Branched endovascular stent–graft for suprarenal aortic aneurysm: the future of aortic stent-grafting?

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The use of a branched endovascular stent–graft to repair an aneurysm of the visceral aorta is described. The evolving role of branched endovascular stent–grafts in the management of aortic aneurysms is discussed, and the literature reviewed.

Description de l'utilisation d'une endoprothèse bifurquée pour réparer un anévrisme de l'aorte viscérale, discussion de l'évolution du rôle de l'endoprothèse bifurquée dans le traitement des anévrismes de l'aorte et présentation d'une recension des écrits.

The goal of endovascular repair of aortic aneurysms (AAs) is to prevent aortic rupture. This is achieved by excluding the dilated, aneurysmal segment of aorta from the systemic circulation and arterial pressures. An endograft (a graft that is internally or externally supported by metallic stents) is deployed within the aorta. To achieve complete aneurysm exclusion, the endograft must extend above and below the aneurysm, from nonaneurysmal aorta proximally to nonaneurysmal arterial wall distally. All instrumentation, endograft delivery and endograft deployment are carried out from within the arterial lumen under fluoroscopic guidance. The site of arterial access is usually through small incisions at sites remote from the lesion being treated, such as a femoral artery cutdown. This approach avoids large thoracic or abdominal incisions, or both. Most procedures can be performed under local or regional anesthesia.

The first report of such techniques for aneurysm treatment in humans was by Parodi and colleagues[1] in 1991. Since that time the techniques and materials used for endovascular procedures have developed rapidly, and the use of these techniques to treat AAs has become increasingly common. Given the less invasive and less traumatic nature of endovascular procedures compared with standard open surgical techniques, they have become an attractive alternative for many patients, particularly those who are elderly or considered to be at high risk due to multiple comorbid conditions.

One of the method's main restrictions is unsuitable aortic anatomy. Adequate proximal and distal landing zones for the endovascular stent–graft are required to securely exclude the aneurysm. Ideally, these should be at least 2 cm proximal and distal to the aneurysm, to create a circumferential seal above and below the aneurysm sac. However, if the aneurysm extends proximally to involve the renal or mesenteric arteries, the proximal landing zone for an endograft would have to be situated above these arteries to exclude the aneurysm, and would compromise perfusion to the viscera.

A branched endograft allows for secure exclusion of the aneurysm while maintaining vital perfusion to the renal and mesenteric arteries. It allows for treatment of aneurysms of the visceral aorta in a minimally invasive manner through small groin and arm incisions. The concept of branched endografts is novel, and the design, construction, delivery and deployment are complex. To our knowledge, this is the first case in

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Canada where a branched endovascular stent–graft was used to repair a suprarenal abdominal aortic aneurysm (AAA).

Case selection and preparation

A 79-year-old man with a 6.4-cm suprarenal AA was assessed for surgery (Fig. 1). The patient had multiple comorbid conditions, including previous open repair of an infrarenal AAA, an ileal conduit for bladder cancer, a large incisional hernia, obesity, obstructive sleep apnea, paroxysmal atrial fibrillation and chronic renal insufficiency with a single functioning right kidney (serum creatinine 220 μmol/L). The patient was not a candidate for standard open aneurysm repair. Conventional endovascular repair was not possible without covering the origins of the celiac, superior mesenteric (SMA) and both renal arteries. The patient was considered for treatment with a branched endovascular stent–graft. Before treatment, his case was reviewed and approved by the institutional Research Ethics Board.

The patient's left kidney was atrophic and nonfunctional, but the left renal artery was patent. One week before the stent–graft procedure, the left renal artery was coil embolized to prevent possible endoleak. To allow exclusion of the aneurysm while maintaining direct perfusion to the 3 remaining aortic visceral branches (celiac artery, SMA and right renal artery), a homemade branched endograft was designed and constructed (Fig. 2). The dimensions and positions of the 3 visceral side branches were determined from preoperative computed tomographic (CT) images and angiograms of the patient. The proximal diameter of the main aortic component was oversized by 15% relative to the native aorta. This component was then sterilized and loaded into a 22-French delivery sheath.

Case procedure

The procedure was performed under general anesthesia in the angiography suite. A cerebrospinal fluid drain was placed to reduce the risk of paraplegia. The patient was positioned supine with both arms abducted. Access was gained via the right brachial and bilateral femoral arteries. Both femoral arteries were exposed. After systemic heparinization (ACT 250–300 s), the delivery system for the proximal main body of the stent–graft was advanced over a guidewire through the left femoral artery into the supraceliac aorta.

After careful orientation under fluoroscopy, the main body of the stent–graft was deployed so that its branches were oriented adjacent to the origins of their respective visceral aortic branches. All 3 were located on the right anterior aspect of the aorta. By means of standard endovascular techniques, modular endograft components (Zenith, Cook, Blooming-

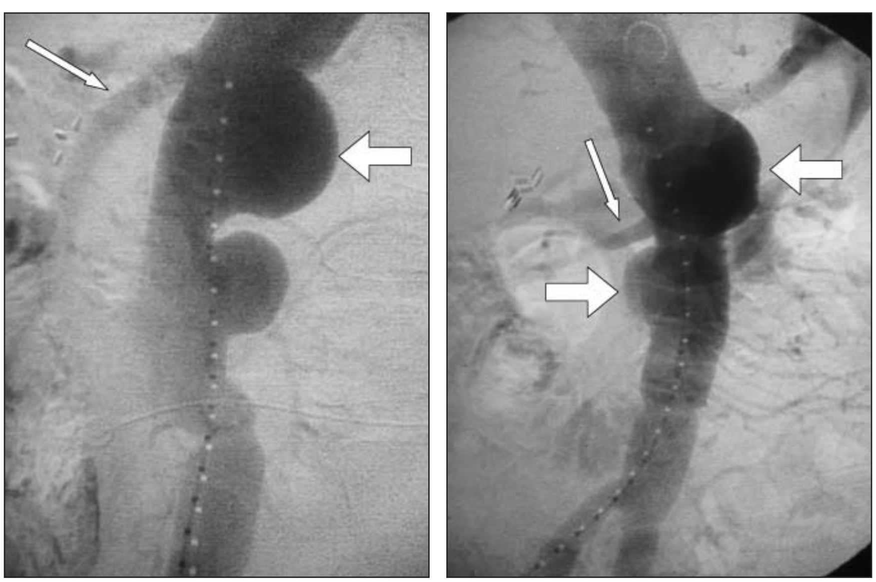

FIG. 1. Preoperative aortograms. A. Lateral view, showing the aortic aneurysm (large arrow) extending superiorly to the level of the patent superior mesenteric artery (small arrow). B. Anteroposterior view, demonstrating the components of the aortic aneurysm (large arrows) above and below a patent right-renal artery (small arrows).

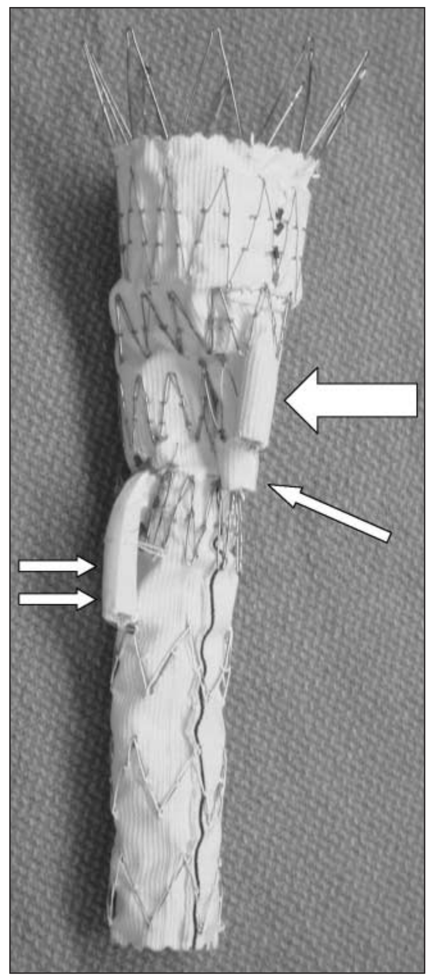

FIG. 2. Photograph of the homemade branched stent–graft prior to sterilization and packaging onto the delivery system. The branches to the celiac (large arrow), the superior mesenteric (small arrow) and right renal arteries (double arrows) were hand-sewn to the main body of the endograft.

ton, Ind.) were used to extend the endograft complex into the left common iliac artery. This directed blood flow from the proximal aorta to the left femoral artery. Flow to the right lower extremity was re-established via an open femoral–femoral crossover bypass graft. Retrograde flow of blood into the aneurysm sac from the right iliac artery was prevented by placing an iliac occluder (Zenith, Cook) into the right common iliac artery. Both groin incisions were then closed.

The right brachial artery was then exposed and used to access the renal and visceral branches from above. A catheter was advanced through the proximal end of the main body of the graft, out through the renal-artery side branch, into the aneurysm sac and then manipulated into the right renal artery. An 8-French delivery sheath was then advanced into the renal artery. Two balloon-expandable PTFE-covered stents (Jostent, Jomed, Rangendingen, Germany) were deployed to bridge the gap between the renal side branch of the endograft and the right renal artery (Fig. 3). By means of the same technique, 2 covered stents were used to connect the SMA to the endograft, and 1 was used for the celiac trunk (Fig. 4). A total of 11 modular components were assembled inside the aorta under fluoroscopic guidance.

During the procedure the patient received 80 mL of iodinated contrast and over 2 hours of fluoroscopy time. Despite a total operative time of 14 hours, the patient was never hypotensive or oliguric, and visceral artery flow was never interrupted for more than 30 seconds.

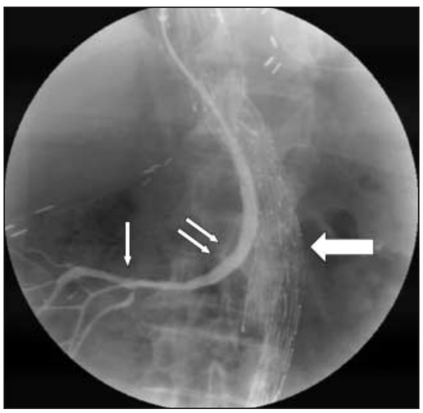

FIG. 3. Intraoperative angiogram demonstrating covered stents (double arrows) connecting the main body of the endograft (large arrow) to the right renal artery (small arrow).

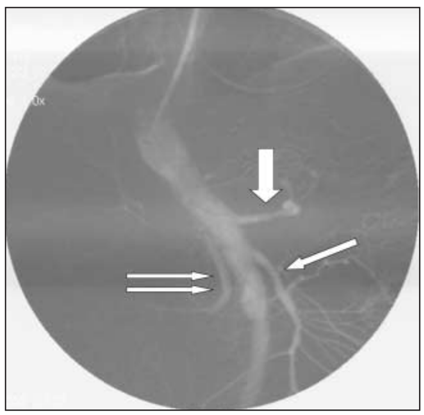

FIG. 4. Completion angiogram showing patent celiac (large arrow), superior mesenteric (small arrow) and renal arteries (double arrows), with no contrast filling in the excluded aneurysm sac.

Case results

The patient's postoperative course was complicated by acute tubular necrosis. Spontaneous recovery to baseline creatinine concentrations occurred in 2 weeks without any need for dialysis. Because the operation was lengthy, the patient developed left-arm paresis secondary to brachial-plexus traction injury (which resolved over 2 months) and a sacral decubitus ulcer that required minor debridement and vacuum-assisted dressings.

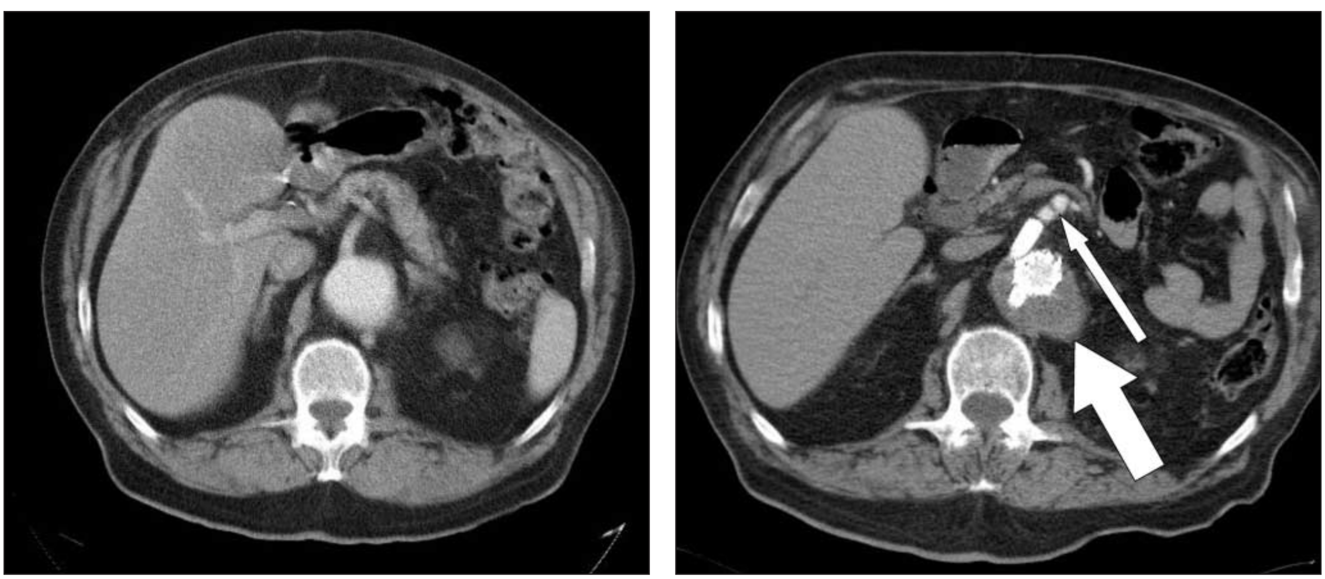

FIG. 5. Axial computed-tomographic images. A. Preoperative, at the level of the superior mesenteric artery. B. Postoperative, showing a patent superior mesenteric artery (small arrow) and no contrast filling in the thrombosed, excluded aneurysm sac (large arrow).

Postoperative CT showed successful exclusion of the aneurysm and patent visceral and renal branches (Fig. 5). At 8 months, the aneurysm sac had decreased in size, the visceral arteries remained patent and there was no endoleak (Fig. 6).

Discussion

An AA is defined as a localized dilation of the aorta having at least a 50% increase over the expected normal diameter.[2] The natural course of this lesion is progressive dilatation, with eventual rupture. The rate of progression and risk of rupture of AAs are associated with multiple factors, including aneurysm diameter, hypertension, chronic obstructive pulmonary disease, smoking, female gender and genetic predisposition.[3–5] However, rupture is still unpredictable, and when it does occur it can be catastrophic. Ruptured AAA is associated with an 80%–90% mortality rate.[6] Those who survive to arrival at hospital still face a significant morbidity and mortality rate. Thus, the goal is to repair aneurysms prophylactically, in a controlled, elective manner, before progression to rupture.

FIG. 6. Three-dimensional reconstruction by computed tomography of the 11-component branched endograft at 8 months postprocedure.

Standard repair of AAs by open surgical techniques requires general anesthesia and either a midline abdominal or a retroperitoneal incision. After obtaining proximal and distal vascular control with clamps, the aneurysm sac is opened and a synthetic interposition graft is anastomosed end-to-end to the healthy proximal neck of the aneurysm, and distally to either the aortic bifurcation or the more distal iliac or femoral arteries.

Open AA repair was first successfully accomplished in 1951.[7] Since that time, significant improvements in surgical technique, materials, anesthesia and postoperative care have decreased the morbidity and mortality of elective open repair to more acceptable rates.[8] However, there still exists a large number of patients for whom the risks of open aneurysm repair are high because of serious medical comorbidities.[9] As well, the risks of aneurysm repair increase significantly in patients whose aneurysms extend proximally above the renal arteries.[10–12]

High-risk patients are commonly denied open surgical repair because of the increased risk of morbidity and mortality. Endovascular repair offers exclusion of the aneurysm from the systemic circulation and systemic arterial pressures (thus reducing the risk of rupture) without the risks that accompany general anesthesia, laparotomy or aortic clamping.

The concept of endovascular repair is not new. Experimental endovascular procedures were described as early as 1969, when Dotter[13] successfully placed coilspring tube grafts into canine popliteal arteries. However, the first reported series of successful endovascular AA repairs in humans was in 1991 by Parodi and associates.[1] Since then, there have been enormous developments in techniques, materials and equipment. There are currently several types of commercially available endografts to treat infrarenal AAs. Typically packaged onto 18–24 French (6–8 mm diameter) delivery systems, they are composed of balloon-expandable or self-expanding metallic stents covered by thin vascular graft material.

One of the limitations to endovascular repair of AAs is the anatomy of the proximal neck. To securely exclude the aneurysm sac from the systemic circulation, an adequate segment is needed of graft-to-artery wall apposition circumferentially, both proximal and distal to the aneurysm. Of the 50%–70% of patients turned down for endovascular AAA repair, up to 65% are rejected because their proximal-neck anatomy is unsuitable.[14] When an aneurysm is too close to the origins of the visceral aortic branches, it may be impossible to securely exclude the aneurysmal aortic segment without occluding the origins of these visceral arteries.

For aneurysms that approach but do not involve the renal or visceral arteries, a number of solutions have been developed and utilized. One is the use of uncovered, bare-wire extensions above the endograft fabric, to extend the landing zone above the renal arteries without covering the arterial orifices with the fabric portion of the endograft.[15–19]

A more sophisticated approach has been the development of fenestrated stent–grafts. This involves homemade fenestrations or holes in the fabric that are positioned adjacent to the branch artery orifices. These fenestraions can be fixed in position by deploying smaller uncovered stents through the fenestrations and into the arterial branches.[20–22] But if the segment of aorta from which the renal or mesenteric branches arise is aneurysmal, fenestrated endografts would not be effective.

In this report we describe the use of a branched endovascular stent–

graft to treat a patient with an aneurysm of the visceral aorta, in whom the visceral aortic branches originated directly from the aneurysm. With this technique, we were able to achieve aneurysm exclusion and maintain visceral artery perfusion through the side branches of the endograft. Interruption of perfusion to the mesenteric and renal arteries throughout the operation was minimal. Access to the arterial circulation was gained by means of 2 small surgical incisions in the groins and 1 small incision in the right arm.

The technique is not straightforward. The equipment and materials used required customized design based on CT imaging and angiograms, and homemade modification of commercially available materials.

The complexity of the technique is reflected in the small number of reports published on the use of branched endografts. Most early reports of branched endovascular stent–grafts describe branched endograft placement in the thoracic aorta. In 1996, Inoue and colleagues[23] described the use of a single-branched endograft to repair a type B thoracic aortic dissection. The side-arm branch of the main endograft was directed into the left subclavian artery by percutaneously passing a snare retrograde through the left subclavian artery from a brachial-artery access site, and pulling the branch into the subclavian artery orifice. Inoue and coauthors[24] later reported a series of 15 cases of branched endografts (including 1 triple-branched graft) used to repair the thoracic aortic arch.

The visceral aorta presents a unique challenge compared with the aortic arch. The snare technique cannot be used and one must push, rather than pull, the side-arm branch into the renal or mesenteric orifice. Inoue's group[25] used a "push" technique to place a side-branch into the celiac artery during endovascular repair of a descending thoracic aortic pseudoaneurysm.

In 2001, Chuter and coauthors[26,27] described using a modular stent–graft to create a quadruple-branched endograft for repair of a ruptured supraceliac aneurysm. In the same year, Hosokawa and associates described 2 cases of endovascular repair using homemade triple-branched Inoue endografts for pararenal AAs.[28] In December 2002, Bleyn and coworkers[29] also used a modular approach with a single side-branch that was positioned in the celiac artery.

The use of branched endovascular stent–grafts is not standard therapy. The procedure is in its developmental stage and is technically very challenging. In the case we describe herein, multiple endovascular modular components were required and assembled under fluoroscopic guidance in order to gain complete aneurysm exclusion. This case took 14 hours under general anesthesia and over 2 hours of fluoroscopy time. This was largely due to prolonged efforts to obtain secure cannulation of the mesenteric branches. The nondilated distal thoracic aorta angulated to the left above the celiac artery. Catheters inserted from above were directed along the axis of the aorta and stent–graft, away from the celiac artery and the SMA. As a result, complex catheter forms were required for celiac and SMA catheterization. As well, the large empty aneurysm sac made visceral-artery catheterization difficult.

Despite the long operative time required to complete the procedure, aortic and visceral blood flow were never interrupted for more than a few seconds at any time. Thus the hemodynamic stress and organ ischemia that are typical of open suprarenal AA surgery were not clinical issues in this case. Although the long-term durability of aneurysm exclusion with this type of graft is unknown, if this type of procedure could be refined and the techniques simplified, branched endovascular stent–grafts could be an alternative option for high-risk surgical patients.

To improve the procedure, advances are needed in the preoperative imaging, procedural technique and equipment. As improved CT imaging becomes available, the design and customized production of the branched endografts will become easier and more accurate. With the aid of simulators, models and animal experiments, new techniques and strategies can be evaluated and perfected. This could decrease the length of the procedure and the amount of fluoroscopy time needed, and potentially improve the safety of the technique.

Conclusion

The design, construction, delivery and deployment of branched endovascular stent–grafts for suprarenal aortic aneurysms is technically feasible. With considerable improvements and refinements in the techniques and materials, branched endografts could be offered as an alternative to open surgery for the treatment of aneurysms of the visceral aorta.

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Competing interests: Dr. Chuter receives income from patent licensing agreements with William Cook, Inc. and Guidant Corp. In addition, Dr. Chuter served as a paid consultant for Guidant Corp. and William Cook, Inc.

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