Fenestrated and Branched Endovascular Aortic Aneurysm Repair for Treating Juxtarenal Aneurysms: An Update

Zia Ur Rehman

Section of Vascular Surgery, Department of Surgery, The Aga Khan University Hospital, Karachi, Pakistan

ABSTRACT

Fenestrated and branched endovascular aortic aneurysm repair (f-EVAR, b-EVAR, respectively) are technically challenging procedures that have evolved over the last decade for complex aortic aneurysms. They are alternatives to surgical repair for suprarenal and juxtarenal aortic aneurysms. A Pubmed database was reviewed by searching keywords related to f-EVAR, b-EVAR, and juxta renal abdominal aortic aneurysm (AAA) from the last five years to see current indications, contemporary techniques, and results of these techniques for juxtarenal aneurysms. Over the years, f-EVAR and b-EVAR have improved, with high technical success (>95%) and mortality rates of 1-5% for pararenal and 5-10% for thoracoabdominal aortic aneurysms.

Key Words: *Fenestrated-branched endovascular repair, Fenestrated EVAR, Branched EVAR, Juxtarenal aortic aneurysm.*

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Endovascular aortic aneurysm repair (EVAR) has become the treatment of choice for abdominal aortic aneurysms (AAAs) with favourable anatomy.[1] However, it is associated with increased complications if performed outside of the instructions for use (IFU). These complications include endoleaks, device failure, device migration, conversion to open, and aneurysm rupture.[2,3] b-EVAR and f-EVAR have been developed for patients with short aortic neck aneurysms.[4,5]

In both procedures, the stent graft achieves a secure proximal landing zone along with the adequate flow to the visceral branches through bridging stent grafts (Figure 1).

f-EVAR endografts are custom-constructed according to each patient's specific vascular anatomy and require several weeks of lead time.

Juxtarenal aneurysms constitute 10 to 15% of total AAAs and have inadequate, short infrarenal necks for proximal stent-graft landing. In these cases, the sealing zone needs to be extended above the renal arteries to the healthy portion of the aorta to prevent endoleaks. Over the last decade, the treatment paradigm for juxtarenal has shifted from open surgical to endovascular treatment.[6,7]

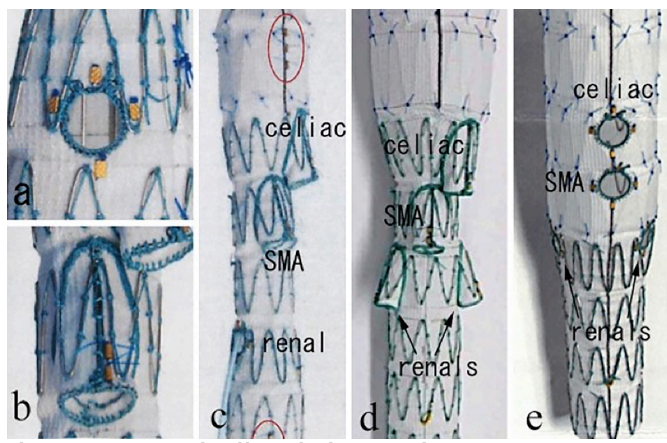

Figure 1: Fenestrated and branched stent grafts.
(a) A fenestration marked by radio-opaque markers to ensure accurate alignment. No strut is crossing the fenestration. (b) A branch is created in the stent graft by sewing the cuff to the graft. The cuff provides a stable base for the branch. (c) Endograft with directional cuffs to provide flow to the celiac axis and superior mesenteric artery (SMA) along with fenestrations for the renal artery. (d) Endograft with cuffs to direct flow to the celiac axis, SMA, and renal arteries. (e) Endograft with fenestrations to provide blood supply to visceral and renal arteries.

A Pubmed database was reviewed by searching keywords related to f-EVAR, b-EVAR, and juxtarenal AAA from January 2018 - 2023 to see the current indications, contemporary techniques, and results of f-EVAR and b-EVAR for juxtarenal aneurysms treatment.

In f-EVAR, balloon expandable stents are used to bridge visceral arteries origin. Examples of various bridging stents are iCast, BeGraft, E-Ventus®, balloon expandable (Bx), VBX, and Lifestream stents.

The f-EVAR was initially used in the late 1900s for type Ia endoleaks to secure the proximal landing zone.[8,9] It was then successfully performed for pararenal AAA and reported in

Correspondence to: Dr. Zia Ur Rehman, Section of Vascular Surgery, Department of Surgery, The Aga Khan University Hospital, Karachi, Pakistan
E-mail: ziaur.rehman@aku.edu

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2001.[10] Fenestrated endografts were historically used for patients with complex AAA where open surgery was unfavourable due to comorbidities. However, with the passage of time f-EVAR has been chosen as a treatment modality for patients with fewer comorbidities.

The most used types of fenestrated stent-graft are the Zenith platform (Cook Medical Inc., Bloomington, IN, USA) and the Vascutek Anaconda Device. The first commercially available fenestrated graft was the Zenith Fenestrated graft, also known as the "Z-Fen" device. It is currently the only fenestrated device approved by the FDA used for juxtarenal AAA. It contains self-expanding Z-stents made of stainless steel along with fenestrations between its struts. The Z-stent is covered with full-thickness woven polyester.[11] The proximal main body of the stent graft is a tube graft that utilises a combination of fenestrations and / or scallops to accommodate the SMA and renal arteries (Figure 2 and 3). The most common graft design employs either a scallop or a large fenestration to provide blood flow to SMA with two small fenestrations for the renal arteries. The proximal main body endograft is deployed with fenestrations that align the target arteries. After the proximal main body device is deployed, the fenestrations and branch arteries are selected from inside the endograft. Sheaths are then advanced into the target arteries to allow the deployment of bridging stent grafts. The proximal main body is subsequently mated to a distal bifurcated endograft which can be designed to extend into the ipsilateral iliac artery, or from which standard iliac limbs can be extended.

Anaconda AAA stent graft system is an infrarenal device that has valleys and peaks and is flexible. Its fabric is made of Dacron, which is not supported by a skeleton. It does not have a suprarenal fixation. The advantage, in this case, is that vessels can be cannulated from above before deploying the main stent graft. Newer techniques for these grafts include the use of preloaded cannulating wires, double-reducing ties, and an enlarging proximal scallop.[13] Fenestration may be small (6 mm wide and 6 or 8 mm high, typically used for the renal arteries) or larger (8 to 12 mm in diameter, usually used for visceral vessels, e.g., coeliac and SMA).

The b-EVAR stent is recommended for aneurysms that involve visceral branches. In such cases, since the target vessel originates from the aneurysm, a gap is present between the main graft and the aortic wall. This gap is bridged using a branched stent graft which is typically used with side-arm branches to accommodate long distances, tortuosity, and to achieve adequate overlap with the aortic device. T and P branches and thoracoabdominal branched endoprosthesis (TAMBE) are some of the currently available branched endografts. In the ultimate four-branch version, the ability to maintain perfusion to all four visceral vessels permits full coverage for EVAR treatment of thoracoabdominal aortic aneurysm (TAAA). f-EVAR are custom-made grafts that take time to obtain and are therefore not suitable for emergency surgery. Hence, to prevent procurement delays, off-the-shelf devices were developed.[14] This is a result of improved preoperative planning, patient selection, improved endovascular techniques, and postoperative care. Initially, the standard treatment for juxtarenal aneurysms involved two renal fenestrations and a scallop for the SMA in the graft.[15] However, now the indications for f-EVAR and b-EVAR have widened to include more complex aneurysms that involve the mesenteric arteries as well. This requires the positioning of a sealing stent in the distal thoracic aorta. The patency of the target vessel depends on the aneurysm size, angulation of the renal artery, and the options available (fenestration, directional branch, or cuffed branch).[16]

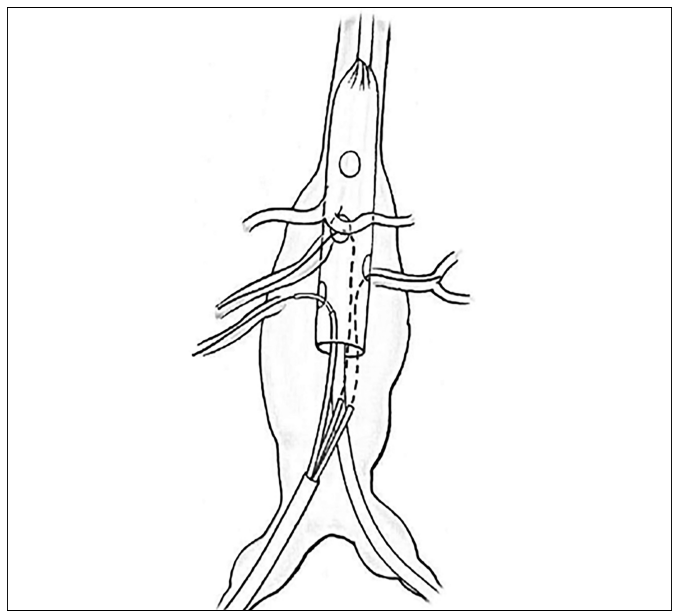

Figure 2: Line diagram demonstrating placement of main body and cannulation of visceral branches.[12]

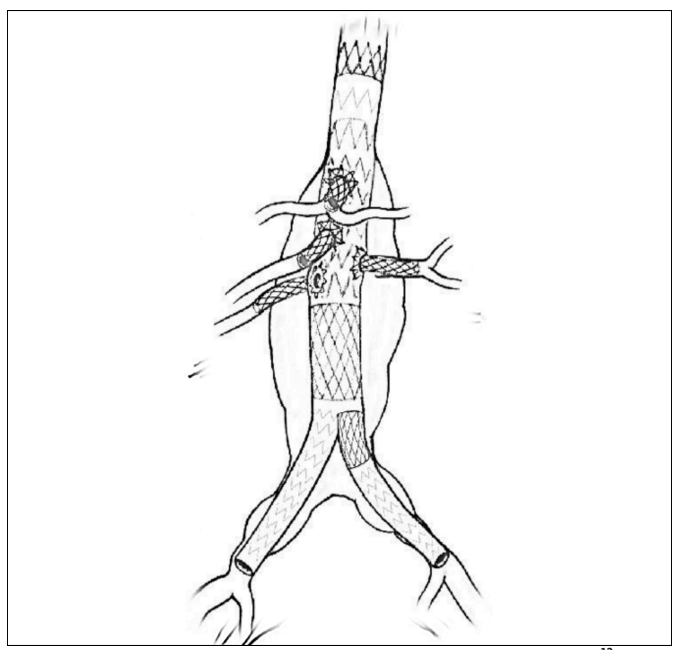

Figure 3: Line diagram showing completion of f-EVAR and b-EVAR.[12]

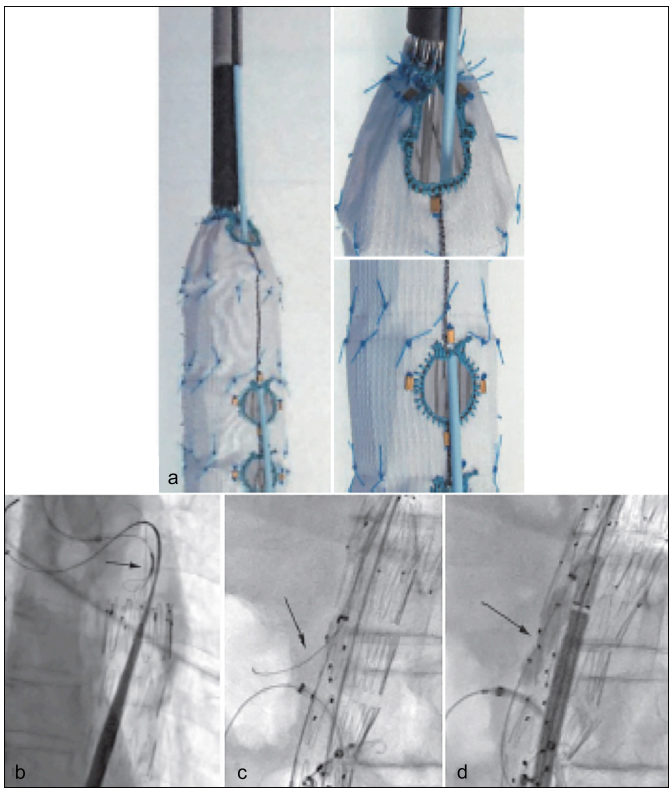

Figure 4: Fenestrated endograft with a pre-assembled system.
(a) An endograft with a preloaded fenestration system designed to fit around the coeliac axis. (b) The guidewire is advanced into a preloaded catheter through the brachial artery. The catheter is then snared using another catheter, which helps to secure the guidewire in place (arrow). (c) The guiding sheath is advanced over the wire *via* the brachial artery and into the fenestration. The catheter and guidewire (arrow) are easily inserted into the target artery. (d) The brachial approach is used to deploy the bridging stent (arrow).

According to the current literature, the 30-day mortality rate of f-EVAR is 1.4-7.8% with a technical success rate ranging from 87-98%. The incidence of spinal cord ischaemia was 2-10%, and the visceral vessel patency rate after one year was 90-98%, with an estimated overall survival rate at 2 years of 78-92%.[14]

The f-EVAR, b-EVAR, and parallel stent grafts have the same indications as open surgical or hybrid repair. Since these procedures carry higher morbidity and mortality risks, it is critical to conduct a balanced risk-benefit analysis that takes institutional outcomes into account. The risk of rupture should be weighed against the risk of perioperative mortality or morbidity, especially of paraplegia, major stroke, and dialysis. Patients with ruptured or symptomatic aneurysms are repaired irrespective of their size. Patients with aneurysms having a maximum diameter of ≥6 cm are treated electively. Body surface area analysis aids in the optimisation of repair indications based on size criteria. Patients with accelerated aneurysm expansion (>5 mm expansion in 6 months) and patients who develop dissection, intramural haematoma, or penetrating ulcers within the aneurysm are also considered for repair. Since saccular aneurysms have a poorly defined natural history, most experts agree that repair should be considered at smaller diameters.

The f-EVAR is preferred for right-angle visceral branches. This is because it allows the stent graft to be placed against the aortic wall, which covers a minimal amount of the normal aorta. However, it is linked to prolonged limb ischaemia as well as increased risk for Type III endoleaks. For emergent or urgent cases, physician-modified stent graft (PMSG) is needed which may require frequent re-interventions.

The b-EVAR has several advantages in comparison to f-EVAR. As the main device is removed after deployment, the limb ischaemia time is shorter. Furthermore, there is a lesser incidence of Type III endoleaks due to the presence of sleeves and the availability of an off-the-shelf device, unlike f-EVAR. However, there are several drawbacks as well. b-EVAR is difficult when the stent graft body is against the aortic wall. There is an increased risk of spinal cord ischaemia as it covers a longer segment of the normal aorta compared to f-EVAR. Furthermore, there is an increased risk of branch occlusion with longer reconstructed branches and tortuosity of the reconstructed branch. Lastly, due to the use of brachial access, there is a relatively higher risk of cerebral infarction.[17]

For supra-coeliac aortic segments, which are defined as having a parallel aortic neck with no thrombus, calcium, and a diameter enlargement of <10%, a minimal proximal sealing zone of at least 25 mm is selected. The fenestrations contain radio-opaque markers which assist in their accurate alignment and have a diameter of 6-12 mm with no strut crossing them for TAAA.[18] Specific design of the device further varies depending on the extent of aneurysm, vessel angulation, and inner aortic diameter, and it includes either patient-specific devices with up to five fenestrations or branches, or off-the-shelf T-branch multi-branch stent grafts (Cook Medical LLC, Bloomington, USA). For renal targets, fenestrations are preferred whenever possible, except when the aortic diameter is large.[19]

Accurate planning is crucial. It is particularly important to work as a team with colleagues who have good endovascular skills. The design and sizing of the device are essential for the success of endovascular repair and for the accurate placement of the fenestration in the accompanying visceral branches during surgery. Full thoraco-abdominal-pelvic computed tomography (CT) including the arch and great vessels is obtained. This is to ensure the identification of an adequate sealing zone. Moreover, f-EVAR planning requires post-processing of imaging using softwares, such as Terarecon, 3 Mensio, Vitrea, and Osiris. Multiplanar reconstruction (MPR) and reformatting straightened MPR generate sagittal, coronal, and oblique views from axial sections. Centre line flow provides accurate measurements of lengths and angles. Femoral, iliac, and renal arteries are assessed for feasibility for F/Br- EVAR. Ideally, renal arteries are at 90°; iliac arteries on both sides must be of good calibre, and aortic bifurcations wide open. In evaluating the axillary artery, a patent axillary-subclavian vessel with suitable anatomy (arch etc.) is desirable. The axillary artery is preferred for down-going renal arteries.

There are several anatomic exclusion criteria. The large delivery system may not be compatible with small femoral or iliac vessels (18F-22F). Inability to perform a conduit due to inadequate femoral / iliac access, if non-aneurysmal segment is not present in the distal thoracic aorta, EVAR cannot be performed. Excessive occlusive disease in visceral vessels makes it unsuitable for EVAR. As the stent graft needs to be secure at the distal end of the iliac artery. If the distal iliac artery fixation site or anatomy are unsuitable, EVAR may not be possible.[20]

All necessary wires, sheaths, and bridging stents need to be checked beforehand. Access is achieved *via* the femoral or left axillary artery. After access, the main body is inserted. The graft is oriented accurately, and fenestrations of the main body are lined with the target vessels.

A dedicated aortic team performs fenestrated and branched EVAR in a hybrid endovascular operating room. This type of room is equipped with specialised imaging equipment that allows for reduced radiation doses, quicker screening, and lower contrast use than a conventional operating room.[21] Most patients are operated under general endotracheal anaesthesia using either total percutaneous or open femoral approach and left-brachial approach. Fusion imaging and cone-beam CT can be helpful adjuncts in locating target vessels and for final assessment, however, they are not conventionally used. Once the target vessels have been localised using fusion imaging, the aortic device is prepared outside the body. It is then introduced into the body through the femoral artery and deployed. The fenestrations in the device are perfectly aligned with the target renal arteries. Few devices are designed with pre-loaded catheters for the coeliac axis and SMA (Figure 4). The guidewires are advanced through catheters and snared *via* the brachial approach. The aortic stent graft is deployed to the level of the renal arteries, and access is sequentially established into the coeliac axis and SMA using brachial access and the preloaded wires.

In spite of the improved outcomes seen in new generation stent-grafts, vascular complications have been reported in up to 23% and 36% of patients treated by thoracic endovascular aortic repair (TEVAR) or F/B-EVAR, respectively.[22,23]

There is no clinical trial that compares open *versus* endovascular repair for juxtarenal aneurysms. There are comparative case series and registries that show that f-EVAR and b-EVAR are associated with minimal perioperative morbidity and mortality. One of them is the Globalstar registry which enrolled 314 cases in the UK with a mortality of 4.1%.[24]

According to current literature, the one-month mortality of f-EVAR has been reported to range from 1.4-7.8% with a technical success rate of 87-98%. Its 2-year survival rate ranges from 78-92% with a 1-year visceral patency rate of 90-98%.[14] The rate of spinal cord ischaemia was 2-10%,[25] with an estimated overall survival rate at 2 years ranging from 78-92%. Secondary interventions following f-EVAR are common due to Type III endoleaks that often occur. The rate of freedom from secondary interventions is unsatisfactory and has been reported at 79-96.7% at 1 year and 63-80% at 3 years.[14]

The common femoral artery (CFA) is used for the insertion of the main device whereas the contralateral CFA is used for the insertion of sheaths. Hence this makes the patient prone to limb ischaemia which may lead to myonephropathic syndrome.

CONCLUSION

While early outcomes of f-EVAR and B-EVAR are promising, long-term outcomes are still largely unknown. Furthermore, specific, such as target vessel occlusion and Type III endoleaks at the side branch joints should be considered during the initial perioperative period and throughout follow-up. Duplex ultrasound is used to assess these patients on follow-up. Limitations of f-EVAR and b-EVAR include higher cost issues and re-interventions.

With advances taking place at a rapid pace, one needs to be wary of the techniques evolving in the spectrum of endovascular f-EVAR and b-EVAR to deal with the challenging entity of the juxtarenal AAA.

COMPETING INTEREST:
The author declared no conflict of interest.

AUTHOR'S CONTRIBUTION:
Design of the work, acquisition, analysis and interpretation of the data, drafting of the first draft, clinical analysis, revision, and approval of the final draft.

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