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A New Angle on EVAR

How an innovative conformable device provides a solution for treating highly angulated necks.

BY ADAM W. BECK, MD, AND KRISTINA A. GILES, MD

Endovascular aneurysm repair (EVAR) has progressed greatly since Juan Parodi implanted a tube graft that was handcrafted from Palmaz stents and Dacron grafts.[1] Improvements in design to address enormous variation in patient anatomy have affected the durability of devices and thus patient outcomes. Although devices have changed, the basic tenets of EVAR have not, with the success and durability of repair relying on two basic principles: fixation and seal.

EVOLUTION OF EVAR

Anatomic constraints to achieving successful repair are those related to delivery of the device, such as iliofemoral arterial diameter, atherosclerotic disease, and tortuosity, as well as issues related to proximal and distal seal, which include thrombus, calcification, infrarenal neck length, nonparallel aortic wall anatomy, and angulation of the aortic "neck" above the aneurysm. To address these issues, device manufacturers have worked to improve upon existing designs, and those that are currently available on the market represent vast advances over first-generation devices. These improvements have extended our ability to offer EVAR to patients with difficult anatomy, but there are still many challenges.

One particular anatomic issue that remains is angulation within the proximal seal zone. With increasingly severe angulation, a longer neck is typically necessary to provide approximation of the device to the aortic wall and allow necessary seal and fixation for long-term durability. In fact, most physicians would agree that the aneurysm neck anatomy is the single most important characteristic for successful infrarenal EVAR. The aortic neck angle alone excludes more than 15% to 20% of patients from infrarenal EVAR.[2,3] Specifically, for devices with suprarenal fixation, a suprarenal aortic neck angle > 45° and an infrarenal neck angle > 60° fall outside of the suggested treatment parameters for the majority of devices currently available on the market.[3]

Physicians have pushed the envelope of EVAR using adjunctive techniques such as chimney EVAR[4] and the "endowedge" technique described by Minion et al[5] to lengthen the available proximal landing zone, as well as supplemental Palmaz stenting to increase radial force[6] and stapling[7] to improve fixation in short or angulated necks, among other reported techniques. Although these adjuncts allow surgeons to offer EVAR to patients who would otherwise not be anatomically amenable, their effect on the long-term durability of devices remains in question.

EUROSTAR data evaluating severe neck angulation demonstrated that type Ia endoleaks are associated with this anatomic characteristic.[2] More recent meta-analyses have also demonstrated a significant influence of "hostile" neck anatomy on outcomes, including type I endoleak, need for adjunctive procedures, limb occlusion, and aneurysm-related mortality.[8,9] Further, Schanzer et al reported that straying from device instructions for use (IFU) is common in the practice of many vascular specialists and is associated with poor durability.[10]

Extending the proximal landing zone to the suprarenal aorta using fenestrated EVAR (FEVAR) has also extended the capability of treating aneurysms close to or involving the renal arteries. Despite these advances in device design, angulation of the aorta at the infrarenal neck often precludes treatment, even with FEVAR, as it presents challenges with accessing and revascularizing the renal arteries through graft fenestrations and problems with graft apposition to the aortic wall.

Additionally, female patients have unique challenges with EVAR due to a comparatively higher incidence of difficult neck anatomy along with inherently smaller access vessels. In the United States, women represent 21% of abdominal aortic aneurysm (AAA) patients, but have been generally underrepresented in existing literature, with many device trials including only 6% to 13% women.[11-16] This is due in part to women having angled aortic neck anatomy, which is often prohibitive to on-label use of aortic devices and thus inclusion in clinical trials.[3]

Tortuous iliac anatomy also affects distal endograft seal and limb patency. The iliac tortuosity index has been described as a method to quantify tortuosity and relate it to patient outcomes.[17] Iliac tortuosity has been implicated in limb complications including occlusion by kink or thrombosis, type Ib endoleak, and device dislocation.[18] Graft limb flexibility has improved across most devices compared to early generations; however, iliac tortuosity still affects the approach to EVAR.

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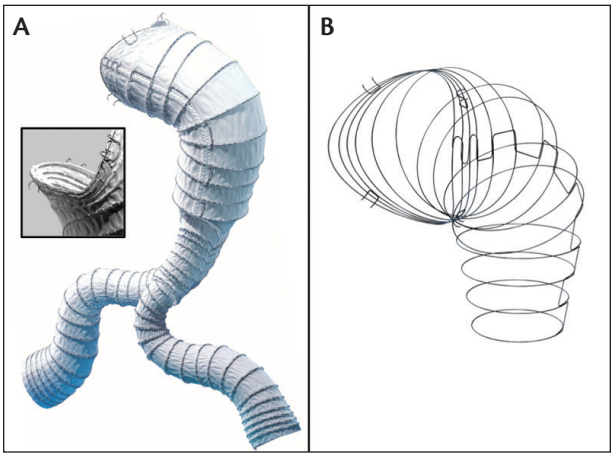

Figure 1. The Aorfix device demonstrating the "fish mouth" design, allowing for transrenal fixation when appropriately sized (A). The Aorfix wireform demonstrating concentrated concentric rings within the first 8 mm of the device, as well as four aggressive sets of hooks that provide proximal fixation (B).

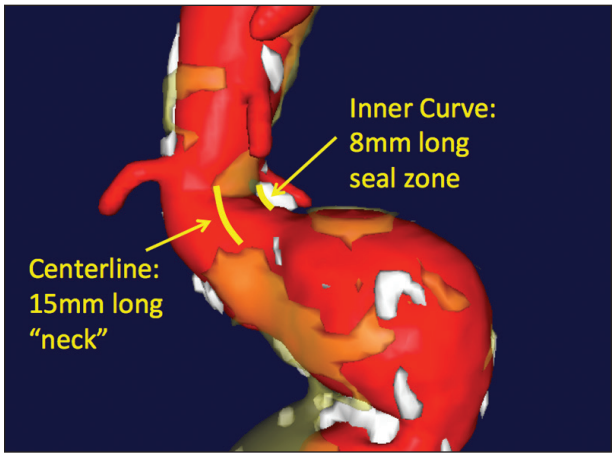

Figure 2. Three-dimensional reconstruction of a highly angulated infrarenal aortic neck. This aortic neck measures 15 mm along the centerline of flow, but only 8 mm along the lesser curve of the neck, illustrating one of the challenges of treating highly angulated neck anatomy.

Given these challenges, the female AAA population and those with angulated necks and aortoiliac tortuosity clearly show an area where improvements in aortic device design could expand the population amenable to infrarenal EVAR.

THE AORFIX™ ENDOVASCULAR STENT GRAFT

In 2013, the US Food and Drug Administration approved the Aorfix endograft (Lombard Medical, Inc.) for the treatment of infrarenal AAAs. This device was specifically designed to address the issue of angulated necks and tortuous iliac anatomy. The device is a polyester graft designed with circular nitinol rings around the proximal device and helical rings in the iliac limbs (Figure 1), which allow for high flexibility and provide a construct that is kink-resistant. This design maintains flow lumen in heavily tortuous and highly angulated anatomy, as demonstrated in ex vivo studies by Demanget et al to be superior to Z-stent designs.[19]

Aorfix has two primary active fixation mechanisms, which are located within the first 8 mm of the proximal graft. A concentrated set of closely spaced nitinol rings at the proximal end of the graft provide outward radial force in concert with additional active fixation provided by four sets of aggressive hooks (Figure 1A) located halfway between the peak and trough of the proximal device.

Further, the proximal endograft also has a notable "fish mouth" configuration (Figure 1A, inset), which, when properly oversized, creates transrenal fixation. This provides additional seal and fixation adjacent to and above the renal arteries when deployed with the renal arteries within the troughs of the fish mouth. The iliac limbs have spiral nitinol rings, which allow for deployment in tortuous vessels with a low limb occlusion rate.

Lombard's PYTHAGORAS premarket approval trial was unparalleled in the aortic anatomy that was sought and treated. The intention of the trial was to target patients with 60° to 90° angulation in the infrarenal aortic neck, which constituted untreatable anatomy within the IFU of all existing endografts on the market.

Notably, the trial was designed to approximate what would occur in "real-world" use of the device by allowing the individual investigator to chose patients based on the inclusion/exclusion criteria, with no core lab assessment of anatomy prior to implantation.

The exclusion criteria included a centerline aortic neck length of < 15 mm from the lowest renal artery, or a superior mesenteric artery to AAA length of < 20 mm, in addition to neck or iliac artery diameters that fell outside the device IFU.

Patients were grouped based on neck angulation (< 60°, 60°–90°, > 90°). Extreme degrees of angulation were permitted in the presence of an aortic neck centerline length measurement of 15 mm. In the setting of a highly angulated neck, this length of landing zone is a remarkable inclusion criterion given the generally accepted philosophy that increasing neck angulation requires a longer landing zone to allow for graft to aortic wall apposition for proper seal and fixation. The 15-mm neck requirement was based on a centerline measurement on three-dimensional (3D) imaging, which does not accurately represent the true circumferential length of landing zone. The length along the lesser curvature of the neck decreases with increasing neck angulation and can be substantially shorter than 15 mm (Figure 2).

A group of open control subjects (n = 76) was enrolled and analyzed along with a Society for Vascular Surgery open control registry to provide a comparison to open AAA

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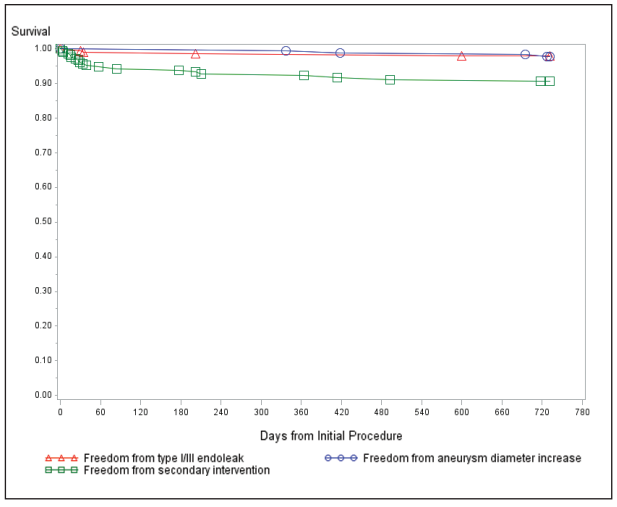

Figure 3. Kaplan-Meier curves demonstrated excellent freedom from secondary intervention, freedom from aneurysm diameter increase, and freedom from type I/III endoleak at 2 years after device implantation.

repair outcomes. A total of 210 patients underwent successful device placement, and the trial enrolled a majority of patients with neck angulations > 60° (n = 151). A group was enrolled with angulation < 60° for comparison to previous device trials, comparison to more angulated anatomy treated with Aorfix, and for training of the investigators.

Interestingly, as a result of differences between the measurement methodologies at the various investigational sites and the core lab, it was found that a substantial number of patients had neck lengths shorter than 15 mm (n = 62) and that many of the patients in the 60° to 90° angulation cohort were found in post hoc analysis by the core lab to have neck angulation in excess of 90° (n = 42). These patients certainly reflect real-world patient selection, as would be expected after device approval.

Despite these extreme anatomic inclusion criteria, the device fared well, with rates of endoleak, secondary intervention, and AAA remodeling rivaling all other existing infrarenal devices on the market. Limb occlusion rates also rivaled the existing devices on the market (Figure 3).

Notably, women represented 29% of the study cohort, more than double the percentage of women in previous infrarenal device trials. The percentage of women in each cohort of neck angulation increased with increasing angulation, representing 35% of patients with a neck angulation > 60°. Despite severe anatomy, women had similarly favorable results when compared to men and when compared to previous device studies.

THE UNIVERSITY OF FLORIDA EXPERIENCE

Our participation in the PYTHAGORAS trial and subsequent implantations of the device at the University of

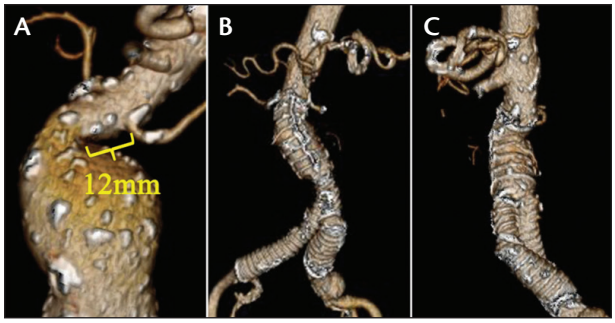

Figure 4. Patient treated at the University of Florida with a highly angulated neck (88°) at implantation. The infrarenal neck measured 16 mm along the centerline and 12 mm along the lesser curve (A). Complete sac shrinkage around the graft was noted on the 4-year follow-up CT. Panels B and C demonstrate straightening of the infrarenal neck along with the graft at last follow-up.

Florida has been favorable, and this device has become our "go-to" device for patients with highly angulated necks. We have successfully treated both men and women with angulation as severe as 88° based on the trial neck measurement methodology (Figure 4). The patient depicted in Figure 4 has been followed for 4 years after treatment and has had near-complete remodeling around the graft. Interestingly, the neck angulation has decreased over time, with the aorta straightening along with the endograft, as demonstrated in the figure.

Graft deployment of Aorfix is somewhat different from other devices on the market, due in part to the fish mouth design of the proximal graft. The deployment system allows for partial deployment of the graft with repositioning after the proximal stents are exposed.

The lessons we have learned about deployment of the Aorfix endograft in patients with highly angulated necks relate to both preoperative planning and deployment. Careful attention to the preoperative 3D imaging is important for the success of the procedure, with special attention paid to the proper gantry angles necessary for orthogonal visualization of the renal artery origins.

Although the centerline neck length on preoperative imaging may seem well within the limitations of the graft, the practitioner should remember that there is sometimes a difference in measured neck and functional neck; you may not be able to use all of the neck measured along the centerline without optimal graft deployment. To that end, the deployment system will often lay to the side of the aorta opposite the side of delivery. Thus, consideration should be given to the direction of angulation and the lowest renal artery when choosing the side of delivery.

Further, the angulated aorta can change configuration with the stiff wires and deployment system in

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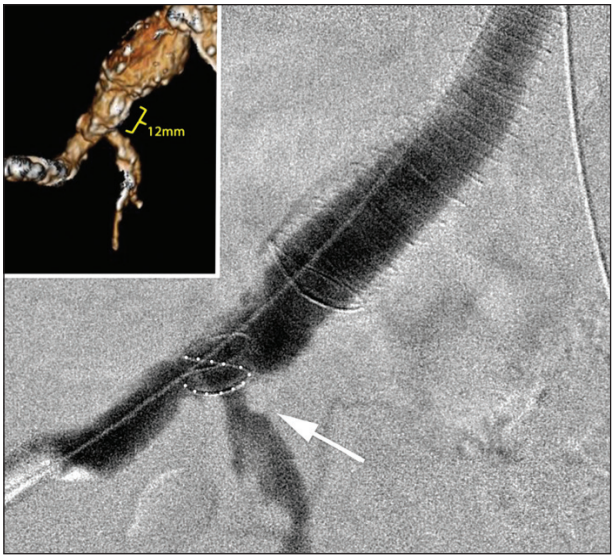

Figure 5. Patient recently treated at the University of Florida with a short distal common iliac landing zone. The fish mouth design of the graft allowed for deployment around the hypogastric origin, providing additional distal seal.

place, which may change the optimal gantry angle and the orientation necessary during graft deployment. A flush catheter for intermittent low-volume injections to confirm the location of the renal arteries is helpful, especially in difficult anatomy. The ultimate goal is to have the device align in a coaxial fashion to the walls of the aorta, which can be quite challenging in cases of extreme angulation.

Our preference is to partially deploy the graft 1 to 2 cm proximal to the intended landing zone, then retract to the proper position before full deployment. We treat these patients much like we would a FEVAR patient, paying close attention to the location and configuration of the renal arteries and making sure the gantry angle during deployment allows for utilization of every millimeter of landing zone. When possible, we prefer the lowest renal artery to sit in the mid-trough of the fish mouth of the graft after deployment. Taking advantage of the design intention provides transrenal fixation of the graft and increases the length of seal and fixation by utilizing the aortic wall proximal to the renal arteries.

The iliac limbs also have a fish mouth configuration at the distal end, which can allow for additional seal distal to the hypogastric artery when the trough is placed around the origin of the vessel. If a long length of landing zone is present, the limb can be deployed as you would any other device. This can be advantageous when iliac aneurysms are present, and in some instances, allows preservation of the hypogastric artery when a seal would have otherwise been compromised (Figure 5).

CONCLUSION

The PYTHAGORAS trial set out to recruit patients with highly challenging angled aortic necks that were off-label for other devices in the United States. In addition to this challenge, the trial included a substantial quantity of shorter and more angulated necks than was intended. Despite these real-world factors, the Lombard Aorfix device performed with outcomes similar to other devices studied in benign anatomy. Aorfix has extended the patient population that is anatomically suitable for infrarenal EVAR. Its innovative engineering makes off-label use of existing devices in patients with highly angulated necks unnecessary and has provided a novel answer to a difficult clinical problem. ■

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