REVIEW ARTICLE

Fenestrated and Branched Aortic Grafts

Patency, Perioperative Mortality and Spinal Ischemia

Bartosz Rylski, Martin Czerny, Michael Südkamp, Maximilian Russe, Matthias Siepe, Friedhelm Beyersdorf

SUMMARY

Background: Abdominal and thoracic aortic aneurysms are diagnosed in 40 and 10 to 15 out of 100 000 persons per year, respectively. Fenestrated (fEVAR) and branched (bEVAR) stent grafts have been developed for abdominal juxtarenal and thoracoabdominal aneurysms. We discuss the patency and complication rates of fEVAR and bEVAR procedures and compare them with the outcome of open surgery.

Methods: This review is based on pertinent publications from 2011 to 2014 that were retrieved by a selective literature search. The clinical outcomes of case series involving a total of more than 1500 patients are presented. The discussion takes account of recommendations contained in the literature and the authors' own experience.

Results: Open surgery and aortic stent grafting have not been compared in any randomized trial to date. We identified 7 clinical series that included a total of 1270 fEVAR patients and 5 with a total of 408 bEVAR patients. The perioperative mortality after fEVAR procedures was 0–4%. Spinal cord ischemia arose in 1% of cases. The stent patency rate in visceral vessels ranged from 93 to 98%. bEVAR procedures were associated with both higher mortality (4–7%) and more common spinal cord ischemia (4–13%). 5–8% of all patients needed dialysis perioperatively, and the stent patency rate in visceral vessels was 94–97%. Preoperative renal insufficiency was a risk factor for peri-interventional death. Impaired renal function after fEVAR/bEVAR procedures was mainly associated with intermittent lower limb ischemia.

Conclusion: The results of fEVAR/bEVAR procedures in the last 5 years are similar to those of open surgery. The high postoperative rate of spinal cord ischemia remains a serious problem in the endovascular treatment of thoracoabdominal aortic aneurysms. The decision to implant a stent graft by an endovascular approach or to treat surgically should be made on a case-to-case basis in an interdisciplinary vascular conference.

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The anatomy of the aorta changes in the course of life. Up to the age of 15, its diameter and length increase relatively swiftly. It continues to grow in adulthood: the diameter of the ascending aorta is 20 to 30% greater in 70-year-olds than in 20-year-olds (1). Rapid growth of the aorta—usually segmental—causes an aneurysm.

Three quarters of all aneurysms occur in the abdominal aorta. The annual incidence of abdominal aortic aneurysm (diameter >3.0 cm) is 40 in every 100 000 population. Six times more men than women are affected (2–4). Intervention is required (aneurysmal diameter >5.0 cm) in 10% of patients with a diagnosed abdominal aortic aneurysm (3). In up to 55% of these persons the aneurysm is not amenable to insertion of a conventional tube graft or Y-graft (5).

The annual incidence of thoracic aneurysm is 10–15 per 100 000 (6, 7). Men are 1.8 times more frequently affected than women. No population studies of the incidence of thoracic abdominal aneurysm have been published.

The pathological aorta can be treated surgically or via the endovascular route. One crucial advantage of the endovascular approach is the minimally invasive access with relatively low strain on the cardiovascular system and thus lower perioperative mortality. In a total of 22 830 patients, mortality was 1.2% for endovascular treatment and 4.8% for open surgery (8, 9).

Not every affected aorta is amenable to insertion of a thoracic tube stent graft or infrarenal Y-stent graft. In patients with a juxtarenal or thoracoabdominal aneurysm there is no proximal or distal zone for anchorage (landing zone) and therefore conventional tube and Y-grafts cannot be safely attached. These patients therefore often undergo open surgery. Relatively young and otherwise healthy patients recover comparatively quickly from an open thoracic, thoracoabdominal, or abdominal intervention. However, patients with vascular disease are usually of advanced age and not uncommonly have numerous comorbidities. One of the endovascular treatment options in such cases is the chimney technique. Chimney grafts are placed in the visceral vessels so that their aortic segments lie parallel to the aortic stent graft. However, use of this technique is limited by the elevated risk of leakage between the chimney graft, the aortic stent graft, and the aorta (10, 11).

Department of Cardiovascular Surgery, University Heart Center Freiburg: Dr. Rylski, PD Dr. Czerny, PD Dr. Südkamp, Prof. Siepe, Prof. Beyersdorf
Center for Diagnostic and Therapeutic Radiology, Medical Center—University of Freiburg: Dr. Russe

The very first implantation of a stent graft into the thoracic aorta was performed by Volodos in 1987 (12). The first such interventions in Germany—in centers including Freiburg (13)—were carried out in 1995. There have been rapid developments in stent grafts, pre- and intraoperative diagnostic procedures, endovascular instrumentation, catheter techniques, and many other relevant areas. Preoperative diagnostic, high-resolution computed tomography, three-dimensional (3-D) reconstruction of the aorta, preoperative simulation of the intraoperative angiographic visualization, the possibility of treatment in hybrid operating suites, and printing of 3-D models all help in planning the intervention and now form part of standard management. Hydrophilic coating and reduced diameter of the insertion port permit access via distinctly sclerosed vessels. The first fenestrated endovascular aneurysm repair (fEVAR) was carried out by Park in 1996 (14). Fenestrated (Figures 1a, 2) and branched stent grafts (bEVAR) (Figure 1b) were developed for treatment of patients with juxtarenal, perirenal, or thoracoabdominal aneurysms. Now, with the sole exceptions of the aortic root and the proximal ascending aorta, all segments of the aorta are amenable to endovascular treatment with standard stent grafts.

Methods

This article is based on the data of studies published between January 2011 and December 2014 that were identified by a selective literature search of Medline, Google Scholar, ScienceDirect, and SpringerLink. We used the search terms “thoracic aortic aneurysm”, “abdominal aortic aneurysm”, “fenestrated endovascular aortic repair”, and “branched endovascular aortic repair.” The electronic reference lists of the following cardiac and cardiovascular journals were searched for these terms: *Circulation*, *European Journal of Cardiothoracic Surgery*, *Journal of Vascular Surgery*, *Seminars in Vascular Surgery*, *European Journal of Vascular and Endovascular Surgery*, *Interactive CardioVascular and Thoracic Surgery*, *Journal of Endovascular Therapy*, and *Journal of Endovascular Surgery*.

Results

fEVAR procedure

Following the first implantation of a fenestrated graft in 1996 (14), numerous series of patients treated by fEVAR have been described in the literature. In the first of these, an account of 13 patients published in 2001, the authors reported fixation of the main stent in the visceral vessels by means of Palmaz stents (balloon-expandable stents with high radial strength) (15). Nowadays each window is usually connected with the corresponding visceral vessel by a covered stent (a stent with its mesh covered over) to reduce the risk of an endoleak. The results of recent fEVAR studies are summarized in Table 1. Comparison of the individual studies with regard to the various fEVAR products or strategies is impossible because of the considerable variability of patients' risk profiles, the different

Stent grafts

- Double-fenestrated stent graft with scallop in a juxtarenal abdominal aortic aneurysm. A fenestrated stent graft is an implant with windows for the visceral target vessels located in the—corresponding to the normal-caliber aorta—sealing zone of the graft. These fenestrations are extended into the target vessels by means of covered stents.
- Stent graft with four branches in a thoracoabdominal aortic aneurysm. The fenestrations with cuffs are extended into the target vessels by means of covered stents.

CLT, Celiac trunk; SMA, superior mesenteric artery; RRA, right renal artery; LRA, left renal artery

degrees of experience with fenestrated grafts at the different aorta centers, and the still relatively small numbers of patients.

Perioperative mortality—The fEVAR studies published in the past 5 years report perioperative mortality of 0 to 4% (16–22). In most cases the cause of death was myocardial infarction or an intraoperative technical complication, e.g., rupture of the access vessel, rupture of the aneurysm, injury of the renal artery, or occlusion of the superior mesenteric artery (21). The cumulative perioperative mortality in these studies was 2%.

bEVAR procedure

The literature includes only a small number of series of patients treated with branched stent grafts (Table 2). To date, the most extensive experience has been described by Reilly in 2012 (23) and by Kasprzak in 2014 (24). Reilly et al. treated 81 patients and reported rates of 4% for perioperative mortality, 4% for spinal ischemia, 5% for perioperative dialysis, and 95% for patency of the stents in visceral vessels (23). In a total of 83 patients, Kasprzak et al. found 7% perioperative mortality, 13% permanent spinal ischemia, 8% perioperative dialysis, and 97% stent patency (24). The results of both series compare well with those of open surgery studies.

Figure 2: Treatment of a juxtarenal abdominal aortic aneurysm with a fenestrated stent graft

Printed model of a juxtarenal abdominal aortic aneurysm (a) and a 3-D reconstruction of a double-fenestrated stent graft in the juxtarenal aortic aneurysm (b).

1, left renal artery; 2, right renal artery; 3, common origin of celiac trunk and superior mesenteric artery

Spinal ischemia after fEVAR/bEVAR

Implantation of fenestrated stent grafts may be followed by paraplegia owing to the reduced perfusion pressure in the collateral arterial network of the spinal cord. The risk of spinal ischemia increases with the number of spinal arteries originating from the stented portion of the aorta and is also greater in the case of occlusion of the internal iliac artery or subclavian artery or previous intervention involving the thoracic descending aorta (25). The average incidence of paraplegia after endovascular elimination of juxta- and perirenal aortic aneurysms is 1 to 2% (17, 19, 22). Endovascular treatment of thoracoabdominal aneurysms is associated with a far higher frequency of spinal ischemia, in most studies between 4 and 13% (23, 24, 26, 27).

Renal failure after fEVAR/bEVAR

Renal function may worsen considerably after implantation of fenestrated or branched stents. Alongside exposure to contrast medium, the principal potential cause is lower-limb ischemia. During the operation, the relatively large introducer sheaths hamper blood flow into the external iliac artery and not infrequently also the internal iliac artery, potentially leading to crural ischemia with an increase in the concentration of creatine kinase, resulting in deterioration of renal function. Other possible causes of impaired kidney function include overstenting of the renal arteries, dissection of

the renal arteries by wire manipulation, and occlusion or stenosis of renal artery stents. In a review published in 2009, an increase of over 30% in blood creatinine levels was found in 15% of fEVAR patients (28). A study from Birmingham in which cystatin C and creatinine were measured revealed that renal dysfunction following endovascular interventions is greatly underestimated and may occur up to 12 months after treatment (29). Pre-existing renal failure increases the risk of peri-interventional mortality eightfold (30).

In the early years of fEVAR the fenestrations over the renal arteries were not always extended with subsidiary stents. Stenting of the renal arteries is now recommended to reduce the danger of kidney malperfusion owing to dislocation of the main graft (2).

Patency rate of stents in the visceral vessels after fEVAR/bEVAR

Studies with short (up to 1 year) and medium-term (up to 5 years) follow-up show patency rates of between 93% and 98% for side stents implanted in the fenestrations (16, 17, 19, 20, 23, 24, 31, 32). To reduce the risk of stenosis or a type III endoleak (leak due to a defective implant), fenestrations are currently extended with covered stents.

In a Cleveland Clinic report on 650 patients with fenestrated and branched stent grafts who were followed up for a mean 3 years, the 30-day, 1-year, and 5-year patency rates after visceral stent reintervention were 98 % (95% confidence interval [96; 99]; 94 % [92–96]; and 84 % [78; 90] respectively (33). The rates of reintervention in the visceral vessels were as follows: celiac trunk 0.6%, superior mesenteric artery 4%, right renal artery 6%, left renal artery 5%. Three patients (0.5%) died owing to complications of the stents implanted in the visceral vessels. Multivariate analysis revealed no risk factors for reintervention on stents in the visceral vessels (23). In a study from Münster reporting the findings in 150 fEVAR and bEVAR patients (523 target vessels, mean follow-up 1.2 years), 2% of stents in the visceral vessels were occluded and 4% required reintervention. The sole identified risk factor for complications was implantation of branched stent grafts (34).

Discussion

Setting up a fEVAR/bEVAR program

Successful establishment of a fEVAR/bEVAR program depends on many factors. A high degree of expertise in vascular surgical and interventional techniques is important to reduce the danger of mishaps. The procedures should be carried out exclusively at centers with extensive experience in endovascular and open aortic surgery. In the early phase of a new fEVAR/bEVAR program, advice is generally provided by product specialists from the manufacturers. The companies also offer the assistance of a proctor for the first interventions. It is advisable to begin with less complex procedures (e.g., insertion of double-fenestrated grafts) and only move on to implantation of branched stents

TABLE 1

Results following implantation of fenestrated stent grafts in the aorta

Author, year	N (FU)	Number of fenestrations	Technical success rate (%)	Perioperative mortality (%)	Spinal ischemia (%)	Temporary dialysis (%)	Patency rate (%) ^{*1}
Tambyraja et al., 2011 (16)	29 (20)	79	100	0	0	0	93
GLOBALSTAR Registry, 2012 (17) ^{*2}	318 (6)	688	99	4	2	4	96
Canavati et al., 2013 (18)	318 (6)	113	100	4	0	0	–
Vemuri et al., 2014 (19) ^{*2}	57 (2)	120	100	2	2	2	98
Oderich et al., 2014 (20) ^{*2}	67 (37)	127	100	2	0	0	97
Sveinsson et al., 2015 (21)	288 (12)	689	95	2	–	0	–
Glebova et al., 2015 (22) ^{*2}	458 (0)	–	–	2	–	2	–
Total	1270	1816	98	2	1	2	96

Articles identified by a literature search for publications on fenestrated stent grafts in the period 2011–2014

^{*1} Patency rate of stents in visceral vessels at short- and medium-term follow-up

^{*2} Multicenter studies

FU, follow-up (months)

when the fEVAR techniques have been mastered. Particularly in more complex interventions it is sensible to use shunts to decrease the risk of crural ischemia, which may result from occlusion of the arteries used for access by large introducer sheaths (35, 36).

The treatment can be planned by an interdisciplinary team of vascular surgeons, angiologists, and radiologists (37). Three-dimensional evaluation of the CT scans using programs such as Aquarius iNtuition or 3-Mensio is standard and is indispensable for planning of the procedures. Implantation of stent grafts is best carried out in hybrid operating rooms that not only possess modern angiography equipment but also offer the possibility of conversion to open surgery.

Because of the complexity of fEVAR/bEVAR techniques and the specific complications that may arise from the treatment, postoperative follow-up should take place in the same hospital as the intervention. Regular diagnostic imaging is important and should also be carried out at the same center each time for the sake of consistent assessment of the patient's progress.

If the nearest aorta center is a long way from where the patient lives, or if medical considerations make transport problematic, follow-up can be carried out by a local specialist. However, the findings of diagnostic imaging must always be made available to the staff of the center where the intervention took place.

Close cooperation with local specialists is particularly crucial in the treatment of arterial hypertension and other comorbidities such as renal failure, obesity and diabetes mellitus, and risk factors such as smoking, because these influence the aortic pathology.

Endovascular versus open surgical treatment of the aorta

Endovascular interventions can be carried out in all patients whose aorta is anatomically suitable. The only exceptions are patients who suffer from congenital weakness of the connective tissues, e.g., Marfan,

Loeys–Dietz, or Ehlers–Danlos syndrome. In these cases endovascular treatment is feasible only if the landing zone for the stent graft has already been replaced by a vascular implant (38, 39).

The decision whether a patient should undergo endovascular treatment or open surgery must always be taken on an individual basis. Endovascular intervention should be preferred in the case of several comorbidities or advanced age. The same applies to both covered and traumatic aortic ruptures (40). Young, otherwise healthy patients, on the other hand, benefit from open surgery, as it has been demonstrated that endovascular treatment of the aorta is associated with an elevated reintervention rate (28). Open surgery is also advantageous for patients with renal failure and for those who are allergic to contrast medium. In the latter case this is because postoperative CT scanning is far less frequently necessary after open surgery. The regular exposure to contrast medium is therefore much lower.

No randomized studies comparing open surgery with fEVAR/bEVAR procedures have been published, for the simple reason that no long-term results are yet available and fEVAR/bEVAR is currently being used only for patients for whom open surgery would be a high-risk option. The retrospective studies comparing the two courses of action are summarized in Table 3. The results of a systematic review that compared fEVAR studies with open surgery studies seem to show that fEVAR has the advantage of lower perioperative mortality (28) but the disadvantages of an elevated reintervention rate and higher late mortality (e1).

Summary and prospects

Fenestrated and branched grafts form an alternative to open surgery, and are already increasingly being

TABLE 2

Results following implantation of branched stent grafts in the aorta

Author, year	N (FU)	Number of visceral branches	Technical success rate (%)	Perioperative mortality (%)	Spinal ischemia (%)	Temporary dialysis (%)	Patency rate (%) ^{*1}
Reilly et al., 2012 (23)	81 (21)	306	100	4	4	5	95
Ferreira et al., 2012 (31)	48 (0)	180	96	21	2	8	96
Kitagawa et al., 2013 (e5)	30 (20)	–	100	0	0	0	–
Kasprzak et al., 2014 (24)	83 (0)	306	88	7	13	8	97
Verhoeven et al., 2015 (27) ^{*2}	166 (29)	600	95	9	9	5	94
Total	408	1392	95	8	7	5	95

Articles identified by a literature search for publications on branched stent grafts in the period 2011–2014

^{*1} Patency rate of stents in visceral vessels at short-term and medium-term follow-up

^{*2} Series of patients with thoracoabdominal aortic aneurysms, 24% of whom were treated with fEVAR; two-center study
FU, follow-up (months)

TABLE 3

Results of studies comparing fEVAR/bEVAR procedures with open aortic surgery

Author, year	N		Perioperative mortality (%)			Freedom from reintervention			Dialysis (%)		
	Open surgery	fEVAR/bEVAR	Open surgery	fEVAR/bEVAR	p	Open surgery	fEVAR/bEVAR	p	Open surgery	fEVAR/bEVAR	p
Juxtarenal aortic aneurysm											
Shahverdyan et al., 2015 (e6)	34	35	0	3	0.32	–	–	–	0	0	–
Barillà et al., 2014 (e7)	50	50	8	4	0.34	90	92	–	14 ^{*1}	2 ^{*1}	0.027
Canavati et al., 2013 (18)	54	53	9	4	–	85	89	0.34	6	2	–
Chisci et al., 2009 (e8)	61	52	3	6	n. s.	92	83	NS	2	0	n.s.
Raux et al., 2014 (e9)	147	42	2	10	–	–	–	–	7	3	0.1
Juxtarenal and thoracoabdominal aortic aneurysm											
Shahverdyan et al., 2015 (e6) ^{*2}	1678	262	5	7	0.40	–	–	–	17.2	13.4	0.12
Tsilimparis et al., 2013 (e11) ^{*2}	1091	264	5	1	<0.001	–	–	–	–	–	–

^{*1} Temporary dialysis

^{*2} Multicenter studies

fEVAR, fenestrated implant; bEVAR, branched implant; n.s., nonsignificant

offered as part of the standard spectrum of treatment in aorta centers. The past 20 years have seen rapid advances in fEVAR/bEVAR technology, to the point where the results are attractive and can compete with those of conventional surgery. Further developments can be expected in the areas of high-resolution preoperative diagnostic imaging, improved intraoperative visualization with no or only minimal use of ionizing radiation, the design of stent grafts and the instruments for implanting them, and possibly robot-assisted implantation techniques.

Endovascular surgery is a standardized option for the entire aorta, with the sole exceptions of the aortic root and the proximal ascending segment. The aortic arch can be successfully treated with chimney grafts (e2). These grafts are released in supra-aortic branching vessels, lie parallel with the aortic stent graft in the

aortic arch, and extend beyond the stent into the free aortic lumen. Alternatively, an aneurysm of the aortic arch can be treated by inserting an endograft with two inner branches that is connected via supra-aortic branching vessels with two further stent grafts (e3). However, experience with this implant is extremely limited. The University Heart Center Freiburg is developing a new endovascular implant for the ascending aorta in cooperation with the Hospital of the University of Pennsylvania in Philadelphia. Details of the new concept and the early stages of product planning have been published (e4).

Conflict of interest statement

Dr. Südkamp has received reimbursement of conference fees and travel costs from Cook.

The remaining authors declare that no conflict of interest exists.

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REFERENCES

- Rylski B, Desjardins B, Moser W, Bavaria JE, Milewski RK: Gender-related changes in aortic geometry throughout life. *Eur J Cardiothorac Surg* 2014; 45: 805–11.
- Lederle FA, Johnson GR, Wilson SE, et al.: Prevalence and associations of abdominal aortic aneurysm detected through screening. Aneurysm Detection and Management (ADAM) Veterans Affairs Cooperative Study Group. *Ann Intern Med* 1997; 126: 441–9.
- Khashram M, Jones GT, Roake JA: Prevalence of abdominal aortic aneurysm (AAA) in a population undergoing computed tomography colonography in Canterbury, New Zealand. *Eur J Vasc Endovasc Surg* 2015. DOI: 10.1016/j.ejvs.2015.04.023 (Epub ahead of print).
- Pleumeekers HJ, Hoes AW, van der Does E, et al.: Aneurysms of the abdominal aorta in older adults. The Rotterdam Study. *Am J Epidemiol* 1995; 142: 1291–9.
- EVAR trial participants: Endovascular aneurysm repair versus open repair in patients with abdominal aortic aneurysm (EVAR trial 1): randomised controlled trial. *Lancet* 2005; 365: 2179–86.
- Olsson C, Thelin S, Ståhle E, Ekblom A, Granath F: Thoracic aortic aneurysm and dissection: increasing prevalence and improved outcomes reported in a nationwide population-based study of more than 14,000 cases from 1987 to 2002. *Circulation* 2006; 114: 2611–8.
- Clouse WD, Hallett JW Jr, Schaff HV, et al.: Improved prognosis of thoracic aortic aneurysms: a population-based study. *JAMA* 1998; 280: 1926–9.
- Rylski B, Blanke P, Siepe M, et al.: Results for high-risk endovascular procedures in patients with non-dissected thoracic aortic pathology: Intermediate Outcomes. *Eur J Cardiothorac Surg* 2013; 44: 156–62.
- Schermerhorn ML, O'Malley AJ, Jhaveri A, Cotterill P, Pomposelli F, Landon BE: Endovascular vs. open repair of abdominal aortic aneurysms in the Medicare population. *N Engl J Med* 2008; 358: 464–74.
- Bin Jabr A, Lindblad B, Dias N, Resch T, Malina M: Efficacy and durability of the chimney graft technique in urgent and complex thoracic endovascular aortic repair. *J Vasc Surg* 2015; 61: 886–94.
- Filippi F, Ficarelli R, Tirotti C, Stella N, Taurino M: Emergent fully endovascular treatment of a free ruptured thoracoabdominal aneurysm. *Ann Vasc Surg* 2015; 29: 842.e9–13.
- Volodos' NL, Karpovich IP, Shekhanin VE, Troian VI, Iakovenko LF: A case of distant transfemoral endoprosthesis of the thoracic artery using a self-fixing synthetic prosthesis in traumatic aneurysm. *Grudn Khir* 1988; 6: 84–6.
- Blum U, Voshage G, Lammer J, et al.: Endoluminal stent-grafts for infrarenal abdominal aortic aneurysms. *N Engl J Med* 1997; 336: 13–20.
- Park JH, Chung JW, Choo IW, et al.: 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.
- 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.
- Tambyraja AL, Fishwick NG, Bown MJ, et al.: Fenestrated aortic endografts for juxtarenal aortic aneurysm: medium term outcomes. *Eur J Vasc Endovasc Surg* 2011; 42: 54–8.
- British Society for Endovascular Therapy and the Global Collaborators on Advanced Stent-Graft Techniques for Aneurysm Repair (GLOBALSTAR) Registry: Early results of fenestrated endovascular repair of juxtarenal aortic aneurysms in the United Kingdom. *Circulation* 2012; 125: 2707–15.
- Canavati R, Millen A, Brennan J, et al.: Comparison of fenestrated endovascular and open repair of abdominal aortic aneurysms not suitable for standard endovascular repair. *J Vasc Surg* 2013; 57: 362–7.
- Vemuri C, Oderich GS, Lee JT, et al.: Postapproval outcomes of juxtarenal aortic aneurysms treated with the Zenith fenestrated endovascular graft. *J Vasc Surg* 2014; 60: 295–300.
- Oderich GS, Greenberg RK, Farber M, et al.: Results of the United States multicenter prospective study evaluating the Zenith fenestrated endovascular graft for treatment of juxtarenal abdominal aortic aneurysms. *J Vasc Surg* 2014; 60: 1420–8.
- Sveinsson M, Sobocinski J, Resch T, et al.: Early versus late experience in fenestrated endovascular repair for abdominal aortic aneurysm. *J Vasc Surg* 2015. DOI: 10.1016/j.jvs.2014.11.007 (Epub ahead of print).
- Glebova NO, Selvarajah S, Orion KC, et al.: Fenestrated endovascular repair of abdominal aortic aneurysms is associated with increased morbidity but comparable mortality with infrarenal endovascular aneurysm repair. *J Vasc Surg* 2015; 61: 604–10.
- Reilly LM, Rapp JH, Grenon SM, Hiramoto JS, Sobel J, Chuter TA: Efficacy and durability of endovascular thoracoabdominal aortic aneurysm repair using the caudally directed cuff technique. *J Vasc Surg* 2012; 56: 53–63.
- Kasprzak PM, Gallis K, Cucuruz B, Pfister K, Janotta M, Kopp R: Editor's choice-Temporary aneurysm sac perfusion as an adjunct for prevention of spinal cord ischemia after branched endovascular repair of thoracoabdominal aneurysms. *Eur J Vasc Endovasc Surg* 2014; 48: 258–65.
- Czerny M, Eggebrecht H, Sodeck G, et al.: Mechanisms of symptomatic spinal cord ischemia after TEVAR—insights from the European Registry of Endovascular Aortic Repair Complications (EuREC). *J Endovasc Ther* 2012; 19: 37–43.
- Guillou M, Bianchini A, Sobocinski J, et al.: Endovascular treatment of thoracoabdominal aortic aneurysms. *J Vasc Surg* 2012; 56: 65–73.
- Verhoeven EL, Katsargyris A, Bekkema F, et al.: Editor's choice – Ten-year experience with endovascular repair of thoracoab-

KEY MESSAGES

- The entire aorta, with the exceptions of the aortic root and the ascending aorta, is amenable to endovascular treatment.
- A fenestrated stent graft is an implant with windows for the visceral target vessels which seals the aneurysm (sealing zone). A branched stent graft has fenestrations with or without cuffs and is used when the visceral vessels originate from the aneurysm.
- The perioperative mortality after implantation of fenestrated stent grafts ranges from 0 to 4%, after implantation of branched grafts from 4 to 7%. These results resemble those in open surgery series; however, no direct comparisons have been made.
- Stent patency rates are 93–98%.
- Fenestrated and branched stents were developed for patients with juxtarenal, perirenal, or thoracoabdominal aneurysms.

- dominal aortic aneurysms: Results from 166 consecutive patients. *Eur J Vasc Endovasc Surg* 2015; 49: 524–31.
28. Nordon IM, Hinchliffe RJ, Holt PJ, et al.: 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.
 29. Abdelhamid MF, Davies RS, Vohra RK, Adam DJ, Bradbury AW: Assessment of renal function by means of cystatin C following standard and fenestrated endovascular aneurysm repair. *Ann Vasc Surg* 2013; 27: 708–13.
 30. Haddad F, Greenberg RK, Walker E, et al.: Fenestrated endovascular grafting: the renal side of the story. *J Vasc Surg* 2005; 41: 181–90.
 31. Ferreira M, Lanzotti L, Cunha R, d'Utra G: Endovascular repair of thoracoabdominal aneurysms: results of the first 48 cases. *Ann Cardiothorac Surg* 2012; 1: 304–10.
 32. Oikonomou K, Kopp R, Katsargyris A, Pfister K, Verhoeven EL, Kasprzak P: Outcomes of fenestrated/branched endografting in post-dissection thoracoabdominal aortic aneurysms. *Eur J Vasc Endovasc Surg* 2014; 48: 641–8.
 33. Mastracci TM, Greenberg RK, Eagleton MJ, Hernandez AV: Durability of branches in branched and fenestrated endografts. *J Vasc Surg* 2013; 57: 926–33.
 34. Panuccio G, Bisdas T, Berekoven B, Torsello G, Austermann M: Performance of bridging stent grafts in fenestrated and branched aortic endografting. *Eur J Vasc Endovasc Surg* 2015; 50: 60–70.
 35. Österberg K, Falkenberg M, Resch T: Endovascular technique for arterial shunting to prevent intraoperative ischemia. *Eur J Vasc Endovasc Surg* 2014; 48: 126–30.
 36. Österberg K, Falkenberg M, Resch T: Endovascular technique for arterial shunting to prevent intraoperative ischemia. *Eur J Vasc Endovasc Surg* 2014; 48: 126–30.
 37. Grabenwöger M, Alfonso F, Bachet J, et al.: Thoracic Endovascular Aortic Repair (TEVAR) for the treatment of aortic diseases: a position statement from the European Association for Cardio-Thoracic Surgery (EACTS) and the European Society of Cardiology (ESC), in collaboration with the European Association of Percutaneous Cardiovascular Interventions (EAPCI). *Eur J Cardiothorac Surg* 2012; 42: 17–24.
 38. Nordon IM, Hinchliffe RJ, Holt PJ, et al.: Endovascular management of chronic aortic dissection in patients with Marfan syndrome. *J Vasc Surg* 2009; 50: 987–91.
 39. Rylski B, Beyersdorf F, Desai ND, et al.: Distal aortic reintervention after surgery for acute DeBakey type I or II aortic dissection: open versus endovascular repair. *Eur J Cardiothorac Surg* 2015; 48: 258–63.
 40. Erbel R, Aboyans V, Boileau C, et al.: 2014 ESC guidelines on the diagnosis and treatment of aortic diseases: document covering acute and chronic aortic diseases of the thoracic and abdominal aorta of the adult. The Task Force for the Diagnosis and Treatment of Aortic Diseases of the European Society of Cardiology (ESC). *Eur Heart J* 2014; 35: 2873–926.

Corresponding author

Dr. med. Bartosz Rylski
 Universitäts-Herzzentrum Freiburg Bad Krozingen
 Herz- und Gefäßchirurgie
 Hugstetter Str. 55, 79106 Freiburg, Germany
bartosz.rylski@universitaets-herzzentrum.de

Supplementary material
 For eReferences please refer to:
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Supplementary material to:

Fenestrated and Branched Aortic Grafts

Patency, Perioperative Mortality and Spinal Ischemia

by Bartosz Rylski, Martin Czerny, Michael Südkamp, Maximilian Russe, Matthias Siepe, and Friedhelm Beyersdorf

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eREFERENCES

- e1. Rao R, Lane TR, Franklin IJ, Davies AH: Open repair versus fenestrated endovascular aneurysm repair of juxtarenal aneurysms. *J Vasc Surg* 2015; 61: 242–55.
- e2. Shahverdyan R, Gawenda M, Brunkwall J: Triple-barrel graft as a novel strategy to preserve supra-aortic branches in arch-TEVAR procedures: clinical study and systematic review. *Eur J Vasc Endovasc Surg* 2013; 45: 28–35.
- e3. Haulon S, Greenberg RK, Spear R, et al.: Global experience with an inner branched arch endograft. *J Thorac Cardiovasc Surg* 2014; 148: 1709–16.
- e4. Rylski B, Szeto WY, Bavaria JE, et al.: Development of a single endovascular device for aortic valve replacement and ascending aortic repair. *J Card Surg* 2014; 29: 371–6.
- e5. Kitagawa A, Greenberg RK, Eagleton MJ, Mastracci TM, Roselli EE: Fenestrated and branched endovascular aortic repair for chronic type B aortic dissection with thoracoabdominal aneurysms. *J Vasc Surg* 2013; 58: 625–34.
- e6. Shahverdyan R, Majd MP, Thul R, Braun N, Gawenda M, Brunkwall J: F-EVAR does not impair renal function more than open surgery for juxtarenal aortic aneurysms: single centre results. *Eur J Vasc Endovasc Surg* 2015. DOI: 0.1016/j.ejvs.2015.04.028 (Epub ahead of print).
- e7. Barillà D, Sobocinski J, Stilo F, Maurel B, Spinelli F, Haulon S: Juxtarenal aortic aneurysm with hostile neck anatomy: midterm results of minilaparotomy versus f-EVAR. *Int Angiol* 2014; 33: 466–73.
- e8. Chisci E, Kristmundsson T, de Donato G, et al.: The AAA with a challenging neck: outcome of open versus endovascular repair with standard and fenestrated stent-grafts. *J Endovasc Ther* 2009; 16: 137–46.
- e9. Raux M, Patel VI, Cochenne F, et al.: A propensity-matched comparison of outcomes for fenestrated endovascular aneurysm repair and open surgical repair of complex abdominal aortic aneurysms. *J Vasc Surg* 2014; 60: 858–63.
- e10. Michel M, Becquemin JP, Clément MC, Marzelle J, Quelen C, Durand-Zaleski I: WINDOW trial participants. Thirty day outcomes and costs of fenestrated and branched stent grafts versus open repair for complex aortic aneurysms. *Eur J Vasc Endovasc Surg* 2015. DOI: 10.1016/j.ejvs.2015.04.012 (Epub ahead of print).
- e11. Tsilimparis N, Perez S, Dayama A, Ricotta JJ 2nd: Endovascular repair with fenestrated-branched stent grafts improves 30-day outcomes for complex aortic aneurysms compared with open repair. *Ann Vasc Surg* 2013; 27: 267–73.