Fenestrated Stent Graft Repair for Complex Aneurysms

How to improve outcomes with optimal device design, planning, and techniques using the Zenith Fenestrated stent graft system.

BY GUSTAVO S. ODERICH, MD

Endovascular aortic aneurysm repair has been shown to reduce blood loss, operative time, hospital stay, mortality, and morbidity compared to open surgical repair of infrarenal abdominal aortic aneurysms.[1-3] Inadequate proximal necks limit the use of endovascular approaches in up to 40% of patients because of short length, angulation, or involvement of the visceral arteries.[4] In these patients, stent grafts designed with fenestrations and/or scallops provide a means to incorporate segments of the visceral arteries into the proximal sealing zone.[5-7] Single-center reports, multicenter registries, and systematic reviews indicate that the technique is reproducible, with rates of high technical success, low morbidity, and low mortality.[5,8-13]

The Zenith Fenestrated stent graft system (Cook Medical, Bloomington, IN) has been implanted in more than 5,500 patients worldwide to treat complex aortic aneurysms (A. Smith, personal communication, April 2013). The preliminary results of the United States prospective multicenter trial have shown no aneurysm-related mortalities, low morbidity, and no ruptures, conversions, or type I or III endoleaks at the attachment sites, although there has been one case of device migration.[14] The device was approved by the US Food and Drug Administration for commercial use in April 2012. This article summarizes concepts of device design, case planning, and techniques of implantation using the Zenith Fenestrated stent graft system.

DEVICE DESCRIPTION

The Zenith Fenestrated stent graft has been approved to treat patients with short-necked abdominal aortic aneurysms that are ≥ 4 mm in length and those who do not meet the proposed anatomical criteria for the use of infrarenal stent grafts. The device consists of a proximal fenestrated component, a distal bifurcated component, and a contralateral iliac limb extension (Figure 1). The fenestrated tubular component is custom-made to fit the patient's anatomy with up to three fenestrations, of which, two can be of the same type. There are three types of fenestrations that can be manufactured in the fenestrated component, including small, large, and scallop fenestrations (Figure 1). Small fenestrations have dimensions of 6 X 6 mm or 6 X 8 mm, do not have struts crossing the middle of the fenestration, and are reinforced by a nitinol ring. Small fenestrations can be fashioned > 15 mm and < 36 mm (for 24- to 32-mm devices) or < 46 mm (for 34- to 36-mm devices) from the edge of the fabric. Large fenestrations are not reinforced by a nitinol ring, measure 8 to 12 mm in diameter, and can be fashioned > 10 mm from the edge of the fabric. Large

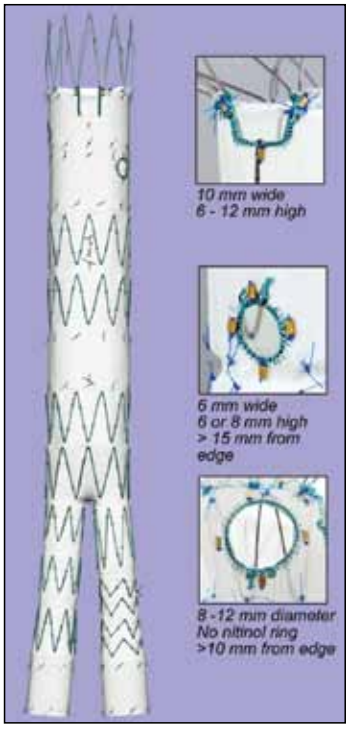

Figure 1. Configuration of the Zenith Fenestrated stent graft system with a proximal fenestrated component, distal bifurcated universal component, and contralateral iliac limb extension. The fenestrated component is custom-made with a maximum of three fenestrations, including scallop, large, or small fenestrations.

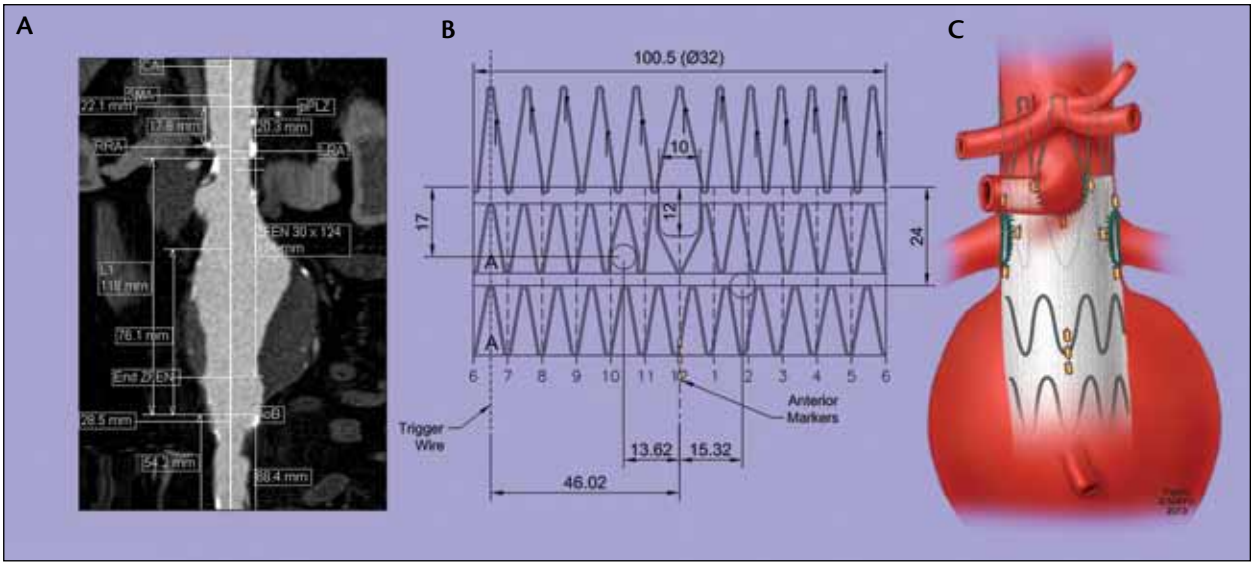

Figure 2. Digital computed tomography angiography with centerline-of-flow analysis (A) is used for measurements. The most common device design in 70% of patients includes two small fenestrations and a scallop (as depicted in B and C).

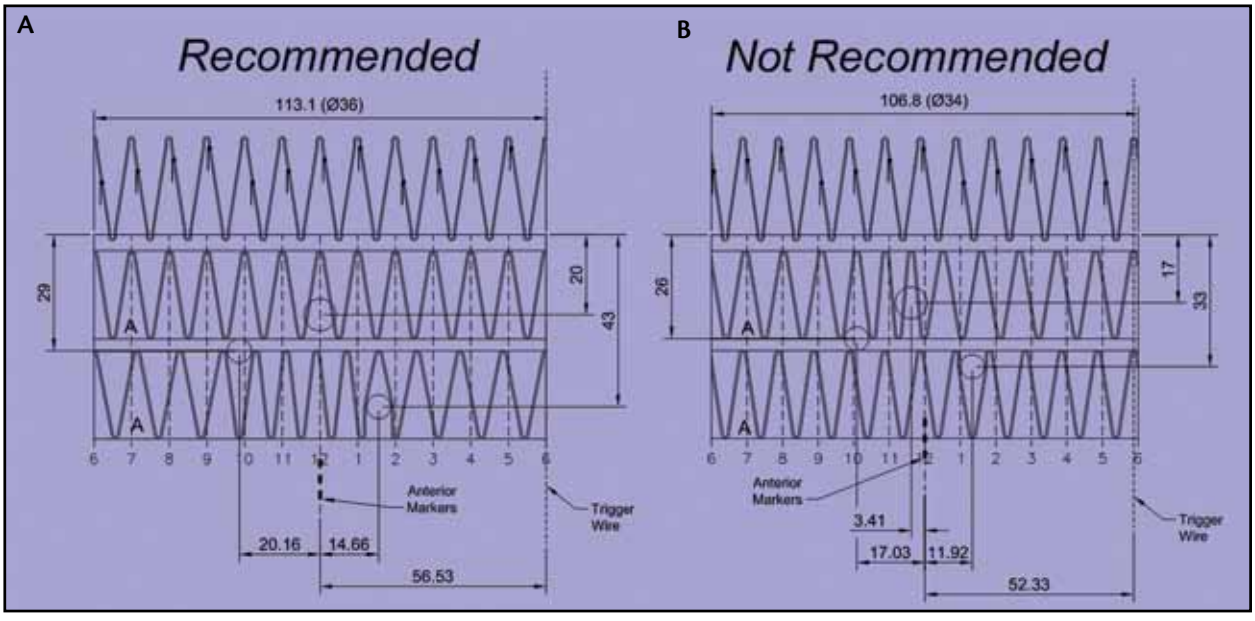

Figure 3. Large fenestrations have struts at the edge (A) or middle of the fenestrations (B). A design with struts at the middle of the fenestration (B) is not recommended, whereas large fenestrations with no struts or minimal struts at the edge of the fenestration are preferable by allowing placement of alignment stents.

fenestrations have struts crossing at the edge or middle of the fenestration, which limit the ability to place alignment stents. Scallops are openings in the upper edge of the fabric that are 10 X 6 to 12 mm.

DESIGN AND PLANNING

Device design and planning are based on careful analysis of aneurysm morphology using high-resolution CT angiography (CTA) datasets. CTA with small (1–3 mm) cuts is recommended for optimal imaging, allowing review with three-dimensional reformatting techniques, maximum-intensity projection, and volume rendering. The design is based on analysis of centerline-of-flow measurements to determine accurate estimates of lengths, axial clock position, arc lengths and angles (Figure 2).

Device planning starts with selection of the proximal landing zone based on "healthy" aortic anatomy. A normal aorta should have parallel walls with an outer-to-outer diameter of ≥ 19 and ≤ 31 mm and no calcium or thrombus. The portion of the aorta selected as a landing zone should not be larger than the aorta proximal to the fixation site. Although a proximal landing zone > 15 mm is

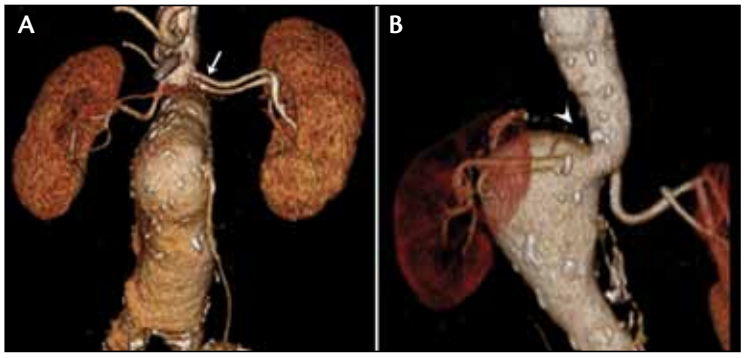

Figure 4. Common anatomical reasons limiting the application of fenestrated endografts include inadequate renal anatomy from early bifurcation or multiple, small accessory renal arteries (A) and severe angulation in the visceral segment of the aorta (B).

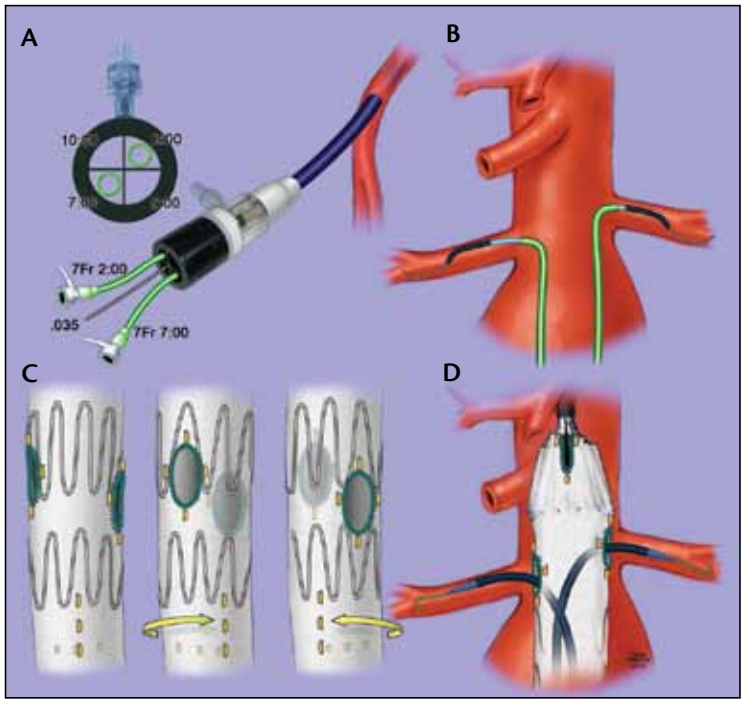

Figure 5. Multisheath femoral access is achieved using a 20- to 22-F Check-Flo sheath (Cook Medical). The sheath valve is punctured to allow placement of multiple small (5–7 F) sheaths (A). Catheters and guide catheters are used for selective catheterization of the target arteries before deployment of the device (B). The device is oriented extracorporeally by fluoroscopic visualization of the anterior and posterior radiopaque markers (C). After the device is oriented and deployed, the catheters are sequentially removed from each vessel and used to regain access into the main fenestrated component, fenestration, and target artery (D).

considered acceptable according to the instructions for use, I recommend a minimal length of 20 mm, similar to what is needed in the thoracic aorta. The most common design used in 66.7% of patients in the US multicenter pivotal trial includes two small fenestrations for the renal arteries and a scallop for the superior mesenteric artery.[14] Scallop fenestrations are rarely utilized for renal arteries.

When selecting large fenestrations, it is useful to review the design outline provided by the manufacturer (Figure 3). I recommend using large fenestrations only if the stent struts are located at the edge of the fenestration; fenestrations with struts crossing in the middle cannot be aligned by a stent, and higher rates of vessel occlusion have been reported in these cases.[15] Anatomical factors limiting the use of the Zenith Fenestrated stent graft system include proximal aneurysm extension requiring more than three fenestrations, excessive angulation at the visceral segment, or inadequate renal artery anatomy due to multiple small accessory renal arteries or early renal artery bifurcation (Figure 4).

ANCILLARY TOOLS

The implantation of fenestrated stent grafts requires advanced endovascular skills and a comprehensive inventory with a wide range of catheters, balloons, and stents (Table 1). These procedures should be performed by physicians with extensive experience with endovascular treatment of complex aortic anatomy and visceral artery disease. Most importantly, dedicated training in fenestrated and branched techniques is highly recommended, even for physicians who are already very experienced with other types of endovascular procedures. One of the basic tenets of the technique, which cannot be overemphasized, is a clear understanding of proximal neck selection combined with the techniques of branch catheterization and "bailout" maneuvers to deal with intraprocedural complications, if they occur.

PERIOPERATIVE MEASURES

Some of the perioperative measures, as later proposed in this article, should be considered during the learning phase and may not be necessary once an operator gains more experience with these procedures. Preadmission for bowel preparation and intravenous hydration with bicarbonate infusion and oral acetylcysteine minimizes the risk of renal function deterioration. These procedures should be performed in a hybrid endovascular suite with a fixed imaging unit. The type of anesthesia used varies with the institution, but our preference has been general endotracheal anesthesia. Intraoperative blood salvage is highly recommended at the beginning of one's experience for difficult cases and thoracoabdominal repair (more than three vessels); a useful tip is

TABLE 1. LIST OF ANCILLARY TOOLS RECOMMENDED FOR PHYSICIANS PERFORMING FENESTRATED STENT GRAFT PROCEDURES

Category	Manufacturer	Application
Sheaths		
Check-Flo sheath 20–24 F (30 cm)	Cook Medical	Femoral access for multivessel catheterization
Ansel sheath 7 F (55 cm, flexible dilator)	Cook Medical	Femoral access for branch artery stenting
Raabe sheath 7 or 8 F (90 cm long)	Cook Medical	Brachial access for branch artery stenting
Ansel sheath 12 F (55 cm, flexible dilator)	Cook Medical	Brachial access for tortuous aortic arch to facilitate branch artery stenting
Shuttle 5 F (90 cm)	Cook Medical	Branch artery access during difficult arch
Catheters		
Kumpe catheter 5 F (65 cm)	Multiple	Selective vessel catheterization
Kumpe catheter 5 F (100 cm)	Multiple	Selective vessel catheterization
C1 catheter 5 F (100 cm)	Multiple	Selective vessel catheterization
MPA catheter 5 F (125 cm)	Multiple	Selective vessel catheterization
MPB catheter 5 F (100 cm)	Multiple	Selective vessel catheterization
Van Schie 3 catheter 5 F (65 cm)	Cook Medical	Selective vessel catheterization
Vertebral catheter 4 F (125 cm)	Multiple	Selective vessel catheterization
VS1 catheter 5 F (80 cm)	Multiple	Selective vessel catheterization
Simmons I catheter 5 F (100 cm)	Multiple	Selective vessel catheterization
Diagnostic flush catheter 5 F (100 cm)	Multiple	Diagnostic angiography
Diagnostic pigtail catheter 5 F (100 cm)	Multiple	Diagnostic angiography, selective vessel catheterization
Quick-Cross catheter 0.014–0.035 inch (150 cm)	Spectranetics Corporation	Selective vessel catheterization
Renegade catheter (150 cm)	Boston Scientific Corporation	Selective vessel catheterization
Guide Catheters		
LIMA guide 7 F (55 cm)	Cordis Corporation	Precatheterization
Internal mammary guide 7 F (100 cm)	Multiple	Selective vessel catheterization
MPA guide 7 F (100 cm)	Multiple	Selective vessel catheterization
Balloons		
10-mm X 2-cm angioplasty balloon	Multiple	Proximal stent flare
12-mm X 2-cm angioplasty balloon	Multiple	Proximal stent flare
5-mm X 2-cm angioplasty balloon	Multiple	Advance sheath over balloon
Wires		
Benson wire 0.035 inch (150 cm)	Multiple	Initial access
Soft Glidewire 0.035 inch (260 cm)	Terumo Interventional Systems	Target vessel catheterization
Stiff Glidewire 0.035 inch (260 cm)	Terumo Interventional Systems	Target vessel catheterization
Rosen wire 0.035 inch (260 cm)	Multiple	Branch artery stenting
1-cm tip Amplatzer wire 0.035 inch (260 cm)	Multiple	Branch artery stenting
Lunderquist wire 0.035 inch (260 cm)	Multiple	Aortic stent graft
Glidewire Gold 0.018 inch (180 cm)	Terumo Interventional Systems	Target vessel catheterization
Stents		
iCast stent grafts 5–10 mm	Atrium Medical Corporation	Branch artery stenting
Balloon-expandable stents 0.035 inch	Multiple	Branch artery stenting or reinforcement
Self-expandable stents 0.035 inch	Multiple	Distal branch artery stenting
Self-expandable stents 0.014 inch	Multiple	Distal branch artery stenting

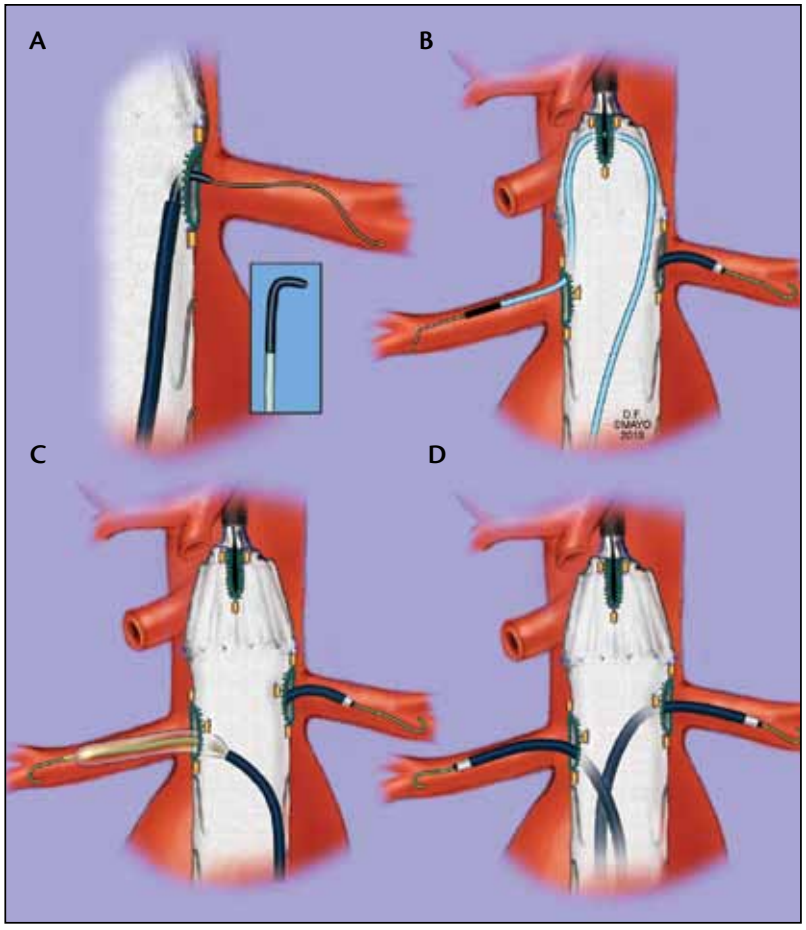

Figure 6. Selective catheterization of the target vessels is the most critical step of the procedure. In most cases, this is done without difficulty. If there is misalignment, occlusive disease or tortuous vessels, several maneuvers can be used to secure access and to advance the sheath. Placement of a 7-F sheath with a 0.018-inch guidewire (A) through the fenestration allows use of a 5-F "buddy catheter" (A, inset) for manipulations to locate the renal artery while the guidewire maintains the sheath in close proximity to the fenestration. For down-going renal arteries, the catheter and Glidewire are allowed to bounce up toward the top cap (B), providing enough support for the catheter to be advanced into the renal artery. If the sheath and dilator cannot be advanced over the guidewire, a useful maneuver is to use an undersized angioplasty balloon as a dilator (C), while the sheath is advanced over the inflated balloon. Finally, once the sheath is advanced, the alignment stents are positioned under protection of the sheath (D).

to create large pockets in the surgical drape, allowing the blood to be collected with cell saver. The use of iodinated contrast should be minimized during all steps of the procedure. Conventional angiography using the power injector should be avoided during the implantation phase, and completion angiography should be performed using a diluted contrast agent (iodixanol with normal saline in a 50:50 ratio). For selective angiography, hand injections of a small volume of diluted contrast (3 mL of contrast with 7 mL of saline) are sufficient to visualize the anatomy. I use precatheterization and/or on-lay CTA prior to deployment of the fenestrated component; in experienced hands, this step requires minimal manipulation and can be accomplished in a short time. Most recently, this has been replaced by fusion imaging using on-lay CTA. Iliac conduits are recommended in patients with small or narrowed iliac arteries.

My preference is to use a totally percutaneous technique with a double Perclose device (Abbott Vascular, Santa Clara, CA) whenever possible, provided that the patient has suitable femoral arteries and no excessive calcification. Intravenous heparinization is administered immediately after femoral access. A target activated clotting time > 300 seconds should be maintained throughout the procedure, with frequent rechecks every 30 minutes and repeated doses of heparin as needed. Diuresis is induced prior to deployment of the fenestrated component with mannitol and/or furosemide.

DEVICE IMPLANTATION

The procedure is performed using a bilateral femoral approach. The left brachial approach is typically not needed for juxtarenal aortic aneurysms unless there is difficulty with catheterization. For right-handed operators, the branches and fenestrations are accessed using the right femoral approach, whereas the fenestrated and bifurcated components are introduced via the left side. The procedure can be summarized in 10 critical steps:

Step 1: Multisheath Femoral Access

Bilateral percutaneous femoral access is established under ultrasound guidance. Each femoral puncture is preclosed using two Perclose devices oriented medially and laterally. Next, 8-F sheaths are introduced to the external iliac arteries over Benson guidewires (Cook Medical). These are exchanged to 0.035-inch soft Glidewires and Kumpe catheters, which are advanced to the ascending aorta. The Glidewires are exchanged for 0.035-inch (260 cm in length) Lunderquist guidewires (Cook Medical). Multisheath access is achieved in the right femoral artery using a 20- or 22-F Check-Flo sheath for two or three fenestrations, respectively. The valve of the Check-Flo sheath has four leaflets, which are accessed by two short 7-F sheaths at 2- and 7-o'clock positions (Figure 5A).

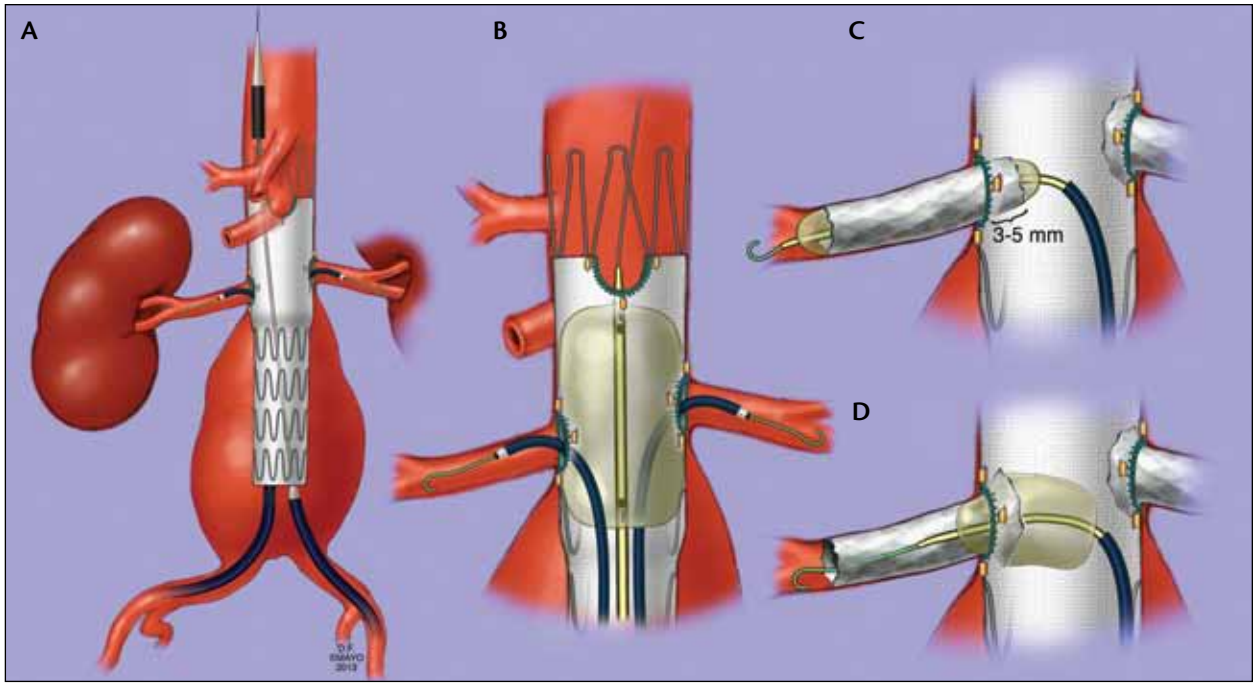

Figure 7. The diameter-reducing tie is removed after all sheaths and side stents are positioned, allowing deployment of the top cap and device (A). After the top cap is retrieved, the proximal sealing stents are gently dilated (B). Sequential stenting is performed by deployment of the alignment stents with 3 to 5 mm into the aortic lumen (C) followed by flaring of the proximal portion of the stent using a 10-mm angioplasty balloon (D).

Step 2: Precatheterization of Target Vessels

Precatheterization or use of on-lay CTA is recommended. This step avoids multiple angiographies during deployment of the device. Typically, a 5-F Kumpe or C1 catheter (Cook Medical), supported by a 7-F LIMA guide catheter, is advanced over 0.035-inch, soft, angled Glidewires (Terumo Interventional Systems, Inc., Somerset, NJ) into the renal arteries (Figure 5B). Access into the renal arteries is confirmed by hand injection. It is useful to acquire anterolateral and oblique views of the catheters (without contrast injection), which can later be "faded" to facilitate branch catheterization.

Step 3: Device Orientation and Deployment

Once the target vessels are catheterized, the fenestrated component is oriented extracorporeally (Figure 5C), introduced via the left femoral approach, and deployed with perfect apposition between the fenestrations and the target catheters. Prior to deployment, it is critical to ensure proper orientation of the device using the anterior and posterior gold markers. Typically, the first two or three stents are deployed, confirming alignment between the catheters and each respective fenestration. The device should be deployed slightly higher than what is anticipated, with the catheters matching the lowest of the four radiopaque markers in the fenestration. The diameter-reducing tie constricts the expansion of the fenestrated component and allows some rotational and craniocaudal movement of the main stent graft to optimize alignment.

Step 4: Fenestration and Target Vessel Catheterization and Sheath Advancement

This is the most critical step of the procedure. Each selective catheter is sequentially removed from the target artery and used to regain access into the fenestrated component, fenestration, and target vessel. Some advocate advancing the Check-Flo sheath into the fenestrated component, but my preference is to avoid this maneuver and instead use sequential catheterization (Figure 5D). The renal arteries are typically catheterized using the same catheter or guide catheter that was used for precatheterization. Although in most cases the target vessel is accessed without difficulty, several maneuvers can be used if there is misalignment. Initially, the catheter and guidewire are rotated to "probe" the aortic wall in search of the vessel. To avoid losing access into the fenestration during this maneuver, it is useful to secure access into the fenestration by advancing the 0.035-inch guidewire and catheter out of the fenestration and into the thoracic aorta followed by a 7-F Ansel sheath (Cook Medical) through the fenestration (Figure 6).

The guidewire is then exchanged for a 0.018-inch guidewire, and the sheath is repositioned at the level of the fenestration; the 0.018-inch guidewire allows the sheath to stay close to the fenestration while a 5-F "buddy" catheter (eg, Van Schie 3 [Cook Medical]) is used to locate the renal artery (Figure 6A). It may be difficult to advance the catheter over a soft Glidewire if

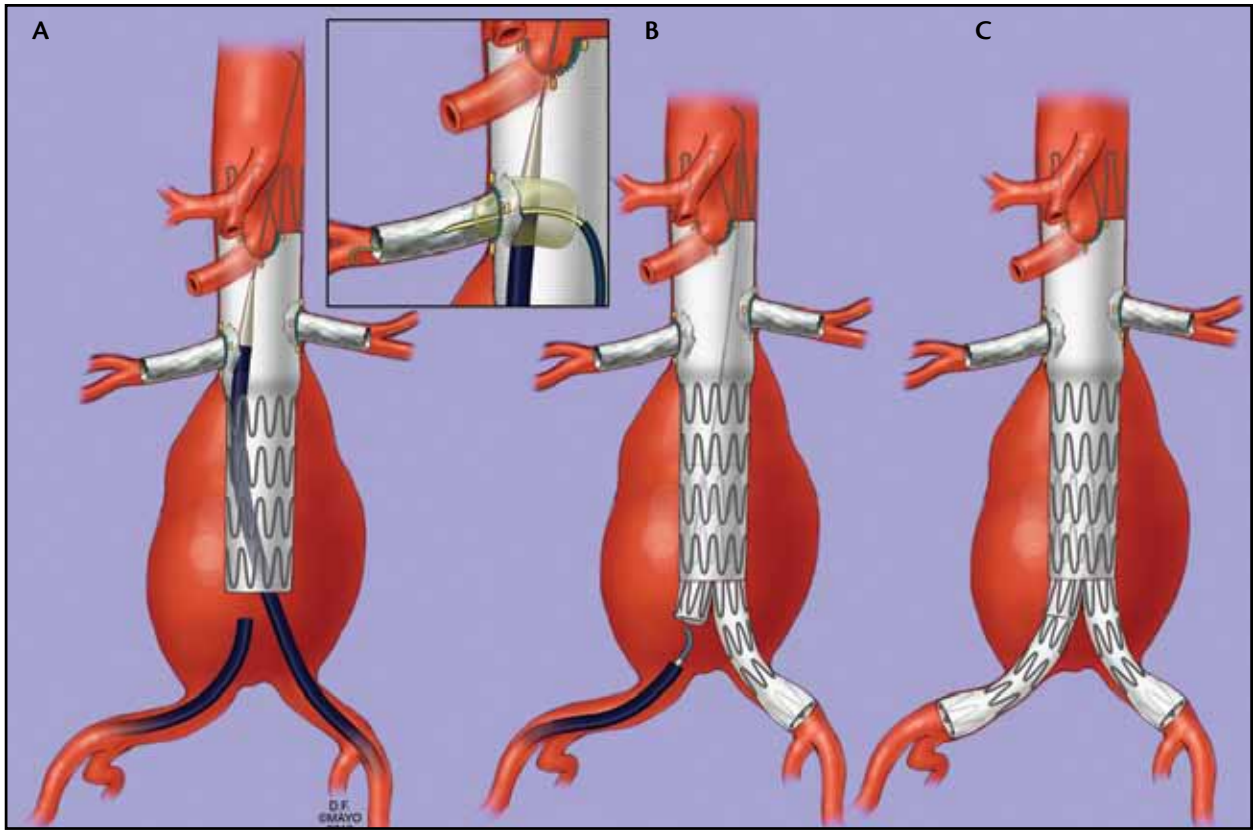

Figure 8. The universal bifurcated component is deployed after placement of the alignment stents. In some cases, the dilator of the bifurcated component encroaches one of the renal stents, usually the contralateral side (A). It is useful to leave a balloon positioned in the renal stent. This can be inflated during movement of the dilator across the renal stent (A, inset). The bifurcated component is deployed with at least two stents overlapped to minimize the risk of component separation (B). Access to the contralateral gate is established followed by placement of the iliac limb extension (C).

the artery is down-going, tortuous, or diseased. In these cases, the catheter and Glidewire bounce up into the top cap (Figure 6B), allowing a Kumpe or Quick-Cross catheter (Spectranetics Corporation, Colorado Springs, CO) to be advanced deep into the renal artery.

After the renal artery is catheterized, the soft Glidewire is removed, and hand injection is used to confirm that the renal artery branch is of adequate diameter to accept a 0.035-inch Rosen wire (Cook Medical). The choice of the interventional guidewire varies, but my preference is for a Rosen wire, which is less traumatic and has a J tip. If more support is needed, an Amplatz guidewire (Cook Medical) with a 1-cm soft tip can be used, but this guidewire is more prone to cause dissections and perforations. After a stiff guidewire is positioned, a 7-F Ansel sheath with flexible dilator is advanced into the renal artery. If the sheath cannot be advanced, an undersized balloon may be used as a dilator to facilitate advancement (Figure 6C). The alignment stent is advanced under protection of the sheath, with the tip of the stent just beyond the tip of the sheath to serve as a dilator during the next step of the procedure (Figure 6D).

Step 5: Deployment and Retrieval of the Top Cap

The diameter-reducing tie is removed after the target arteries are accessed by 7-F hydrophilic sheaths and the alignment stents are in position. The top cap is advanced forward, allowing deployment of the uncovered fixation stent (Figure 7A). This is followed by retrieval of the top cap, which should be done before placing the renal alignment stents to prevent damage during retrieval of the top cap. One should note that the dilator of the device often encroaches the contralateral renal stent.

Step 6: Proximal Neck Balloon Dilatation

After the top cap and dilator are retrieved, the proximal neck is gently dilated using a compliable balloon such as the Coda balloon (Cook Medical). It is critical that this is performed prior to placement of the alignment stents, or alternatively, each stent has to be protected by separate balloons (Figure 7B).

Step 7: Target Vessel Stenting

Target vessel stenting is only performed after removal of the diameter-reducing tie and retrieval of the top cap and neck dilatation balloon. All small fenestrations should

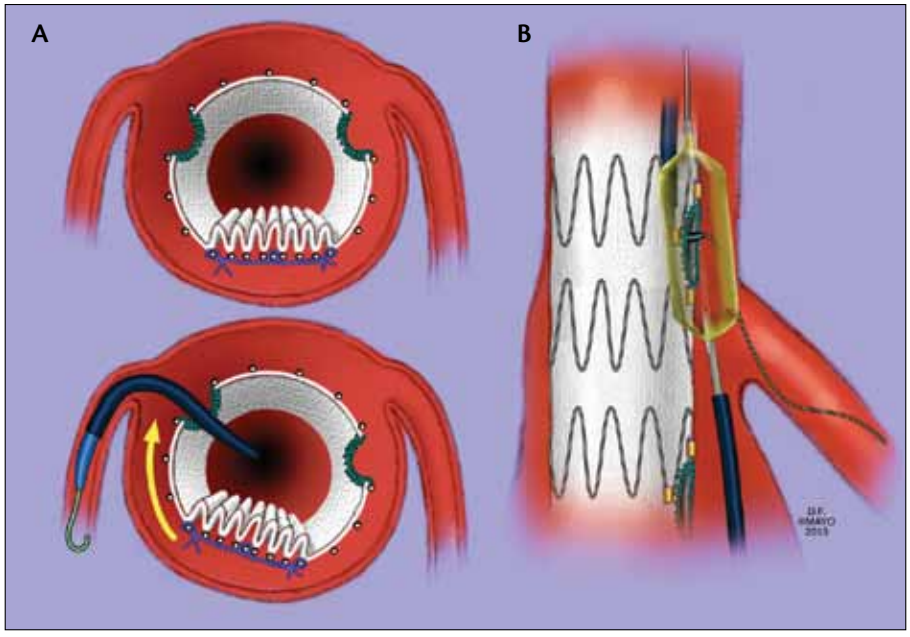

Figure 9. Misaligned fenestrations are infrequent but can increase technical difficulty. Because the device is constrained in the posterior aspect, the fenestrations may be facing posterior (A). Gentle rotation of the device and fenestration anterior may be sufficient to allow catheterization of the target vessel. Less frequently, in cases of severe misalignment, a balloon can be inflated between the aorta and stent graft to create space for catheter manipulations (B).

be aligned by stents, starting with the renal arteries. Prior to stent deployment, positioning is confirmed by hand injection. The stent should be deployed 3 to 5 mm into the aorta (Figure 7C) and flared using a 10-mm X 2-cm balloon (Figure 7D). Selective hand-injection angiography is performed after administration of 100 to 200 µg of nitroglycerin to minimize spasm. In general, short stents (15–22 mm) are preferred to minimize kinks. A short, self-expandable stent may be needed distal to the alignment stent if there is kinking on angiography. A kink can often be anticipated based on review of preoperative CTA.

The approval for the Zenith Fenestrated device also included approval for the Zenith Alignment stent, a bare-metal balloon-expandable stent. However, superior patency has been reported with the use of covered stents compared to bare-metal stents.[16] This is likely due to the polytetrafluoroethylene coverage, which prevents intimal growth through the struts of the stent. With bare-metal stents, intimal hyperplasia occurs predominantly in the proximal portion of the stent, likely from damage to the intima and media due to flaring of the proximal aspect of the stent.[17] Therefore, for alignment of fenestrations, my preference is to use a covered stent (iCast, Atrium Medical Corporation, Hudson, NH).

The use of alignment stents for large fenestrations and scallops remains controversial among clinicians. I favor stenting all large fenestrations, when possible, and most 10-mm scallops. For large fenestrations, I only accept the design if the stent struts are minimally present at the edge of the fenestration (Figure 3). Large fenestrations are aligned by a covered stent and reinforced by another bare-metal stent to improve radial force and prevent lateral compression of the alignment stent. For scallop fenestrations, I recommend a low threshold for using alignment stents.

Step 8: The Distal Bifurcated Component

Limited iliac angiography demonstrates the location of the internal iliac artery. The bifurcated component is advanced, positioned, and deployed with preservation of the ipsilateral internal iliac artery. If the dilator of the bifurcated device encroaches on the contralateral renal stent, it is useful to have a 10-mm balloon ready to be inflated in the renal stent to protect it from any damage (Figure 8A and inset). The recommended overlap between the bifurcated and the fenestrated component is more than two full-length stents in order to minimize the risk of component separation (Figure 8B).[17] After deployment of the bifurcated device, the dilator is removed with attention to avoid damage to the renal stents.

Step 9: Gate Catheterization and Contralateral Iliac Extension

The contralateral gate is catheterized, and access to the main bifurcated and fenestrated component is confirmed by a 360° catheter rotation (Figure 8B). A 0.035-inch Lunderquist guidewire is advanced, followed by oblique iliac angiography using hand injection of a small volume of contrast via one of the renal sheaths to determine the location of the internal iliac artery. The contralateral limb extension is deployed with preservation of the internal iliac artery (Figure 8C).

Step 10: Balloon Dilatation of Attachment Sites and Distal Landing Zones

The procedure is completed by balloon dilatation of the attachment sites between the fenestrated and bifurcated components and the iliac limb extensions. Completion angiography (typically the only power injection performed during the case) should demonstrate

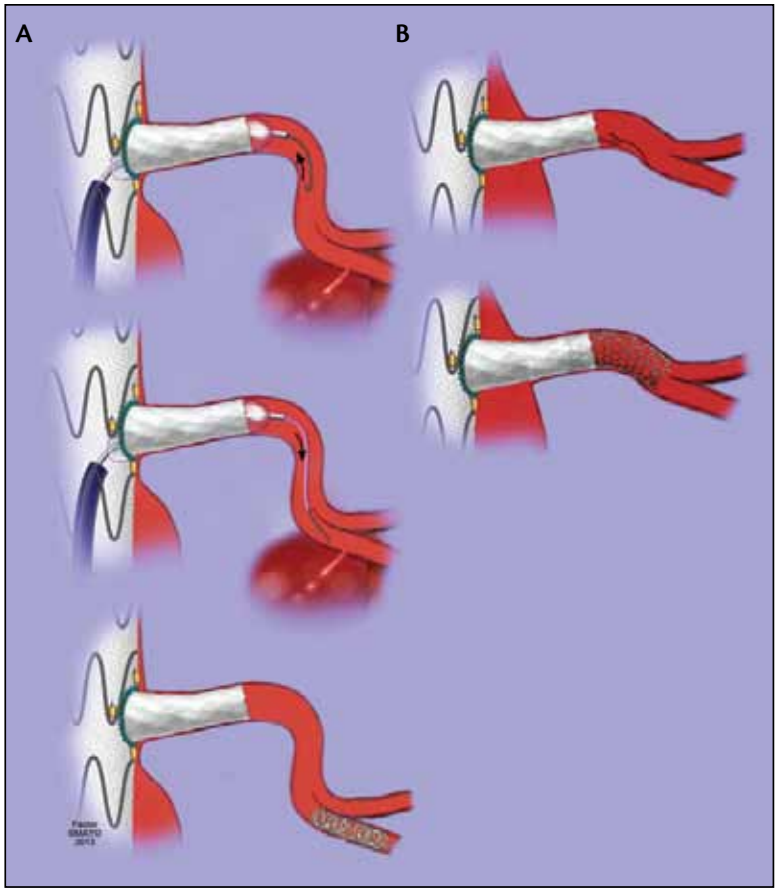

Figure 10. Branch perforations are infrequent and should be avoided by meticulous technique, attention to detail and visualization of the tip of the guidewire. In the unfortunate event of a perforation (A), the balloon can be inflated in the stent while the guidewire is removed, and angiography is performed through the shaft of the balloon. A 3-F microcatheter can be introduced via the inflated balloon and advanced into the perforated branch, which should be immediately embolized. A dissection (B) may be treated by placement of a short-length self-expandable stent.

patency of the visceral arteries, main body, iliac limbs, and iliac arteries.

DEALING WITH INTRAPROCEDURAL COMPLICATIONS

Misalignment of Fenestrations

The Zenith Fenestrated stent graft undergoes extensive quality control and is precisely designed to fit the patient's anatomy. Planning and sizing by experienced physicians or by the Cook sizing team allow little room for errors of design. Nonetheless, neck angulation, tortuosity, and errors of design can lead to misalignment between the fenestration and the target vessel. Diameter-reducing ties are located posteriorly, which may result in the fenestrations being pulled slightly more posterior than its intended location (Figure 9A). A useful maneuver is to gently rotate each fenestration, usually anteriorly. Other maneuvers are rarely needed but include the use of curved catheters (eg, VS1 [Cook Medical] or SOS [AngioDynamics, Queensbury, NY]) for downward-facing vessels or vessels that are originating from the lower part of the fenestration, microcatheters, and balloon displacement of the main stent graft. The latter is rarely needed but may provide more room for catheter manipulations (Figure 9B).

Branch Perforation or Dissection

Branch vessel perforation and/or dissection can be prevented by meticulous technique, visualization of the tip of the guidewire, and avoiding excessive manipulations. The guidewire should not be positioned in small terminal branches, which are prone to perforate or dissect. It should be visualized and stabilized during exchange manipulations, avoiding forward or retrograde movement. If perforation occurs, it should be immediately recognized and treated. Renal artery perforations rarely seal off and may lead to large parenchymal or subcapsular hematomas with loss of the kidney.

In the unfortunate event of a perforation, the balloon should be reintroduced and inflated in the renal stent to minimize bleeding. The 0.035-inch guidewire is removed, and angiography is performed via the shaft of the balloon (Figure 10A). Using a microcatheter and Glidewire Gold (Terumo Interventional Systems, Inc.), the perforated branch is accessed and coiled with 0.018-inch coils (Figure 10B). Dissections within the main renal artery can be treated by placing a self-expandable stent (Figure 10C).

Endoleaks

Type II and type IV endoleaks may occur and should be left untreated. Type I and type III endoleaks are infrequent (< 3%) with proper selection of a healthy landing zone and adequate planning.[5,18,19] In the event of a type IA endoleak, the proximal neck may be redilated (Figure 11), but all of the alignment stents need to be protected by separate balloons. Type III endoleaks may result from inadequate flare, lack of apposition, use of a bare-metal stent, or inadequate length into the aorta. Fortunately, these rarely occur, but in such cases, I redilate or restent the stent and reflare.

Stent Kinking or Narrowing

Kinks are highly preventable and can be anticipated from review of vessel anatomy on CTA. These remain a

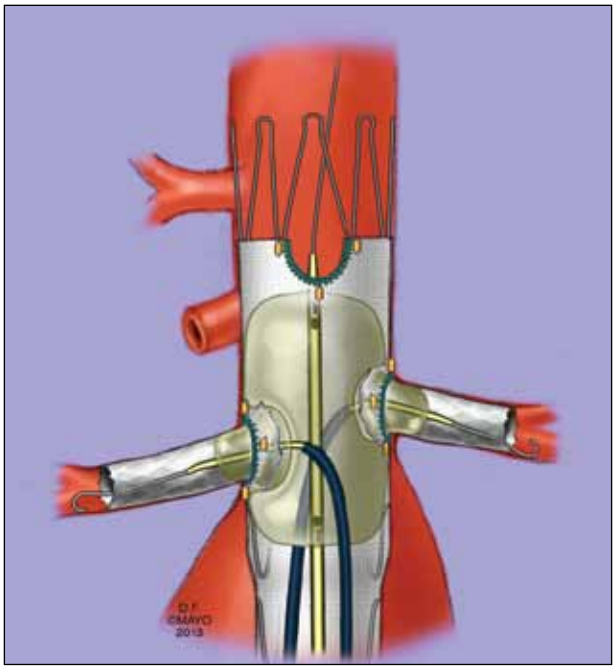

Figure 11. Type I endoleaks are infrequent with proper patient selection and adequate design. In the event redilatation of the neck is needed for treatment of a type I endoleak after the renal stents are deployed, each stent needs to be protected by a separate balloon while the aortic balloon is inflated.

cause for reintervention or branch vessel loss if not recognized. The use of short stents (< 2 cm) avoids landing the stent in the mid or distal portion of the renal artery, which have greater respiratory motion. The right renal artery may have a posterior orientation from its course behind the inferior vena cava. If a kink is anticipated by review of the anatomy on CTA or is evident on completion angiography, a self-expandable stent should be placed (Figure 12). Further, kinks or narrowing may result from inadequate flare, strut compression, and/or ostial disease. In these cases, angioplasty or stenting with a second balloon-expandable stent may be considered.

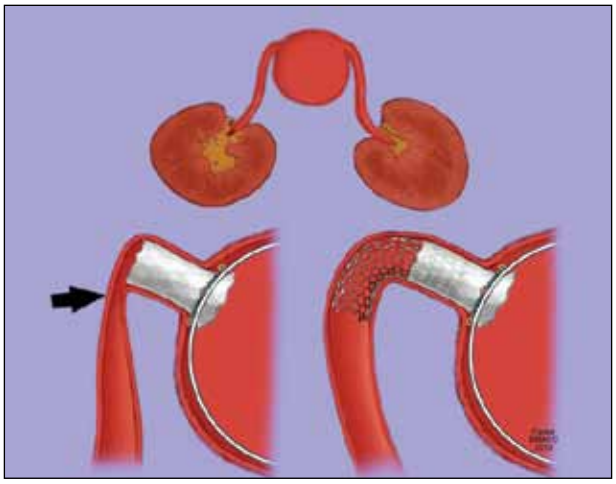

Figure 12. If a kink is anticipated based on the trajectory of the renal artery or it is noted on completion angiography, a self-expandable stent should be placed at the distal aspect of the stent for better transition.

POSTOPERATIVE MEASURES

The length of hospital stay averages from 2 to 3 days for uncomplicated cases. Oral diet is resumed the day after the operation. I perform CTA and baseline duplex ultrasound prior to patient discharge (Figure 13). Follow-up includes clinical examination and imaging (CTA and ultrasound) at 6 to 8 weeks, every 6 months for a year, and yearly thereafter. All patients are on aspirin. Clopidogrel is not prescribed unless there are concerns of branch vessel disease, small branch vessel size (< 4 mm) or dissection.

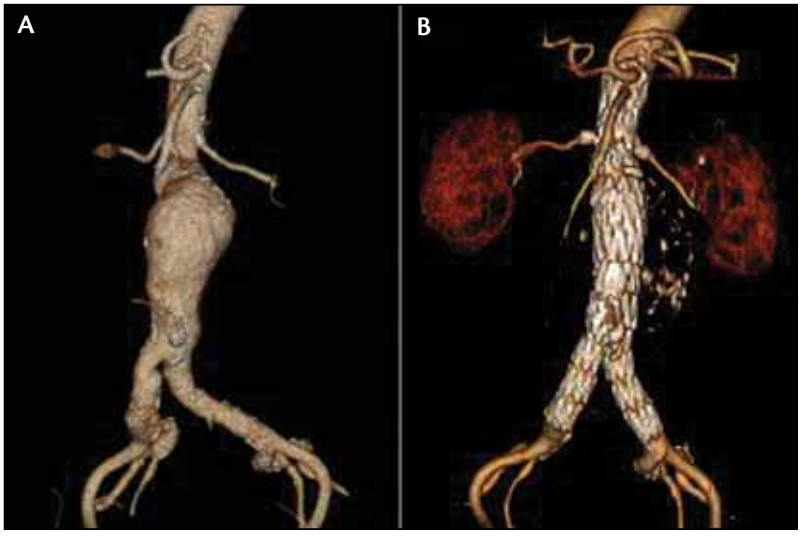

Figure 13. Preoperative CTA of a patient treated for juxtarenal aortic aneurysm (A) with a Zenith Fenestrated stent graft (B).

SUMMARY

Endovascular repair of complex aneurysms involving the visceral arteries has become a reality. Fenestrated stent grafts have been increasingly utilized to treat pararenal and thoracoabdominal aneurysms. The technique is safe, effective, and can be performed with high technical success and low risk of complications in the hands of experienced physicians.[5] More than 5,500 patients have been treated with Zenith Fenestrated endografts (more than 5,500 with the iliac branch devices and more than 1,500 with the thoracoabdominal branch devices worldwide).

The Zenith Fenestrated stent graft system is the first fenestrated device

approved for commercial use in the US. Based on the results of the US prospective trial and large single-center experiences, rates of type I and III endoleak, migration, aneurysm rupture, and conversion to open repair are exceptionally low.[14] Branch patency averages > 95% with covered stents.[16,20] These results should serve as benchmarks for comparison with alternative endovascular techniques of branch vessel incorporation, including debranching, snorkel, and physician-modified grafts. ■

Gustavo S. Oderich, MD, is Professor of Surgery, Director of Endovascular Therapy, Division of Vascular and Endovascular Surgery, Mayo Clinic in Rochester, Minnesota. He has disclosed that he is a consultant to Cook Medical and Gore & Associates, has a proctoring agreement with Cook, and is the National Principal Investigator for Cook's t-Branch trial. Dr. Oderich may be reached at (507) 284-1575; oderich.gustavo@mayo.edu.

1. De Bruin JL, Baas AF, Buth J, et al. Long-term outcome of open or endovascular repair of abdominal aortic aneurysm. N Engl J Med. 2010;362:1881-1889.
2. Greenhalgh RM, Brown LC, Powell JT, et al. Endovascular versus open repair of abdominal aortic aneurysm. N Engl J Med. 2010;362:1863-1871.
3. Schermerhorn ML, O'Malley AJ, Jhaveri A, et al. Endovascular vs. open repair of abdominal aortic aneurysms in the Medicare population. N Engl J Med. 2008;358:464-474.
4. Carpenter JP, Baum RA, Barker CF, et al. Impact of exclusion criteria on patient selection for endovascular abdominal aortic aneurysm repair. J Vasc Surg. 2001;34:1050-1054.
5. Greenberg R, Eagleton M, Mastracci T. Branched endografts for thoracoabdominal aneurysms. J Thorac Cardiovasc Surg. 2010;140(6 Suppl):S171-178.
6. Park JH, Chung JW, Choo IW, et al. Fenestrated stent-grafts for preserving visceral arterial branches in the treatment of abdominal aortic aneurysms: preliminary experience. J Vasc Interv Radiol. 1996;7:819-823.
7. Uflacker R, Robison JD, Schonholz C, Ivancev K. Clinical experience with a customized fenestrated endograft for juxtarenal abdominal aortic aneurysm repair. J Vasc Interv Radiol. 2006;17:1935-942.
8. Ontario Health Quality Initiative. Fenestrated endovascular grafts for the repair of juxtarenal aortic aneurysms: an evidence-based analysis. Ont Health Technol Assess Ser. 2009;9:1-51.
9. Amiot S, Haulon S, Becquemin JP, et al. Fenestrated endovascular grafting: the French multicentre experience. Eur J Vasc Endovasc Surg. 2010;39:537-544.
10. GLOBALSTAR Collaborators. Early results of fenestrated endovascular repair of juxtarenal aortic aneurysms in the United Kingdom. Circulation. 2012;125:2707-2715.
11. Nordon IM, Hinchliffe RJ, Holt PJ, et al. Modern treatment of juxtarenal abdominal aortic aneurysms with fenestrated endografting and open repai—a systematic review. Eur J Vasc Endovasc Surg. 2009;38:35-41.
12. Linsen MAM, Jongkind V, Nio D, et al. Pararenal aortic aneurysm repair using fenestrated endografts. J Vasc Surg. 2012;56:238-246.
13. Cross J, Gurusamy K, Gadhvi V, et al. Fenestrated endovascular aneurysm repair. Br J Surg. 2012;99:152-159.
14. Greenberg RK, Sternbergh WC 3rd, Makaroun M, et al. Intermediate results of a United States multicenter trial of fenestrated endograft repair for juxtarenal abdominal aortic aneurysms. J Vasc Surg. 2009;50:730-737.
15. Stanley BM, Semmens JB, Lawrence-Brown MM, et al. Fenestration in endovascular grafts for aortic aneurysm repair: new horizons for preserving blood flow in branch vessels. J Endovasc Ther. 2001;8:16-24.
16. Mohabbat W, Greenberg RK, Mastracci TM, et al. Revised duplex criteria and outcomes for renal stents and stent grafts following endovascular repair of juxtarenal and thoracoabdominal aneurysms. J Vasc Surg. 2009;49:827-837; discussion 837.
17. Dowdall JF, Greenberg RK, West K, et al. Separation of components in fenestrated and branched endovascular grafting--branch protection or a potentially new mode of failure? Eur J Vasc Endovasc Surg. 2008;36:2-9.
18. Guillou M, Bianchini A, Sobocinski J, et al. Endovascular treatment of thoracoabdominal aortic aneurysms. J Vasc Surg. 2012;56:65-73.
19. Haulon S, Amiot S, Magnan PE, et al. An analysis of the French multicentre experience of fenestrated aortic endografts: medium-term outcomes. Ann Surg. 2010;251:357-362.
20. Mastracci TM, Greenberg RK, Eagleton MJ, Hernandez AV. Durability of branches in branched and fenestrated endografts. J Vasc Surg. 2013;57:926-933.