestrated endografting and open repair—a systematic review. *Eur J Vasc Endovasc Surg* 2009;**38**(1): 35–41.

9 Verhoeven EL, Muhs BE, Zeebregts CJ, Tielliu IF, Prins TR, Bos WT, et al. Fenestrated and branched stent-grafting after previous surgery provides a good alternative to open redo surgery. *Eur J Vasc Endovasc Surg* 2007;**33**(1):84–90.
10 Beck AW, Bos WT, Vourliotakis G, Zeebregts CJ, Tielliu IF, Verhoeven EL. Fenestrated and branched endograft repair of juxtarenal aneurysms after previous open aortic reconstruction. *J Vasc Surg* 2009;**49**(6):1387–94.
11 Moore R, Hinojosa CA, O'Neill S, Mastracci TM, Cinà CS. Fenestrated endovascular grafts for juxtarenal aortic aneurysms: a step by step technical approach. *Catheter Cardiovasc Interv* 2007;**69**(4):554–71.
12 Greenberg RK, Sternbergh 3rd WC, Makaroun M, Okhi T, Chuter T, Bharadwaj P, et al. Intermediate results of a United States multicenter trial of fenestrated endograft repair for juxtarenal abdominal aortic aneurysms. *J Vasc Surg* 2009;**50**(4):730–7.
13 Greenberg RK, Lytle B. Endovascular repair of thoraco-abdominal aneurysms. *Circulation* 2008;**117**(17):2288–96.
14 Verhoeven EL, Tielliu IF, Bos WT, Zeebregts CJ. Present and future of branched stent grafts in thoraco-abdominal aortic aneurysm repair; a single centre experience. *Eur J Vasc Endovasc Surg* 2009;**38**(2):155–61.
15 Scurr JR, Brennan JA, Gilling-Smith GL, Harris PL, Vallabhaneni SR, McWilliams RG. Fenestrated endovascular repair for juxtarenal aortic aneurysm. *Br J Surg* 2008;**95**(3):326–32.
16 Haddad F, Greenberg RK, Walker E, Nally J, O'Neill S, Kolin G, et al. Fenestrated endovascular grafting: the renal side of the story. *J Vasc Surg* 2005;**41**(2):181–90.
17 Mills Sr JL, Duong ST, Leon Jr LR, Goshima KR, Ihnat DM, Wendel CS, et al. Comparison of the effects of open and endovascular aortic aneurysm repair on long-term renal function using chronic kidney disease staging based on glomerular filtration rate. *J Vasc Surg* 2008;**47**(6):1141–9.
18 Knott AW, Kalra M, Duncan AA, Reed NR, Bower TC, Hoskin TL, et al. Open repair of juxtarenal aortic aneurysms (JAA) remains a safe option in the era of fenestrated endografts. *J Vasc Surg* 2008;**47**(4):695–701.
19 Sarac TP, Clair DG, Hertzer NR, Greenberg RK, Krajewski LP, O'Hara PJ, et al. Contemporary results of juxtarenal aneurysm repair. *J Vasc Surg* 2002;**36**(6):1104–11.
20 Pearce JD, Edwards MS, Stafford Jm, Deonanan JK, Davis RP, Corriere MA, et al. Open repair of aortic aneurysms involving the renal vessels. *Ann Vasc Surg* 2007;**21**(6):676–86.