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Review

Fenestrated Endovascular Aneurysm Repair versus Snorkel Endovascular Aneurysm Repair: Competing yet Complementary Strategies

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Juxtarenal/pararenal aortic aneurysms and type IV thoracoabdominal aneurysms pose particular technical challenges for endovascular repair as they involve the visceral segment in addition to insufficient infrarenal neck for the use of standard endovascular aneurysm repair (EVAR) devices. To overcome these challenges, complex EVAR techniques have been developed to extend the proximal landing zone cephalad with maintaining perfusion to vital aortic branches, thereby broadening the applicability of endografting from the infrarenal to the suprarenal aorta. Complex EVAR can be divided into two broad categories: fenestrated endovascular aneurysm repair (FEVAR) and snorkel EVAR. FEVAR is a valid procedure with the standardized procedure, although it remains as a relatively complex procedure with a learning curve. Given time constraints for the custom fenestrated graft, snorkel EVAR may be an alternative for complex repairs in symptomatic or ruptured patients for whom custom-made endografts may not be immediately available. This article discusses these two most commonly used complex EVAR strategies.

Key Words: Complex aortic aneurysms, Fenestrated, Endovascular repair, Snorkel

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INTRODUCTION

With the advent of endovascular techniques, endovascular aneurysm repair (EVAR) has largely replaced open surgical repair for anatomically suitable abdominal aortic aneurysm (AAA) [1-3]. However, approximately one-third of patients presenting with AAAs are deemed unsuitable for conventional EVAR because of anatomic constraints most often related to proximal neck anatomy [4,5]. In two-third of these patients with challenging anatomy, the proximal neck is less than the required 10 to 15 mm or is unsuitable as a proximal landing zone [6,7]. Complex AAAs, comprised of juxtarenal/pararenal AAAs and often grouped with type IV thoracoabdominal aneurysms (TAAAs), pose particular technical challenges for endovascular repair as they involve the visceral segment in addition to insufficient infrarenal neck for the use of standard EVAR devices [8]. To overcome these challenges, complex EVAR techniques have been developed to extend the proximal landing zone cephalad with maintaining perfusion to vital aortic branches, thereby broadening the applicability of endografting from the infrarenal to the suprarenal aorta.

Complex EVAR can be divided into two broad categories: fenestrated endovascular aneurysm repair (FEVAR) and repair with debranching of the renovisceral branches using snorkel/chimney stent grafts followed by complete exclusion using a standard endograft (snorkel EVAR) [9]. This article discusses these two most commonly used complex EVAR strategies, with particular attention to several variables that may favor one strategy over the other.

FEVAR

FEVAR was first reported in 1999 for the treatment of a juxtarenal aortic aneurysm [10]. In 2001, Anderson et al. [11] published the first series of EVAR experience incorporating the renal and the superior mesenteric artery (SMA) with fenestrations in 13 patients with juxtarenal aortic aneurysm. In the United States (US), after a prospective trial at 14 United States academic centers, the Zenith Fenestrated stent graft (ZFEN; Cook Medical Inc., Bloomington, IN, USA) was approved by the US Food and Drug Administration (FDA) for commercial use in April 2012 [8].

Since the approval of the device, fenestrated stent grafts have been increasingly used to treat complex aortic aneurysms involving visceral branches [1,2,12]. Recently, O'Donnell et al. [9] analyzed all endovascular repairs of complex AAAs from 2014 to 2018 in the Vascular Quality Initiative (VQI). This study included all commercially available FEVAR, snorkel EVAR, and physician-modified endografts (PMEGs), exclusive of investigational device exemptions and clinical trial devices. There were 880 FEVAR (63%), 256 PMEGs (18%), and 260 snorkel EVAR (19%). While no change in aneurysm extent was noted, the length of proximal seal extended over time. In line with this finding, the number of centers managing complex AAAs using endovascular techniques expanded steadily from 39 in 2014 to 81 in 2017 [9].

Fenestrated device usually consists of three components: a proximal fenestrated component, a distal bifurcated component, and one contralateral limb (Fig. 1) [13]. Fenestrated stent graft components are provided with custom-made fenestrations and scallops. The flow to vital aortic branches is preserved through fenestrations. The most commonly used configuration includes small fenestrations (8×6 mm) for the renal arteries and a scallop (10-mm wide, 12-mm deep) for the SMA. Using a combination of fenestrations and scallops, the proximal landing zone can be extended to the suprarenal aorta, whilst maintaining the patency of the renal and visceral arteries (Fig. 2) [14]. Hence, the absence of an infrarenal neck is no longer a limiting factor. In addition, this composite three-part system allows some sliding between the fenestrated tube and the bifurcated component, which in turn helps to avoid traction on the fenestrations with subsequent risk of crushing the renal arteries [15].

Current anatomic and clinical indications for primary FEVAR include short-necked (4 to 14 mm in length) and juxtarenal/pararenal AAAs. This strategy can also be used to repair previous failed open surgery or EVAR [16]. The

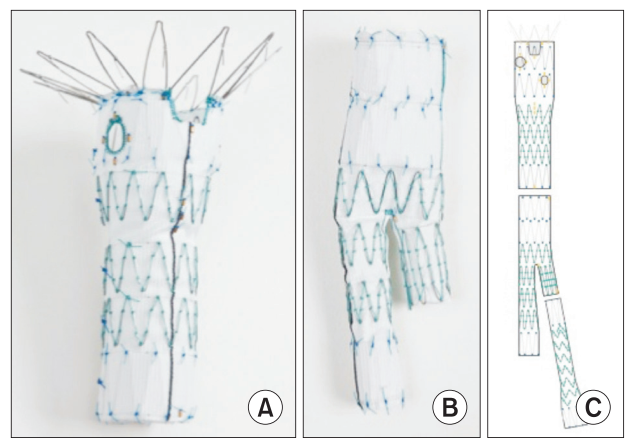

Fig. 1. Zenith fenestrated stent graft (Cook Medical Inc.) consisting of a fenestrated proximal component (A), a bifurcated distal component (B), and a contralateral iliac limb extensions (C). Images from the Cook Medical Inc. with original copyright holder's permission.

Fig. 2. Intraoperative angiogram showing standard Zenith Fenestrated (ZFEN): pre-deployment (A), at completion (B).

technique of implantation of fenestrated stent graft to treat juxtarenal AAAs has been previously described in the literature [15,17,18]. Of note, compared with standard EVAR, FEVAR requires a better access vessel that is large and healthy enough to allow not only insertion of the delivery system, but also repositioning and reorientation to achieve successful catheterization of the target vessels through the fenestrations. Additionally, the anatomy of the target vessels must also be adequate to achieve insertion and sealing with a stent graft. Thus, small caliber (<4 mm), extensive arteriosclerotic disease, early bifurcation and sharp downward take-off are unfavorable anatomic characteristics of a target vessel because catheterization is more difficult [15].

With the increasing application of the FEVAR approach, much data have been collected and outcomes have been assessed. Critical issues that need to be addressed when evaluating FEVAR outcomes include patency of visceral branches, endoleaks, reinterventions, changes in renal function, and prevention of aneurysm rupture. The results of the United States Zenith Fenestrated trial showed a low mortality rate of 1.5% with no aneurysm rupture and with a low rate of renal artery occlusion (4%) [8]. Type Ia endoleak occurred in only one patient at 3 years due to enlargement of the aortic neck. These results have been replicated in systemic reviews, as well as multicenter and single-center series, with high rates of technical success and low morbidity (12%-16%) and mortality (2%-6%) [12,19-22]. Due to the inherent disease progression, approximately 2% to 3% of FEVAR patients will eventually develop a proximal type I endoleak given enough time [23]. Nevertheless, endoleaks from the attachment sites (type I and type III) has been reported to occur in less than 3% of patients [12,22].

Maintaining branch vessel patency is one of the keys to long-term FEVAR success. Midterm branch vessel patency rates in recent literature range from 93% to 98% (at 3-5 years) [24-27]. Mastracci et al. [28] conducted the largest study to date that evaluated the durability of branch vessels after FEVAR. This study included not only short-necked and juxtarenal AAAs, but also more extensive TAAAs. Patency of fenestrated branches was greater than 98% at 5 years. Secondary procedures were performed in only 0.6% of celiac arteries, 4% of SMA, 6% of right renal artery, and 5% of left renal arteries. The 5-year freedom from branch vessel reintervention rate was 89%.

Considering the manipulation of the renal arteries, as well as the use of contrast media used during the procedure and in the repeated follow-up imaging, renal dysfunction following FEVAR has been one of the greatest concerns. According to the long-term data from the Cleveland Clinic, permanent renal function deterioration occurs in 4% to 8% of patients, which is comparable with open repair [29]. In the published literature, the need for hemodialysis after FEVAR ranges from 0% to 6% and varies based on the extent and complexity of the aneurysm repaired [19,22-24].

Beyond anatomic limitations and technical difficulties, there are some disadvantages. First, there is the need for customized devices, requiring a delay of 4 to 6 weeks for device manufacturing, thereby precluding the treatment of patients requiring urgent interventions [30]. To overcome this obstacle, PMEGs have been described with good outcomes [31]. This approach involves creation of fenestrations on a back table with commercially available aortic stent grafts to suit the patient's anatomy. However, this is an off-label use of devices, technically challenging, and, above all, the long-term implications on the durability of the modified device are unknown [32].

Second, due to its design constraints, two-thirds of patients with complex AAAs are not candidate for the ZFEN device, which is the only currently commercially available device in the United States. The maximum of two fenestrations and the use of single-diameter scallops limit the ability to achieve sealing zones above the SMA or celiac axis [33]. Thus, effort has been placed on the creation of off-the-shelf fenestrated devices, and trials of those devices are ongoing in the US [9]. The Ventana Engologix (Endologix, Irvine, CA, USA) design applies the concept of movable fenestrations, with 85% visceral artery incorporation [34]. The p-branch design (Cook Medical Inc.) uses pivot fenestrations with two possible designs that incorporate the visceral arteries in 80% of patients [35]. Mendes et al. [36] recently reported the anatomic feasibility of the aforementioned two off-the-shelf fenestrated stent grafts in 390 patients treated for juxtarenal/pararenal AAAs. In their report, only 42% and 49% of patients met anatomic recommendations for the Ventana fenestrated system (Endologix) and p-branch design, respectively. Thus, additional design options are still desired.

SNORKEL EVAR

The main alternative strategy to compare with FEVAR is the use of snorkel grafts. The term 'snorkel' was given because the imagery of the curved distal end and the straighter proximal end, when deployed into final position, looks like snorkels, and is used interchangeably with 'chimney' [37]. The snorkel technique, first described by Greenberg and colleagues, was originally developed as a rescue procedure of renal arteries accidentally covered by a main aortic endograft during regular EVAR. To maintain sufficient blood flow, in this technique, stent grafts are placed in the inadvertently obstructed artery in a parallel course adjacent to the main aortic stent graft. In doing so,

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the stent graft (snorkel graft) travels in the cranial direction with the proximal portion extending beyond the proximal edge of the main aortic stent graft. This extension of the proximal edge in turn makes it possible to achieve a stable proximal suprarenal proximal landing zone [38]. Resultantly, the snorkel graft lies between the main aortic endograft and the aortic wall. This configuration, however, conduces to the inevitable zones of potentially suboptimal conformation, which are called 'gutters' [39].

Beyond extending the proximal landing zone in a short or no-neck aortic aneurysm, it has the several additional advantages. The most significant advantage is its immediate availability using immediately available off-the-shelf endograft devices [40]. The ability to use off-the-shelf devices designed for smaller access confers another advantage. The use of low-profile devices also helps lower the cost of snorkel EVAR compared to that of FEVAR [41]. In addition, compared to FEVAR where there is a learning curve, this approach is relatively easier due to cannulation of branches without first going through another device/fenestration. Furthermore, the typical downward angle of most renal and visceral vessels makes things easier with the snorkel EVAR strategy.

Like in FEVAR, the length of the proximal landing zone will prescribe which renal and/or visceral vessels require debranching, and thus the number of snorkel grafts required. Unfortunately, however, there is no consensus exists for the maximum number of stent graft that can be employed without compromising the integrity of the procedure. Also, there is the lack of standardization of the technique, with no recommendation as to the most appropriate type of snorkel graft or the best combinations of aortic stent graft and snorkel graft [32,40]. Studies are ongoing to try to identify the best combinations of aortic and branch stent-grafts to minimize theoretical gutter concerns.

In vitro testing by Troisi et al. [42], the combination of Endurant stent graft (Medtronic, Santa Rosa, CA, USA) as a standard aortic device and balloon-expandable covered stent Advanta/iCAST V12 (Atrium Medical, Hudson, NH, USA) as snorkels was shown to be an effective combination in minimizing the presence of gutters. This combination was investigated in the PROTAGORAS study, which included a total of 187 snorkel grafts deployed for the 128 patients with pararenal pathologies. After 2-year radiologic follow-up, the investigators reported that this combination is associated with significant pathologic sac regression and low incidence of new type Ia endoleaks requiring reintervention. Further, the results from this study indicated creation of a proximal landing zone of >15 mm might be sufficient to reduce the risk for late type Ia endoleak and the need for subsequent reintervention. In this study, primary snorkel graft patency was 95.7%, and freedom from snorkel graft-related reinterventions was 93.1% [43].

Another combination that has been suggested in the literature is the use of the Excluder endograft (W.L. Gore & Associates, Flagstaff, AZ, USA) combined with self-expanding covered stents like the Viabahn (W.L. Gore & Associates). It has shown that the Excluder device has similar radial force to the Viabahn, so that it wraps around the snorkel graft more harmoniously and thereby minimizing the risk for persistent gutters [44]. Additionally, in a geometric study of various snorkel graft configurations in an in-vitro juxtarenal aneurysm model, the authors demonstrated the Viabahn is more compressible than the iCAST and thus facilitates a better wrap-around the aortic endograft body, thereby achieving a better seal around the gutter [45]. This combination was used in recent studies, which showed promising results [46,47].

With regard to balloon-expandable versus self-expanding stent grafts used in snorkel procedures, Donas's group compared these two types of stent grafts. In their study, 46 target vessels (43 renal arteries, 3 superior mesenteric arteries) were revascularized by the balloon-expandable Advanta and 81 target vessels (64 renal arteries, 11 superior mesenteric arteries, 6 celiac truks) by the self-expanding Viabahn. Overall, one type Ia endoleak was detected in the Advanta group, whereas 5 type Ia endoleaks were present in the Viabahn group. The authors claimed that this difference was less important because only one of them was persistent and was able to be treated by proximal extension with a cuff. The patency of Advanta group was 97.8% and that of the Viabahn group was 100% in the entire follow-up. Also no patient suffered from a persistent deterioration of the renal function [48].

The technical success and short-term outcomes of snorkel EVAR are well published [46-50]. The largest collected world experience of snorkel EVAR was recently published from the PERICLES registry [51], which included 898 snorkel grafts in 517 patients in 13 centers worldwide. Snorkel EVAR were performed for a pararenal AAA in patients who have anatomic contraindication to FEVAR and/or with an aneurysm requiring immediate repair. Only three (0.6%) late-onset type Ia endoleaks, which were judged to be gutter-related endoleaks, were detected at 6-month but successfully treated by neck lengthening. A 30-day mortality rate of 4.9%, a persistent type Ia endoleak rate of 0.4%, and primary patency of 94% during a mean follow-up of 17.1 months were reported. These numbers are nearly identical to the results from the PROTAGORAS study and also comparable with published results from series of fenestrated grafts.

FEVAR VERSUS SNORKEL EVAR

Few studies have compared the techniques, and some of studies have reported similar results when using FEVAR or snorkel EVAR with regard to technical success, target branch vessel patency, early mortality, type Ia endoleak, postoperative renal dysfunction, or need for secondary intervention [50,52,53]. Banno et al. [40] compared early-term and midterm results of FEVAR and snorkel EVAR with 80 patients undergoing FEVAR and 38 undergoing snorkel EVAR for juxtarenal or pararenal AAAs. The FEVAR and snorkel groups did not differ significantly in 30-day mortality (6.3% after FEVAR vs. 7.9% after snorkel), primary patency of the revascularized vessel rates (71.4% vs. 72.0%), or in moderate to severe complications (27.5% vs. 39.5%). Ducasse et al. [54] conducted a systematic search and included 227 patients (510 target vessels) in the FEVAR group and 126 patients (174 target vessels) in the snorkel EVAR group. The 30-day mortality rate (4.4% after FEVAR vs. 4.8% after snorkel), overall target vessel patency rate at 12-month (97.8% for FEVAR vs. 95.9% for snorkel), and the 12-month rates of type Ia endoleak (1.7% for FEVAR vs. 3.7% for snorkel) did not differ significantly between the techniques.

On the contrary, in the recent report from the O'Donnell group reporting early results from their study in the VQI (a three-arm study also including PMEGs), there was a trend toward higher rates of perioperative death after snorkel (3.4% for FEVAR vs. 2.7% for PMEG vs. 6.1% for snorkel; P=0.13), while rate of AKI remained similar (17% vs. 18% vs. 19%; P=0.42) [9]. Further, in this study, even after adjustment, snorkel was associated with significantly higher odds of stroke (odds ratio [OR], 7.3; P=0.15) and major adverse cardiac events (OR, 11.1; P=0.005). This trend was also shown in a previous meta-analysis study by Katsargyris et al. [50] comparing early results between snorkel EVAR and FEVAR for juxtarenal aortic aneurysms. This study indicated, although not statistically significant, FEVAR (2,465 vessels targeted) emerges with numerically better outcomes than snorkel EVAR (151 vessels targeted) for 30-day mortality (2.4% vs. 5.3%) and also for renal dysfunction (9.8% vs. 12%). In the same study, early proximal type Ia endoleak was also lower after FEVAR compared to snorkel EVAR (4.3% vs. 10%, P=0.002).

Numerically inferior outcomes of snorkel EVAR in aforementioned studies certainly deserve further attention. Snorkel techniques have been advocated by some clinicians but remain unproven clinically and standardization is also lacking. On the other hand, FEVAR is a valid procedure with the standardized procedure. Ideally, direct comparison in a prospective randomized controlled trial would be needed to evaluate superiority of FEVAR over snorkel repair in standard surgical risk patients. Unfortunately, such trials are not feasible because of the different patient cohort.

CONCLUSION

With rapid technological advances and increasing operator experience, the use of EVAR in the management of complex aneurysms has expanded. Currently, FEVAR and snorkel EVAR represent the two most commonly utilized advanced endovascular techniques to overcome the obstacles of unfavorable hostile proximal neck anatomy. FEVAR is a valid procedure with the standardized procedure, although it remains as a relatively complex procedure with a learning curve. Given time constraints for the custom fenestrated graft, snorkel EVAR may be an alternative for complex repairs in symptomatic or ruptured patients for whom custom-made endografts may not be immediately available. Ultimately, with the long-term goal of achieving the most durable repair possible, both of these strategies should be in the armamentarium of surgeon treating complex aortic pathologies.

CONFLICTS OF INTEREST

William J. Yoon, M.D. is a paid consultant to Cook Medical Inc. He also has a consulting agreement contract with W.L. Gore.

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REFERENCES

1) United Kingdom EVAR Trial Investigators, Greenhalgh RM, Brown LC, Powell JT, Thompson SG, Epstein D, et al. Endovascular versus open repair of abdominal aortic aneurysm. N Engl J Med 2010;362:1863-1871.
2) De Bruin JL, Baas AF, Buth J, Prinssen M, Verhoeven EL, Cuypers PW, et al. Long-term outcome of open or endovascular repair of abdominal aortic aneurysm. N Engl J Med 2010;362:1881-1889.

https://doi.org/10.5758/vsi.2019.35.3.121

3) Sicard GA, Zwolak RM, Sidawy AN, White RA, Siami FS; Society for Vascular Surgery Outcomes Committee. Endovascular abdominal aortic aneurysm repair: long-term outcome measures in patients at high-risk for open surgery. J Vasc Surg 2006;44:229-236.
4) Aburahma AF, Campbell JE, Mousa AY, Hass SM, Stone PA, Jain A, 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.
5) Leurs LJ, Kievit J, Dagnelie PC, Nelemans PJ, Buth J; EUROSTAR Collaborators. Influence of infrarenal neck length on outcome of endovascular abdominal aortic aneurysm repair. J Endovasc Ther 2006;13:640-648.
6) Carpenter JP, Baum RA, Barker CF, Golden MA, Mitchell ME, Velazquez OC, et al. Impact of exclusion criteria on patient selection for endovascular abdominal aortic aneurysm repair. J Vasc Surg 2001;34:1050-1054.
7) Green RM. Patient selection for endovascular abdominal aortic aneurysm repair. J Am Coll Surg 2002;194(1 Suppl):S67-S73.
8) Oderich GS, Greenberg RK, Farber M, Lyden S, Sanchez L, Fairman R, et al. Results of the United States multicenter prospective study evaluating the Zenith fenestrated endovascular graft for treatment of juxtarenal abdominal aortic aneurysms. J Vasc Surg 2014;60:1420-1428.e1-e5.
9) O'Donnell TFX, Patel VI, Deery SE, Li C, Swerdlow NJ, Liang P, et al. The state of complex endovascular abdominal aortic aneurysm repairs in the Vascular Quality Initiative. J Vasc Surg 2019;70:369-380.
10) Browne TF, Hartley D, Purchas S, Rosenberg M, Van Schie G, Lawrence-Brown M. A fenestrated covered suprarenal aortic stent. Eur J Vasc Endovasc Surg 1999;18:445-449.
11) Anderson JL, Berce M, Hartley DE. Endoluminal aortic grafting with renal and superior mesenteric artery incorporation by graft fenestration. J Endovasc Ther 2001;8:3-15.
12) Greenberg R, Eagleton M, Mastracci T. Branched endografts for thoracoabdominal aneurysms. J Thorac Cardiovasc Surg 2010;140(6 Suppl):S171-S178.
13) Verhoeven EL, Katsargyris A, Oikonomou K, Kouvelos G, Renner H, Ritter W. Fenestrated endovascular aortic aneurysm repair as a first line treatment option to treat short necked, juxtarenal, and suprarenal aneurysms. Eur J Vasc Endovasc Surg 2016;51:775-781.
14) Verhoeven EL, Prins TR, Tielliu IF, van den Dungen JJ, Zeebregts CJ, Hulsebos RG, et al. Treatment of short-necked infrarenal aortic aneurysms with fenestrated stent-grafts: short-term results. Eur J Vasc Endovasc Surg 2004;27:477-483.
15) Verhoeven EL, Katsargyris A, Fernandes e Fernandes R, Bracale UM, Houthoofd S, Maleux G. Practical points of attention beyond instructions for use with the Zenith fenestrated stent graft. J Vasc Surg 2014;60:246-252.
16) Oikonomou K, Katsargyris A, Bekkema F, Tielliu I, Verhoeven EL. Fenestrated endografting of juxtarenal aneurysms after open aortic surgery. J Vasc Surg 2014;59:307-314.
17) Oderich GS, Correa MP, Mendes BC. Technical aspects of repair of juxtarenal abdominal aortic aneurysms using the Zenith fenestrated endovascular stent graft. J Vasc Surg 2014;59:1456-1461.
18) Moore R, Hinojosa CA, O'Neill S, Mastracci TM, Cinà CS. Fenestrated endovascular grafts for juxtarenal aortic aneurysms: a step by step technical approach. Catheter Cardiovasc Interv 2007;69:554-571.
19) Mastracci TM, Eagleton MJ, Kuramochi Y, Bathurst S, Wolski K. Twelve-year results of fenestrated endografts for juxtarenal and group IV thoracoabdominal aneurysms. J Vasc Surg 2015;61:355-364.
20) British Society for Endovascular Therapy and the Global Collaborators on Advanced Stent-Graft Techniques for Aneurysm Repair (GLOBALSTAR) Registry. Early results of fenestrated endovascular repair of juxtarenal aortic aneurysms in the United Kingdom. Circulation 2012;125:2707-2715.
21) Oderich GS, Ribeiro M, Hofer J, Wigham J, Cha S, Chini J, et al. Prospective, nonrandomized study to evaluate endovascular repair of pararenal and thoracoabdominal aortic aneurysms using fenestrated-branched endografts based on supraceliac sealing zones. J Vasc Surg 2017;65:1249-1259.e10.
22) Amiot S, Haulon S, Becquemin JP, Magnan PE, Lermusiaux P, Goueffic Y, et al. Fenestrated endovascular grafting: the French multicentre experience. Eur J Vasc Endovasc Surg 2010;39:537-544.
23) O'Callaghan A, Greenberg RK, Eagleton MJ, Bena J, Mastracci TM. Type Ia endoleaks after fenestrated and branched endografts may lead to component instability and increased aortic mortality. J Vasc Surg 2015;61:908-914.
24) Eagleton MJ, Follansbee M, Wolski K, Mastracci T, Kuramochi Y. Fenestrated and branched endovascular aneurysm repair outcomes for type II and III thoracoabdominal aortic aneurysms. J Vasc Surg 2016;64:930-942.
25) Reilly LM, Rapp JH, Grenon SM, Hiramoto JS, Sobel J, Chuter TA. Efficacy and durability of endovascular thoracoabdominal aortic aneurysm repair using the caudally directed cuff technique. J Vasc Surg 2012;56:53-63.
26) Verhoeven EL, Katsargyris A, Bekkema F, Oikonomou K, Zeebregts CJ, Ritter W, et al. Editor's choice - ten-year experience with endovascular repair of thoracoabdominal aortic aneurysms: results from 166 consecutive patients. Eur J Vasc Endovasc Surg 2015;49:524-531.
27) Verhoeven EL, Vourliotakis G, Bos WT,

Tielliu IF, Zeebregts CJ, Prins TR, 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.

28) Mastracci TM, Greenberg RK, Eagleton MJ, Hernandez AV. Durability of branches in branched and fenestrated endografts. J Vasc Surg 2013;57:926-933; discussion 933.

29) Eagleton MJ. FEVAR: long-term data from the cleveland clinic. Endovasc Today 2017;16:5-7.

30) Kitagawa A, Greenberg RK, Eagleton MJ, Mastracci TM. Zenith p-branch standard fenestrated endovascular graft for juxtarenal abdominal aortic aneurysms. J Vasc Surg 2013;58:291-301.

31) Starnes BW. Physician-modified endovascular grafts for the treatment of elective, symptomatic, or ruptured juxtarenal aortic aneurysms. J Vasc Surg 2012;56:601-607.

32) Quatromoni JG, Orlova K, Foley PJ 3rd. Advanced endovascular approaches in the management of challenging proximal aortic neck anatomy: traditional endografts and the snorkel technique. Semin Intervent Radiol 2015;32:289-303.

33) Oderich GS. ZFEN technology: why it works and what's in its future. Endovasc today 2017;13:3-4.

34) Holden A, Mertens R, Hill A, Mariné L, Clair DG. Initial experience with the Ventana fenestrated system for endovascular repair of juxtarenal and pararenal aortic aneurysms. J Vasc Surg 2013;57:1235-1245.

35) Resch TA, Dias NV, Sobocinski J, Sonesson B, Roeder B, Haulon S. Development of off-the-shelf stent grafts for juxtarenal abdominal aortic aneurysms. Eur J Vasc Endovasc Surg 2012;43:655-660.

36) Mendes BC, Oderich GS, Macedo TA, Pereira AA, Cha S, Duncan AA, et al. Anatomic feasibility of off-the-shelf fenestrated stent grafts to treat juxtarenal and pararenal abdominal aortic aneurysms J Vasc Surg 2014;60:839-847; discussion 847-848.

37) Patel RP, Katsargyris A, Verhoeven ELG, Adam DJ, Hardman JA. Endovascular aortic aneurysm repair with chimney and snorkel grafts: indications, techniques and results. Cardiovasc Intervent Radiol 2013;36:1443-1451.

38) Dias NV, Resch T, Sonesson B, Malina M. Single superior mesenteric artery periscope grafts to facilitate urgent endovascular repair of acute thoracoabdominal aortic pathology. J Endovasc Ther 2011;18:656-660.

39) Greenberg RK, Clair D, Srivastava S, Bhandari G, Turc A, Hampton J, et al. Should patients with challenging anatomy be offered endovascular aneurysm repair? J Vasc Surg 2003;38:990-996.

40) Banno H, Cochennec F, Marzelle J, Becquemin JP. Comparison of fenestrated endovascular aneurysm repair and chimney graft techniques for pararenal aortic aneurysm. J Vasc Surg 2014;60:31-39.

41) Massmann A, Serracino-Inglott F, Buecker A. Endovascular aortic repair with the chimney technique using the ultra low-profile Ovation stent-graft for juxtarenal aneurysms having small iliac access vessels. Cardiovasc Intervent Radiol 2014;37:488-492.

42) Troisi N, Torsello G, Weiss K, Donas KP, Michelagnoli S, Austermann M. Midterm results of endovascular aneurysm repair using the Endurant stent-graft according to the instructions for use vs. off-label conditions. J Endovasc Ther 2014;21:841-847.

43) Donas KP, Torsello GB, Piccoli G, Pitoulias GA, Torsello GF, Bisdas T, et al. The PROTAGORAS study to evaluate the performance of the Endurant stent graft for patients with pararenal pathologic processes treated by the chimney/snorkel endovascular technique. J Vasc Surg 2016;63:1-7.

44) Mestres G, Uribe JP, García-Madrid C, Miret E, Alomar X, Burrell M, et al. The best conditions for parallel stenting during EVAR: an in vitro study. Eur J Vasc Endovasc Surg 2012;44:468-473.

45) de Bruin JL, Yeung KK, Niepoth WW, Lely RJ, Cheung Q, de Vries A, et al. Geometric study of various chimney graft configurations in an in vitro juxtarenal aneurysm model. J Endovasc Ther 2013;20:184-190.

46) Lachat M, Veith FJ, Pfammatter T, Glenck M, Bettex D, Mayer D, et al. Chimney and periscope grafts observed over 2 years after their use to revascularize 169 renovisceral branches in 77 patients with complex aortic aneurysms. J Endovasc Ther 2013;20:597-605.

47) Lee JT, Greenberg JI, Dalman RL. Early experience with the snorkel technique for juxtarenal aneurysms. J Vasc Surg 2012;55:935-946; discussion 945-946.

48) Donas KP, Pecoraro F, Torsello G, Lachat M, Austermann M, Mayer D, et al. Use of covered chimney stents for pararenal aortic pathologies is safe and feasible with excellent patency and low incidence of endoleaks. J Vasc Surg 2012;55:659-665.

49) Wilson A, Zhou S, Bachoo P, Tambyraja AL. Systematic review of chimney and periscope grafts for endovascular aneurysm repair. Br J Surg 2013;100:1557-1564.

50) Katsargyris A, Oikonomou K, Klonaris C, Töpel I, Verhoeven EL. 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.

51) Donas KP, Lee JT, Lachat M, Torsello G, Veith FJ; PERICLES investigators. Collected world experience about the performance of the snorkel/chimney endovascular technique in the treatment of complex aortic pathologies: the PERICLES registry. Ann Surg 2015;262:546-553.

52) Lee JT, Lee GK, Chandra V, Dalman RL. Comparison of fenestrated endo-

https://doi.org/10.5758/vsi.2019.35.3.121

grafts and the snorkel/chimney technique. J Vasc Surg 2014;60:849-856; discussion 856-857.

53) Donas KP, Torsello G, Bisdas T, Osada N, Schönefeld E, Pitoulias GA. 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.

54) Ducasse E, Caradu C, Berard X, Sassoust G, Midy D. Meta-analysis of Chimney vs fenestrated endovascular aneurysm repair for complex aortic aneurysms. Vasc Dis Manag 2016;13:E265-E274.