

Managing Difficult Aortic Necks

A perspective from a Chinese vascular program.

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Since Parodi and his colleagues introduced the important concept of endovascular aneurysm repair (EVAR) in 1991,¹ the technology has become widespread and is still evolving. In 1998, the first EVAR case was performed in our center. Since then, more than 1,000 EVAR procedures have been performed, with satisfying immediate and long-term results. Meanwhile, this technology has been widely adopted in China. The number of EVAR cases far exceeds 100 per hospital in several centers. Some centers, including our own, have been utilizing minimally invasive percutaneous EVAR. The results of EVAR for treating patients with abdominal aortic aneurysms (AAAs) have improved steadily over the past 20 years, and published data show that the perioperative mortality was much lower for EVAR than traditional open repair.^{2,3}

Although refinements in endovascular technique have further expanded the indications of EVAR, there are still some limitations. An adequate proximal landing zone is one of the absolute requirements for successful EVAR. According to most manufacturer instructions for use (IFU), hostile anatomy is defined as the presence of one or all of the following characteristics: neck length < 15 mm, diameter > 28 mm, and neck angulation > 60°. Other adverse morphological parameters include

proximal neck circumferential thrombus or calcification (> 50%) or a tapered/conical neck, wherein the diameter progressively increases between the renal arteries and the sac with a > 2- to 3-mm change over the first 15 mm of proximal neck (Figure 1).

In the endovascular era, the number of EVAR patients with hostile aortic anatomy keeps growing.⁷ A recent review of the collected data from a nationally available EVAR imaging system revealed that 58% of EVAR procedures performed in the United States were done outside of the device-specific IFUs.⁸ In our center, approximately 40% of patients with AAAs have aneurysm neck morphology that is inadequate for a standard stent graft, according to the previously mentioned criteria and definitions. AAA repair with a hostile neck is more challenging compared to that with friendly neck anatomy. Unfavorable anatomical characteristics have been shown to be associated with specific EVAR-related complications, such as device migration and a high incidence of type IA endoleak and reintervention. Further insight on how to expand EVAR treatments to more challenging cases with difficult necks and how to prevent potential complications will be key for improvements in the efficacy and applicability of EVAR.

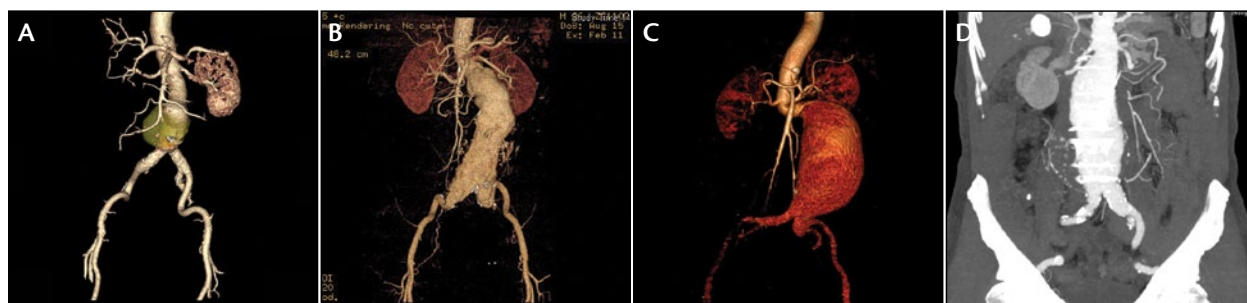


Figure 1. AAA with friendly neck anatomy (A). Hostile neck anatomy with a short infrarenal neck (B). Hostile neck anatomy with a severely angulated neck (C). Hostile neck anatomy with a tapered/conical neck (D).

SHORT PROXIMAL NECK

Improvements in imaging constitute the first step toward optimal endovascular therapy planning. Compared with angiography, CT arteriography (CTA) is the gold standard of preoperative visualization, sizing, and planning for EVAR. Because dynamic CTA studies have demonstrated that the aortic diameter varies during the cardiac cycle,⁹ diameter measurements from axial CTA slices may under- or overestimate the true size of the vessel, which is essential to selecting a proper diameter of stent graft. It is important to adjust the optimal C-arm angulation in the lateral angulation, as well as the craniocaudal angulation, in a view perpendicular to the proximal aortic neck at the orifice of the lowermost renal artery during deployment of the top of the endograft.

Endografts should usually be oversized 10% to 20% in comparison to the aortic neck. In our experience, more aggressive oversizing of 20% to 25% should be considered for a short proximal neck. Patients with tapered or conical aortic necks pose a conundrum. Because oversizing is based on the largest measured diameter, in a conical neck, this could mean stretching the narrower portion of the neck and abruptly oversizing. Some researchers prudently split the difference by oversizing by a minimum of 10% in the larger segment and < 30% in the smaller segment. If the stent graft is not fully apposed to the aortic wall, the risk of type I endoleak is substantial.

Because available aortic stent grafts have different characteristics, it could be assumed that various stent grafts might be a fit for specific aortic morphologies. Selection of an appropriate stent graft is critical to EVAR for aneurysms with hostile necks. The Endurant (Medtronic, Inc., Minneapolis, MN), Zenith (Cook Medical, Bloomington, IN), and Excluder (Gore & Associates, Flagstaff, AZ) devices are the leading stent grafts for EVAR in the Chinese market. According to the morphology limits set by the IFU, only the Endurant stent graft could be used in patients with a proximal neck length between 10 and 15 mm and an infrarenal neck angulation $\leq 60^\circ$. Compared with the infrarenal fixation of the Excluder device, Endurant and Zenith devices have both been designed with an active suprarenal fixation mechanism based on proximal bare stent and anchor pins to reduce the risk of device migration. In theory, the suprarenal aortic neck is less likely to dilate over time; thus, transrenal bare-metal stents might provide additional and durable fixation. For this reason, many vascular surgeons believe that suprarenal fixation is better for treating patients with short proximal aortic necks. However, in a recent study comparing the midterm performance of two specific types of endograft systems utilizing two different fixation methods

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(transrenal and infrarenal), it was demonstrated that there were no differences in the rates of migration, AAA sac stability, and other associated complications. The midterm results, even in these relatively high-risk EVAR patients, were excellent using both types of stent grafts.¹⁰ Compared with the unique rapid deployment of the Excluder device, the Endurant and Zenith devices are both designed with a tip-capture mechanism that allows for accurate positioning and partial deployment of the stent graft, which would be more suitable for EVAR with a hostile neck. A clinical trial has revealed the similar performances of the Zenith and the Endurant endograft systems in AAAs with hostile infrarenal aortic anatomy.¹¹

Fenestrated EVAR made it possible to treat short-necked and juxtarenal AAAs, and even suprarenal AAAs, totally through endovascular means. A number of published series have demonstrated excellent early and midterm results of the technique.^{12,13} Some Chinese physicians have also used the Zenith custom-made fenestrated stent graft from Cook Medical, which had long been the only fenestrated device approved by the US Food and Drug Administration, with satisfactory results.¹⁴ The fenestrated technique is more complex than standard EVAR and requires advanced catheter skills and imaging measurements. Besides the cost itself, one of the disadvantages of fenestrated grafts is the delay of 4 to 6 weeks or more that is required for device planning, manufacturing, and delivery. Therefore, it is not suitable for urgent cases. Some physicians have modified a standard device using handmade fenestrations and markers.¹⁵ The creation of a standard off-the-shelf device or devices suitable for a majority of aneurysm morphologies would be the main direction for the development of fenestrated grafts. The design of off-the-shelf stent grafts, such as the Ventana system (Endologix, Inc., Irvine, CA) and the Anaconda endograft (Vascutek Ltd., Inchinnan, UK), had been based on aortic anatomical studies, and the fenestrations were standardized.¹⁶ The Ventana stent is covered with expanded polytetrafluoroethylene, except on a 4-cm-length proximal scallop with radiopaque markers intended to encompass the superior mesenteric artery and celiac arteries. Unique to this device, the stent graft has two nonreinforced, 3-mm-diameter fenestrations, which



Figure 2. A CTA scan revealed a type IA endoleak after EVAR (A). The type IA endoleak was treated with a proximal cuff and chimney stents in the bilateral renal arteries (B). A follow-up CTA scan demonstrated no endoleak and the patency of the chimney stents (C).

can be expanded to 10 mm in diameter and are movable to accommodate a wide range of renal artery anatomies. Recent research shows that standardized fenestrated designs suitable for endovascular treatment of > 70% of patients with juxta- and pararenal aneurysms currently treated with custom-made fenestrated endografts will soon be available.¹⁷ However, the anatomical characteristics and morphometric features of the abdominal aorta and its branches were initially recorded from western patients. Fenestrated devices should be carefully assessed before their introduction into the Chinese market.

Because many Chinese centers do not have balloon-expandable covered stents, such as the Jostent (Abbott Vascular, Santa Clara, CA) or iCast (Maquet Vascular Systems, Hudson, NH) devices, fenestrated stent grafts are not as popular as the chimney/snorkel technique in China. The latter technique is based on the deployment of a covered or bare-metal stent parallel to and outside of the main aortic endograft, extending distally into the side branch that is to be preserved (Figure 2). The proximal seal thus depends on conformation of the main body aortic endograft and the aortic wall around the chimney stent graft. Although this technique should be viewed as a complementary therapy, one major advantage is the use of standard EVAR devices that offers an option in some patients with acute disease.

The chimney technique has some special anatomical inclusion and exclusion criteria. Severe angulation in the aortic arch and the descending thoracic aorta is a relative contraindication. However, compared to the fenestrated stent graft, the chimney technique can handle sharp renal artery takeoffs much more easily, as the approach is from above. This technique is gaining greater acceptance;¹⁸ however, the current published experience is limited.¹⁹ Longer

follow-up is clearly needed to understand whether the unavoidable gutters between chimney stents and main stent grafts present a risk for type I endoleak in the long term. Some investigators have suggested that two chimney grafts are the maximum number that can be used without compromising the proximal seal,²⁰ but another analysis did not reveal a significantly increasing incidence of early type I endoleak in patients undergoing chimney grafts of three or four visceral vessels.²¹ The maximum number of chimney grafts, the difference between covered and bare chimney stents, and the proximal neck anatomy required to safely achieve a proximal seal should all be investigated systematically. The chimney technique was also associated with an increased ischemic risk for branches. A small proportion of the chimney vessels showed thrombosis or stenosis during follow-up, which could be managed with either angioplasty and repeat stenting or extra-anatomic bypass.

ANGULATED PROXIMAL NECK

The aorta can angulate in several directions (dimensions) simultaneously. Two neck angles are evaluated in the preoperative evaluation. *Suprarenal neck angulation* refers to an angle measured between the long axis of the immediate suprarenal aorta and the infrarenal aorta. The second angle is aortic neck angulation. This is measured between the long axis of the infrarenal neck to the long axis of the AAA. For most EVAR devices, aortic neck angulation is one of the most important parameters of the landing zone, whereas suprarenal neck angulation is more important to the application of stent grafts with suprarenal fixation or fenestrated stent grafts.

The relationship between these two angles is also of value. Opposing angles will result in opposing forces on the most proximal part of the stent grafts, possibly

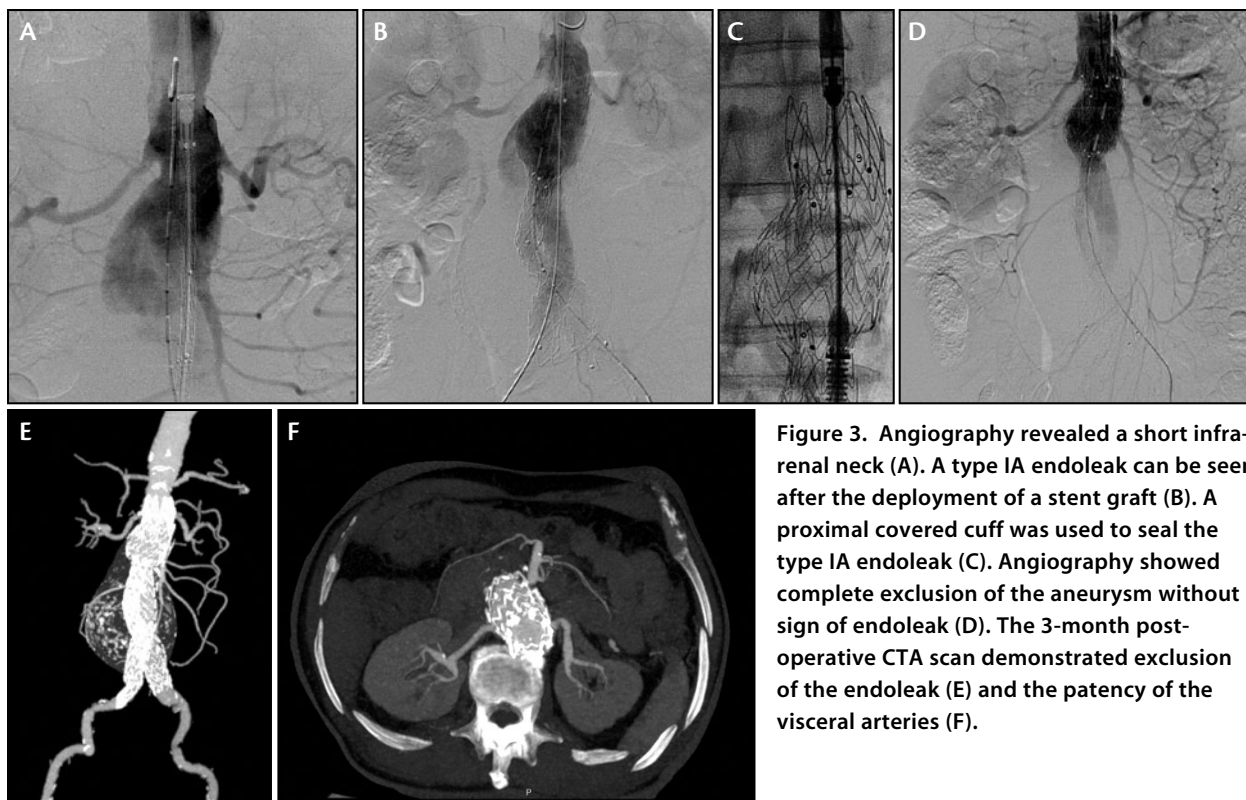


Figure 3. Angiography revealed a short infrarenal neck (A). A type IA endoleak can be seen after the deployment of a stent graft (B). A proximal covered cuff was used to seal the type IA endoleak (C). Angiography showed complete exclusion of the aneurysm without sign of endoleak (D). The 3-month post-operative CTA scan demonstrated exclusion of the endoleak (E) and the patency of the visceral arteries (F).

influencing the sealing and fixation of the endograft. To minimize the influence of angulation itself on angle measurements, an angle should be measured perpendicular to the aortic axis in the middle of the flexure. The aortic center lumen line reconstructions are of great help and should be adopted, especially in challenging proximal anatomy.²² This center lumen line allows precise diameter and length measurements alongside the proximal aortic neck, as well as determines the C-arm position during the EVAR procedure.

The Excluder stent graft has a fully supporting sinusoidal stent design and sutureless attachment between the stent and graft. This combination provides flexibility and enables the Excluder device to adapt to the AAA proximal neck once deployed. This important feature makes the Excluder stent graft the most frequently used device in long proximal necks with severe angulation. Compared with the Zenith and Excluder stent grafts, the length of the first covered stent just below the proximal bare stent for the Endurant device is the shortest (8 mm). Also, the M-shaped proximal sealing stent provides the Endurant stent graft adequate fixation and high conformability. So, in our center, the Endurant device has become the first choice for a short proximal neck with severe angulation. Recently, the US Food and Drug Administration approved the Ovation stent graft system (TriVascular,

Inc., Santa Rosa, CA) for short necks and Aorfix (Lombard Medical Technologies PLC, Oxfordshire, UK) for neck angulations up to 90°. Except for the active fixation with suprarenal stent and integral anchors, the Ovation aortic body contains a network of inflatable channels and sealing rings that are filled with polymer that cures in situ to create a conformable seal during deployment. The Aorfix stent graft has a unique coil design that gives it unrivalled flexibility, enabling it to be used in patients with tortuous anatomies. New-generation endografts may offer solutions for sealing and stability in difficult cases.

Previous reports have shown that endovascular treatment of aneurysms with challenging neck anatomy is associated with the need for adjunctive procedures, such as angioplasty or uncovered stent and extension cuff placement to achieve proximal seal.²³ All of these procedures reflect the anatomic complexity and the requirement for physician experience. A Lunderquist wire (Cook Medical) can exert large forces and help to advance the endovascular device through the tortuous segment, but this extra-stiff wire can also straighten the angulated neck and significantly alters the geometry of the vessel. In patients with highly angulated necks, we typically prefer to use the Amplatz Super Stiff wire (Boston Scientific Corporation, Natick, MA), which could align with the anatomy of the aneurysm during the delivery and deployment of the stent

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graft. Routine ballooning at the juxtarenal neck and suprarenal barbs could aid the apposition between the stent graft and the native aortic neck wall. To further reduce the risk of proximal endoleaks after EVAR for patients with unfavorable neck anatomy, the prophylactic use of Palmaz (Cordis Corporation, Bridgewater, NJ) or Max (Covidien, Mansfield, MA) stents has been suggested by some physicians. The balloon-expandable stent could straighten out the angulated aortic neck and improve the seal at the interface between the stent graft and the aortic wall. However, the long-term effects of oversizing the fixation to prevent migration remain controversial. Because the giant Palmaz stents are not available in China, we preferentially use proximal covered cuffs to seal type IA endoleaks that are detected either on completion angiography or during follow-up (Figure 3). Especially when the stent graft has been undersized or maldeployed, there may be sufficient proximal neck length (> 5 mm) to place a proximal extension cuff. Care must be taken to preserve the renal artery while still achieving proximal seal.

Some manufacturers have recently developed endoluminal aortic staples (endostaples or endoanchors) to aid device fixation in unfavorable necks. The HeliFX aortic securement system (Aptus Endosystems, Inc., Sunnyvale, CA) has been approved in Europe and the United States for use as an adjunctive measure during the primary and reintervention procedure to enhance proximal migration resistance. The early results of this method have been promising.²⁴

CONCLUSION

All of these findings have underlined the importance of proper patient selection and careful morphometric assessment of the AAA proximal neck before an endograft is used outside the specific IFU. The off-label use of commercially available stent grafts may thwart EVAR outcomes and increase the rate of complications. But there is no doubt that with continued improvement in device design, later-generation devices will be developed to provide more accurate deployment systems, better conformability, and optimal fixation. The future is bright, especially for off-the-shelf fenestrated grafts. ■

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1. Parodi JC, Palmaz JC, Barone HD. Transfemoral intraluminal graft implantation for abdominal aortic aneurysms. *Ann Vasc Surg.* 1991;5:491-499.
2. Lederle FA, Freischlag JA, Kyriakides TC, et al. Outcomes following endovascular vs open repair of abdominal aortic aneurysm: a randomized trial. *JAMA.* 2009;302:1535-1542.
3. Jackson RS, Chang DC, Freischlag JA. Comparison of long-term survival after open vs endovascular repair of intact abdominal aortic aneurysm among Medicare beneficiaries. *JAMA.* 2012;307:1621-1628.
4. Choke E, Munneke G, Morgan R, et al. Outcomes of endovascular abdominal aortic aneurysm repair in patients with hostile neck anatomy. *Cardiovasc Intervent Radiol.* 2006;29:975-980.
5. Aburahma AF, Campbell JE, Mousa AY, et al. Clinical outcomes for hostile versus favorable aortic neck anatomy in endovascular aortic aneurysm repair using modular devices. *J Vasc Surg.* 2011;54:13-21.
6. Stather PW, Sayers RD, Cheah A, et al. Outcomes of endovascular aneurysm repair in patients with hostile neck anatomy. *Eur J Vasc Endovasc Surg.* 2012;44:556-561.
7. Antoniou GA, Georgiadis GS, Antoniou SA, et al. A meta-analysis of outcomes of endovascular abdominal aortic aneurysm repair in patients with hostile and friendly neck anatomy. *J Vasc Surg.* 2013;57:527-538.
8. Schanzer A, Greenberg RK, Hevelone N, et al. Predictors of abdominal aortic aneurysm sac enlargement after endovascular repair. *Circulation.* 2011;123:2848-2855.
9. van Keulen JW, van Prehn J, Prokop M, et al. Dynamics of the aorta before and after endovascular aneurysm repair: a systematic review. *Eur J Vasc Endovasc Surg.* 2009;38:586-596.
10. Hager ES, Cho JS, Makaroun MS, et al. Endografts with suprarenal fixation do not perform better than those with infrarenal fixation in the treatment of patients with short straight proximal aortic necks. *J Vasc Surg.* 2012;55:1242-1246.
11. Antoniou GA, Georgiadis GS, Glancz L, et al. Outcomes of endovascular aneurysm repair with 2 different endograft systems with suprarenal fixation in patients with hostile infrarenal aortic anatomy. *Vasc Endovascular Surg.* 2013;47:9-18.
12. Verhoeven EL, Vourliakis G, Bos WT, et al. Fenestrated stent grafting for short-necked and juxtarenal abdominal aortic aneurysm: an 8-year single-centre experience. *Eur J Vasc Endovasc Surg.* 2010;39:529-536.
13. Amiot S, Haulon S, Becquemin JP, et al. Fenestrated endovascular grafting: the French multicentre experience. *Eur J Vasc Endovasc Surg.* 2010;39:537-544.
14. Guo W, Zhang HP, Liu XP, et al. Fenestrated endovascular aortic repair for juxtarenal abdominal aortic aneurysm. *Chin Med J (Engl).* 2013;126:409-414.
15. Starnes BW. Physician-modified endovascular grafts for the treatment of elective, symptomatic, or ruptured juxtarenal aortic aneurysms. *J Vasc Surg.* 2012;56:601-607.
16. Mertens R, Bergoeing M, Mariné L, et al. Ventana fenestrated stent-graft system for endovascular repair of juxtarenal aortic aneurysms. *J Endovasc Ther.* 2012;19:173-178.
17. Sobocinski J, d'Utra G, O'Brien N, et al. Off-the-shelf fenestrated endografts: a realistic option for more than 70% of patients with juxtarenal aneurysms. *J Endovasc Ther.* 2012;19:165-172.
18. Donas KP, Torsello G, Bisdas T, et al. Early outcomes for fenestrated and chimney endografts in the treatment of pararenal aortic pathologies are not significantly different: a systematic review with pooled data analysis. *J Endovasc Ther.* 2012;19:723-728.
19. Katsargyris A, Oikonomou K, Klonaris C, et al. Comparison of outcomes with open, fenestrated, and chimney graft repair of juxtarenal aneurysms: are we ready for a paradigm shift? *J Endovasc Ther.* 2013;20:159-169.
20. Bruen KJ, Feezor RJ, Daniels MJ, et al. Endovascular chimney technique versus open repair of juxtarenal and suprarenal aneurysms. *J Vasc Surg.* 2011;53:895-904.
21. Antoniou GA, Schiro A, Antoniou SA, et al. Chimney technique in the endovascular management of complex aortic disease. *Vascular.* 2012;20:251-261.
22. van Keulen JW, Moll FL, Tolenaar JL, et al. Validation of a new standardized method to measure proximal aneurysm neck angulation. *J Vasc Surg.* 2010;51:821-828.
23. Grisafi JL, Rahbar R, Nelms J, et al. Challenging neck anatomy is associated with need for intraoperative endovascular adjuncts during endovascular aortic aneurysm repair (EVAR). *Ann Vasc Surg.* 2011;25:729-734.
24. Perdikides T, Melas N, Lagios K, et al. Primary endoanchoring in the endovascular repair of abdominal aortic aneurysms with an unfavorable neck. *J Endovasc Ther.* 2012;19:707-715.