Fenestrated and branched endograft repair of juxtarenal aneurysms after previous open aortic reconstruction

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Objective: Para-anastomotic aortic aneurysms and progressive aneurysmal degeneration of the aorta after previous open aortic reconstructions pose a challenging clinical scenario. Due to the proximity to the visceral arteries, endovascular exclusion is typically not an option. However, the development of fenestrated and branched endografts has provided a less invasive means of repair. We sought to evaluate our experience using fenestrated endografts in the management of juxtarenal aortic aneurysms after previous open aortic reconstruction.

Methods: This is an analysis of patients who have undergone fenestrated endovascular repair specifically for juxtarenal aneurysms in the setting of previous infrarenal open aortic surgery. Patients were treated with customized Cook (William A. Cook Australia, Ltd, Brisbane, Australia) endografts manufactured based on preoperative 3-dimensional (3-D) imaging. All patients underwent repair under the direction of a single surgeon.

Results: Eighteen patients were treated from March 2004 to November 2008. All patients had a previous open aortic reconstruction, and 3 patients had two prior reconstructions. The mean time since the last operation was 8.5 years (range, 1-15 years). Mean patient age was 72-years-old (range, 57-80 years). All patients were considered high risk for open surgery due to pre-existing medical co-morbidities and/or the redo nature of their surgery. The mean number of fenestrations per patient was three vessels, including proximal graft scallops. All but one operation (94%) was completed by totally endovascular means. One operation required a planned celiotomy for retrograde access to a left renal artery. Of 56 target vessels, all were successfully revascularized using a combination of: fenestrations with stents (12), or stent grafts (25), as well as graft scallops (18), and directional graft branches with a bridging stent graft (1). Mean operative time was 215 minutes (range, 135-420 minutes) and mean blood loss was 560 cc (range, 100-1500 cc). Thirty-day and 1-year mortality was 0 and 11%, respectively. Perioperative complications occurred in 2 patients. One patient developed a congestive heart failure exacerbation and myocardial infarction, and the other patient a groin wound infection. Mean follow-up time was 23 months and cumulative primary patency was 95% (53/56 vessels), with no follow-up interventions.

Conclusion: Endovascular treatment of juxtarenal aneurysms after prior aortic reconstruction is a viable alternative to open repair with high success and low reintervention rates. These devices will broaden the available treatment modalities for these conditions, and will likely significantly decrease the complication rate of treatment in these high-risk patients.


The recent advent of fenestrated and branched aortic endografts has greatly broadened the management options for patients with aortic aneurysms. Use of these devices is becoming increasingly prevalent, and clinical outcomes with the technology have been demonstrated to be quite good.1-5

Anastomotic pseudo-aneurysms and aneurysmal degeneration of the aorta after open infrarenal aneurysm repair poses a difficult clinical problem, especially in high-risk patients. Repair of anastomotic aneurysms can sometimes be managed using a standard infrarenal endograft, but often the aneurysm encroaches on the visceral vessels such that it could traditionally only be repaired by either open means or a hybrid open and endovascular repair. Similarly, aneurysms above a previous repair typically cannot be managed using standard infrarenal endografts. Because of the proximity to the visceral vessels, this patient population by definition requires at least a suprarenal aortic clamp, if not higher. The suprarenal aortic clamp site, by itself, has been variably associated with an increased morbidity and mortality.7-12 Additionally, the redo nature of the surgery leads to added technical difficulty, morbidity, mortality, and a prolonged recovery time.12-15

We have previously reported our early results with fenestrated and branched endografting in a heterogeneous group of patients with previous open and endovascular aortic reconstructions.8 Although we now preferentially repair all juxtarenal aneurysms using endovascular means, we have identified specific difficulties associated with the management of patients after a prior open aneurysm repair.
We seek to report our experience with the use of fenestrated endografts in this patient population.

METHODS

Subjects and database. All patients who have undergone fenestrated and branched endografts for aneurysms in close approximation to, or involving the visceral segment of the aorta, at the University Medical Center of Groningen or by the senior author at outlying hospitals were entered into a database.

The database was queried for patients who have undergone fenestrated endografts for juxtarenal aneurysms after a previous open infrarenal aortic reconstruction. Patients with primary aortic aneurysms (those without a prior operation) or prior endovascular aortic aneurysm repair (EVAR) were excluded from this review. Additionally, patients with a suprarenal or thoracic component to their aneurysm (including all types of thoraco-abdominal aneurysms) were excluded primarily because of significant differences in the endograft configuration.

Preoperative planning and operative technique. Patients were treated using custom designed fenestrated Cook endografts (William A. Cook, Australia, Ltd, Brisbane, Australia) based on the Zenith system. The endografts were designed for the patients’ anatomy using preoperative 3-dimensional (3D) computerized tomographic angiography (CTA). Over-sizing of the endograft diameter was essentially the same as routine over-sizing with Cook Zenith endografts for infrarenal aneurysm repair. The CTA was the only preoperative imaging performed unless there was some indication that there might be difficulties with target vessel catheterization. On one occasion, CTA demonstrated a severely stenotic, angulated, and tortuous left renal artery which prompted preoperative digital subtraction angiography and attempted vessel catheterization. This confirmed the inability to sufficiently access the vessel from either a brachial or femoral arterial approach, and led to a planned celiotomy for retrograde catheterization of the renal artery during endovascular repair.

Patients were repaired with a variety of endograft types, including fenestrated composite grafts, fenestrated bifurcated grafts, as well as fenestrated tube grafts (Fig 1). A fenestrated composite graft consisted of a fenestrated proximal tube, a bifurcated distal graft, and two iliac limbs (Fig 1, A). If the aortic anatomy allowed, repairs were performed using a composite graft. However, a variety of graft configurations were used in order to accommodate individual patient anatomy. These variations included, but were not limited to, customized scallops/fenestrations, caudally oriented branch grafts that were completely external or partially internal and external to the graft, and docking limbs that were partially internal and external to the graft in order to accommodate a short working distance between the aortic or neo-aortic bifurcation and the visceral segment (Fig 1).

Proximal graft scallops were customized to the target vessel location and were 10 mm in width and 6 to 12 mm in depth. Since 2004, all scallops were reinforced with nitinol around the perimeter due to an association of non-supported scallops with late vessel stenosis/thrombosis (data not published). The vessels treated with scallops were routinely left non-stented unless inadvertent partial coverage of the vessel orifice warranted stent placement. Fenestrations were
either 6 × 6 or 6 × 8 mm in size and were designed to closely approximate or overlie the vessel orifice to facilitate stent/stent graft placement. All fenestrations were routinely stented to assure that there was not unrecognized partial coverage of the vessel that might impede flow.

Radiologic imaging was performed in the operating room with a mobile C-arm (OEC 9800, General Electric Medical Systems, Salt Lake City, Utah). The technique for endograft deployment has been described in detail previously. Briefly, open femoral artery exposure was performed on one or both sides depending on the number of fenestrations and type of visceral revascularization planned. Axillary artery cut-down was used when a caudally-oriented directional graft branch was used for branch vessel revascularization. The main body of the endograft was placed via the femoral artery into the aorta at the desired level and unsheathed, leaving the top cap over the proximal uncovered stent. Access to the inner portion of the graft was then obtained from the contralateral groin. A percutaneous contralateral access was selectively performed in the setting of a single fenestration, but in patients with multiple fenestrations a 20F sheath was placed via an open femoral exposure. This allowed placement of multiple smaller guiding sheaths by direct puncture of the diaphragm of the 20F sheath at the hub (Fig 2).

Prior to removing the top cap, the branch vessels were catheterized and stable guiding sheath or wire access obtained to assure stability of the endograft before full deployment. In the case of an endograft with two fenestrations for the renal arteries and a scallop for the superior mesenteric artery (SMA), both renal arteries were catheterized and bilateral 7F sheaths, usually Ansel 1 guiding sheaths (FLEXOR, Ansel: ANL1 Curve; Cook Medical Inc, Bloomington, Ind), were placed into each renal artery over a Rosen wire (0.035” Rosen curved; Cook Medical Inc). In the case of an additional fenestration for the SMA (ie, two fenestrations for the renal arteries, one fenestration for the SMA +/− a scallop for the celiac artery), an Amplatz wire (0.035” Amplatz Superstiff J-tip; Boston Scientific Corporation, Natick, Mass) was placed through the 20F sheath hub without a guiding sheath (a third sheath does not fit within the 20F sheath lumen), and positioned in the SMA prior to completion of proximal endograft deployment. This assured access to all visceral vessels via fenestrations before complete endograft deployment, and prevented inadvertent coverage of the vessel orifices. After complete deployment of the endograft and retrieval of the top cap, each target vessel fenestration was fitted with a stent or stent graft.

Regarding the selection of stents vs stent grafts, uncovered stents were used when the endograft was in apposition to the aortic wall around the vessel orifice for a length sufficient enough to provide seal, and stent grafts were used when the vessel was close to or within aneurysmal aorta, necessitating a seal between the endograft and the target vessel.

A variety of uncovered stents were utilized in sizes varying from 6 to 10 mm in diameter depending on the target vessel diameter. The preferred stent grafts were either Atrium iCAST (Atrium Medical Corporation, Hudson, NH) or JOMED stent grafts (JOMED International AB, Helsingborg, Sweden). The usual nominal stent graft diameter was 6 or 7 mm and the length varied and depended on whether the endograft was directly apposed to the aortic wall or there was aneurysmal aorta to be traversed. Stents/stent grafts were deployed such that 3-4 mm remained within the main body of the endograft, and the portion within the graft was flared using a 12 mm balloon. This was done to seal the stent/stent graft to the main body of the aortic endograft and to allow easier access to the visceral vessel if future intervention were to be required. The portion of the stent/stent graft within the native vessel was balloon-dilated to ~5-10% over the size of the native vessel. Completion angiography was performed to assure a good seal and no technical problems with the stented vessel.

In a composite endograft, the distal body was then placed and deployed, ideally with at least 4 cm of graft overlap to prevent component separation. The docking limb was catheterized and the iliac extensions placed similar to a standard Cook Zenith bifurcated infrarenal endograft.

Operations were performed using general, epidural, or local anesthesia depending on the preference of the patient, surgeon, and anesthesiologist.

**Follow-up.** Patients were routinely followed clinically and with a CTA at 1 month postoperatively, unless clinical factors required alteration of this protocol. If there was no endoleak noted on the first CTA, they underwent aortic and visceral duplex at 6 months, post-op followed by a CTA at 12 months, and yearly thereafter. Additionally, a plain abdominal x-ray was performed to evaluate for any graft component migration or separation, and a serum creatinine was measured to evaluate renal function.
Data analysis. Data were analyzed using Microsoft Excel or MedCalc statistical software (MedCalc Software, Mariakerke, Belgium). Patient survival after operation as well as target vessel primary patency was analyzed using Kaplan-Meier methodology.

RESULTS

Patient characteristics. A total of 18 patients underwent elective endovascular repair of juxtarenal aortic aneurysms after a previous open aortic reconstruction. There were 16 men and 2 women with a mean age of 72 years (range, 57-80 years). The previous aortic reconstruction was performed from 1-15 years prior to this intervention (mean, 8.5 years). Table I demonstrates specifics of each patient’s disease process and intervention.

The most recent open aortic reconstructions were all performed for aortic aneurysm disease using a tube (7), aorto-bi-iliac (ABI) (8), or aorto-bi-femoral (ABF) graft (3). Three of these patients had two prior open aortic reconstructions which included a tube graft followed by another tube graft in 2 patients, and a tube graft followed by an ABI in 1 patient. Additionally, 2 patients had additional procedures that might impact the difficulty of their fenestrated endograft repair. One such patient had a left renal artery re-implantation with the ABI graft, and the other had a left iliac endograft placed for an ABI anastomotic pseudo-aneurysm in the past.

No patient had clinical or radiographic evidence of an infectious etiology of the pseudo-aneurysm development.

All patients had some combination of pre-existing co-morbidities including coronary artery disease (50%), congestive heart failure (22%), pulmonary disease (17%), or renal insufficiency (creatinine $\geq 1.3$ mg/dL) (6%) making them high risk for open intervention.

Technical success. All patients underwent a successful endovascular repair of their aneurysm without unplanned conversion to an open operation. Aneurysms were repaired with: a composite fenestrated endograft (11), single tube endograft (5), or fenestrated bifurcated endograft (2). Mean operative time was 215 minutes (range, 135-420 minutes) and mean blood loss was 560 mL (range, 100-1500 mL). Mean contrast volume was 192 mL (range, 75-300 mL), and mean radiation exposure time was 39 minutes (8-129 minutes). Mean creatinine was not significantly different before the procedure and at 1-month follow-up (1.1 vs 1.2 mg/dL; $P = .85$).

Of 56 target vessels, all were successfully revascularized with a combination of: fenestrations with stents (12), or stent grafts (25), proximal scallops (18), and caudally-oriented graft branches with a bridging stent graft (1) (Table II). As mentioned, 1 patient had a planned celiotomy for retrograde access to a left renal artery. Otherwise, all procedures were completed by totally endovascular means. Two patients had a proximal graft scallop used for renal artery revascularization, and 1 of these required a stent due to partial coverage of the vessel orifice by the edge of the scallop.

### Table I. Individual patient data

<table>
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<th>Patient age</th>
<th>Previous surgery</th>
<th>Disease process</th>
<th>Graft type</th>
<th># Fenest</th>
<th>Type revasc (scallop, stent, stent graft)</th>
<th>F/U (months)</th>
<th>Patency last F/U</th>
<th>Death</th>
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</table>

*Patient had a preoperatively occluded left renal artery.
**Three mortalities in the series shown in the Death column unrelated to the operation or aneurysm.
†Patient presented to an outside facility with bilateral renal artery occlusions due to an unknown etiology, was placed on chronic dialysis and has otherwise done well.
‡Patient presented at 6-month follow-up with an asymptomatic right renal artery occlusion adjacent to an unsupported graft scallop.

ABF, Aorto-bi-femoral graft; ABI, aorto-bi-iliac graft; EVG, endovascular graft; PSA, pseudoaneurysm; An Deg, aneurysmal degeneration above graft; Comp, composite endograft; Tube, fenestrated tube endograft; Bifurc, bifurcated fenestrated endograft; Sc, scallop; St, uncovered stent; SG, stent graft; Occl, chronically occluded; F/U, follow-up.

Data analysis. Data were analyzed using Microsoft Excel or MedCalc statistical software (MedCalc Software, Mariakerke, Belgium). Patient survival after operation as well as target vessel primary patency was analyzed using Kaplan-Meier methodology.
There were no intra-operative complications. Unplanned technical difficulties leading to a prolonged procedure were encountered in 5 patients. Two of these were related to previous ABF grafts. In 1 patient, dense periprosthetic scar led to a difficult exposure of the ABF limb, and direct access through the Dacron graft limb was poorly hemostatic around the introducer sheath. This patient ultimately had a large amount of blood loss (1500 cc) due to persistent bleeding around the sheath during the procedure. Another patient with a previous ABF graft had a high deployment of the main body of the endograft due to a funnel-shape of the aorta. The graft moved upward immediately during deployment (before being completely released from the deployment system) resulting in malalignment of the fenestrations with the target vessels. During attempts to pull the endograft downward, the bottom stent was deformed and required placement of a distal aortic cuff, which led to a good result.

The other three unplanned technical difficulties involved renal artery revascularization. In 2 patients, passage of a Jomed stent graft into the artery proved difficult due to vessel stenosis, angulation, and tortuosity, and resulted in the stent graft being pushed off of the balloon. These were both successfully retrieved and replaced in both cases. The third patient had a severely tortuous left renal artery leading to difficulties with tracking of the stent graft into the artery (Fig 3). This vessel was revascularized from a left axillary artery access using a custom caudally-oriented endograft branch and a bridging stent graft. The angulation of the mid portion of the artery proved difficult to navigate, but eventually was revascularized with a Wallgraft (Boston Scientific). To ease the transition and prevent kinking of the vessel at the distal Wallgraft, a self-expanding EV3 Everflex bare metal stent (EV3 Endovascular, Inc, Plymouth, Minn) was placed (Fig 3, C).

Operative outcome, complications, and mortality. Patients were ambulating at a median of 1 day (range, 1-6 days), and eating a regular diet at 1 day (range, 1-5 days). Median hospital stay for these patients was 4 days (range, 2-40 days), with 2 patients requiring a stay greater than 5 days. Perioperative complications occurred in 2 patients. One patient had perioperative decompensation of his chronic congestive heart failure and a subsequent myocardial infarction (MI) leading to a 23-day hospital stay. The other patient had a groin wound infection resulting in a prolonged hospital stay of 40 days for intensive wound care. All patients in this series were discharged to their home.

Long-term outcomes. Mean follow-up time was 23 months (range, 5-60 months) and follow-up information was complete in all patients. Thirty-day and 1-year mortality was 0% and 11% after repair, and overall mortality was 17.6%. The Kaplan-Meier survival curve is shown in Fig 4. The 2 patients who died within 1 year of operation died of non-aneurysm-related conditions, 1 of MI after 5 months and 1 of sepsis related to pneumonia at 9 months. The third
There were no endograft migrations or iliac limb occlusions noted on follow-up imaging to date. Primary patency over the entire follow-up period was 95% (53 of 56 fenestrations) (Fig 5), with no subsequent interventions performed for the occluded arteries. One patient was noted on routine follow-up to have an occluded right renal artery. This vessel was originally revascularized using an unsupported proximal graft scallop without a stent. The occlusion was noted at 6 months follow-up and was asymptomatic. There was no change in the patient’s creatinine level at the time of diagnosis, and no intervention was pursued. CTA demonstrated no apparent endograft migration or stent graft kinking that might explain the vessel occlusion. The other two occluded vessels were both renal arteries in the same patient, which were originally revascularized with two 28 mm long JOMED covered stents through fenestrations, traversing aneurysmal aorta. This occurred 8 months after the operation, and no apparent technical difficulties were noted on the patient’s first two postoperative CTA studies. The patient developed these occlusions while traveling to another country after a brief illness involving severe gastroenteritis and volume depletion. The patient was initiated on dialysis at another hospital and eventually presented in follow-up to our hospital. At our institution, follow-up imaging confirmed the stent graft occlusions, but despite in-depth review at a multi-disciplinary conference by multiple surgeons and radiologists, no apparent technical issues could be identified. The endograft appeared to be in the same position as the immediate postoperative imaging, and there was no evidence of kinking or crushing of the stents.

DISCUSSION

Fenestrated and branched endografts are broadening the treatment options for minimally invasive therapy in aortic aneurysm patients. Patients who have had previous aortic reconstruction represent a somewhat uncommon but challenging patient population.

Previous reports have involved a more heterogeneous patient population than ours, making comparison difficult, but have demonstrated that open redo aortic surgery for aneurysms encroaching on or involving the visceral segment have major morbidity rates as high as 30%. Similarly, hybrid aortic de-branching and endovascular treatment, often touted as a less-invasive means of managing patients with aneurysmal disease of the visceral segment, has a major morbidity rate as high as 48%, along with prolonged intensive care and hospital stays. Thus, this patient population generally represents a group who could benefit greatly from management by less-invasive means.

Previous reports from our institution and others have demonstrated that primary aneurysms involving the visceral segment of the aorta can successfully be managed with totally endovascular procedures with good outcomes. Because both our short and long-term results have been excellent with this method of repair, we prefer to repair all juxtarenal aneurysms by endovascular means, even in good operative risk patients.

There are a number of technical considerations that are worthy of further discussion. Fenestrated endograft repair is preferentially performed using a composite system (Fig 1, A). Previous tube graft repair of an infrarenal aneurysm produces no specific technical difficulties over and above those of primary juxtarenal aneurysms, but there are graft design considerations that should be considered. Although it is possible to obtain a distal seal/fixation in a tube prosthesis, our preference is to use a composite system in these patients because the existing aortic prosthesis diameter is not fixed, and there is some concern for stretching of the existing distal anastomosis between the aortic prosthesis and the native aorta. Additionally, the distal component of the composite endograft provides column strength and off-loads some of the downward stress on the stents/stent grafts within the fenestrations of the proximal graft. This should make the likelihood of device migration less likely. The trade-off to this being the possibility of component separation between the proximal tube and the bifurcated second component, as demonstrated by O’Neill, et al. This is likely mitigated by routine generous overlap of at least 4 cm between the first two components of the composite endograft.
Additionally, the composite system including a fenestrated proximal tube provides easier deployment and target vessel revascularization, but often cannot be used in patients with previous open aortic reconstruction involving a bifurcated graft. Depending on the length of the main body of the graft, there can be a severely limited working distance between the visceral vessels and the graft bifurcation (neo-aortic bifurcation), especially in light of the usual practice of making a very short graft body above the neo-bifurcation during the primary open procedure (Fig 2, A). Due to this limited distance, a composite endograft cannot fit above the neo-bifurcation. Consequently, all patients in this series with existing fenestrated ABF grafts were preferentially managed with a fenestrated tube endograft (Fig 1, C).

If it is necessary to seal in the iliac vessels, and there is not enough distance from the visceral segment to the aortic bifurcation for a composite endograft, a fenestrated bifurcated endograft is used (Fig 1, B). This configuration is somewhat less desirable than a tube due to the difficulties associated with catheterization of the docking limb and limited maneuverability of the endograft during deployment. Maneuvering the endograft during attempts to catheterize branch vessels can facilitate catheter and sheath placement, but this manipulation risks twisting, kinking, or deformation. Fenestrated fenestrated endografts (ie, those without the proximal tube portion) are much more vulnerable to this during deployment, especially at the ipsilateral iliac limb.

With regard to arterial access, previous reconstruction using an ABF graft can present some degree of additional difficulty. Because of the possibility of damage to the ABF prosthesis, it is best to avoid direct puncture of the bypass limb. Additionally, direct access of the ABF limb and placement of a large introducer sheath is often poorly hemostatic, and may lead to a large amount of blood loss in prolonged procedures. Our current practice is to isolate a small segment of the ABF limb and sew a conduit onto the graft limb. After completion of the endovascular intervention, the conduit is cut such that a small portion of graft remains and is sewn closed at its end.

Regarding graft modifications for target vessel revascularization, fenestrations rather than proximal graft scallops have become our preference for renal artery revascularization. Only 2 patients in this series had a scallop used for revascularization of a renal vessel. One of these vessels was stented and the other was not. The non-stented vessel occluded 6 months after graft placement for unknown reasons, but was likely due to the unsupported scallop partially overlying the vessel orifice. Our current practice of relying on stented fenestrations rather than scallops for renal artery revascularization should prevent this problem. However, we have had 1 patient occlude both renal arteries, which were revascularized using Jomed stent grafts through fenestrations. Despite a lack of apparent technical issues at the time of the operation and follow-up imaging demonstrating the same, both arteries went on to occlude 8 months after the operation. As mentioned, imaging after the occlusions has unfortunately failed to reveal an etiology for the branch vessel thromboses, and casts some degree of doubt on the utility of follow-up CTA in these patients. However, in our larger series of branched endografts for primary juxtarenal aneurysms as well as thoraco-abdominal aneurysm patients, CTA has identified issues such as iliac limb kinking, component separation, and branch vessel stent graft kinking, leading to repeat intervention (data not published). Thus, we continue to use CTA routinely for follow-up evaluation of our patients.

Despite the technical challenges inherent in this patient population, our results demonstrate that patients with juxtarenal aneurysms can be managed using fenestrated endografts with a high degree of technical success, low morbidity, and mortality, as well as low reintervention rates. With the dissemination of this technology, these methods may, in fact, largely replace open repair in the management of these disease processes.

**AUTHOR CONTRIBUTIONS**

Conception and design: AB, WB, CZ, EV

Analysis and interpretation: AB, GV, CZ, IT, EV

Data collection: AB, WB, GV, IT, EV

Writing the article: AB, WB, GV, EV

Critical revision of the article: AB, WB, GV, CZ, IT, EV

Statistical analysis: AB, CZ

Obtained funding: EV

Overall responsibility: AB

**REFERENCES**


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