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REVIEW ARTERIAL INTERVENTIONS

Current Status of Endovascular Preservation of the Internal Iliac Artery with Iliac Branch Devices (IBD)

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Abstract Endovascular aneurysm repair (EVAR) has become the most utilized treatment for abdominal aortic aneurysms (AAA), but the presence of common iliac dilatation or aneurysm may prevent the achievement of effective distal seal and fixation. Ideal repair in these cases should involve both effective preservation of the pelvic circulation and durable exclusion of the AAA. Unilateral or bilateral internal iliac artery (IIA) preservation with iliac branch devices (IBD) is safe, feasible and effective with technical and clinical outcomes comparable to standard EVAR. The versatility of current devices has allowed extended application to complex cases, but must be considered carefully in difficult anatomies. Pending long-term durability results and formal cost-effectiveness appraisals, IBD implantation has several advantages to anatomically eligible patients as compared with other available open or endovascular/hybrid solutions for IIA preservation during EVAR for aortoiliac aneurysms.

Keywords Iliac branch · Aortoiliac disease · Endovascular repair · Review

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Introduction

Endovascular aneurysm repair (EVAR) has become the most utilized treatment for abdominal aortic aneurysms (AAA), and adequacy of landing zones is vital to achieve successful and durable outcomes [1, 2]. However, the presence of common iliac dilatation or aneurysm may prevent the achievement of effective distal seal and fixation, and ideal repair of aortoiliac aneurysms should ensure both effective preservation of pelvic circulation and durable exclusion of AAA. The development of iliac branch devices (IBD) has now allowed totally endovascular incorporation of one or both internal iliac arteries (IIA) in most cases using an on-label option as they are specifically designed for this purpose. In this article, we provide a narrative review on the current status of endovascular preservation of the IIA with IBD.

Indications for IIA Preservation

One of the basic tenets of vascular surgery is vessel preservation/reconstruction whenever possible. Even if IIA sacrifice has been generally reported to be safe, pelvic ischemic complication may actually occur and they can significantly impair patients' quality of life. A recent systematic review has showed that buttock/thigh claudication develops in approximately one-third of patients undergoing IIA exclusion (although it may resolve in half of those affected), and about 10% of men experience a new-onset erectile disfunction [3]. The factors that influence the development of buttock/thigh claudication and erectile dysfunction are not completely understood, but the adequacy of pelvic collateral circulation likely plays an important role. Even though the exact definition of patients at high risk of pelvic ischemia is difficult, the likelihood and severity of postoperative ischemic manifestations are consistently higher after bilateral than unilateral occlusion [4, 5]. Thus, preservation of blood flow to at least one IIA is strongly recommended, if it does not compromise aneurysm exclusion, by clinical practice guidelines from vascular surgical societies in USA and Europe [6, 7]. The way the IIA is excluded also seems to play a major role in the development of pelvic ischemic complications: Coils are generally associated with poorer outcomes than plugs, and occlusion of the proximal IIA trunk is generally associated with reduced rates of pelvic ischemic complications as compared with occlusion of the distal IIA branches [8]. The timing of IIA embolization might be another determinant of pelvic ischemic complications. Bilateral embolization is usually performed in a two-stage fashion a few weeks apart to allow for collateral circulation development; similarly, unilateral embolization may also be staged or performed concomitantly with EVAR. However, despite claims that buttock/thigh claudication is more common after concomitant rather than staged procedures, there is no obvious benefit for sequential versus simultaneous IIA embolization [9].

Preservation of IIA perfusion is also important to minimize the risk of spinal cord injury after endovascular treatment of thoracoabdominal aortic aneurysms [10]. Indeed, the IIA contributes to flow into the collateral spinal network and its patency significantly reduces the incidence of spinal cord ischemia after extensive aortic endografting [11, 12]. IIA preservation may assume an integral role as part of multimodal spinal cord protection during fenestrated-branched EVAR [13, 14].

Failure of a distal landing zone after prior EVAR may also necessitate distal extension using an IBD to preserve pelvic perfusion. Clinical studies have shown that IIA preservation can be achieved with IBD in patients with prior bifurcated endografts to treat common iliac artery (CIA) degeneration or type 1B endoleaks, with safety and efficacy comparable to the standard technique for de novo aneurysms [15, 16]. In such cases, it is important that there is enough diameter and length from the distal edge of the iliac limb to the origin of the IIA to open the branch portion of the IBD. Also, if the procedure is done in patients with prior fenestrated endografts, it is important to avoid any inadvertent compression/dislodging of the side stents.

Devices Design

Five IBD configurations by three manufacturers have been developed from Cook Medical (Bloomington, IN), Gore (Flagstaff, AZ) and Jotec (Hechingen, Germany). According to the manufacturers' instructions for use (IFU), both the Gore and the Jotec devices can be used in isolated iliac aneurysms, whereas the Cook device must be connected to an aortic stent graft. In this article, we provide a brief description of the most salient features of the three platforms [17] (Fig. 1).

The Cook Zenith IBD is a bifurcated branch vessel endograft with openings to connect the common iliac to the side branch and external iliac segments. It is available in three different configurations: straight, helical and bifurcated–bifurcated. The endograft is fully stented with nitinol rings positioned at the proximal end and within the side branch to help maintain lumen patency during access and secure bridging stent graft (BSG) seal. The device is preloaded with a curly catheter into the introduction system and has a sequential deployment method providing continuous control throughout the procedure. The delivery system allows for readjustment of the final position before full deployment.

The Gore Excluder Iliac Branch Endoprostheses IBE is made up of two components: the iliac branch component and the internal iliac component. The iliac branch component is an IBD with a 5.5-cm main body length (3 cm for AAA limb overlap and 2.5 cm for the internal iliac limb), a proximal diameter of 23 mm, and has two limbs (a longer external iliac limb with a length of 10 cm and available distal diameters of 10–12–14.5 mm; a shorter internal iliac limb or gate with a distal diameter of 13 mm). The internal iliac component has a proximal diameter of 16 mm, a length of 7 cm, and available distal diameters of 10–12–14.5 mm. There are two deployment knobs, an outer white knob and an inner gray knob. The outer white knob is pulled to release the proximal endoprosthesis past the gate, and the device may be repositioned at this time. Once the inner gray knob is deployed, no further repositioning is permitted. The main body flexibility has proven to be highly conformable with the anatomy of the patient, providing kink resistance even in case of severe tortuosity and reducing the risk of limb thrombosis [18].

The Jotec E-liac IBD consists of a bifurcated stent graft including a main iliac limb with an additional reinforced stump for the side branch. The design of the device incorporates an asymmetric spring configuration which provides good conformability to the vessel's shape as well as visibility during the deployment process. The device has a squeeze-to-release mechanism for stepwise or continuous release of the device while focusing on precise positioning and safe handling. The proximal diameter of the Jotec E-liac is available in three different measures (14–16–18 mm) for the treatment of isolated iliac aneurysms.

Preoperative Assessment

Technical success and durable outcomes are contingent upon meticulous preoperative assessment using computed

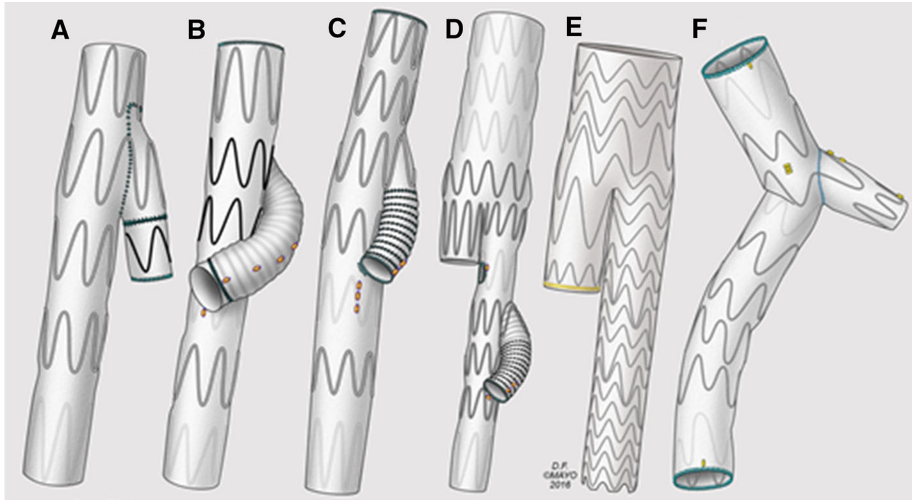

Fig. 1 Current design of iliac branch devices, which were pioneered by Cook Medical, including the straight (**A**), helical (**B**, **C**) and bifurcated–bifurcated configurations (**D**). More recently, the Gore Iliac Branch Endoprosthesis (**E**) and the Jotec device (**F**) have also been used clinically. With the Gore IBE, it is important to assure that there is enough length to allow the connection with the 27-mm iliac limb extensions without compromising the iliac branch

tomographic angiography (CTA) with software post-processing and centerline measurements. In addition to the planning and sizing pertinent to the aortic repair, there are some aspects which are unique to IBD cases [19] (Fig. 2).

1. Understanding the specifics of each component needed to complete the procedure. Specifically, the bridging limb is selected based on the length between the aortic stent graft and the IBD so that maximum overlap can be achieved without compromising or covering the side branch.
2. Anticipating potential causes for difficult side branch cannulation, such as lack of enough space in the CIA or IIA ostial occlusive disease.
3. Knowing the quality of the distal landing zone to ensure adequate run-off, preserve important collateral branches and achieve successful aneurysm exclusion.
4. Identifying the exact location of the IIA origin. An uncommon occurrence may be the so-called pseudo-occlusion which occurs in patients with very tortuous non-calcified external iliac arteries, who may develop occlusion of the IIA origin from kinks after placement of a stiff guidewire. In this case, removal of the delivery system and repeat angiography would reveal the actual ostial patency of the IIA.

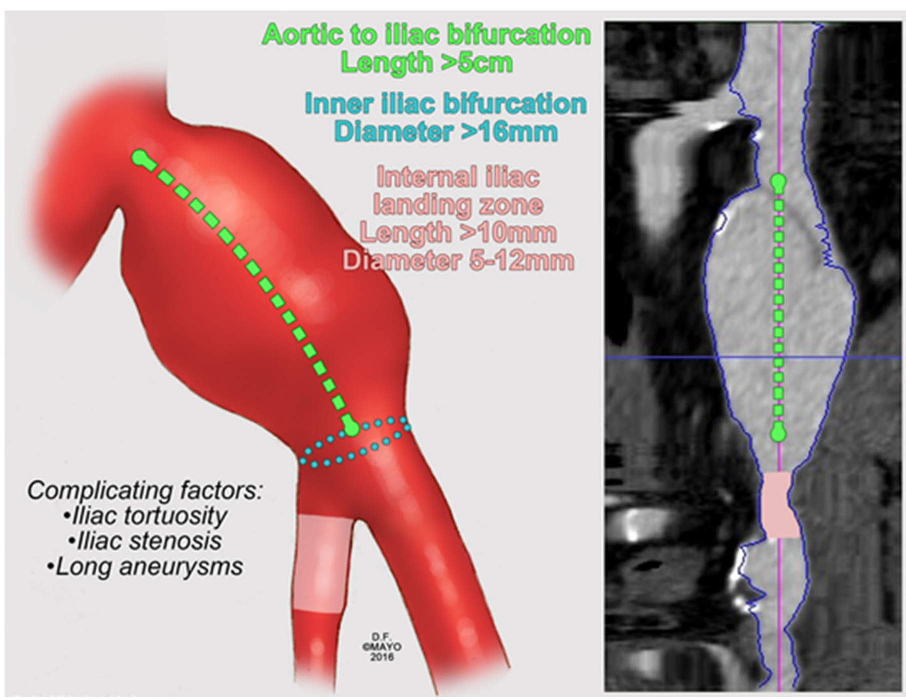

Fig. 2 Sizing of iliac artery aneurysms for planning endovascular repair using iliac branch devices requires centerline analysis of length and diameter. Identification of factors that can constitute challenges or compromise repair is a critical step during preoperative assessment

Considerations for Implantation

Techniques of IBD implantation require a comprehensive inventory of endovascular tools with wide variety of guidewires, sheaths, catheters, balloons and stents. Although many of the tools can be variable depending on physician preference and local availability, a few are essential to the success of the procedure. According to the IFU, through-and-through femoral access is required to snare the guidewire and guide the sheath through the device and into the side branch exiting within the IIA (Fig. 3). The 0.25-in Metro guidewire (Cook Medical, Bloomington, IN, USA), which is 480 cm long and has enough length for exchanges while allowing continuous traction from the foot of the table, is a valid option. In the ipsilateral side, a catheter and guidewire are advanced into the descending thoracic aorta and exchanged for a 0.035-in stiff guidewire while most of the subsequent manipulations are done from the contralateral side using a 0.035-in floppy guidewire and the catheter of choice.

The standard crossover technique may be more challenging in patients with narrow aortic bifurcation or previous bifurcated endografts but can be overcome using brachial access [20, 21], femoral access with steerable sheaths [22, 23], or an up-and-over technique [24]. The latter uses a coaxial 12Fr flexible sheath that is docked with a through-and-through wire into a 7Fr sheath advanced from the contralateral femoral approach allowing both sheaths to be moved as a unit while maintaining position of the apex of the system as it loops over the flow divider so to avoid damage to or displace the preexisting endograft. Once the 12Fr sheath is positioned in the iliac limb of the aortic stent graft and secured in place with the through-and-through wire, the repair is extended into the IIA using a BSG introduced via a coaxial sheath. Notably, the up-and-over technique can also be useful in selected patients with unusual short distance from the lowest renal artery to the iliac bifurcation. After full device deployment, removal of the delivery system should be done carefully to avoid any compression/dislodging of the BSG which can be protected with balloon inflation while the delivery system is removed.

Adequate run-off distally to both limbs of the endovascular reconstruction must be obtained and documented after performing kissing angioplasty (Figs. 4, 5, 6). The presence of severe angulation/calcification of the native vessel [25–27], landing into the external iliac artery [28, 29], and excessive oversizing [30] are all risk factors for endograft kinking which predicts failure and reinterventions [31, 32] (Fig. 7). If any stent-graft kinging/compression is detected, prompt revision should be carried out. If available, use of cone-beam CT may allow immediate assessment and revision of technical problems [33]. Indeed, the use of advanced intraoperative imaging for guidance and control has shown potential to reduce perioperative use of contrast and radiations, improve procedural success and reduce the need for reinterventions [34–37].

A wide range of balloon-expandable (BECS) and self-expandable (SECS) covered stents can be deployed within the side branch, and the current literature is not adequately powered to address the question about the type of BSG to be used [38]. The BSG should not be extended too high with the proximal end above the gate of the device, so to avoid creating radial or protrusion mismatches that will have an impact on patency [39]. When the repair is extended beyond the IIA bifurcation and more stents are necessary to bridge the longer distance to the distal landing

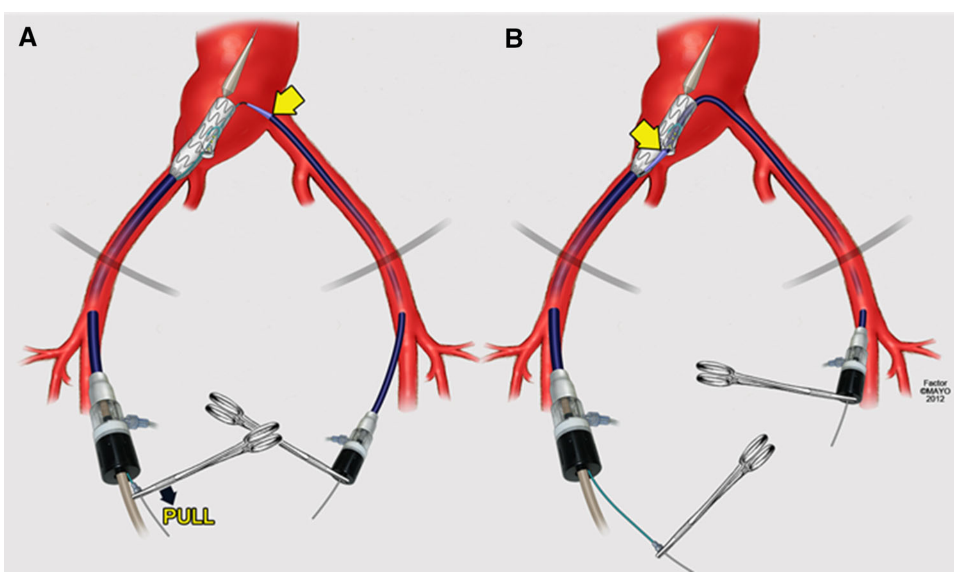

Fig. 3 The push-and-pull maneuver is most useful for advancing the contralateral sheath without damaging the tip of the sheath (**A**) or the iliac branch device. The sheath is positioned at the terminus of the branch (**B**). For through-and-through femoral access, the guidewire should have enough length for easy exchanges while allowing continuous traction from the foot of the table and the hydrophilic sheath should be kink-resistant to be easily advanced up and over the aortic bifurcation. The same maneuver (here depicted with the Cook device) is easily reproduced with the Gore device

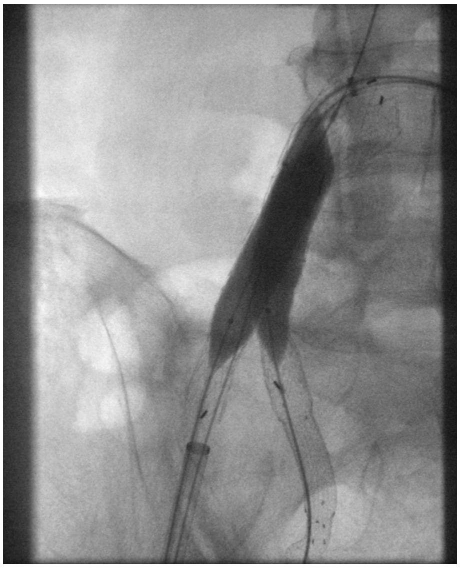

Fig. 4 Intraoperative angiogram. Kissing balloon angioplasty of the bridging stent graft and the external iliac limb is always advised after full deployment of the iliac branch device to ensure appropriate molding of the stent graft to the vessel wall and avoid any competition between the two limbs of the device. (Gore device)

Fig. 5 Intraoperative angiogram. After device deployment, presence of adequate run-off with widely patent vessels distal to the endovascular reconstruction must be documented

zone, proximal BECS may be preferred to provide stability, while distal SECS may be selected to ensure flexibility.

Bilateral percutaneous or surgical femoral access is needed for IBD implantation. Current evidence has revealed that percutaneous technique is non-inferior and provides some advantages over surgical cutdown in patients undergoing EVAR [40–44]. Although some studies have suggested percutaneous EVAR in obese patients and sheath size $\geq$ 20Fr to be associated with postoperative complications [45, 46], our preference is to use a totally percutaneous approach unless there is a very high bifurcation, the common femoral arteries are severely calcified with anticipated need for adjunctive surgical procedures, or the access vessels are exceedingly small in caliber and use of an ilio-femoral conduit is deemed necessary.

Outcomes and Follow-Up

IBD represents the first dedicated endovascular option to preserve antegrade flow to the IIA, when anatomically feasible [47–49]. Endovascular repair of aortoiliac aneurysms with IBD has showed reduced rates of mortality and morbidity as compared to open approaches, while maintaining excellent technical success and primary patency [50–52] (Table 1). Indeed, open surgery for aortoiliac aneurysms is technically challenging due to the deep pelvic location (especially in obese patients or hostile abdomens) [53]. When compared with IIA embolization, IBD does not lead to increased rates of device-related or procedure-related complications, while preserving antegrade pelvic flow so that nothing will be lost if the side branch occludes when using an IBD [54–57]. Additional radiation exposure and increased amount of contrast medium might represent potential shortcomings of the IBD technique when compared with simple embolization or the bell-bottom technique. In our experience, the learning curve for these devices is minimal, and we believe that, when implanted in appropriately selected anatomies by experienced interventionists (and more so if using modern state-of-the-art hybrid operating rooms), the additional burden would be minimal and should not be the main deterrent to IBD use when deemed appropriate.

Contemporary series have demonstrated that IBD occlusions mostly occur in the early post-implantation phase, suggesting that they were likely technical-related or patient-related (i.e., they almost always showed a procedural or anatomical culprit reason for occlusion) [58, 59]. This emphasizes the importance of appropriate patient selection and careful intraoperative manipulation for optimal and durable outcomes with IBD [60]. Among factors that may influence success, IIA patency and presence of IIA ostial stenosis seem to be crucial [61]. Indeed, if the device is satisfactorily deployed and the IIA is well preserved, long-term stability may be anticipated. Also, the majority of the reinterventions can still be managed in an endovascular fashion, thus maintaining the minimally invasive nature of the index procedure [62].

The indications of IBD have progressively been expanded to include patients with bilateral iliac aneurysms with no detrimental effect on clinical or technical outcomes [63, 64] (Fig. 8). The Cook bifurcated–bifurcated device is

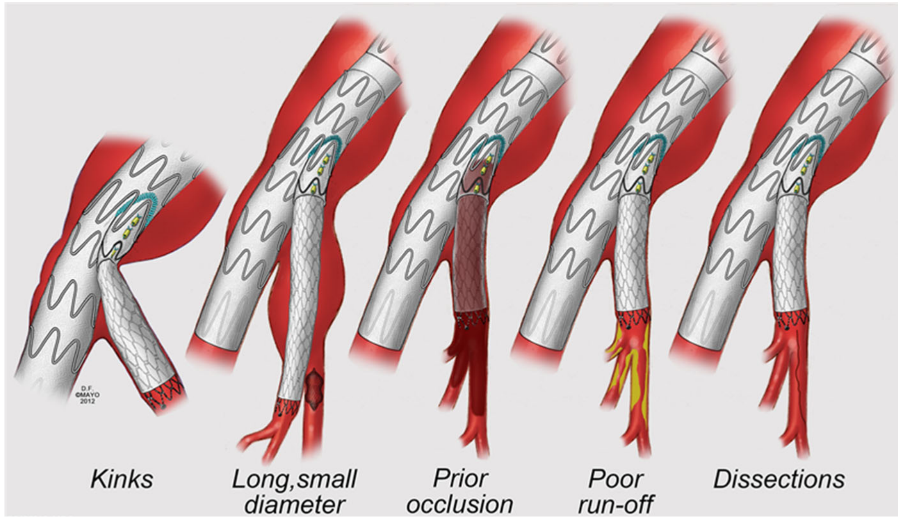

Fig. 6 Common mechanisms of occlusion of iliac branch bridging stents. When extending the repair distal to the bifurcation of the internal iliac artery, any manipulation should be done with a floppy guidewire to avoid inducing dissections or perforations of the distal branch

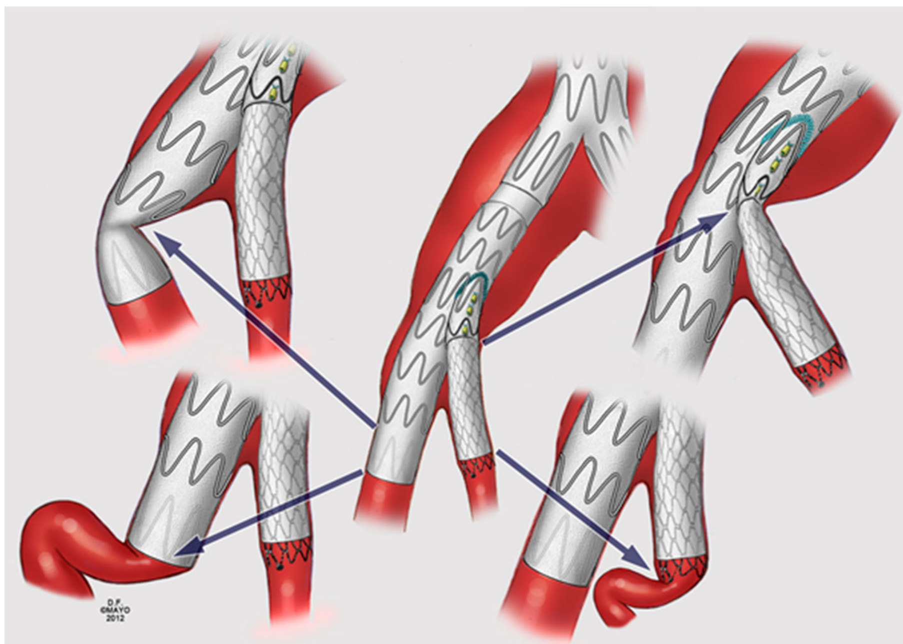

Fig. 7 In Iliac branch devices, kinks are a source of occlusion and should be recognized and treated. Given the multimodular nature of iliac branch devices, kinks may occur at several locations; when the presence of a kink is anticipated or detected, relining with adjunctive self-expandable covered stent (in the native artery) or balloon-expandable covered stent (in the device fabric) may be needed to prevent occlusion. However, kinking of the endograft may not be visualized when the completion angiography is performed with the stiff wire in place. Therefore, it is recommended that the completion angiogram should be performed without stiff wires present

particularly useful for bilateral cases because it eliminates one of the joints and avoids crossing the IBD with the aortic stent graft [65]. Conversely, if bilateral repair is to be carried out using the other available IBD, the preference would be to perform one side at a time and then to introduce the aortic stent graft via the side with the most favorable anatomic conditions [66]. However, the decision to attempt bilateral IBD implantation can be influenced by the perceived risk of increased complexity and costs vs the benefit of maximizing pelvic circulation. Thus, they should be employed judiciously in the context of a comprehensive risk to benefit evaluation to such patients. Ideally, preservation of both IIA would be advised for young physically and sexually active individuals or for those with previous/concomitant extensive aortic repair.

The major disadvantages of IBD still are the anatomical requirements [67–69]. However, recent evidence indicates that $> 60\%$ of the patients who actually benefit from IBD in real-world settings have the repair performed outside the strict IFU that are used in clinical trials [70]. One common limitation is inadequacy of the distal landing zone because of coexisting IIA aneurysm. Although this represents a formal IFU violation, it is not an absolute contraindication since repair can still be done by extending the distal landing zone into healthy main division branches [71, 72]. For preoperative planning and sizing, some anatomical features (extreme angulation/tortuosity, small diameter, inadequate length, severe calcification) must be identified and addressed because they can predispose to side branch occlusion [73–75]. The best strategy so far seems to be the

Table 1 Summary of outcomes from contemporary series on iliac branch devices (IBD)

Authors, year [ref.]	Number of patients (male/female)	Number and type of IBD	Bilateral IBD	Type of BSG for the IIA	Outside IFU	Mean follow-up (months)	Technical success	30-day mortality	30-day patency	Follow-up patency	Endoleaks	Buttock claudication	Reinterventions
Haulon et al., 2007 [45]	52 (47/5)	53 Cook ZHIS	1.9% (1/52)	1 Advanta; 1 Jostent; 48 Fluency/Viabahn	NA	14.2	94% (49/52)	0% (0/52)	89% (46/52)	100% (52/52)	11.5% (6/52)	0% (0/52)	11% (6/52)
Donas et al., 2011 [49]	64 (60/4)	64 Cook ZBIS	0% (0/64)	64 Advanta	NA	30.5 ± 20.9	NA	0% (0/64)	98.4% (63/64)	87.3%	12.5% (8/64)	3.1% (2/64)	4.7% (3/64)
Pratesi et al., 2013 [54]	81	85 (71 Cook ZBIS; 11 Cook ZHIS; 3 Cook BB-IBD)	4.9% (4/81)	10 Advanta	NA	20.4 ± 15.4	98.7% (80/81)	0% (0/81)	98.7% (80/81)	81.8%	3.7% (3/81)	8.6% (7/81)	6.2% (5/81)
Wong et al., 2013 [64]	130 (122/8)	138 (98 Cook ZHIS; 40 Cook BB-IBD)	6.2% (8/130)	NA	70%	20.3 (1–72)	94% (122/130)	0.77% (1/130)	94.6% (123/130)	81%	3.8% (5/130)	3.8% (5/130)	10.2% (4/39)
van Sterkenburg et al., 2016 [47]	46 (45/1)	51 Gore IBE	10.9% (5/46)	NA	15.6% (7/46)	5.6 (1.8–12.2)	93.5% (43/46)	0% (0/46)	98.4% (63/64)	94%	13% (5/40)	2.2% (1/46)	4.3% (2/46)
Mylonas et al., 2016 [50]	70 (69/1)	82 Jotec E-liac	17.1% (12/70)	NA	0% (0/82)	12 (6–16)	100% (82/82)	1 (1.4%)	98.8% (1/82)	92%	13%	NA	5.7% (4/70)
Simonte et al., 2017 [57]	149	134 Cook ZBIS; 23 Gore IBE	5–4% (8/149)	NA	NA	34 (1–121)	97.5% (153/157)	0% (0/149)	96.8% (152/157)	90.4%	8.1% (12/149)	5.3% (8/149)	5.3% (8/149)
Schneider et al., 2017 [58]	63 (62/1)	63 Gore IBE	0% (0/63)	NA	0% (0/63)	6	95.2% (60/63)	0% (0/63)	NA	95.1% (58/61)	54.7% (29/53)	9.5% (6/63)	3.2% (2/63)
Jongsma et al., 2017 [59]	140 (130/10)	162 Cook ZBIS	15.7% (22/140)	161 Advanta	34.9% (64/162)	26.6 ± 24.1	96.9% (157/162)	1.4% (2/140)	NA	89.2% (125/140)	7.1% (10/140)	4.3% (6/140)	7.1% (10/140)

IBD iliac branch device, *BSG* bridging stent graft, *IIA* internal iliac artery, *IFU* instructions for use, *ZHIS* Cook Zenith helical IBD, *ZBIS* Cook Zenith straight IBD, *BB-IBD* Cook Zenith bifurcated–bifurcated IBD, *IBE* Gore iliac branch endoprosthesis

Fig. 8 Intraoperative angiogram (left box) and postoperative computed tomographic angiography with maximum intensity projection at 1-year follow-up (right box). Successful bilateral deployment and patency of both iliac systems using bilateral iliac branch devices. (Gore device)

use of more than one BSG for a smooth transition between the devices and avoidance of diameter discrepancies [76]. Distal extension of the repair beyond IIA bifurcation is normally done into the posterior division branch, while using coils or plugs to exclude the anterior division branch. The safest maneuver in this case is to place first the proximal stent within the main trunk and then extend the repair distally to avoid losing guidewire access into the target branch. In case of large IIA aneurysms with numerous side branches, it is important to exclude all of them to avoid type 2 endoleaks; the technique of going from one side branch to the other using a buddy catheter is very useful to minimize manipulations.

The use of IBD alone has been described as safe and effective for endovascular reconstruction of isolated iliac aneurysms with optimal stability despite the absence of an aortic stent graft [77, 78]. Isolated IBD has the advantages of avoiding coverage of healthy aorta and possibly reducing times and costs. However, providing proper anatomic patient's selection is critical to reduce the risk of failure. IBDs will not have fixation barbs and will rely only on radial force. Then, when the CIA is used as the intended proximal seal segment, it is important to maintain similar requirements as one would for the infrarenal aortic neck. Indeed, the presence of hostile neck anatomy increases the risk of post-EVAR proximal seal failure and reinterventions [79–85]. Furthermore, concerns have also been raised over the durability of landing a standard device in relatively large-diameter aortic segments despite still falling within the IFU criteria [86–91], but it remains controversial whether the radial strength of oversized stent grafts results in neck dilatation or if the neck dilatation is the result of progressive aneurysmal disease [92–95]. In that sense, we believe that adequate seal segment length (10–20 mm), selection of a non-enlarged zone of sufficient quality to ensure proper device oversizing (10–20%), and optimal balloon molding of the endograft are essential to achieve secure apposition of an isolated IBD in the CIA.

Post-procedural pharmacotherapy might play a key role in maintaining satisfactory outcomes in the long term. Unfortunately, few high-quality randomized data to support the use of these therapies after peripheral endovascular interventions exist [96, 97], and none of them focused specifically on IBD. Many operators would currently treat patients with a variable course of dual antiplatelet therapy after stent-graft implantation, followed by lifelong single antiplatelet therapy. However, we usually waive dual antiplatelet regimens for patients on chronic anticoagulation to be resumed postoperatively or in those with high hemorrhagic risk based on preexisting medical conditions.

It is well known that EVAR has an early survival benefit but an inferior late survival as compared with open repair, which needs to be addressed by lifelong surveillance and reinterventions if necessary [98]. Intuitively, the multicomponent nature of IBD might make them more vulnerable to long-term device failure and secondary interventions. Although no studies to date have specifically addressed this topic, the excellent midterm stability of IBD in clinical studies would suggest that implantation of these devices does not significantly modify the general long-term results of elective EVAR. Overall, the importance of follow-up imaging cannot be overstated, but several challenges still remain: Postoperative EVAR surveillance compliance might be poor [99–101], indications for follow-up may vary among providers, and data on long-term survival benefit from adherence to post-EVAR imaging follow-up are controversial [102, 103]. Currently, after standard EVAR most experts would recommend close initial follow-up until the stability of the repair is ascertained, after which the frequency of imaging may be lowered in the absence of high-risk features [104–106]. In the absence of conclusive data about the optimal imaging protocol for follow-up after IBD implantation, patient-specific risk-adjusted protocols based on clinical judgment and local availability are warranted.

CTA remains the modality of choice for post-implantation follow-up, and its main benefits are represented by the high temporal and spatial resolution, the large availability in many hospitals and outpatient settings, and the short time required for the examination. CTA also has an unparalleled capability of detailed 3-dimensional measure of the stent-graft morphology and remains a fundamental tool to assist planning of secondary interventions. However, it is limited by cumulative radiation burden and unsuitability for patients with compromised renal function or contrast medium intolerance. Duplex ultrasound (DUS) is a noninvasive and less expensive imaging test without radiation or contrast usage, easy to perform and widely available. Clinical studies and systematic reviews investigating the role of DUS in post-EVAR surveillance have found that it can be performed accurately, safely, and cost-effectively as the sole imaging study [107] or as first line in combination with on-demand CTA in selected circumstances [108]. Contrast-enhanced ultrasound (CEUS) has several advantages over conventional DUS [109], and the use of sonographic contrast agents prolongs the real-time scanning as opposed to CTA which only captures temporal angiographic images [110–113]. However, ultrasound-based techniques are strongly operator-dependent and cannot provide information on endograft integrity [114]. Although this limitation may be overcome by combining the test with plain abdominal radiography after standard EVAR, IBD might be poorly suited for 2-dimensional techniques given the deep pelvic location, and no studies to date have specifically investigated the role of ultrasound examination in the imaging follow-up after IBD implantation.

Alternative Techniques for IIA Preservation

Before the advent of IBD, presence of ectasia or aneurysm of the CIA prevented the achievement of effective distal seal and fixation with conventional EVAR [115, 116]. Different techniques have been described to maintain pelvic perfusion, and we provide a brief description to allow for critical comparison with IBD [117–119].

- EVAR with flared iliac limbs (i.e., the bell-bottom technique) has been used widely to facilitate achievement of a distal seal in a dilated CIA while preserving pelvic flow [120, 121]. However, concerns about long-term stability still remain, and high incidence of late type 1B endoleaks from loss of distal fixation and seal has been reported [122, 123].
- IIA bypass has excellent results in terms of patency and freedom from ischemic complications but is technically demanding and a more invasive operation that may reduce the benefit from EVAR [124–126]. A novel approach using hybrid polytetrafluoroethylene graft has been recently described, but further experience is required before widespread implementation [127].
- The parallel-graft technique for IIA preservation is also feasible with acceptable short-term results, but the gutters created by the parallel grafts may cause endoleaks and the durability is the main concern [128–132]. Furthermore, the parallel stent grafts may compress each other, therefore potentially increasing the risk of thrombosis [133].
- Use of physician-modified devices has also been described to maintain IIA perfusion [134, 135]. However, they require time for modification and should be used cautiously by adequately trained physicians in patients without other reasonable options.
- Use of aortouniiliac endografting with crossover femoro-femoral bypass is an alternative solution. This may include CIA embolization (such as with a plug) or a "banana" stent graft from the external iliac artery to the IIA [136]. However, these solutions seem less desirable, since they may cause contralateral IIA malperfusion and thrombotic or infective events, which would lead to serious complications following repair [137].
- Simple IIA coverage without prior embolization has been shown by some authors as not increasing the risk of type 2 endoleaks or secondary interventions [138, 139]. However, the available evidence comes from small retrospective series which are difficult to compare [140, 141].

Conclusions

Unilateral or bilateral IIA preservation with IBD is safe, feasible and effective with technical and clinical outcomes comparable to standard EVAR. The versatility of current devices has also allowed extended application to complex cases, but must be considered carefully in difficult anatomies. Adequate preoperative assessment and intraoperative manipulation remain paramount to achieve success. Pending long-term durability results and formal cost-effectiveness appraisals, IBD implantation has several advantages to anatomically eligible patients as compared with other available open or endovascular/hybrid solutions for IIA preservation during EVAR for aortoiliac aneurysms.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no competing interests.

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