Type IV Thoracoabdominal Aneurysms: What's Next?

Advanced endovascular techniques and specialized devices in the pipeline are making fenestrated EVAR a viable option in this challenging anatomic site.

BY NIKOLAOS TSILIMPARIS, MD, AND JOSEPH J. RICOTTA II, MD, MS

The classic anatomic definition of a Crawford type IV thoracoabdominal aortic aneurysm (TAAA) is that of aneurysms extending from the 12th intercostal space to the iliac bifurcation involving the visceral aortic segment and the origins of the renal, superior mesenteric, and celiac arteries.[1] In the endovascular era, however, some investigators have moved away from this strict anatomic criteria and instead use a functional one that considers the required extent of aorta covered by the endograft when repairing the aneurysm.[2] For example, a suprarenal aneurysm (by anatomic criteria) that is repaired endovascularly and requires branch stents to all four visceral vessels and aortic coverage to the supraceliac aorta would be considered functionally a type IV repair by some experts in the field.[2,3]

Traditionally, type IV TAAAs have been treated with open surgery. However, with the introduction and evolution of endovascular aneurysm repair, several treatment alternatives using endovascular therapy alone or in combination with open surgery have been developed to repair these complex aneurysms. These treatment modalities are evolving, new techniques and devices are continuously being introduced, and old ones are being updated and improved upon. The general trend is toward a less invasive approach, which improves patient outcomes, recovery time, and quality of life. In this article, we discuss the current options for treating type IV TAAAs and focus on what the future holds for these complex aneurysms.

PARALLEL ENDOGRAFT ENDOVASCULAR REPAIR

The Snorkel/Chimney/Sandwich Technique

In 2011, Kolvenbach et al[4] reported their multi-institutional experience of nine thoracoabdominal aneurysms repaired with the "sandwich technique." Three of these TAAAs were type IV. Because endovascular techniques have become routine in the daily practice of vascular surgeons and interventionists, many feel confident using these techniques as a quick bailout procedure in urgent or emergent situations in high-risk patients whose lives may be at risk and are unfit for surgery. While this treatment option is technically feasible, there are no reported data on mid- or long-term results, making its use in the elective setting questionable.

It must also be emphasized that there is a large difference in complexity of repair between juxtarenal aneurysms and TAAAs, and that a parallel graft repair of a type IV TAAA may require placement of covered stents into all four visceral vessels. The issue of endoleaks associated with these parallel grafts, as well as the durability of the branches, remains unresolved, and their mid- and long-term outcomes are unknown.

FENESTRATED/BRANCHED STENT GRAFTS

Fenestrated and branched stent grafts have been developed as a minimally invasive, total endovascular alternative for the treatment of complex aortic aneurysms in high-risk

TABLE 1. OVERVIEW OF FENESTRATED/BRANCHED ENDOGRAFTS FOR THE RENAL/VISCERAL AORTIC SEGMENT AND THEIR CURRENT AVAILABILITY

Company Name	Device	Indication	Availability for Clinical Use	Characteristics
Cook Medical	Zenith fenestrated	Pararenal and TAAA	Available in Europe, Australia, Canada, Brazil, China, New Zealand, and Hong Kong	Fenestrations and scallops are premanufactured as ordered according to physician's measurements
	Preloaded fenestrated device	Pararenal	Under investigation; expected 2012	Fenestrations are preloaded with wires to access viscera
	Standardized off-the-shelf FBSG	Pararenal and TAAA	Under investigation	Standardized location of fenestrations expected to accommodate > 70% of cases
Medtronic, Inc.	Branch device	Pararenal and suprarenal aneurysms	In design	Off-the-shelf, precannulated renal branches, and SMA scallop
Vascutek Ltd.	Anaconda custom fenestrated	Juxtarenal/pararenal aneurysms	Postmarket surveillance registry; custom-made regulations: Europe and Canada	Fenestrations are premanufacturered according to individual patient requirements; repositionable, stent-free proximal part to provide flexibility
Endologix, Inc.	Ventana fenestrated stent graft	Juxtarenal and pararenal aneurysms	In clinical trial	Off-the-shelf, precannulated steerable fenestrations

patients. The midterm results for treating TAAAs are excellent and demonstrate the benefits of avoiding extensive aortic and visceral vessel surgical exposure and maintaining visceral perfusion during the repair. Successful results with fenestrated and branched endografting have been reported.[2,5-11] Achieving these results requires appropriate patient selection, proper device design, high-resolution imaging, technical expertise with endovascular grafting and visceral vessel cannulation and stenting, and meticulous postoperative follow-up.

Currently, Cook Medical (Bloomington, IN) has the only commercially available device outside the United States.[12-14] Their United States trial[15] is now complete, and the application for commercial use of the device has been submitted to the FDA. Long-term results and larger series are still needed to further delineate the safety and efficacy of these devices. However, as the technology and technique evolve and become more widely disseminated, fenestrated and branched stent grafts appear destined to play an increasingly important role in the treatment of type IV TAAAs.

Future management and treatment of type IV TAAAs will be driven by evolution in devices and techniques in endovascular repair, in particular with fenestrated/branched stent grafts. However, these advances will not occur just by improving stent grafts and by introducing new devices; rather, it will be a multimodal process, including advances in preoperative imaging and peripheral products, as well as adjunctive tools that will facilitate easier and faster visceral access.

The key for the endovascular approach to ensure its defining role in complex aortic aneurysm repair (and specifically in type IV TAAA repair) is the elimination of factors that may compromise the durability of the repair. Reconstructions need to be as anatomic as possible, with branches coming off at smooth angles from the endograft and bridging stents to the aortic branches following the direction of the native artery. Overlap between aortic endograft and branch stents needs to be maximized to reduce

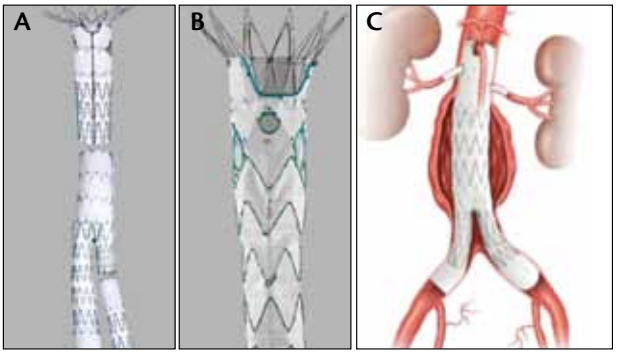

Figure 1. Customized Zenith fenestrated graft with two renal fenestrations and a scallop for the SMA (A), off-the-shelf pararenal device with fenestrations to the renals and SMA and a scallop for the celiac artery (B), and a graphic of the implanted Zenith fenestrated device (C).

the risk of component separation, type III endoleaks, and protrusion of branch stents into the main stent graft.

Currently, customized devices are available to treat patients in the elective setting, but patients presenting emergently have limited treatment options if they are unfit for open surgery. While the backtable construction of a surgeon-modified stent graft is currently the most durable and promising endovascular solution to treat such patients,[9,16,17] the introduction of off-the-shelf standardized devices is expected to bring a new push in the field of fenestrated endovascular aneurysm repair (FEVAR). However, standardization should not be allowed to suppress principles such as preservation of all aortic branches with perfectly aligned fenestrations or branches. The challenge to find the balance between standardized and customized stent grafts will be decisive in the coming years.

Imaging Techniques

Key elements in the planning of endovascular TAAA repair are the generation of a centerline path with measurements using centerline of flow analysis, as well as three-dimensional reconstructions. Currently, the TeraRecon Aquarius Workstation (TeraRecon, San Mateo, CA) is the most widely used in the field;[18] alternative software programs or centerline measurements are available but, to our knowledge, lack the straightened view reconstructed image that significantly simplifies calculation of length measurements, which is essential during preoperative planning.

Advances in imaging technology and in available workstations will provide more exact measurements and accurate planning of FEVAR. Improved intraoperative imaging (eg, the fusion of preoperative CT scans with intraoperative fluoroscopy) will also allow better technical results in shorter operation times, as well as limit radiation exposure and contrast dose.

DEVICES IN THE PIPELINE

With Cook Medical producing the first fenestrated and branched device for use in pararenal as well as thoracoabdominal aneurysms (Figures 1 through 3), other companies in the field of endovascular surgery have begun to produce their own fenestrated/branched devices (Table 1).[19-21] Most of these devices have approval (or approval is being sought) for pararenal aortic aneurysms; however, iterations of the current devices will be evolved in the near future for use in treating type IV TAAAs.

Stent grafts for FEVAR are currently either fenestrated (typically with a reinforcement around the fenestration) or precuffed (with a cuff "branch" coming off the ostium of the fenestrations). The cuffs may be helical or caudally or cranially oriented (Figures 2 and 4). The cuffs provide better sealing with the branch stents when compared with the simple fenestrations because the overlap is better and may facilitate easier cannulation of the branch vessels. Typically, the proximity of the fenestration to the ostium of the visceral branch determines whether a fenestration is sufficient or if a cuff should be preferred. Helical cuffs have a more complex multiplanar configuration, with both axial and rotational elements, and therefore side-arm branches are considered to be more efficient in accommodating a smooth alignment of the side-arm branch to the target vessel.[22]

Standardized "Off-the-Shelf" Stent Grafts

Stent grafts that have been manufactured to fit a population with typical visceral vessel anatomy and thus are not patient-tailored (custom-made) are referred to as *standardized grafts.* Creating an off-the-shelf, one-size-fits-all device is the Holy Grail for FEVAR and for industry. Currently, patients with complex aortic aneurysms may have to wait up to 8 weeks for their devices to be manufactured and delivered. A standardized stent graft would not only prevent ruptures from occurring during this waiting period but would also allow treatment of patients presenting with ruptures and/or symptoms that require urgent or emergent treatment.

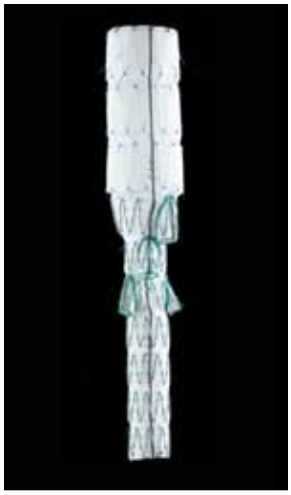

Figure 2. Cook Medical branched stent grafts with axial branches for TAAAs.

Currently, we treat these patients with surgeon-modified grafts.[9,16] In 2009, Sweet et al demonstrated that 88% of the patients treated with stent grafts customized to the patient's anatomy could also

have been treated with standardized endografts.[23] The same group continues to report its experience on the transition from customized to standardized stent grafts with excellent outcomes using standardized branched stent grafts.[22-24]

The off-the-shelf devices currently in the pipeline are aimed at juxtarenal and suprarenal aneurysms (fenestrated design), as well as thoracoabdominal aneurysms (branched design). While these current designs can theoretically treat up to 80% of these pathologies, the remaining 20% remain outside the current design limits and need custom devices. Due to the way the devices are implanted, they are also generally less suitable for treating ruptured aneurysms, particularly in unstable patients.

Standardized Cook Medical Pararenal Device

Cook Medical's off-the-shelf fenestrated device has a four-piece modular design: a proximal tubular component with fenestrations, a second bifurcated component without a top cap, and two iliac limbs. The device is based on the fenestrated platform for elective patients. The standardized location of the fenestrations is expected to accommodate anatomy for approximately 70% of patients, with less than 10 variations of the proximal piece.

Vascular surgeons at the Cleveland Clinic have recently performed the initial first-in-human procedures in the United States with off-the-shelf fenestrated endografts for patients with juxtarenal and type IV TAAAs. Dr. Roy Greenberg is the Principal Investigator for the physician-sponsored study, "Endovascular Exclusion of TAAA/AAA Utilizing Fenestrated/Branched Stent Grafts," which is evaluating a new stent graft design developed in cooperation with Cook Medical. The new device incorporates branches (formed by covered balloon-expandable stents) to both renal arteries and the superior mesenteric artery. The first patient underwent elective endovascular repair, the second patient was treated for a ruptured aneurysm, and the third one was treated for a type IV TAAA.[25]

Dr. Timothy Resch from Malmö University Hospital in Sweden and Dr. Stephan Haulon from Lille, France recently reported the repair of seven patients with complex visceral artery anatomy who were treated with an off-the-shelf stent graft containing preloaded wires to the renals, a fenestration to the superior mesenteric artery, and a scallop for the celiac artery. Technical success was uniform with 100% target vessel catheterization and 0% 30-day mortality. In one case, the graft was displaced slightly during delivery, resulting in a renal artery stent occlusion at 2 months after the procedure.[26]

Cook Medical Preloaded Fenestrated Device

Cook Medical's preloaded device is under consideration as part of the next generation of the Zenith fenestrated endograft in which modifications have been made to the delivery system. A single extra wire was added that runs through the endograft, out one fenestration, through the top of the graft, back through the opposite renal fenestration, and then out through the delivery system (Figure 3). This wire facilitates easier advancement of the sheaths through the fenestrations, which can be one of the most challenging parts of a fenestrated case, thus significantly shortening the duration of the procedure.

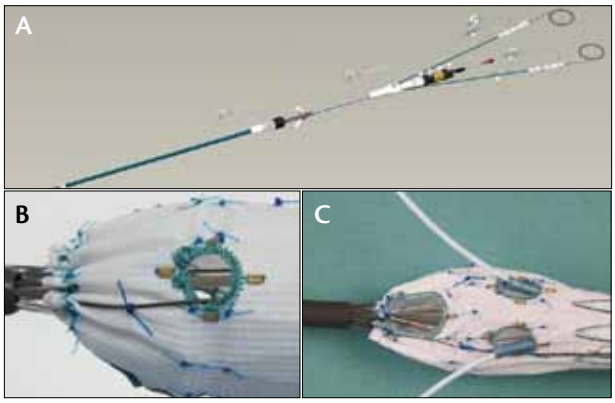

Figure 3. The preloaded Cook Medical fenestrated stent graft (A) with preloaded wire coming through the delivery system, out of the left renal fenestration, and then through the top cap and back to the right renal fenestration (B). Removal of preloaded wire and advancement of sheaths through fenestrations to facilitate branch vessel cannulation (C).

In 2010, Ivancev et al[21] reported preliminary results of the preloaded fenestrated device, which demonstrated its feasibility and safety. Studies on this graft are ongoing in Europe and the United States.

Medtronic Endovascular Therapies AAA Branch Stent Graft System

Medtronic, Inc. (Minneapolis, MN) is currently developing its own branch stent graft. The Medtronic Branch stent graft system (Figure 4) was developed to treat patients with short neck infrarenal AAAs (neck length of < 10 mm), juxtarenal, and suprarenal AAAs. The AAA Branch stent graft system capitalizes on some of the successful design features of the Endurant AAA stent graft system, while utilizing next-generation materials to offer low-profile, flexibility, conformability, and durability.

The design targets are promising for an easy-to-use, off-the-shelf solution for complex aneurysms in a broad range of patients. Incorporated into the design are precannulated lumens to facilitate access into the visceral vessels and a delivery system that allows for femoral artery conveyance and deployment of the complete AAA Branch stent graft system.

The stent graft system includes a self-expanding, covered renal stent design that provides high radial force with optimal flexibility to ensure lumen patency. The variable radial force of the main stent graft accommodates the presence of the renal stent branches. The Medtronic Branch stent graft is expected to be available within clinical trials in the near future.

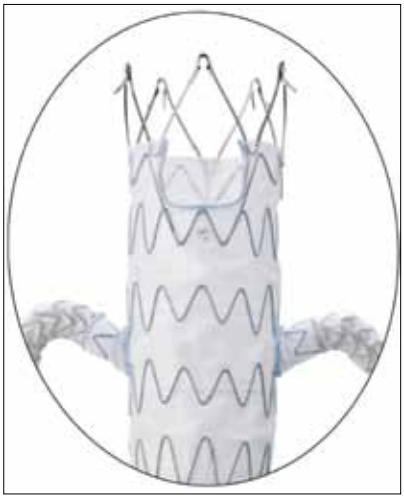

Figure 4. The Medtronic AAA Branch stent graft system.

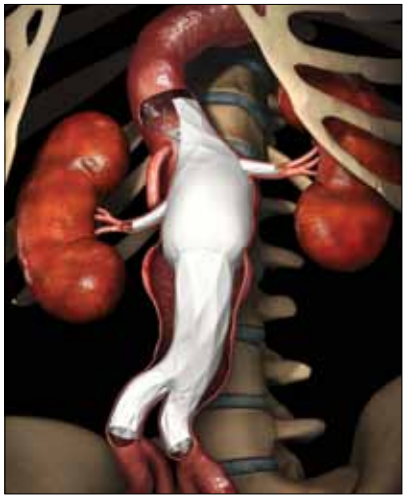

Figure 5. The Ventana fenestrated stent graft.

Endologix Ventana Off-the-Shelf Fenestrated Stent Graft

The Ventana stent graft (Endologix, Inc., Irvine, CA) (Figure 5) is an off-the-shelf fenestrated device with steerable fenestrations intended for juxtarenal and pararenal aneurysms. Unlike current fenestrated grafts that are customized for individual patients, the Ventana device has two 3-mm-diameter renal fenestrations with renal sheaths preloaded through the fenestrations that can be dilated up to 8 mm in diameter and can be moved up to 15 mm from their nominal locations. The device incorporates a 4-cm-deep scallop for the celiac and superior mesenteric artery preservation and is used in combination with the Endologix Xpand balloon-expandable renal stent grafts. The Ventana fenestrated proximal extension graft is delivered after an AFX bifurcated graft (Endologix, Inc.) has been deployed with anatomic fixation at the aortic bifurcation.

Nevertheless, there are some anatomic eligibility requirements, the most important being an infrasuperior mesenteric artery neck length of 15 mm or longer. In January 2012, the device acquired IDE approval in the United States to begin clinical trials. The results of the pilot study, which include 15 patients with successful exclusion of their aneurysms, will be announced at the 2012 Society for Clinical Vascular Surgery meeting.

Vascutek Anaconda Fenestrated Stent Graft

The Anaconda fenestrated stent graft (Vascutek Ltd., Inchinnan, United Kingdom) (Figure 6) is currently regulated as a custom device within Europe and Canada. The device is not in clinical trials, but there is a postmarket surveillance registry in which data on patients will be captured for up to 5 years. Its primary indication is for juxta- or pararenal aneurysms with an adequate suprarenal neck diameter of 18 to 31 mm. The standard device design has two fenestrations for the renal arteries and two valleys anteriorly and posteriorly. The anteriorly oriented valley is usually used to accommodate the superior mesenteric or celiac artery. Seventy-nine grafts have been implanted to date worldwide, two of which had four fenestrations.

The advantage of this custom-made device is that it can be repositioned by reconstraining the top of the graft, thereby providing more flexibility for alignment of the visceral vessels. The proximal portion of the graft is stent-

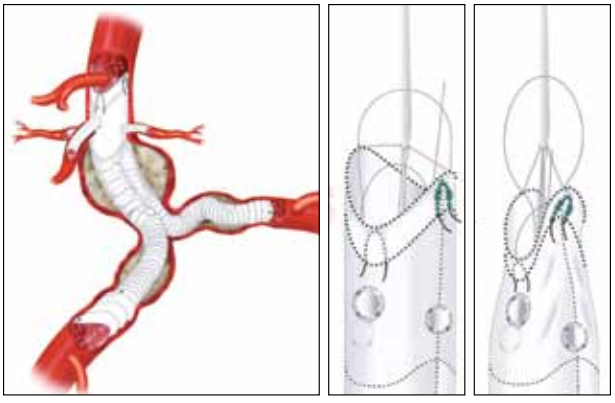

Figure 6. The repositionable Anaconda fenestrated device.

free, which, according to the manufacturer, offers flexibility and kink-resistance to the graft to better cope with more angulated necks. In addition, the fenestrations are made in unsupported fabric and are therefore not limited in terms of size and position.

Recently, a preliminary report presented four patients undergoing successful repair of their pararenal aneurysms with the custom-made Anaconda custom fenestrated device with perfusion of all 12 target vessels and no perioperative adverse events.[19] The Avanta V12 stent graft (Atrium Medical Corporation, Hudson, NJ) was used as bridging stents to the renal arteries.

ENROLLING, PLANNED, AND NEEDED CLINICAL TRIALS

Currently, ongoing registered trials for TAAAs are being conducted in the United States at the Cleveland Clinic with the fenestrated branched Cook device (trial identifier: NCT00583050) and in France as part of multicenter clinical trial investigating medical and economical aspects of fenestrated and branched stent grafts (trial identifier: NCT01168037).[27] However, the first trial is not a comparative randomized study but rather a cohort study on consecutive patients who are at high risk for open repair, therefore leaving the comparative factor of the two therapeutic options unaddressed.

The French trial is a multicenter, prospective, nonrandomized trial designed to compare the perioperative mortality, severe morbidity, and the costs of endovascular versus conventional surgical repair of pararenal, suprarenal, and type IV TAAAs. The primary goal of the study is to demonstrate a significant reduction in 30-day mortality and life-threatening morbidity in the endovascular arm of the study by comparing 220 patients from seven university hospitals with significant experience in fenestrated endografts to 660 similar patients undergoing open repair analyzed from the French national database.

CONCLUSION

The value of repair with fenestrated/branched stent grafts is obvious in high-risk patients who are unfit for open repair. As endovascular techniques and experience with fenestrated/branched endografts evolve, and the durability of the repair is proven and improved upon, we expect that FEVAR will be used more frequently as the treatment of choice for patients with type IV TAAAs. ■

Nikolaos Tsilimparis, MD, is with the Division of Vascular Surgery and Endovascular Therapy, Emory University School of Medicine in Atlanta, Georgia. He has disclosed that he has no financial interests related to this article.

Joseph J. Ricotta II, MD, MS, is with the Division of Vascular Surgery and Endovascular Therapy, Emory University School of Medicine in Atlanta, Georgia. He has disclosed that he is a paid consultant to Medtronic, Inc. and Cook Medical. Dr. Ricotta may be reached at (404) 727-8407; jjricot@emory.edu.

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