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Antegrade in situ laser fenestration of aortic stent graft during endovascular aortic repair: A case report

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Abstract

BACKGROUND

The endovascular repair of juxtarenal abdominal aortic aneurysms (JAAA) usually requires combination treatment with various stent graft modifications to preserve side branch patency. As a feasible technique, according to the situation, antegrade in situ laser fenestration still needs to be improved.

CASE SUMMARY

This report describes a case that was successfully treated with endovascular repair facilitated by antegrade in situ laser fenestration while maintaining renal arterial flow. Laser fenestration was performed using a steerable sheath positioned in the stent graft lumen in front of the renal artery ostium. With the bare stent region unreleased, renal artery perfusion could be maintained and accurate positioning could be achieved by angiography in real time.

CONCLUSION

This study suggests the feasibility and short-term safety of this novel antegrade in situ laser fenestration technique for select JAAA patients.

Key Words: Juxtarenal abdominal aortic aneurysm; In situ fenestration; Thoracic endovascular aortic repair; Antegrade; Case report

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Core Tip: This report describes the feasibility and short-term safety of a novel antegrade in situ laser fenestration technique. During the operation, laser fenestration was performed using a steerable sheath positioned in the stent graft lumen in front of the renal artery ostium. With the bare stent region unreleased, renal artery perfusion could

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be maintained and accurate positioning could be achieved by angiography in real time. The technique is uncomplicated and has potential as an alternative approach when dealing with a hostile proximal aortic neck during endovascular aortic repair.

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INTRODUCTION

An inadequate proximal neck is the most common anatomical challenge during the endovascular repair of juxtarenal abdominal aortic aneurysms (JAAAs)[1]. Retrograde in situ fenestration (ISF) has been reported to preserve the major aortic branches during thoracic endovascular aortic repair (TEVAR) effectively and safely[2]; however, because of the lack of downstream branch artery access, retrograde revascularization cannot be achieved easily in EVAR without a laparotomy or retroperitoneal incision[3-5]. If endovascular therapy is deemed to be the best treatment option, antegrade ISF may be an ideal method to preserve the patency of visceral arteries. Many animal experiments[6-9], benchtop studies[10-12], and clinical studies[13-17] have demonstrated that the antegrade ISF of aortic stent grafts during EVAR is technically feasible. The following report describes a novel approach of antegrade in situ laser fenestration (ISLF) during EVAR. We found that the ostium of the right renal artery (RRA) could be accurately positioned by angiography in real time. Moreover, RRA perfusion could be maintained during the procedure.

CASE PRESENTATION

Chief complaints

A 55-year-old man presented to the emergency department of our hospital complaining of worsening lower abdomen pain.

History of present illness

The patient's symptoms started a week prior with recurrent episodes of lower abdomen pain and distention, which had worsened in the last 4 h. The patient had no fever or diarrhea. Color Doppler ultrasound in a community hospital showed an abdominal aortic aneurysm (AAA).

History of past illness

The patient had a clear previous medical history.

Personal and family history

However, he had smoked at least five cigarettes a day for ten years.

Physical examination

The abdomen was soft, with mild periumbilical tenderness and no rebound tenderness. A pulsatile abdominal mass could be palpated. The liver and spleen were impalpable.

Laboratory examinations

The patient's blood pressure was approximately 108/80 mmHg. The blood routine examination findings were normal. The prothrombin and partial thromboplastin times were normal, and the D-dimer level was slightly increased, at 0.47 mg/L. The serum C-reactive protein level was increased, at 66.48 mg/dL (normal range: < 5 mg/dL), and the erythrocyte sedimentation rate was 23 mm/h. The results of blood biochemistry, urinalysis, electrocardiography and arterial blood gas analysis were also

normal.

Imaging examinations

Preoperative computed tomography angiography (CTA) showed a JAAA with a diameter of 50.4 mm, a thick hematoma and multiple penetrating aortic ulcers (PAUs). Preoperative sizing showed an aortic ulcer with a hematoma below the right renal ostium, a short (4-mm-long) infrarenal aortic neck, and a proximal healthy landing zone of approximately 16.0 mm between the two renal arteries. The diameter of RRA was 6.1 mm. The diameter of the aortic bifurcation was 32 mm. The diameter of the vessel at the lower edge of the left renal artery was 20.9 mm. The diameter of the vessel at the lower edge of the RRA was 20.5 mm. The distance from the lower edge of the RRA to the aortic bifurcation was 91.2 mm. The distance from the lower edge of the RRA to the bifurcation of the right iliac artery was 124.3 mm (Figure 1A-D).

MULTIDISCIPLINARY EXPERT CONSULTATION

After a thorough patient evaluation, we discussed the possible treatment alternatives. The PAUs involved the RRA, so open surgery was likely to be more traumatic and technically complex than traditional infrarenal repair[18]. EVAR has been widely accepted as the treatment of choice for patients who are unfit for open surgery. To achieve an adequate proximal seal, the RRA might need to be covered and then revascularized. "Off-the-shelf" techniques (such as chimney, periscope, and sandwich techniques) have a high risk of type IA endoleakage and reintervention and are thus not preferred. Customized fenestrated and branched endografts are expensive and not available for the treatment of acute syndromes. Even physician-modified stent grafts still need to be rotated and moved as needed for cannulation of the visceral vessels. In this case, the enhanced abdominal pain and thick perivascular hematoma suggested that the risk of aneurysm rupture was high. Therefore, for early and minimally invasive treatment, after obtaining informed consent, EVAR with antegrade ISF was planned.

FINAL DIAGNOSIS

Confirmed JAAA combined with PAUs.

TREATMENT

Emergency surgery was performed 24 h after admission. The surgical procedure was as follows. A sizing catheter was advanced *via* left femoral access, allowing for angiography and pertinent measurements to be achieved (Figure 1E). A long sheath (Flexor, Cook Medical) was used to deploy a guidewire and a balloon catheter into the RRA *via* brachial access to allow RRA salvage in case of fenestration failure. First, the right internal iliac artery was embolized. An Endurant II stent graft (25 mm × 13 mm × 166 mm, Medtronic Vascular, Inc.) was advanced through the right femoral sheath and deployed just below the left renal artery. The short leg of the stent graft was released while leaving the bare stent in place. Thereafter, a 10-F steerable sheath (FuStar, Lifetech Scientific Corp.) was inserted into the stent graft from the left groin through the short leg. The ostium of the RRA was displayed in real time by contrast injection from the brachial access point. Meanwhile, the tip of the steerable sheath was adjusted to align with the ostium of the RRA (Figure 2A), and the site of perforation was determined *via* 2 different fluoroscopic projections. A 4-mm balloon catheter (Bard Rival, Bard Peripheral Vascular) was passed *via* the sheath followed by a laser fiber (GIGAA Laser, Wuhan, China), which was calibrated to deliver energy pulses of 18 W in 3 s, to fenestrate the membrane of the thoracic aortic stent graft[2]. After fenestration, the laser was removed and replaced with a 0.035-inch guide wire that was advanced into the proximal abdominal aorta. A 4-mm balloon was passed along the wire across the opening, and balloon dilation was achieved (Figure 2B). Due to the straight angle, after trying a variety of catheters, we finally used a trimmed pigtail catheter (Merit Medical Systems, Inc.) to reach the RRA (Figure 2C). An angioplasty balloon (5 mm × 10 mm, Mustang, Boston Scientific Corp.) was passed from the opening into the renal artery, followed by balloon dilation. Then, the balloon was

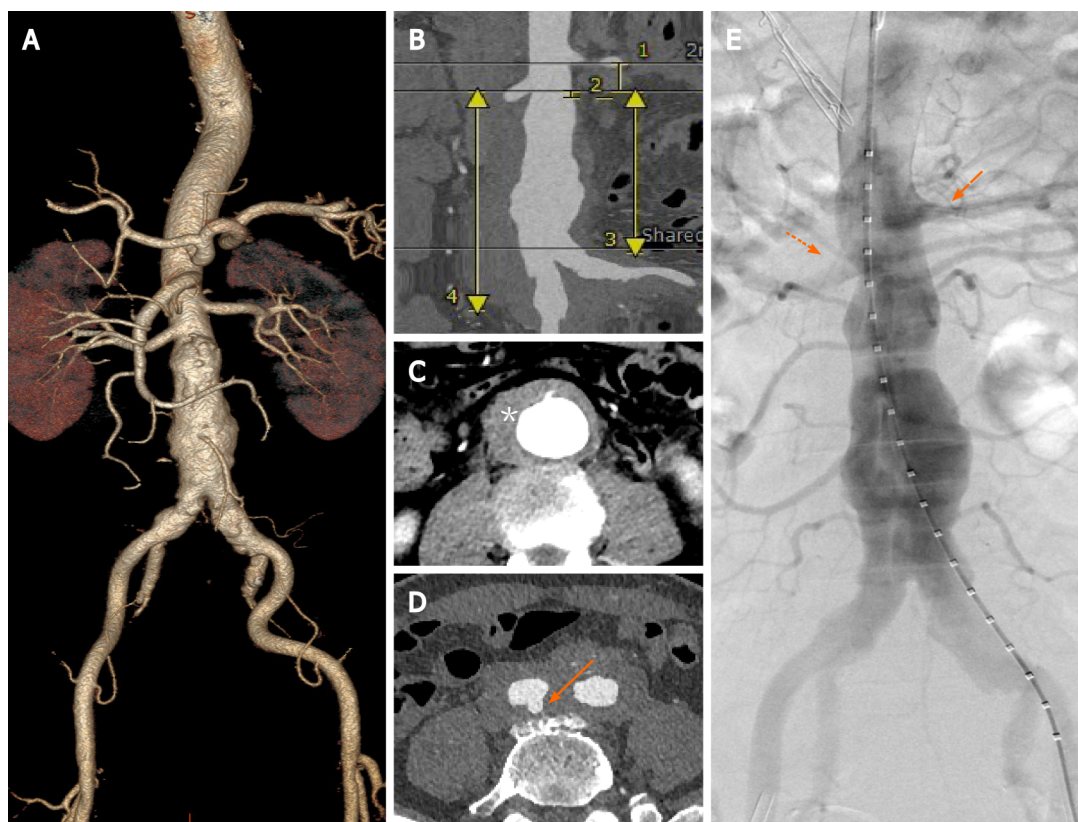


Figure 1 Preoperative imaging. A: 3D reconstruction of the aorta; B: Proximally healthy, 20-mm-long landing zone between renal arteries; C: Perivascular hematoma (asterisk); D: Penetrating aortic ulcers near the bifurcation of the right iliac artery (solid arrow); E: Angiography consistent with preoperative computed tomography angiography.

deflated to 2 atmospheres, with no residual waist, while the bare stent was fully released. The stent was opened smoothly, without any balloon kinking (Figure 2D). Thereafter, a covered stent (8 mm × 50 mm, GORE VIABAHN) was deployed. Then, a 7-mm angioplasty balloon was used to “flare” the RRA stent (Figure 2E). Angiography demonstrated that the RRA was patent, with no endoleakage (Figure 2F). Then, the contralateral iliac limb was placed, with no issues. Repeat ballooning of the regions of stent overlap was performed with a Coda® balloon (Cook Medical). Imaging on completion demonstrated good renal perfusion, with no evidence of endoleakage or stenosis (Figure 3A).

OUTCOME AND FOLLOW-UP

The patient had an uneventful recovery and was continued on aspirin daily. The total procedure time was 2 h. The fluoroscopy time was 45 min, and the total amount of contrast used was 100 mL. The estimated blood loss was 20 cc. Because the left renal artery was not involved, RRA perfusion was maintained during the operation. Postoperatively, there was no abnormal renal function, and the patient was discharged home on postoperative day 7. The 1-year follow-up CTA confirmed patency of both renal arteries and the absence of endoleakage (Figure 3B).

DISCUSSION

The endovascular repair of complex aortic aneurysms involving renal and/or visceral branches usually requires combination treatment with various types of stent graft modifications to preserve side branch patency. These techniques feature devices with parallel grafts, fenestrations, or branches. The parallel graft technique has a high risk of type 1A endoleakage, especially when multiple arteries require reconstruction[17]. The use of such customized systems, including those involving fenestrated grafts and branched endografts, requires accurate preoperative imaging and planning. During

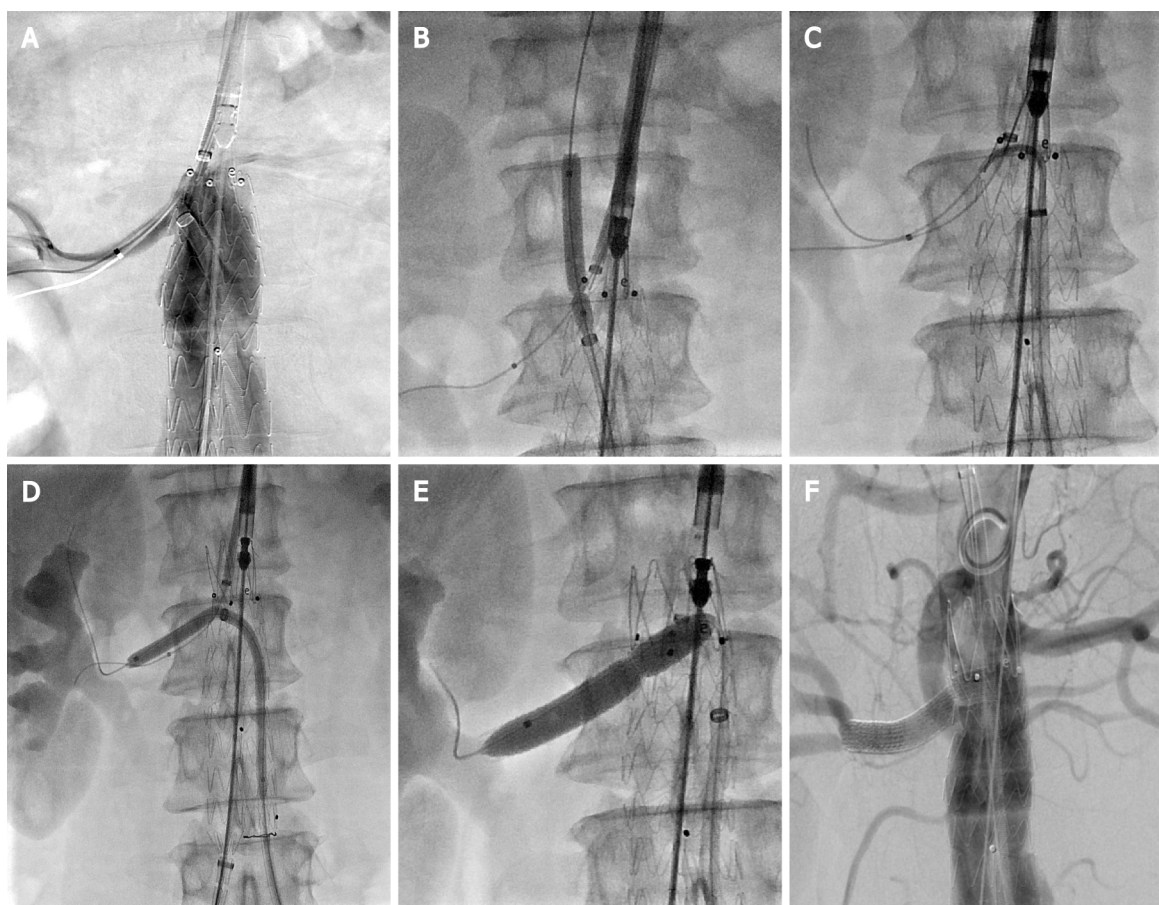


Figure 2 Steps for fenestrations. A: The tip of the steerable sheath was adjusted to align with the ostium of the right renal artery (RRA); B: Progressive enlargement of the fenestration was performed using balloons; C: A trimmed pigtail catheter was used to guide the guidewire to the RRA; D: The bare stent region was released with a balloon anchored at the RRA; E: The covered bridging stent was deployed; F: Angiography demonstrated that the RRA was patent, with no endoleakage.

the procedure, alignment of the vessel ostia with the fenestrations or branches can be difficult[3-5,19]. In addition, the high cost and long waiting time reduce the accessibility of these technologies to patients, particularly in emergent cases. In retrograde ISF, as the site is approached from within the target vessel, it is easy to place the stent graft at the correct site, and this method has been confirmed to be effective and safe for use in major aortic branches[2]. Unfortunately, retrograde endovascular revascularization cannot be easily achieved in visceral arteries[3,4,20]. Since Tse *et al*[6] first reported the feasibility of antegrade ISF in the placement of abdominal aortic stent grafts to preserve the patency of the renal arteries in a canine model, many studies have explored this technique (Tables 1 and 2).

Fenestration devices are important components of antegrade ISF. Graft perforation is achieved easily with most devices, including mechanical and energetic fenestration devices. Mechanical fenestration requires rigidity to transfer force from the operator's hands to the graft. If the angulation of the needle is not sufficiently acute, target vessel cannulation becomes difficult[6,9]. Additionally, the rigidity of the needle may make it difficult to cross the typically tortuous and diseased iliac vessels. However, the occurrence of complications, such as retroperitoneal hematoma, has been rarely reported in previous studies[6,7,9]. Compared with needles, radiofrequency probes and laser fibers have been found to be sufficiently compliant for perforation[8]. Therefore, we decided to perform ISLF in this case.

When using an antegrade approach in visceral arteries, finding the right puncture site can be challenging. To allow for fluoroscopic visualization, various landmarks can be deployed in target arteries prior to endograft deployment. In Tse *et al*[6]'s first report, bare stents were deployed in both renal arteries; however, stent fractures were observed bilaterally. No renal stent fractures were observed in a second study by the same team[8], in which the modified stent grafts had an unsupported portion in the fenestration area. In this study, they marked target vessels with detachable coils or hydrophilic catheters. However, thrombosis of the renal artery was observed after the

Table 1 Summary of published antegrade in situ fenestration animal and benchtop studies

Ref.	Year	Model	Fenestration device	Guidance/landmarks of visceral arteries	Stent graft	Technical success rate ¹	Experimental results
Tse <i>et al</i> [6]	2007	Canine	Needle	(1) Intravascular ultrasound; and (2) Preliminary stenting of all visceral arteries	Endurant	(1) 0/2; and (2) 2/2	(1) The experiment was terminated; and (2) At the 1-mo follow-up, both renal arteries were patent. Stent fractures were observed bilaterally
Riga <i>et al</i> [7]	2009	Porcine	Needle	On a fixed fluoroscopic projection, the position of these target vessels was marked on the fluoroscopy screen	Valiant	2/2	There were no immediate complications. Both renal arteries were patent
Tse <i>et al</i> [8]	2010	Canine	Radiofrequency	Target vessels were marked with detachable coils or with hydrophilic catheters	Zenith	2/3	Thrombosis was seen in one stent during 1 mo of follow-up, while the other fenestrated artery remained patent
Saari <i>et al</i> [9]	2012	Porcine	Needle	Target vessels were marked with balloon catheters	Endurant, Talent	2/6	In one pig, the kidney showed clear signs of ischemic injury when autopsied
Ruthrauff <i>et al</i> [10]	2015	Benchtop	Radiofrequency	NA	Zenith, Endurant	8/8	NA
Piazza <i>et al</i> [11]	2017	Benchtop	Laser	A guiding catheter with EM sensor	NA	NA	NA
Condino <i>et al</i> [12]	2020	Benchtop	Laser	Simultaneous EM-guided navigation of guidewires and catheters	Zenith	22/22	NA

¹Number of successful fenestrations/number of target vessels.

NA: Not applicable; EM: Electromagnetic.

procedure, which was likely related to partial coil deployment. Le Houérou *et al*[14] confirmed the feasibility of preliminarily stenting each target artery in a large clinical study[14]. Hsiao *et al*[21] found that overlapping stents exhibited lower fatigue resistance during respiration than a single stent. In Saari *et al*[9]'s study, deflation of the balloon in the renal artery indicated successful puncture, but a long warm ischemia time for the left kidney caused infarction. Furthermore, stents, balloons, and coils result in additional costs.

To avoid using invasive landmarks, Riga *et al*[7] marked target vessels on a fluoroscopy screen on a fixed projection with robot-assisted antegrade ISF. Leger *et al* [15] and Salib *et al*[17] succeeded under fused CT guidance. However, the configuration of the aorta may change after stent graft insertion[5]. To accurately position stent grafts in real time, various navigation devices have been tested for guidance during antegrade ISF. Intravascular ultrasound probes were not able to visualize the renal orifices for fenestration both within the stent graft and within the inferior vena cava[6]. However, electromagnetically guided endovascular instrumentation was successful in *in vitro* trials[11,12]. Therefore, in our case, fenestration was performed while the stent graft was positioned well with the bare stent region unreleased, allowing real-time positioning by angiography.

Blocking a visceral artery may cause visceral ischemia[9]. Le Houérou *et al*[14] implanted an undersized stent graft at the level of the visceral aorta to avoid temporary visceral ischemia. Tse *et al*[8] thought that, in theory, the marking catheter could serve to cold-perfuse renal arteries during the fenestration procedure. Bismuth *et al*[13] performed antegrade ISF with a constrained stent graft. In our case, fenestration was performed while the bare stent region was unreleased, and RRA perfusion was maintained during the procedure.

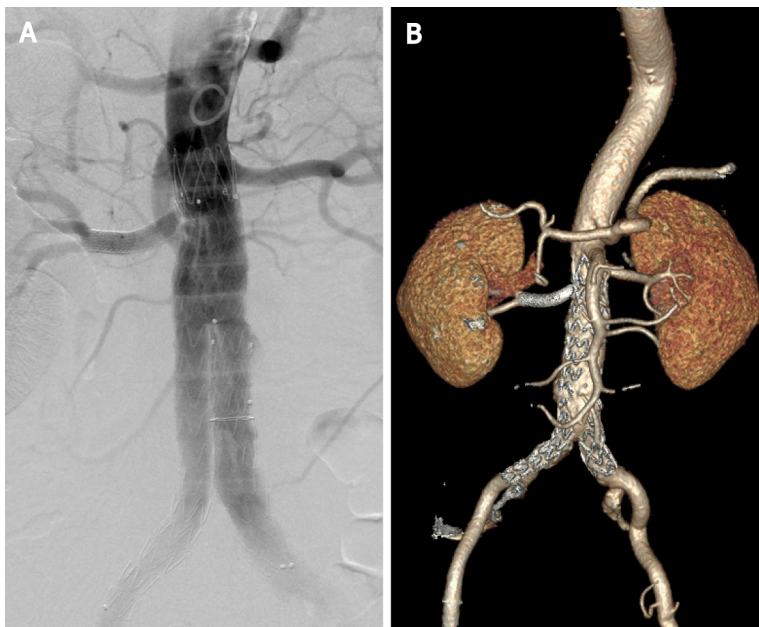
The stability of supporting devices is also important for correct positioning of the perforation site. Tse *et al*[6] described that support for the needle was provided by inflating a balloon catheter against the contralateral aortic wall. However, this catheter does not provide sufficient needle angulation. In most studies, a steerable catheter or sheath has been used to support fenestration devices. Riga *et al*[7] used a remotely controlled robotic steerable catheter system to improve accuracy and stability. Piazza *et al*[11] also proposed some design solutions for catheter stabilization. In this study, a FuStar steerable sheath was used. In addition, the main body of the stent graft was fixed, and the space in the proximal part was limited, which improved the stability of

Table 2 Summary of published antegrade in situ fenestration clinical studies

Ref.	Year	No. of patients	Puncture method	Guidance/landmarks	Stent graft	Technical success rate ¹	Clinical outcomes
Bismuth <i>et al</i> [13]	2012	1	Needle	NA	C3 Excluder	1/1	At the 1-mo follow-up, the patient remained without complications. There was no evidence of endoleakage, migration or stent occlusion, and the bilateral renal arteries remained patent
Kölbel <i>et al</i> [19]	2013	1	Needle	Angiography and the marker at the proximal graft edge	Zenith	1/1	On CTA 4 d postoperatively, all side branches were fully preserved. Renal function was completely restored
Le Houérou <i>et al</i> [14]	2018	16	Laser	Preliminary stenting of all visceral arteries	Valiant, Endurant, Zenith	33/35	During a mean follow up of 17 mo, no deaths occurred. Four secondary procedures were required: Two related to fenestrations; one for stent dislocation; and one for stent stenosis. The follow up CTA demonstrated 97% primary patency
Leger <i>et al</i> [15]	2019	20	Laser	Image fusion guidance	Endurant	48/50	The 30-d safety rate was 90% ($n = 2$ deaths). At the one-week follow-up, all target vessels were patents, and two patients (15%) required a secondary procedure for endoleakage
Zhang <i>et al</i> [16]	2020	1	Laser	Preliminary stenting of all visceral arteries	Valiant	4/4	The 3-mo CTA demonstrated a decreased aneurysm sac, patent stent branches, and no endoleakage
Salib <i>et al</i> [17]	2021	1	Laser	Image fusion guidance	Endurant	3/3	The postoperative course was uneventful. The 6-mo CTA demonstrated an excluded aneurysm, patent stent branches, and no endoleakage

¹Number of successful fenestrations/number of target vessels.

NA: Not applicable; CTA: Computed tomography angiography.

**Figure 3** Postoperative imaging. A: Final angiogram; B: Computed tomography reconstruction at 1 year demonstrated graft patency.

the fenestration system.

Other aspects, such as fatigue resistance[21], are also important issues in antegrade ISF. Our technique may be suitable for use in select JAAA patients with the involvement of only one renal artery. Due to the length limitation of the bare area, whether other visceral arteries can be cannulated in the same fashion needs further study.

CONCLUSION

This study suggests the feasibility and short-term safety of this novel antegrade ISF technique as an off-label technique for use in select JAAA patients. Renal artery perfusion was maintained during the procedure, and accurate positioning was achieved using angiography. This technique could serve as an alternative approach for the management of hostile proximal aortic necks during EVAR. However, the long-term effects of this method require further study in a larger cohort with long-term follow-up.

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