Snorkel/Chimney Versus Fenestrated Endovascular Aneurysm Repair:
What Works and When?

A discussion of the two most commonly utilized advanced endovascular techniques to combat hostile proximal neck anatomy.

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Up to 30% to 40% of patients are unsuitable anatomic candidates for conventional endovascular aneurysm repair (EVAR), most commonly due to challenging proximal aortic neck anatomy.[1] With increasing operator experience and significant advances in endovascular technology, a rapidly expanding array of complex endovascular strategies has evolved to address the issue of proximal neck fixation. These strategies include the deployment of conventional infrarenal aortic stent grafts outside the instructions for use of the device, homemade and physician-modified endografts, snorkel/chimney approaches with parallel covered stents, and utilization of customized fenestrated endografts.

The conceptual basis for complex EVAR involves cranial extension of the proximal seal zone with preservation of branch vessel patency, thereby expanding the applicability of aortic endografts from the infrarenal to the suprarenal aorta. Snorkel/chimney EVAR and fenestrated EVAR (FEVAR) currently represent the two most commonly utilized advanced endovascular techniques to combat hostile proximal neck anatomy. Despite excellent early and midterm outcomes using both of these strategies,[2-7] uncertainties remain regarding the sustained durability of these endovascular approaches. This article highlights several patient and anatomic variables that may favor one approach over the other in this select group of patients with challenging aortic neck morphology, thereby facilitating a more efficient endovascular repair and optimizing long-term clinical outcomes.

SNORKEL/CHIMNEY EVAR
Technique

First described by Greenberg and colleagues,[8] the snorkel approach was originally developed as a bailout procedure using balloon-expandable bare-metal stents for accidental coverage of renal arteries during deployment of aortic main body devices requiring close approximation to renal ostia. Inadvertent partial or complete coverage of one or more renal arteries during such cases prompted post hoc renal artery catheterization and stenting. Recognizing the importance of a quality proximal seal zone, planned unilateral or bilateral renal artery coverage and subsequent renal artery stenting in conjunction with EVAR evolved as an alter-

native treatment for those with unfavorable neck anatomy and an inadequate infrarenal seal zone. The largest collected world experience of snorkel/chimney EVAR was recently published from the PERICLES registry, which included 898 chimney grafts in 517 patients and noted an early mortality rate of 4.9%, as well as a persistent type Ia endoleak rate of 0.4% and primary patency of 94% during a mean follow-up of 17.1 months.[9]

The terms *chimney, periscope,* and *snorkel* are often used interchangeably and are occasionally referred to categorically using the acronym CHIMPS. The flow directionality of the conduit defines the basis for each term. A chimney or snorkel configuration requires antegrade catheterization from a transbrachial approach to facilitate placement of a covered stent into one or more branch vessels in a parallel course adjacent to the main intra-aortic stent graft. The proximal portion of the snorkel stent(s) extends above the proximal edge of the main aortic stent graft, thereby extending the proximal seal zone in a short or no-neck aortic aneurysm. In contrast, a periscope configuration features retrograde catheterization of the branch vessel(s) from a transfemoral approach, such that the distal aspect of the parallel branch vessel stent graft extends beyond the distal margin of the main aortic stent graft. This periscope configuration permits caudal extension of the distal seal zone, most commonly used in the setting of thoracoabdominal aneurysms. The related sandwich technique incorporates snorkel or periscope branch vessel stents between two main aortic stent grafts to preserve branch vessel patency in the mid-graft position and is used as an alternative to hypogastric and thoracoabdominal branched grafts.

When Snorkel/Chimney EVAR Works

Urgent cases. As a result of the lack of available off-the-shelf fenestrated devices, one of the primary advantages of the snorkel/chimney technique is the ability to use this approach in the urgent or emergent setting for patients presenting with symptomatic, rapidly expanding, or ruptured abdominal aortic aneurysms (AAAs). Moreover, the technical requirements of this approach are less demanding compared to the fenestrated approach, therefore offering the potential for decreased procedural duration and less fluoroscopy time among most operators.[10]

Hostile iliofemoral access. Small, calcified, and/or tortuous iliofemoral systems can prohibit safe advancement of any endovascular prosthesis. The Zenith fenestrated AAA endovascular graft (Cook Medical), serving as the only device of its kind approved by the US Food
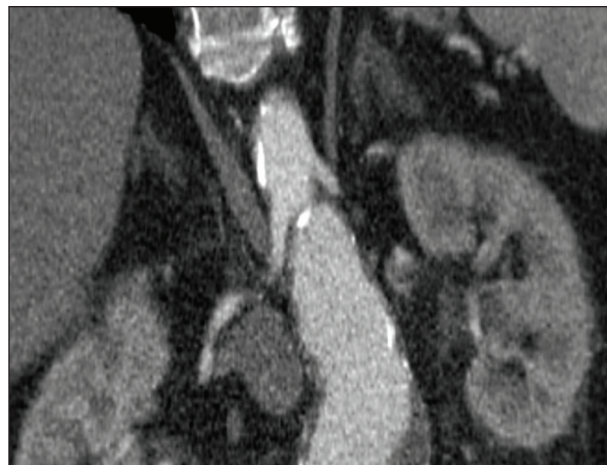
Figure 1. Renal arteries with significant caudal angulation can be challenging to catheterize from a retrograde approach in FEVAR and may instead favor the antegrade approach used in snorkel/chimney EVAR.

and Drug Administration, requires a larger delivery sheath profile (20-F inner diameter/7.7-mm outer diameter or 22-F inner diameter/8.5-mm outer diameter) relative to the majority of other commercially available standard EVAR devices. When small-caliber iliofemoral arteries serve as the major limiting factor, snorkel/chimney EVAR can provide an alternative endovascular solution by allowing utilization of a standard EVAR device, which typically features main body delivery profiles ranging from 14 to 18 F. In addition, the rigidity of the larger fenestrated delivery system may also hinder trackability of the device in iliac systems with severe tortuosity and make snorkel/chimney EVAR a better option in cases with challenging access anatomy.

Caudal-directed renal arteries. Significant variability exists with regard to normal renal artery anatomy, particularly as it relates to branch vessel angulation (commonly defined as the angle above or below the orthogonal plane perpendicular to the aortic wall at the midpoint of the renal ostia). We recently explored the impact of renal artery angulation on procedural efficiency during both FEVAR and snorkel/chimney EVAR.[11] A total of 111 renal artery cannulations were performed (39 FEVAR and 72 snorkel/chimney EVAR) among 77 complex EVAR cases, with a median renal artery angulation of −33° (range, +37° to −60°) for FEVAR and −32° (range, +22° to −65°) for snorkel/chimney EVAR. As expected, the antegrade approach in snorkel/chimney EVAR facilitated catheterization of caudal-directed (or downward) renal arteries as evidenced by the fact that renal artery cannulation

Figure 2. The close proximity of the SMA and most cranial renal artery in this large pararenal aneurysm prohibits construction of a customized fenestrated device.

was performed significantly faster in cases with greater downward (> −30°) angulation (10.9 vs 17.3 minutes; $P = .05$). Renal cannulation time in snorkel/chimney EVAR was defined from the initial introduction of the sheath in the exposed high brachial or axillary artery until the 7-F sheath was delivered into the renal ostium (Figure 1).

Target vessel stenosis. The presence of ostial occlusive lesions can add significant difficulty in wire catheterization and stent placement in target vessels. This

added complexity may translate into increased fluoroscopy time, contrast usage, procedural duration, as well as worse end-organ function and clinical outcomes due to potential atheroembolism to the visceral or renal arteries.

Close proximity of superior mesenteric artery and most cranial renal artery. A variety of anatomic limitations can preclude the construction of a customized fenestrated device, including close proximity of the superior mesenteric artery (SMA) and the most cranial renal artery (Figure 2). Although there is no exact minimum distance between the SMA and most cranial renal artery, the distance and orientation of these two vessels need to fit within the handful of Zenith fenestrated AAA endovascular graft engineering rules. Large fenestrations must be 10 mm from the proximal edge and can sometimes be used when the renal arteries and the SMA are close together; however, these large fenestrations will always have struts crossing them. Small fenestrations, on the other hand, require a minimum distance of 15 mm from the proximal edge. As a general rule, a 2-hour separation should be present between the SMA and most cranial renal artery, but this may vary depending on the inner aortic diameter. For cases involving anatomy that prohibits construction of a customized fenestrated device, a snorkel approach (alone or in combination with a fenestration/scallop for the visceral vessel[s]) may still permit endovascular repair (Figure 3).

Courtesy of Jason T. Lee, MD.
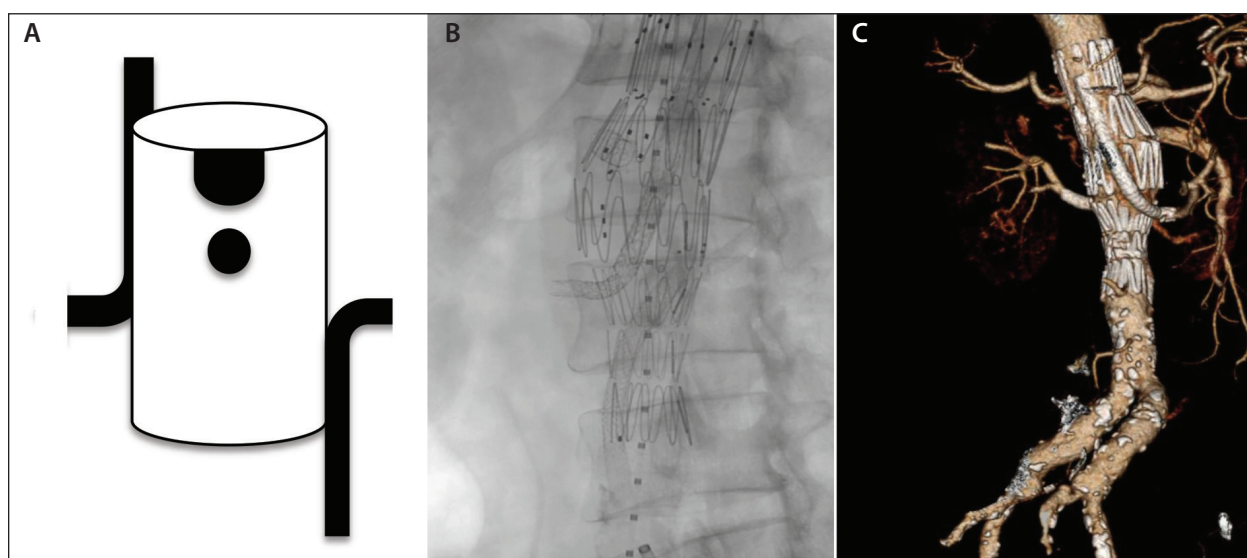
Figure 3. An example of a combined parallel graft (renal snorkel and periscope) and fenestrated approach (celiac scallop and SMA fenestration) that may be used for pararenal and suprarenal aneurysms having anatomy not amenable for construction of a standard fenestrated device. Schematic (A), intraoperative fluoroscopy (B), and 1-year follow-up CT angiography (C).

Prior aortic reconstruction. In patients with previous open or endovascular aortic reconstruction, there commonly exists only a short distance between the proximal main body (or proximal anastomosis in the case of open repair) and the flow divider/graft bifurcation. FEVAR may be prohibited in such cases, given that the proximal main body may be too long and will "jail" the contralateral limb. The minimum proximal main body graft length required to sit above the flow divider is 76 mm (up to 129 mm for larger diameters) for fenestrated devices with one internal sealing stent and 94 mm (up to 137 mm for larger diameters) for devices with two internal sealing stents. In addition to an excessively long main body graft length, FEVAR can also be challenging in patients who have had prior aortic endografts with suprarenal fixation because the suprarenal barbs and struts can cross over the branch vessel ostia and hinder alignment of fenestrations and/or scallops. Snorkel/chimney EVAR can, at times, circumvent both of these issues as it allows for utilization of a standard EVAR device, which features main body graft lengths as short as 40 mm above the flow divider. Branch vessels can typically be cannulated, and snorkel stents can be deployed relatively easily, even in the presence of a previous aortic stent graft with suprarenal fixation. Occasionally, balloon predilation of the struts may be required to allow advancement of a 6- or 7-F sheath into the branch vessel before snorkel stent deployment.

Tortuous visceral aortic segment. The instructions for use for the Zenith fenestrated device restrict implantation to suprarenal neck and aortic neck angulations < 45°. A hostile visceral aortic segment with calcium, thrombus, and severe tortuosity can significantly impede complex EVAR, regardless of endovascular strategy. There are several distinct disadvantages to FEVAR in this setting, particularly the difficult task of navigating a relatively large, rigid device into a tortuous segment that demands precise alignment to the branch vessel origins. Failure to account for even seemingly mild neck tortuosity during preoperative planning may contribute to misalignment of the fenestrations/scallops and subsequent target vessel occlusion. Even in the absence of significant visceral aortic tortuosity, misalignment (or "shuttering") of the SMA scallop has been reported to occur in up to 50% of FEVAR cases.[12] Although renal artery shuttering is less of a concern due to routine composite stenting in this location, poor alignment of the fenestrations with the branch vessels will lead to a more tortuous course of the branch vessel stents and potentially contribute to worse long-term durability due to stent kinking or fracture. Increased

aortic tortuosity further limits maneuverability and predictability of the final endograft position, which may be less detrimental during snorkel/chimney EVAR because the branch vessels are stented independently from the aortic segment, and there is no concern for visceral/renal misalignment.

FEVAR
Technique

The Zenith fenestrated endovascular device has a modular design consisting of three primary components: a proximal main body graft, a distal bifurcated main body graft, and one iliac limb. Each component is composed of full-thickness woven polyester fabric and self-expanding stainless steel stents that are secured together as a composite endograft using braided polyester and monofilament polypropylene suture. The proximal main body component may accommodate a combination of up to three fenestrations or scallops, thereby maintaining visceral arterial patency and facilitating a more proximal sealing position compared to standard EVAR devices. The two most common endograft configurations involve a single scallop for an asymmetrically positioned renal artery or two renal fenestrations and a single scallop for the SMA. A scallop represents a U-shaped gap within the proximal fabric of the stent graft; all scallops are 10-mm wide and have heights ranging from 6 to 12 mm, with the most common choice being a 12-mm height. In contrast, fenestrations are circular or elliptical holes within the proximal main body
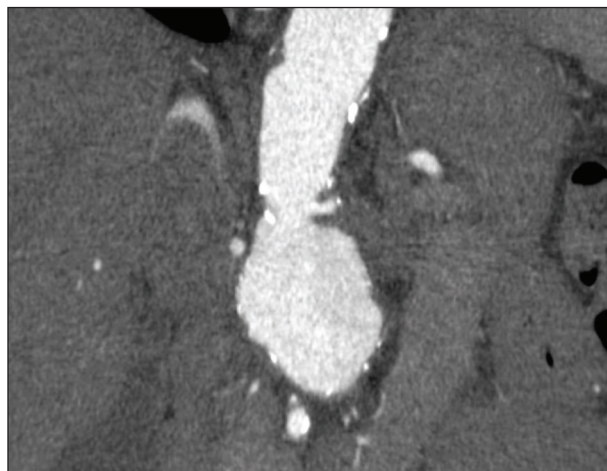

Figure 4. The cranially directed left renal artery in this juxtarenal AAA may preclude antegrade catheterization in snorkel/chimney EVAR and/or subject a snorkel stent to excessive bending at the origin of the target vessel. This renal angulation may be more suitable to retrograde catheterization using a fenestrated approach.

fabric. The fenestrations are either small (elliptical shape with 6-mm width and height measuring 6 or 8 mm) and fit entirely between the struts of the seal stent or large (circular shape with diameters measuring 8, 10, or 12 mm) and cross struts of the seal stent. In accordance with the instructions for use for this device, it is recommended that all vessels accommodated by a small fenestration be stented in order to optimize and secure proper alignment of the fenestration with the ostium of the visceral vessel.

Technical details regarding implantation of fenestrated endovascular AAA devices have previously been described.[6,13] The technique begins preoperatively with custom design of the scallop and fenestrations relative to clock positions and at chosen distances from the proximal edge of the fabric. During the actual procedure, the proximal main body is introduced, with proper rotational orientation confirmed by the overlap of an anterior row of vertical and a posterior row of horizontal markers to form a cross. Correct orientation is also confirmed with reference to the marginal radiopaque markers of the renal fenestrations and SMA scallop. Selective catheterization of the target visceral vessels is performed at this time and confirmed using a small contrast medium injection. Sheaths are advanced into all target vessels and prepositioning of stents within the sheaths, where applicable, is performed before endograft deployment. It is our practice to place covered stents within target vessels accommodated by small fenestrations. We do not routinely stent target vessels accommodated by either scallops or large fenestrations. The proximal main body graft is deployed at this time. Stents are flared approximately 5 mm within the aortic lumen to enhance fixation and minimize the risk of endoleak. Completion angiography following assembly and deployment of all modular components is performed to document target vessel patency and the presence of any endoleak.

When FEVAR Works

Elective only. Excluding physician-modified endografts ("backtable fenestrations"), which are primarily limited to operators who have a physician-sponsored investigational device exemption, commercially available customized Zenith fenestrated endovascular devices require a minimum of 3 to 4 weeks to manufacture and deliver. As such, routine FEVAR is presently limited to elective cases only. The Zenith pivot branch (p-branch) device (Cook Medical) is in active clinical trials and is predicated to alleviate this barrier in the near future, as it represents an off-the-shelf standard fenestrated device that is compatible with the majority of anatomies.[14]
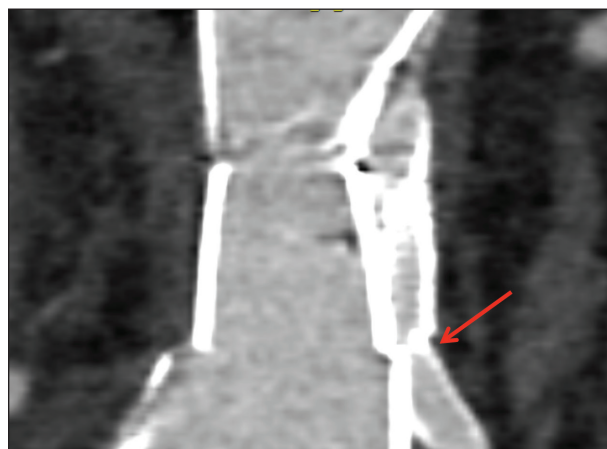

Figure 5. Snorkel stent with evidence of kinking at the left renal artery ostium on postoperative surveillance imaging.

Cranially directed renal arteries. Although caudal-directed renal arteries are more amenable to catheterization from an antegrade approach (as seen in snorkel/chimney EVAR), the retrograde approach in FEVAR facilitates catheterization of more cranially directed, or upward, renal arteries (Figure 4). In our previous report,[11] renal artery cannulation time in FEVAR began with the introduction of the 7-F sheath into the contralateral femoral sheath and ended when a 7-F Flexor Ansel sheath (Cook Medical) was placed into the renal ostium through the corresponding renal fenestration. We noted that renal cannulation was performed significantly faster in cases with less downward (≥ −30°) renal artery angulation (16 vs 32.8 minutes; $P = .04$). FEVAR cases involving ≥ −30° renal artery angulation were also associated with significantly shorter procedural time (187.7 vs 246.2 minutes; $P = .01$) and decreased fluoroscopy time (70.3 vs 98.2 minutes; $P = .04$) compared to those with more downward (< −30°) angulation.

Upper extremity occlusive disease. Axillosubclavian occlusive disease can prohibit safe passage of one or more delivery sheaths to the renal or visceral vessels during snorkel/chimney EVAR. Each snorkel stent typically requires a separate 6- or 7-F guiding sheath to be delivered from either the brachial or axillary artery. In cases involving multiple snorkel stents (particularly in those who have small-caliber, heavily calcified vessels), options are limited primarily to either utilization of an axillary conduit to facilitate antegrade cannulation in snorkel/chimney EVAR or avoiding the upper extremity altogether in favor of a retrograde approach using FEVAR. Using FEVAR in cases with extensive upper extremity occlusive disease eliminates both the risk of

upper extremity atheroembolic access site complications and excessive manipulation in the aortic arch.

Difficult arch. Challenging aortic arch anatomies, including some bovine and type III arch configurations, may significantly affect the ability to perform visceral and/or renal cannulation from an antegrade approach. The addition of arch and descending aortic calcification further compounds these anatomic challenges. FEVAR is an attractive option in such cases, as it obviates the need to manipulate the aortic arch and, as a result, should minimize the overall risk of periprocedural stroke and distal embolization.

Atheromatous ("shaggy") thoracic aorta. Due to the risk of distal embolization, a thoracic and/or abdominal aorta heavily laden with atheroma should prompt pause when considering any endovascular intervention. Although extremely rare, fatal diffuse atheromatous embolization following conventional EVAR has been reported.[15] FEVAR serves as a safer option in cases involving a "shaggy" thoracic aorta rich in mobile atheromatous plaque or intramural thrombus because wire and catheter manipulation of the thoracic aorta is minimized.

Proximal renal artery branching and/or baseline renal impairment. Target vessel stents in FEVAR are generally shorter in length, straighter, and situated in a position more closely reflecting native anatomy. In contrast, snorkel stents are typically longer and have a more unpredictable course relative to the main aortic stent graft. These longer snorkel stents may require covering an early renal branching point and may force an acute bend, or kink, of the stent at the target vessel ostium (Figure 5), thereby predisposing to differential effects on long-term renal artery patency, integrity, and renal function.[16] We recently performed a geometric analysis of renal artery anatomy following complex EVAR and noted snorkel/chimney EVAR to induce a significantly greater change in angle at the stent end and change in curvature distal to the stent compared to FEVAR, although no difference in patency was noted due to the modest sample size and relatively short follow-up.[17] Early renal function decline of varying severity has been reported to be a relatively frequent occurrence following both snorkel/chimney EVAR and FEVAR; however, most series have reported renal complication rates that closely approximate those of open surgery.[18-20] Given the absence of long-term renal function and patency data following complex EVAR, the relative benefit of the more favorable renal stent con-

figuration in FEVAR over snorkel/chimney EVAR, as it relates to preservation of renal function and stent graft patency, remains theoretical at this time.

CONCLUSION

Snorkel/chimney and fenestrated endovascular techniques serve as valid solutions to hostile aortic neck anatomy based on available short- and midterm results. Although superiority of one technique over the other has yet to be determined, there are specific clinical and anatomic situations that may favor one technique relative to ergonomics, acuity, thromboembolic risk, and procedural efficiency. ∎

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