Endovascular Repair of Complex Aortic Pathology

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Abstract Aortic aneurysms are classified as complex based on their extent and involvement of side branches. Complex aortic aneurysms include arch, thoracoabdominal, juxtarenal and suprarenal aortic aneurysms. Open surgical repair carries high morbidity and mortality beyond large tertiary care centers. During the last decade, numerous technological advances have allowed incorporation of side branches using hybrid and total endovascular techniques. Fenestrated and branched endografts have been widely applied to treat patients with complex aneurysm anatomy. Newer stent graft designs are currently under clinical investigation offering an off-the-shelf alternative to custom-made stent grafts for patients with complex aortic aneurysms. Alternatively, a number of endovascular techniques have been described including chimney, snorkel, periscope and sandwich stent grafts. This article summarizes the current status of hybrid and total endovascular techniques to repair of thoracoabdominal, juxtarenal and suprarenal aortic aneurysms.

Keywords Complex aortic aneurysms · Thoracoabdominal · Juxtarenal · Suprarenal aortic aneurysms · Hybrid repair · Fenestrated and branched stent grafts · Complex aortic pathology · Endovascular repair

Introduction

Complex aortic aneurysms are defined by their extent of aortic and side branch involvement. These aneurysms include arch, thoracoabdominal, suprarenal and juxtarenal aortic aneurysms. Complex abdominal aortic aneurysms are defined by involvement of the renal and/or mesenteric arteries [1]. Contemporary reports from centers of excellence have demonstrated that open surgical repair can be performed safely and is durable. Mortality and spinal cord injury are the outcomes most frequently analyzed, but other important outcome measures are renal insufficiency, morbidity rates, quality of life and functional status after the operation. A recent review of reports dealing with open repair of pararenal aortic aneurysms has shown an average mortality of 6 % (0–15 %) [2]. A contemporary review of 598 patients treated for pararenal aneurysms by open repair using the NSQIP database showed a 30-day mortality of 4.5 % and morbidity of 30 %, including respiratory failure in 13 %, reoperation in 9 % and dialysis in 6 % of patients [3]. Reports from large aortic centers have shown that open repair of complex abdominal aortic aneurysms can be performed with satisfactory results, but mortality and morbidity rates are associated with increasing level of aneurysm complexity. Oderich and associates reported a 1.3 % 30-day mortality rate among 461 patients treated for complex abdominal aortic aneurysms at the Mayo Clinic between 2000 and 2010. In that study, mortality rates of 0 % for juxtarenal, 1.1 % for suprarenal and 7.8 % for type IV TAAAs were reported [4]. There was significant morbidity, which affected 38 % of patients treated for juxtarenal, 58 % of suprarenal and 69 % of type IV TAAAs.

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Hybrid Aortic Repair

The need to incorporate side branches into the repair has led to the introduction of hybrid procedures as a less invasive alternative to open conventional repair, avoiding the need for a thoracotomy and in many patients the requirement of aortic cross clamping (Fig. 1). The first report was by William Quinones-Baldrich from UCLA in 1999 [5]. The aim of the operation was to reduce the anatomic and physiologic stress to the patient by avoiding several shortcomings of open surgery: thoracotomy, single lung ventilation, aortic cross clamping, and prolonged end-organ ischemia.

Although there are logical advantages over open repair, results of hybrid procedures have been tempered by high morbidity and mortality rates in several centers. The UCLA and University of Michigan groups have reported two of the largest experiences with remarkably low mortality rates of 0 and 3.4 %, respectively [6, 7]. Others (Cleveland Clinic, Mayo Clinic, Massachusetts General Hospital, and Methodist Hospital Houston) have shown higher mortality rates in the range of 10–25 %. Hybrid repair of TAAAs has been recently analyzed by two systematic reviews of the available literature. Bakoyiannis and associates [8] reviewed the outcomes of 108 patients from 15 reports between 1999 and 2008. Technical success was 92 % and 30-day mortality 10 %. In this report, 19 patients (17 %) had primary endoleaks, spinal cord injury occurred in three patients (3 %) and renal insufficiency in 12 (11 %). More recently, a review by Moulakakis and associates [9•] included 507 patients and 19 reports published since 1999. Thirty-day or in-hospital mortality was 13 % and the most common causes of death were multisystem organ failure, ischemic colitis, respiratory failure and aneurysm rupture prior to a second

stage procedure. Pooled rates of spinal cord injury were 7.5 %, with irreversible paraplegia in 4.5 %. In 2011, Oderich and colleagues presented at the Society for Vascular Surgery Vascular Annual Meeting the preliminary results of the North American Complex Abdominal Aortic Debranching registry (NACAAD) [10]. A total of 208 patients included in this study were treated for complex abdominal aortic aneurysms in 14 academic centers of North America. A total of 659 visceral arteries were reconstructed using single stage debranching in 92 patients (44 %) or two-stage approach in 116 (56 %). Thirty-day or in-hospital mortality was 14 % for all patients, 16 % for TAAAs and 9 % for pararenal aneurysms. Mortality rates ranged from 0 to 21 % in centers with a volume greater than 10 cases. In this study, mortality was associated with severity of comorbidities as determined by Society for Vascular Surgery (SVS) clinical scores: 3 % for low risk patients (SVS score <9) and 17 % for high-risk patients (score >9). Independent predictors of early mortality included >3 vessel reconstruction, coronary artery disease, CHF, high SVS scores and chronic kidney disease stage >3. Any morbidity occurred in 73 % of the patients, most commonly pulmonary (22 %), renal (19 %), and gastrointestinal complications (14 %). Spinal cord injury occurred in 21 patients (10 %) and ischemic colitis in 13 (6 %).

The current role of hybrid repair in the treatment of patients with complex aortic aneurysms has evolved, and most centers with access to fenestrated and branched endografts (Europe, Canada, Asia and South America) have relegated hybrid procedures to high-risk patients who are neither candidates for total endovascular repair or open surgery [11, 12]. It is likely that hybrid repair will be replaced by total endovascular techniques in most centers;

Fig. 1 Pre- and post-operative computed tomography angiography of an anastomotic aneurysm (a) in a high risk patient submitted to hybrid repair using iliac-based extra-anatomic bypass to the visceral arteries (b) and aortic stent graft replacement of the thoracoabdominal aorta (c)

its future applications may be in patients who fail total endovascular repair or who are not candidates for fenestrated and branched endografts because of unusual anatomy. Hybrid repair also remains an option in centers with no access or experience with fenestrated and branched endografts.

Fenestrated and Branched Stent Grafts

Fenestrated and branched stent grafts were introduced as a minimally-invasive alternative to treat complex aneurysms in higher risk patients using total endovascular techniques [13]. Fenestrated endografts contain reinforced “holes or scallops”, which permit the incorporation of the visceral and renal arteries into the endovascular repair, enabling an adequate proximal sealing zone without compromising successful aneurysm exclusion (Fig. 2). Initial experiences with these devices have shown that total endovascular repair is effective and may reduce morbidity rates in patients with arch, thoracoabdominal, pararenal and juxtarenal aneurysms [14–21]. Treatment of chronic type B aortic dissection with the use of fenestrated devices has also been reported with good preliminary results [22, 23]. Based on the contemporary evidence from high-volume centers, endovascular repair of complex aortic aneurysms can be safely and effectively carried out in the hands of an experienced endovascular team.

Clinical Risk Assessment and Pre-operative Planning

Patient selection must be optimized with a comprehensive evaluation of cardiac, pulmonary and renal function. The evaluation includes noninvasive cardiac stress test (dobutamine stress echocardiography or Sestamibi study), pulmonary function tests, and carotid ultrasound. The clinical comorbidity score suggested by the SVS is a tool that can be used to stratify operative risk [24]; however, the criteria have not been prospectively validated in patients undergoing complex aortic surgery. Nonetheless, most surgeons agree that an increased surgical risk is associated with unstable angina, poor controlled or symptomatic ectopy, ejection fraction <25 %, recurrent congestive heart failure, myocardial infarction <6 months, vital capacity <1.8 L, FEV1 (forced expiratory volume in 1 s) <800 mL, diffusing capacity of the lung for carbon monoxide <30 %, resting pO₂ (oxygen partial pressure 60 mmHg and pCO₂ (partial pressure of carbon dioxide) >50 mmHg, and serum creatinine >2.5 mg/dL.

Patients with unfavorable anatomy for conventional bifurcated or tubular endografts are considered potential candidates for fenestrated and branched endografts. These anatomical constraints frequently include infra-renal aortic aneurysms with short or angulated necks, or more extensive pararenal and thoracoabdominal aneurysms with

involvement of the renal, visceral and internal iliac arteries. The presence of difficult access due to small and diseased iliac arteries or due to occlusive visceral artery are important predictors of technical difficulty with these types of repair. In addition to the number and location of each visceral artery, the presence of early bifurcation can also pose a technical challenge. For pararenal and thoracoabdominal repair, a minimum neck length of 20 mm should be selected. For the neck to be considered ideal, the aortic walls should be parallel with normal diameter (<32 mm for abdominal and <38 mm for thoracic aorta), with minimal or no aortic wall calcifications and thrombus; the sealing zone should be located in an area with minimal or no tortuosity or angulation. These basic principles should be followed in order to avoid an antegrade endoleak, which leads to pressurization of the aneurysmal sac and ultimately compromises the durability of the repair. Anatomical aspects of the iliac arteries should not be underestimated. Iliac artery rupture during the procedure can lead to hypotension, blood loss and increase risk of spinal cord injury [25], and should be avoided with careful patient selection [26]. Small iliac diameter, calcifications, tortuosity or previous stents are factors that increase the risk of introduction of the device. In these patients, the use of a conduit should be considered during procedure planning, with several techniques described on the literature [27–29].

Stent Graft Designs

Current designs include both fenestrated and branched stent grafts. Both devices have conceptual advantages and disadvantages. A fenestrated design requires precise planning and implantation, with little room for errors in any step, in which consists the main disadvantage. There is limited space for manipulation of catheters due to the narrow area between the target vessel and the fenestration, and misalignment may result in target vessel loss. Nonetheless, fenestrated endografts have been demonstrated to be very useful for treatment of juxtarenal, suprarenal and TAAAs, particularly when there is limited space in the aorta, and are remarkably well adapted for transversely oriented vessels, such as the renal arteries. Conversely, the use of cuffs or directional branches relies on the ability to direct the catheterization through longitudinally oriented branches, which is typically done via a brachial approach in down-going branches, with the femoral approach utilized for upgoing branches (Fig. 3). The presence of a large aortic luminal space facilitates the navigation of catheters from the stent graft cuff to the target visceral artery, eliminating the issue of misalignment that occurs with fenestrations while providing longer attachment site for the mating stent graft. The use of mixed designs combining the use of branches for longitudinally oriented vessels (celiac

Fig. 2 Endovascular repair of a juxtarenal abdominal aortic aneurysm with a fenestrated stent graft, and 3D reconstruction of postoperative computed tomography angiography demonstrating patency of visceral arteries and exclusion of the aneurysm sac

artery, superior mesenteric artery) and for vessels that originate from larger aortic lumen, while fenestrations can be reserved for transversely oriented vessels (renal arteries) or those originating from narrow aortic diameter.

Custom-made devices have the advantage of fitting the patient anatomy and adapting to numerous anatomical variations including tortuosity, vessel location, accessory branches, prior open or endovascular repair. These devices can be designed with fenestrations, directional branches and pre-loaded catheters, at the discretion of the treating physician, accommodating the patients' anatomical needs. For example, the presence of a target vessel arising from an area of large aortic lumen may favor the use of a directional branch, whereas a vessel arising from the seal zone may be best dealt with by fenestrations. Nonetheless, a limitation to these designs has been the need for customization and the time delay of at least 6–8 weeks to manufacture the device prior to implantation. In the United States, access to fenestrated and branched stent grafts has been limited to centers participating in investigational trials or to patients who are prospectively enrolled in physician-initiated investigational device exemption protocols. The custom-made Zenith (Cook Medical, Bloomington IN) fenestrated stent graft was the first fenestrated stent graft to become commercially approved in the United States in April 2012. However, this design is adequate for only a minority of patients due to its limitation of maximum of three fenestrations, two of the same type, which will exclude most patients with suprarenal aneurysms and all of those who have type IV thoracoabdominal aortic

aneurysms. In addition, the device customization requires a 6- to 8-weeks time period, which limits the use of these devices in patients with unstable aneurysms.

Most recently, standardized stent graft designs emerged as an option to be used off-the-shelf, which eliminates time delay for individualized customization. Standardized off-the-shelf designs include the Ventana^{TM} Endologix, the Cook Zenith p-Branch^{TM} and the Terumo device. Several other designs are currently under development by other stent graft manufacturers. The design of these new devices has been based on the relative predictability of the anatomy of the visceral arteries. Assuming a fixed position for the superior mesenteric artery (SMA), the location of the renal arteries and the celiac axis occurs at a somewhat constant location [15, 30, 31]. Currently, the Ventana^{TM} endograft (Endologix, Inc. Irvine CA) device is under investigation, offering an off-the-shelf design, with a large scallop to the SMA and a new concept of movable fenestrations. A minimum seal zone of 15 mm starting below the SMA is required, which makes patients with short neck infra-renal and select patients with pararenal aneurysms suitable to the device. Two other off-the-shelf designs are currently under investigation. The Zenith p-Branch^{TM} Endovascular Graft is intended to treat pararenal aortic aneurysms with a seal zone of 15 mm starting immediately below to the SMA and extending proximally. The Zenith t-Branch^{TM} Endovascular Graft is intended to treat thoracoabdominal aneurysms using a multi-branch device with four directional branches in standardized position. The Anaconda^{TM} fenestrated stent graft (Vascutek, Inchinnan, United Kingdom) is a

Fig. 3 Endovascular repair of a type II thoracoabdominal aortic aneurysm using a physician-modified branched stent graft with a post-operative computed tomography angiography demonstrating exclusion of the aneurysm and patency of the visceral branches. Note in the inset the use of bare-metal stents to avoid kink in the renal artery after deployment of the covered stent

custom-made device intended to treat short neck infrarenal and juxtarenal AAAs, with up to four fenestrations of any type and the ability to reposition the device even after it is completely unsheathed, with realignment of the orientation or longitudinal position of the stent graft. The device is still under investigation in Europe and has not been used in the United States. A preliminary study by Bungay and associates [32] demonstrated the feasibility of the system in four patients, with 100 % target vessel cannulation success rate and successful exclusion of the aneurysm in all patients.

A new endovascular classification has been proposed to describe technical complexity of these procedures. The classification is based on the number of vessels requiring incorporation into the repair by means of fenestrations or branches. In our analysis of 461 patients treated for complex abdominal aortic aneurysms, half of the patients would not be ideal candidates for the currently available Zenith fenestrated stent graft taking into consideration the maximum of three fenestrations [4]. The highest variation was observed for suprarenal aortic aneurysms, which required most often three fenestrations (55 %), but also two (22 %) or four (23 %) fenestrations. The interaction between the aortic component and its side branches may affect long-term results. A limitation of current reports is that there is no standardization for selection of the ideal mating stent graft, and operators frequently reinforce the stent graft by placement of a second self-expandable stent. The delivery, mating characteristics, profile and durability are critical to the success of such therapy. A shortcoming of off-the-shelf designs as compared to custom-made stent

grafts include the need to adapt to a standard design, which may affect angles of side branches and consequently its long-term durability. These off-the-shelf designs are currently undergoing clinical investigation, and long-term follow up will be needed to compare with the excellent patency rates reported for custom-made designs.

Iliac Branch Devices (IBDs)

IBDs are designed to incorporate the internal iliac artery while providing excellent seal and maintaining flow into the internal and external iliac arteries (Fig. 4) [33]. There are currently three different stent graft designs based on the Cook Medical Inc. platform, including a bifurcated iliac side (ZBIS) branch, also known as straight side-arm IBD, the helical branch, and the bifurcated–bifurcated IBD. W.L. Gore also has an iliac branch device under development. The ideal length of the common iliac artery should be at least 50 mm, with a diameter at the iliac bifurcation of at least 16 mm. Other anatomical criteria for using iliac branch devices takes into consideration iliac tortuosity, calcifications, or stenosis that may predispose stent grafts to kink or occlude; while the presence of internal iliac artery stenosis is not a contraindication but may increase technical difficulty. The quality of the hypogastric arteries affects patency, including inadequate run-off due to distal branch vessel disease or aneurysmal involvement with insufficient distal landing zone are limitations to the use of IBDs as well as other endovascular or open revascularization strategies, including sandwich stent grafts. An alternative in the absence of commercially available IBDs,

a modification technique of the Cook Zenith (Cook Medical, Bloomington, IN) iliac extension limb was described by Oderich and Ricotta [34]. The procedure may be beneficial for high-risk patients with bilateral internal iliac artery aneurysms who do not have access to a manufactured IBD.

Results

Several reports from Australia, Asia, Europe, Canada, South America and from select centers in the United States demonstrate the increasing worldwide use of fenestrated and branched stent grafts. Their clinical application has been well described in patients with complex aortic anatomy, as well as for salvage of anastomotic aneurysms or failed endovascular procedures. During the last decade, several centers have accumulated a large experience with these types of repairs and reported their early and late outcomes (Table 1) [17–19, 35–57, 58•, 59–63]. The Cleveland Clinic group reported their clinical outcomes in 406 patients treated for thoracoabdominal aortic aneurysms and 227 patients treated for juxtarenal or suprarenal aortic aneurysms. The 30-day mortality and 2-year survival were nearly identical for juxtarenal/suprarenal aneurysms (1.8 and 78 %) and type IV thoracoabdominal aortic aneurysms (2.3 and 82 %), and markedly different than outcomes obtained with more extensive thoracoabdominal aortic aneurysms. Operative mortality was 5.2 % for types II and III thoracoabdominal aortic aneurysms [17].

Multi-center series have demonstrated that fenestrated stent grafts can be performed with high technical success rates, and that results can be duplicated in experienced centers. The GLOBALSTAR registry has reported on 318

patients treated in 14 centers in the United Kingdom between 2007 and 2010. Primary procedure success was achieved in 99 % of patients, with only five of 889 target vessels lost during the procedure. Perioperative mortality was 4.1 and 7 % of patients needed a reintervention. Long-term survival at 3 years was 89 % with a freedom from secondary intervention of 70 % at same interval [58•]. Haulon and colleagues reported the French multicenter experience, with 80 patients enrolled in a prospective database from 2004 to 2008. There was one conversion to open repair. Target vessel catheterization and stenting was 99 %. Operative mortality at 30 days was 2.5 %. No aneurysm ruptures or conversion to open repair were noted after a mean follow up of 10 months. Aneurysm sac shrinkage was 58 % at 18 months. Five patients were treated for endoleaks and three had re-stenting for restenosis or kink, with secondary interventions needed in 10 % of patients [52].

A prospective non-randomized study evaluating the results of custom-made fenestrated Zenith stent graft in 30 patients treated at five centers was reported in 2009 [48]. There were no aneurysm-related deaths, ruptures or conversions to open repair. Target vessel stenting was 100 %. There were no type I or III endoleaks in the study, which has independent auditing of follow up imaging studies in a core lab. Six patients had type II endoleaks (26 %). Sac shrinkage was observed in 70 % of patients at 2 years, and none of the patients had aneurysm sac growth >5 mm. Eight patients had renal events which included four renal artery stent stenosis, two renal artery occlusions and two renal infarcts. The authors concluded that fenestrated stent graft repair was safe and effective at centers with experience in endovascular repair of aortic aneurysms and renal/mesenteric stent placement.

The outcomes of treatment of juxtarenal abdominal aortic aneurysms with fenestrated stent grafts and open

Fig. 4 Total endovascular repair of aortoiliac aneurysm using a straight-arm iliac branch device (S-IBD) (a). The procedure is completed by placement of a bifurcated aortic stent graft via the contralateral side (b). Postoperative computed tomography angiography demonstrating successful exclusion of the aneurysm sac with patency to the right internal iliac artery (c)

Table 1 Outcomes of repair of complex abdominal aortic aneurysms using fenestrated and branched stent grafts

Author	Years	N	Target vessels	30-day mortality %	Endoleaks	Reintervention	Branch patency	Mean follow-up (months)
Anderson et al.	2001	13	33	0	0	0	–	14
Greenberg et al.	2004	32	83	3.1	6.5	–	98	9
Greenberg et al.	2004	22	58	0	9	18		6
Verhoeven et al.	2004	18	46	0	17	–	98	9
Anderson et al.	2005	4	13	25	0	25	100	12
O’Neil et al.	2006	119	302	0.8	25	–	92	19
Semmens et al.	2006	58	116	3.4	6.9	24	95	24
Muhs et al.	2006	38	87	2.6	24	12	92	25
Halak et al.	2006	17	35	0	0	–	94	20
Roselli et al.	2007	73	–	5.5	11	18	100	12
Ziegler et al.	2007	63	122	1.5	19	25	92	23
Scurr et al.	2008	45	117	2	0	13	97	24
Chuter et al.	2008	22	81	9	9	9	99	12
Gilling-Smith et al.	2008	6	–	0	33	33	–	17
Ferreira et al.	2008	11	43	18	0	–	97	8
Beck et al.	2009	18	56	0	–	0	95	23
Greenberg et al.	2009	30	54	0	60	17	93	24
Bicknell et al.	2009	15	40	0	40	–	97	12
Mohabbat et al.	2009	287	518	4.2	–	20	94	26
Kristmundsson et al.	2009	54	134	3.7	31	–	96	25
Vourliotakis et al.	2009	9	20	0	22	–	100	31
Verhoeven et al.	2009	30	97	6.7	–	6.7	90	12
Amiot et al.	2010	134	403	2	18	9	97	15
Haulon et al.	2010	80	237	2.5	11	10	95	10
Haulon et al.	2010	33	116	9	15	3	100	11
Greenberg et al.	2010	633	–	5.7	–	–	98	15
Verhoeven et al.	2010	100	275	1	–	9	94	24
Tambyraja et al.	2011	29	79	0	21	38	–	20
Manning et al.	2011	20	68	10	10	25	96	1
Global Collaborators	2012	318	889	3.5	15	14	98	21
Metcalf et al.	2012	42	95	7	17	7	94	11
Starnes et al.	2012	47	82	2	13	5	–	20
Guillou et al.	2012	89	292	8.9	3.4	4.5	97	17

conventional repair were compared in two systematic reviews. Nordon and associates reviewed 12 studies and included 368 patients treated with fenestrated stent grafts and 1164 treated with open conventional repair. Early renal dysfunction rates and 30-day mortality were significantly higher for the open repair group. There was an absolute increase in operative mortality of 2 % with open repair, but this was associated with less early re-interventions. The incidence of type I endoleak in the reported studies varied between 0 and 7 %, and most of these resolved with observation alone. More frequently, type II endoleak occurred in 3–18 % of patients, but its treatment was only indicated if there was sac enlargement. Based on the

intermediate-term results from these selected series, the use of fenestrated stent grafts can be safely and effectively performed with very high procedural success, with mandatory close surveillance for early identification of visceral or branched vessel stenosis or pre-occlusion. The patients appear to be at higher risk of failure within the first post-operative year, with a plateau in subsequent follow-up. Secondary intervention rates range between 10 and 20 % are noted in these studies [14].

An evidence-based analysis of fenestrated endovascular repair of juxtarenal aortic aneurysms was also reported in 2009 by the Ontario Health Technology committee. In this systematic review, 12 studies included five reports of

fenestrated endografts, one comparative study and seven reports of open conventional repair. Overall, 274 patients were treated by fenestrated endografts and 856 by open repair. Fenestrated stent grafts were associated with lower early (1.8 vs. 3.1 %) and late mortality rates (13 vs. 24 %). Cardiac and pulmonary complications among patients treated by endovascular approach were lower [64].

Technical success rates for iliac branch devices have been reported as greater than 95 % in several publications, with a clear improvement after the advent of newer generation devices [65–71]. A systematic analysis by Karkhiesalingam and associates [72] included 196 patients treated with IBDs, with technical success rates ranging from 85 to 100 %, with no aneurysm-related deaths. Buttock claudication occurred in only one patient who had a patent IBD. However, late thrombosis of the IBD occurred in 24 patients (12 %), and resulted in buttock claudication in half of them. Twelve patients required reintervention (6 %), including five with stent graft limb occlusion to the external iliac artery. Overall endoleak rates were 0.5 % for type I and 1 % for type III. Furthermore, a comparative analysis of IBDs versus hypogastric exclusion was reported by Verzini and colleagues [73]. The total study population was 74 patients. There were no differences in procedure time, contrast use and technical success, and there were no early deaths associated with the procedure. Nevertheless, a trend towards more endoleaks (19 vs. 4 %) and pelvic ischemic symptoms (22 vs. 4 %) was noted among patients who underwent coil embolization, as compared to those treated with IBDs. The 5-year results of 100 patients treated by the same group were recently reported, with 91.4 % patency in 1 and 5 years and an intervention-free rate in 5 years of 81.4 % [74].

Chimneys, Snorkels and Parallel Endografts

A variety of creative techniques have been reported by different centers to incorporate the visceral arteries in a total endovascular repair, while several endograft designs are still not widely available [75–81]. These techniques include chimney, periscope, octopus, sandwich and physician-modified endografts. Nevertheless, the lack of quality control, off-label indications, questionable durability and violation of basic engineering concepts limit the use of these techniques as bail-out maneuvers as compared to the first line of treatment. A recent literature review by Moulakakis and colleagues [76] reported 15 studies with a total of 93 patients who underwent EVAR with visceral revascularization by chimney or snorkel technique, with 134 total grafts implanted. A total of 13 patients (14 %) developed a type I endoleak, which were detected and treated intraoperatively. Ten type I endoleaks were

diagnosed during follow-up, with reintervention required in four patients. Primary patency was 97.8 % during a mean follow-up period of 9 months. Renal function impairment was noted in 11.8 % of patients, with a 30-day in-hospital mortality of 4.3 %. Most recently, Donas and associates [82] reported the use of chimney stents for pararenal aortic pathology. In that study, 127 vessels in a total of 72 patients were revascularized using both balloon-expandable covered stents (Advanta, Atrium, Hudson, NH) and self-expandable stents (Viabahn, WL Gore, Flagstaff, AZ). Success rate for target vessel preservation was 97.8 % for the balloon-expandable covered stent group and 100 % for the self-expandable stent group, in a mean follow up of 15.9 and 12.1 months, respectively. One patient had symptomatic renal artery occlusion in the balloon-expandable stent group and was treated by open thrombectomy and ileorenal bypass, and one patient underwent repeat balloon angioplasty due to in-stent restenosis after follow-up of 12 months. A total of six type Ia endoleaks were detected, with continuous sac enlargement in one patient, who was treated with a proximal extension of the repair. Overall procedure-related mortality was 0 % for the entire cohort.

Conclusions

The need for major operative exposure, extensive arterial reconstruction and high levels of physiological stress limits open repair of complex abdominal aortic aneurysms. Important outcome measures, such as morbidity, recovery time and impact on quality of life should be analyzed in conjunction with higher mortality rates observed in the community using large datasets. The risks associated with open surgical repair of pararenal or thoracoabdominal aneurysms in a constant aging population with several co-morbidities render fewer patients as candidates for open reconstruction. Furthermore, an alternative treatment that can be performed with less risk of complications, shorter recovery time and potential positive impact on quality of life measures benefits a large number of patients who are considered intermediate or low risk for open repair. For these patients, endovascular repair with a stent-graft and incorporation of side branches may be the only treatment option (for higher risk patients) or the preferred option (for those who are potential candidates for either approach). For the treatment of aortoiliac aneurysms, IBDs allow a totally endovascular approach and represent a significant improvement in preserving pelvic flow during these procedures. Physician training, regulatory approval and analysis of late outcomes of patients treated with these devices still limit widespread use of IBDs.

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References

Papers of particular interest, published recently, have been highlighted as:

- Of importance

1. Johnston KW, Rutherford RB, Tilson MD, Shah DM, Hollier L, Stanley JC. Suggested standards for reporting on arterial aneurysms. Subcommittee on Reporting Standards for Arterial Aneurysms, Ad Hoc Committee on Reporting Standards, Society for Vascular Surgery and North American Chapter, International Society for Cardiovascular Surgery. *J Vasc Surg.* 1991;13:452–8.
2. Tallarita T, Sobreira ML, Oderich GS. Results of open pararenal abdominal aortic aneurysm repair: tabular review of the literature. *Ann Vasc Surg.* 2011;25:143–9.
3. Gupta PK, Mactaggart JN, Natarajan B, et al. Predictive factors for mortality after open repair of paravisceral abdominal aortic aneurysm. *J Vasc Surg.* 2012;55:666–73.
4. Oderich GS, Tallarita T, Kalra M, Duncan AA, Gloviczki P, Vrtiska T, Cha S, Bower TC. SS23. Contemporary results of open complex abdominal aortic aneurysm repair using a standardized classification for comparison with fenestrated endografts. *J Vasc Surg.* 2011;53:27S–8.
5. Quinones-Baldrich WJ, Panetta TF, Vescera CL, Kashyap VS. Repair of type IV thoracoabdominal aneurysm with a combined endovascular and surgical approach. *J Vasc Surg.* 1999;30:555–60.
6. Patel HJ, Upchurch GR Jr, Eliason JL, et al. Hybrid debranching with endovascular repair for thoracoabdominal aneurysms: a comparison with open repair. *Ann Thorac Surg.* 2010;89:1475–81.
7. Quinones-Baldrich W, Jimenez JC, DeRubertis B, Moore WS. Combined endovascular and surgical approach (CESA) to thoracoabdominal aortic pathology: a 10-year experience. *J Vasc Surg.* 2009;49:1125–34.
8. Bakoyiannis C, Kalles V, Economopoulos K, Georgopoulos S, Tsigiris C, Papalambros E. Hybrid procedures in the treatment of thoracoabdominal aortic aneurysms: a systematic review. *J Endovasc Ther.* 2009;16:443–50.
9. • Moulakakis KG, Mylonas SN, Avgerinos ED, Kakisis JD, Brunkwall J, Liapis CD. Hybrid open endovascular technique for aortic thoracoabdominal pathologies. *Circulation.* 2011;124:2670–80. *This paper is a meta-analysis of 19 publications with a total of 507 patients that underwent hybrid repair for aortic thoracoabdominal pathologies. It is a study that reaches statistical significance due to its large number of patients.*
10. Oderich GS, Farber M, Quinones-Baldrich W, et al. Abdominal debranching with aortic stent grafts for complex aortic aneurysms: Preliminary results of the North American Complex Abdominal Aortic Debranching (NACAAD) registry. Presented at the 2011 Vascular Annual Meeting, Chicago IL, June 18, 2011; 2011.
11. Oderich GS, Mendes BC, Gloviczki P, Kalra M, Duncan AA, Bower TC. Current role and future directions of hybrid repair of thoracoabdominal aortic aneurysms. *Perspect Vasc Surg Endovasc Ther.* 2012;24:14–22.
12. Oderich GS. The role of debranching in endovascular repair of TAAs. *Endovasc Today.* 2012;11(3):64–9.
13. Park JH, Chung JW, Choo IW, Kim SJ, Lee JY, Han MC. Fenestrated stent grafts for preserving visceral arterial branches in the treatment of abdominal aortic aneurysms: preliminary experience. *J Vasc Interv Radiol.* 1996;7:819–23.
14. Nordon IM, Hinchliffe RJ, Holt PJ, Loftus IM, Thompson MM. Modern treatment of juxtarenal abdominal aortic aneurysms with fenestrated endografting and open repair—a systematic review. *Eur J Vasc Endovasc Surg.* 2009;38:35–41.
15. Nordon IM, Hinchliffe RJ, Manning B, et al. Toward an “off-the-shelf” fenestrated endograft for management of short-necked abdominal aortic aneurysms: an analysis of current graft morphological diversity. *J Endovasc Ther.* 2010;17:78–85.
16. Greenberg RK, Lytle B. Endovascular repair of thoracoabdominal aneurysms. *Circulation.* 2008;117:2288–96.
17. Greenberg R, Eagleton M, Mastracci T. Branched endografts for thoracoabdominal aneurysms. *J Thorac Cardiovasc Surg.* 2010;140:S171–8.
18. Haulon S, D’Elia P, O’Brien N, et al. Endovascular repair of thoracoabdominal aortic aneurysms. *Eur J Vasc Endovasc Surg.* 2010;39:171–8.
19. Verhoeven EL, Tiellu IF, Bos WT, Zeebregts CJ. Present and future of branched stent grafts in thoraco-abdominal aortic aneurysm repair: a single-centre experience. *Eur J Vasc Endovasc Surg.* 2009;38:155–61.
20. Verhoeven EL, Vourliotakis G, Bos WT, 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;39:529–36.
21. Ziegler P, Perdikides TP, Avgerinos ED, Umscheid T, Stelter WJ. Fenestrated and branched grafts for para-anastomotic aortic aneurysm repair. *J Endovasc Ther.* 2007;14:513–9.
22. Verhoeven EL, Paraskevas KI, Oikonomou K, et al. Fenestrated and branched stent grafts to treat post-dissection chronic aortic aneurysms after initial treatment in the acute setting. *J Endovasc Ther.* 2012;19:343–9.
23. Oderich GS, Mendes BC. Commentary: chronic aortic dissections and a new frontier: fenestrated and branched endografts. *J Endovasc Ther.* 2012;19:350–5.
24. Chaikof EL, Fillinger MF, Matsumura JS, et al. Identifying and grading factors that modify the outcome of endovascular aortic aneurysm repair. *J Vasc Surg.* 2002;35:1061–6.
25. Bicknell CD, Riga CV, Wolfe JH. Prevention of paraplegia during thoracoabdominal aortic aneurysm repair. *Eur J Vasc Endovasc Surg.* 2009;37:654–60.
26. Duran C, Naoum JJ, Smolock CJ, et al. A longitudinal view of improved management strategies and outcomes after iatrogenic iliac artery rupture during endovascular aneurysm repair. *Ann Vasc Surg.* 2012;27(1):1–7.
27. Oderich GS, Picada-Correa M, Pereira AA. Open surgical and endovascular conduits for difficult access during endovascular aortic aneurysm repair. *Ann Vasc Surg.* 2012;26:1022–9.
28. Yano OJ, Faries PL, Morrissey N, Teodorescu V, Hollier LH, Marin ML. Ancillary techniques to facilitate endovascular repair of aortic aneurysms. *J Vasc Surg.* 2001;34:69–75.
29. Hinchliffe RJ, Ivancev K, Sonesson B, Malina M. “Paving and cracking”: an endovascular technique to facilitate the introduction of aortic stent grafts through stenosed iliac arteries. *J Endovasc Ther.* 2007;14:630–3.
30. Sweet MP, Hiramoto JS, Park KH, Reilly LM, Chuter TA. A standardized multi-branched thoracoabdominal stent-graft for endovascular aneurysm repair. *J Endovasc Ther.* 2009;16:359–64.
31. Sobocinski J, d’Utra G, O’Brien N, et al. Off-the-shelf fenestrated endografts: a realistic option for more than 70% of patients with juxtarenal aneurysms. *J Endovasc Ther.* 2012;19:165–72.
32. Bungay PM, Burfitt N, Sritharan K, et al. Initial experience with a new fenestrated stent graft. *J Vasc Surg.* 2011;54:1832–8.

33. Greenberg RK, Qureshi M. Fenestrated and branched devices in the pipeline. *J Vasc Surg.* 2010;52:15S–21S.
34. Oderich GS, Ricotta JJ 2nd. Novel surgeon-modified hypogastric branch stent graft to preserve pelvic perfusion. *Ann Vasc Surg.* 2010;24:278–86.
35. Anderson JL, Adam DJ, Berce M, Hartley DE. Repair of thoracoabdominal aortic aneurysms with fenestrated and branched endovascular stent grafts. *J Vasc Surg.* 2005;42:600–7.
36. 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.
37. Greenberg RK, Haulon S, Lyden SP, et al. Endovascular management of juxtarenal aneurysms with fenestrated endovascular grafting. *J Vasc Surg.* 2004;39:279–87.
38. Greenberg RK, Haulon S, O'Neill S, Lyden S, Ouriel K. Primary endovascular repair of juxtarenal aneurysms with fenestrated endovascular grafting. *Eur J Vasc Endovasc Surg.* 2004;27:484–91.
39. Verhoeven EL, Prins TR, Tiellii IF, et al. Treatment of short-necked infrarenal aortic aneurysms with fenestrated stent grafts: short-term results. *Eur J Vasc Endovasc Surg.* 2004;27:477–83.
40. O'Neill S, Greenberg RK, Haddad F, Resch T, Sereika J, Katz E. A prospective analysis of fenestrated endovascular grafting: intermediate-term outcomes. *Eur J Vasc Endovasc Surg.* 2006;32:115–23.
41. Halak M, Goodman MA, Baker SR. The fate of target visceral vessels after fenestrated endovascular aortic repair—general considerations and mid-term results. *Eur J Vasc Endovasc Surg.* 2006;32:124–8.
42. Muhs BE, Verhoeven EL, Zeebregts CJ, et al. Mid-term results of endovascular aneurysm repair with branched and fenestrated endografts. *J Vasc Surg.* 2006;44:9–15.
43. Semmens JB, Lawrence-Brown MM, Hartley DE, Allen YB, Green R, Nadkarni S. Outcomes of fenestrated endografts in the treatment of abdominal aortic aneurysm in Western Australia (1997–2004). *J Endovasc Ther.* 2006;13:320–9.
44. Ziegler P, Avgerinos ED, Umscheid T, Perdikides T, Stelter WJ. Fenestrated endografting for aortic aneurysm repair: a 7-year experience. *J Endovasc Ther.* 2007;14:609–18.
45. Scurr JR, Brennan JA, Gilling-Smith GL, Harris PL, Vallabhaneni SR, McWilliams RG. Fenestrated endovascular repair for juxtarenal aortic aneurysm. *Br J Surg.* 2008;95:326–32.
46. Ferreira M, Lanzotti L, Monteiro M. Branched devices for thoracoabdominal aneurysm repair: Early experience. *J Vasc Surg.* 2008;48:30S–6. (discussion 36S).
47. Beck AW, Bos WT, Vourliotakis G, Zeebregts CJ, Tiellii IF, Verhoeven EL. Fenestrated and branched endograft repair of juxtarenal aneurysms after previous open aortic reconstruction. *J Vasc Surg.* 2009;49:1387–94.
48. Greenberg RK, Sternbergh WC 3rd, Makaroun M, et al. Intermediate results of a United States multicenter trial of fenestrated endograft repair for juxtarenal abdominal aortic aneurysms. *J Vasc Surg.* 2009;50(730–737):e731.
49. Mohabbat W, Greenberg RK, Mastracci TM, Cury M, Morales JP, Hernandez AV. Revised duplex criteria and outcomes for renal stents and stent grafts following endovascular repair of juxtarenal and thoracoabdominal aneurysms. *J Vasc Surg.* 2009;49:827–37. (discussion 837).
50. Kristmundsson T, Sonesson B, Malina M, Bjorses K, Dias N, Resch T. Fenestrated endovascular repair for juxtarenal aortic pathology. *J Vasc Surg.* 2009;49:568–74. (discussion 574–5).
51. Amiot S, Haulon S, Becquemin JP, et al. Fenestrated endovascular grafting: the French multicentre experience. *Eur J Vasc Endovasc Surg.* 2010;39:537–44.
52. Haulon S, Amiot S, Magnan PE, et al. An analysis of the French multicentre experience of fenestrated aortic endografts: medium-term outcomes. *Ann Surg.* 2010;251:357–62.
53. Tambyraja AL, Fishwick NG, Bown MJ, Nasim A, McCarthy MJ, Sayers RD. Fenestrated aortic endografts for juxtarenal aortic aneurysm: medium term outcomes. *Eur J Vasc Endovasc Surg.* 2011;42:54–8.
54. Manning BJ, Agu O, Richards T, Ivancev K, Harris PL. Early outcome following endovascular repair of pararenal aortic aneurysms: triple- versus double- or single-fenestrated stent grafts. *J Endovasc Ther.* 2011;18:98–105.
55. Guillou M, Bianchini A, Sobocinski J, et al. Endovascular treatment of thoracoabdominal aortic aneurysms. *J Vasc Surg.* 2012;56:65–73.
56. Metcalfe MJ, Holt PJ, Hinchliffe RJ, Morgan R, Loftus IM, Thompson MM. Fenestrated endovascular aneurysm repair: graft complexity does not predict outcome. *J Endovasc Ther.* 2012;19:528–35.
57. Starnes BW. Physician-modified endovascular grafts for the treatment of elective, symptomatic, or ruptured juxtarenal aortic aneurysms. *J Vasc Surg.* 2012;56:601–7.
58. • GLOBALSTAR Collaborators. Early results of fenestrated endovascular repair of juxtarenal aortic aneurysms in the United Kingdom. *Circulation.* 2012;125:2707–15. *A total of 318 patients from 14 different high-volume centers of the United Kingdom were enrolled in this study, which demonstrated a high degree of technical and clinical success, with a satisfactory late survival and target vessel patency.*
59. Bicknell CD, Cheshire NJ, Riga CV, et al. Treatment of complex aneurysmal disease with fenestrated and branched stent grafts. *Eur J Vasc Endovasc Surg.* 2009;37:175–81.
60. Chuter TA, Rapp JH, Hiramoto JS, Schneider DB, Howell B, Reilly LM. Endovascular treatment of thoracoabdominal aortic aneurysms. *J Vasc Surg.* 2008;47:6–16.
61. Gilling-Smith GL, McWilliams RG, Scurr JR, et al. Wholly endovascular repair of thoracoabdominal aneurysm. *Br J Surg.* 2008;95:703–8.
62. Roselli EE, Greenberg RK, Pfaff K, Francis C, Svensson LG, Lytle BW. Endovascular treatment of thoracoabdominal aortic aneurysms. *J Thorac Cardiovasc Surg.* 2007;133:1474–82.
63. Vourliotakis G, Bos WT, Beck AW, Van Den Dungen JJ, Prins TR, Verhoeven EL. Fenestrated stent-grafting after previous endovascular abdominal aortic aneurysm repair. *J Cardiovasc Surg (Torino).* 2010;51:383–9.
64. Ontario Health Quality. Fenestrated endovascular grafts for the repair of juxtarenal aortic aneurysms: an evidence-based analysis. *Ont Health Technol Assess Ser.* 2009;9:1–51.
65. Ferreira M, Monteiro M, Lanzotti L. Technical aspects and midterm patency of iliac branched devices. *J Vasc Surg.* 2010;51:545–50. (discussion 550).
66. Ghosh J, Murray D, Paravastu S, Farquharson F, Walker MG, Serracino-Inglott F. Contemporary management of aorto-iliac aneurysms in the endovascular era. *Eur J Vasc Endovasc Surg.* 2009;37:182–8.
67. Greenberg RK, West K, Pfaff K, et al. Beyond the aortic bifurcation: branched endovascular grafts for thoracoabdominal and aortoiliac aneurysms. *J Vasc Surg.* 2006;43:879–86. (discussion 886–7).
68. Huilgol RL, Denton MJ, Cohen T. The iliac bifurcation device for endovascular iliac aneurysm repair: indications, deployment options and results at 1-year follow-up of 25 cases. *ANZ J Surg.* 2009;79:844–9.
69. Malina M, Dirven M, Sonesson B, Resch T, Dias N, Ivancev K. Feasibility of a branched stent-graft in common iliac artery aneurysms. *J Endovasc Ther.* 2006;13:496–500.
70. Serracino-Inglott F, Bray AE, Myers P. Endovascular abdominal aortic aneurysm repair in patients with common iliac artery aneurysms—initial experience with the Zenith bifurcated iliac side branch device. *J Vasc Surg.* 2007;46:211–7.

71. Tielliu IF, Bos WT, Zeebregts CJ, Prins TR, Van Den Dungen JJ, Verhoeven EL. The role of branched endografts in preserving internal iliac arteries. *J Cardiovasc Surg (Torino)*. 2009;50:213–8.
72. Karthikesalingam A, Hinchliffe RJ, Holt PJ, Boyle JR, Loftus IM, Thompson MM. Endovascular aneurysm repair with preservation of the internal iliac artery using the iliac branch graft device. *Eur J Vasc Endovasc Surg*. 2010;39:285–94.
73. Verzini F, Parlani G, Romano L, De Rango P, Panuccio G, Cao P. Endovascular treatment of iliac aneurysm: concurrent comparison of side branch endograft versus hypogastric exclusion. *J Vasc Surg*. 2009;49:1154–61.
74. • Parlani G, Verzini F, De Rango P, et al. Long-term results of iliac aneurysm repair with iliac branched endograft: a 5-year experience on 100 consecutive cases. *Eur J Vasc Endovasc Surg*. 2012;43:287–92. *This article demonstrates long-term data on 100 consecutive patients treated by iliac branch devices in a single institution, with a 95 % technical success rate, 91 % patency in 5 years and 81 % freedom from any reintervention in five years. It is the largest published series on iliac branch devices.*
75. Lobato AC. Sandwich technique for aortoiliac aneurysms extending to the internal iliac artery or isolated common/internal iliac artery aneurysms: a new endovascular approach to preserve pelvic circulation. *J Endovasc Ther*. 2011;18:106–11.
76. Moulakakis KG, Mylonas SN, Avgerinos E, et al. The chimney graft technique for preserving visceral vessels during endovascular treatment of aortic pathologies. *J Vasc Surg*. 2012;55:1497–503.
77. Ohrlander T, Sonesson B, Ivancev K, Resch T, Dias N, Malina M. The chimney graft: a technique for preserving or rescuing aortic branch vessels in stent-graft sealing zones. *J Endovasc Ther*. 2008;15:427–32.
78. Oderich GS, Ricotta JJ 2nd. Modified fenestrated stent grafts: device design, modifications, implantation, and current applications. *Perspect Vasc Surg Endovasc Ther*. 2009;21:157–67.
79. Oderich GS, Fatima J, Gloviczki P. Stent graft modification with mini-cuff reinforced fenestrations for urgent repair of thoracoabdominal aortic aneurysms. *J Vasc Surg*. 2011;54:1522–6.
80. Kasirajan K. Branched grafts for thoracoabdominal aneurysms: off-label use of FDA-approved devices. *J Endovasc Ther*. 2011;18:471–6.
81. Rancic Z, Pfammatter T, Lachat M, et al. Periscope graft to extend distal landing zone in ruptured thoracoabdominal aneurysms with short distal necks. *J Vasc Surg*. 2010;51:1293–6.
82. Donas KP, Pecoraro F, Torsello G, 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;55:659–65.