REVIEW ARTICLE

The Place of Endovascular Treatment in Abdominal Aortic Aneurysm

Andreas Greiner, Jochen Grommes, Michael J. Jacobs

SUMMARY

Background: The endovascular treatment of abdominal aortic aneurysms has become more common. A careful comparison of this technique with the established treatment by open surgery is needed before it can be more widely adopted.

Methods: We selectively searched the Medline database for articles on the endovascular treatment of abdominal aortic aneurysms, with special attention to prospective, randomized trials comparing it to open aortic surgery (keywords: "endovascular abdominal aortic repair" and "prospective randomized trial").

Results: Data on 30-day mortality and long-term survival are now available from four randomized multicenter trials. In three of these trials, endovascular treatment was found to lower 30-day mortality by two-thirds (endovascular: 0.2% to 1.7%, open repair: 0.7% to 4.7%), but this difference in survival was no longer present at two years. Compared to open open aortic surgery, endovascular treatment has a higher long-term complication rate. Endoleakage (perigraft leakage) accounted for more than 30% of complications and was the commonest reason for reintervention and unsuccessful intervention; in nearly all cases, it was successfully treated by the endovascular route. The rate of secondary aortic rupture was 0.8%, and migration of the prosthesis occurred in 5% of cases. Follow-up checks of the stent graft are now recommended at 3, 6 and 12 months after implantation, and annually thereafter.

Conclusion: Prospective randomized trials have shown that the endovascular technique lowers perioperative mortality. In the long term, however, it has a higher complication rate than open aortic surgery and leads to more frequent reintervention.

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The incidence of large-vessel aneurysms is 40 per 100 000 population. An aneurysm is an increase in the diameter of the aorta to more than 3 cm (1, 2). The abdominal aorta is affected in 60% of all patients. While 95% of these aneurysms begin below the renal arteries, the renal arteries are involved in only 3% of cases, and the visceral segment in only 2%. Men suffer large-vessel aneurysms six times more frequently than women (2, 3).

Aneurysms can rupture. The risk of rupture depends on the axial diameter of the aneurysm. The risk is approximately 3% for diameters of 4.0 to 4.9 cm, 10% for diameters of 5.0 to 5.9 cm, 15% for diameters of 6.0 to 6.9 cm, and 60% for diameters of more than 7 cm (4, 5). A further risk factor is the aneurysm's growth rate. If growth over six months is more than 0.5 cm, the risk of rupture must be considered high. Asymptomatic aneurysms that grow by more than 0.5 cm over six months or are more than 5.5 cm in diameter should therefore be electively treated. Symptomatic aneurysms should be treated within 24 hours, and ruptured aneurysms require emergency treatment (3, 6).

Stent prostheses allow minimally invasive treatment of abdominal aortic aneurysms (AAAs) (*Figure 1*). Patients who are ineligible for open surgery as a result of a comorbidity or their age can now be treated with endovascular aneurysm repair (EVAR) with less risk. In particular, this includes patients with ASA (American Society of Anesthesiologists) classification III or IV, concomitant chronic obstructive pulmonary disease (COPD), or heart failure. Open aortic surgery requires cross-clamping while the aorta is reconstructed. Cross-clamping increases cardiac afterload and is the main cause of cardiac ischemia or cardiac decompensation during surgery or in the immediate post-operative period. EVAR avoids this cardiac afterload.

Endovascular treatment has also further reduced the perioperative mortality rate of open surgery (7–9). The introduction of stent prostheses also seems to reduce the risk of death caused by aneurysm rupture (10).

However, the endovascular method must be measured against the established but invasive procedures of open surgery. Further developments since the introduction of endovascular treatment and the use of modern, third-generation prostheses that have resulted from it allow increasingly widespread use of endovascular treatment. As a result, increasingly frequently physicians have to decide which procedure to

European Vascular Center Aachen-Maastricht, Department of Vascular Surgery, Aachen University Hospital: PD Dr. med. Greiner, Dr. med. Grommes, Prof. Dr. med. Jacobs

University Hospital Maastricht: Prof. Dr. med. Jacobs

Endovascular aneurysm repair (EVAR):

The endovascular procedure is performed under general or local anesthesia. Following systemic heparin administration, both femoral arteries are punctured using the Seldinger technique and sluces are inserted. The main body of the endoprosthesis is inserted along a guide wire and released via a pigtail catheter directly underneath the renal artery, under angiography surveillance. The main body is released as far as the aperture of the contralateral leg. In the next step, the contralateral leg must be probed. The ipsilateral leg is now released completely. The stent prosthesis must not cover the ostium of the internal iliac artery at this point. The contralateral leg is extended using an endoprosthesis. Before this, the outlet of the internal iliac artery is also angiographically depicted, in order to prevent the ostium from being covered. Next comes a final angiography. The procedure is completed by removing the wires and sluces and closing the puncture sites

FIGURE 1

recommend to a patient. For a patient with a low surgery risk profile whose aortic aneurysm meets the morphological requirements for EVAR (*Figure 2*), EVAR and open surgery are competing treatment options (11). What data can be used as the basis for a treatment decision, and what problems may arise after the implantation of a stent prosthesis in the abdominal aorta or after open surgery?

The principle of endovascular treatment for abdominal aortic aneurysms

Endovascular aneurysm removal is based on the principle of excluding an aneurysm using a stent prosthesis. Modular bifurcated prosthesis systems are usually used. This reduces the pressure in the aneurysm sac and prevents aneurysm rupture. In order for the procedure to be performed, it must be possible to anchor the endoprosthesis securely outside the aneurysm, proximally and distally. The main body consists of a Y-shaped bifurcated prosthesis with one long and one short leg. The short contralateral leg is lengthened using a contralateral tube graft. The individual components are inserted along the femoral arteries using an unloading system, under x-ray surveillance, and then released. Because of the morphology of aneurysms, this technique is not suitable for all cases. The neck of the aneurysm must have a length of at least 15 mm to act as the anchoring zone, and the diameter of the neck must

not exceed 30 to 34 mm. In addition, this zone must present a normal aortic wall with no significant thrombotic plaque formation and moderate kinking. The distal landing zone must have a diameter of no more than 20 mm and should be at least 30 mm long. The stent prosthesis begins directly at the outlet of the renal arteries and ends before the iliac bifurcation. Its total length is therefore approximately 15 to 20 cm (*Figure 1*).

Outcomes following stent implantation in the abdominal aorta

Outcomes following EVAR from four prospective, randomized multicenter trials have been published to date. Long-term data are provided by the UK Endovascular Aneurysm Repair trial (EVAR 1) (9) and the Dutch Randomized Endovascular Aneurysm Management trial (DREAM) (12). In addition, medium-term outcomes are available from the Open versus Endovascular Aneurysm Repair trial (OVER, USA) (13) and the Anévrisme de l'aorte abdominale: Chirurgie versus Endoprothèse trial (ACE, France) (14). The general characteristics of these four trials are summarized in *Table 1*.

30-day mortality and long-term survival

The overall 30-day mortality rate is shown in *Table 1*. This shows that endovascular aneurysm removal was the superior treatment in the DREAM (EVAR 1.2%

Figure 2: Endoprosthesis measurement and selection: CT angiography shows an infrarenal aortic aneurysm. CT reconstruction is needed to determine whether endovascular aneurysm removal is possible and to select the prosthesis. Endoprosthesis planning requires precise length, diameter, and angle measurements. These can now be taken using a computer program. To provide an accurate length measurement, the centerline of the vessel is determined. The program draws the centerline along the length of the vessel. The vessel is straightened along the centerline (center left in Figure: "Straightened CPR View"). This makes it much easier to measure its length. The measurement obtained can then be used to construct an endovascular stent prosthesis. (Imaging material was prepared using Osirix MD and the SOVA.evar plugin and has kindly been made available to us by SOVAMED GmbH, Koblenz, Germany)

versus OAR 4.6%) (12), EVAR 1 (1.7% versus 4.7%) (9), and OVER (0.2% versus 2.3%) (13) trials, with a significant reduction in the risk of death within 30 days. In the French ACE trial, endovascular treatment (1.3%) could not surpass the excellent outcomes of open AAA removal, which yielded a 30-day mortality rate of 0.9%. The difference between the two groups was not statistically significant, however (14). Comparison of the 30-day mortality rates in all four studies yields an approximately threefold risk reduction (according to the odds ratio) for EVAR (Table 1).

As stated above, in the DREAM, EVAR 1 and OVER trials there was an initial survival advantage for endovascular AAA treatment as a result of its lower 30-day mortality rate. In both EVAR 1 and DREAM, this advantage had been lost by the end of the trial (EVAR 1: 8 years; DREAM: 7 years). The authors of EVAR 1 attribute the EVAR group's cumulative long-term survival rate in part to fatal endograft ruptures (9). Of a total of 25 patients who suffered ruptures following EVAR (3.9% of all patients randomized in EVAR 1), 18 died. No long-term outcomes for the other two trials (OVER and ACE) are yet available. Unlike the EVAR 1 and DREAM trials, in the OVER trial the

Kaplan–Meier curves are parallel to each other: In other words, the EVAR group's initial advantage of its significantly better 30-day mortality rate is not lost over the following 24 months. However, after two years the difference in the cumulative survival rate is no longer significant (13). Three-year outcomes for the ACE study are available. Unlike in the other three trials, in the ACE trial open surgery begins with the advantage of a lower 30-day mortality rate (though the difference is not significant). After a median follow-up period of three years, there was no difference between the cumulative survival rates of the two groups of patients (14).

The data from all four trials show that the original perioperative difference in survival between the two treatment methods is no longer detectable after approximately two years. This is caused by endoprostheses' comparatively high long-term complication rate and the problems that result. However, the trials did not record long-term consequences of open aneurysm surgery, such as fistulas between the prosthesis and the intestine, erectile dysfunction, incisional hernias, abdominal adhesions, and surgery required as a result, making open surgery appear better in the long term.

TABLE 1

Characteristics, 30-day mortality rate, and cumulative survival rates in four randomized trials

	ACE (14)		OVER (13)		DREAM (12)		EVAR 1 (9)	
Patient recruitment period	March 2005 to March 2008		October 2002 to October 2008		November 2000 to December 2003		September 1999 to September 2004	
Treatment arm	OAR	EVAR	OAR	EVAR	OAR	EVAR	OAR	EVAR
Randomized (n)	149	150	437	444	178	173	626	626
Total (N)	299		881		351		1252	
Age (years)	70.0	68.9	70.5	69.6	69.6	70.7	74.0	74.1
AAA diameter (mm)	56	55	57	57	60	61	65	64
30-day (total) mortality rate (%)	0.7	1.3	2.3	0.2	4.6	1.2	4.7	1.7
Odds ratio (95% confidence interval)	0.5 (0.045–5.57)		10.38 (1.3–81.39)		4.07 (0.85–19.46)		0.39 (0.18–0.87)	
	p = 0.5, insig.		p = 0.006		p = 0.1		p = 0.02	
Cumulative 2-year survival rate (%)					89	89	89	85
Cumulative 6-year survival rate (%)					69	69	65	65

OAR: open aortic repair; EVAR: endovascular aneurysm repair; DREAM: Dutch Randomized Endovascular Aneurysm Management study; EVAR 1: The Endovascular Aneurysm Repair Trial; ACE: Anévrisme de l'aorte abdominale: Chirurgie versus Endoprothèse trial; OVER: Open Versus Endovascular Aneurysm Repair trial; AAA: abdominal aortic aneurysm; insig.: insignificant

Follow-up treatment and complications following EVAR

Endoleaks

The most common cause of repeat interventions and treatment failure following EVAR is an endoleak (Table 2). An endoleak is a persistent flow of blood in the aneurysm sac, outside the endoprosthesis (16). The incidence of endoleaks as stated in the literature varies greatly, but it may be above 30% (15). Endoleaks are divided into five types according to etiology. All five are described in detail in Figure 3. This classification can be used to assess the risk of secondary rupture and indicate treatment or monitoring.

Type I endoleaks have a frequency of up to 10%. They may occur either immediately after implantation or subsequently (15). Because type I endoleaks pose a high risk of rupture, treatment is recommended in all cases. In almost all cases, these endoleaks can also be corrected endovascularly. If endovascular treatment proves unsuccessful, open surgery to remove the aneurysm and explant the endoprosthesis must be performed.

Type II endoleaks occur perioperatively in between 15% and 20% of cases. After one year, the type II endoleak rate spontaneously drops to 5% to 10% (15). “Indirect” endoleaks of this kind are usually fed via lumbar segment arteries or the inferior mesenteric artery. Type II endoleaks are treated conservatively provided the aneurysm sac does not grow, or even shrinks, during treatment. An increase in the size of the aneurysm sac represents treatment failure and must be treated if there is evidence of a persistent type II endoleak. Treatment is recommended if the diameter of the aortic aneurysm increases by more than 10 mm (17). In

almost all cases, this can successfully be performed using various minimally invasive embolization methods. The inferior mesenteric artery, which is often the cause of a type II endoleak, can be coiled angiographically through the Riolan arc via the superior mesenteric artery. Similarly, under CT guidance the aneurysm sac can be punctured and the endoleak can be embolized using Histoacryl™ glue (18–20). An alternative to this is laparoscopic retroperitoneal clipping of the lumbar arteries that feed the endoleak (21). Type III and IV endoleaks are now rare, thanks to the use of the latest generation of stent prostheses; they can usually be treated endovascularly.

An aneurysm sac that is under pressure even after EVAR and has no detectable endoleak is called an endotension. Endotensions are classified as type V endoleaks (22). The details of their underlying mechanism are not yet clear. One suspected cause is transmission of pressure via the thrombus or an endoleak that cannot be visualized (22, 23). Where no cause can be detected, treatment takes the form of open conversion if the aneurysm diameter increases (24).

Aneurysm expansion following endovascular aneurysm repair

If an aneurysm has been removed using a stent prosthesis, a reduction in the aneurysm diameter can be observed during follow-up. If an expansion of the aneurysm can be observed after a stent prosthesis has been inserted, there is a potential risk of rupture (25). This is usually caused by an endoleak (Figure 3), and treatment must be considered to have failed. A multicenter data analysis (10 228 patients) showed that five years after EVAR an increase in aneurysm size could be observed in 41% of patients (26). Interestingly, expansion

did not begin until three years after EVAR in 30% of patients. Clearly, this is a problem that can occur in the long term. The trial also showed that patients treated between 2004 and 2008 presented aneurysm expansion significantly more frequently than patients treated between 1999 and 2003. The trial authors attribute this fact to a growing tendency to use stent prostheses off-label.

Off-label use of endoprotheses

Unlike open surgery, in order to be treated safely with EVAR aneurysms must meet certain morphological requirements—these include suitable iliac access routes, proximal and distal landing zones, wall structure, thrombus load, and aortic shaft angle—in order to guarantee secure implantation of commercially available standard prostheses. The various types of commercially available prostheses have different configurations, so the user can select the most suitable prosthesis for the patient according to anatomical requirements. Manufacturers provide usage restrictions and limitations for their stent prostheses. These instructions are based on preclinical tests and simulations and are derived from the engineering-related development of prostheses. The clinical trials that must be conducted as part of the authorization procedure for stent prostheses involve strict patient selection according to these instructions for use. Off-label use of stent prostheses occurs in everyday clinical practice in both Europe and the USA. It has been shown that only 42% of EVAR patients meet the recommended morphological requirements according to the industry's instructions for use. Such off-label use of prostheses has been identified as one of the significant independent risk factors for aneurysm sac expansion following EVAR (26).

Rupture following endovascular aneurysm repair

Analysis of the data of UK EVAR trials 1 and 2 showed that in 27 of 848 patients who received elective EVAR treatment as part of these prospective trials, aneurysm rupture occurred after an average of 4.8 years (25). In five of these patients, rupture occurred within 30 days of EVAR. A total of 18 (67%) of the 27 patients died as result of the rupture. Type I endoleaks, type II endoleaks with sac expansion, and type III endoleaks with stent migration or kink formation were identified as independent, extremely significant ($p < 0.0001$) risk factors (hazard ratio 8.83). In three patients, rupture occurred despite optimum aftercare and no identifiable cause. In all other patients, there were either identifiable causes for the rupture (endoleaks, sac expansion, etc.) or CT monitoring was incomplete. The authors therefore deduce that it is better to treat direct endoleaks aggressively. Regular monitoring is essential after EVAR to identify such complications early.

Recommendations for aftercare following endovascular aneurysm repair

The mortality rate for post-EVAR rupture is high (above 60%). However, the complications after EVAR

TABLE 2

Frequencies of complications following EVAR and OAR

		OAR	EVAR
Early complications	Secondary bleeding	3%	<2%
	– Peripheral thromboembolic complications	1%	1%
	– Renal complications	1%	1 to 2%
	Colorectal ischemia	1%	1%
	Damage to the ureter/pelvic veins	<1%	–
	Erectile dysfunction	>60%	Significantly fewer
	Compromised wound healing	3%	3% (inguinal)
Late complications	Prosthesis infections	1 to 2%	<1%
	Closure of bypass leg	3%	6%
	Suture aneurysms	1%	–
	Incisional hernias	16%	–
	Prosthesis migration	–	5%
	Secondary aneurysm rupture	–	0.8%

Source: Guidelines of the German Society for Vascular Surgery and Vascular Medicine (Deutsche Gesellschaft für Gefäßchirurgie und Gefäßmedizin) (3)
OAR: open aortic repair; EVAR: endovascular aneurysm repair

that lead to secondary aneurysm rupture can be identified using appropriate imaging procedures, with only a very few exceptions (25). Checkups must assess the following:

- Aneurysm sac dynamics (shrinking, expansion)
- Endoleaks (presence, type)
- Position of individual stent graft components (migration, dislocation).

The current gold standard for the follow-up examination is CT angiography (17). In addition to its advantage of being a very quick procedure, this method also provides detailed information on all the points listed above (27, 28). Two-phase CT angiography, with an arterial phase and a second, delayed phase, makes it possible to identify and classify almost all endoleaks. The disadvantage of this method is the radiation burden that accumulates over time and the iodinated, nephrotoxic contrast agent (29, 30). In order to reduce the burden of CT angiography on EVAR patients, annual contrast ultrasound checkups can be performed, in order to determine aneurysm sac size and to evaluate endoleaks. It seems possible that this may allow endoleaks to be identified with the same sensitivity (31). However, conventional two-plane abdominal x-ray must be performed in addition to ultrasound examination, in order to monitor the location of stent graft components (32). Another option, to reduce the cumulative dose of radiation following EVAR, is magnetic resonance angiography (MRA) (33).

FIGURE 3

Endoleaks:

Type I: These endoleaks are caused by leakage from the proximal anchoring (type Ia) or distal anchoring (type Ib) and require treatment. They can be caused by incorrect prosthesis selection with insufficient oversizing of the prosthesis, implantation errors, or secondary migration of the stent prosthesis.

Type II: The aneurysm is further perfused via lateral branches (e.g. the lumbar artery or inferior mesenteric artery). This is the most common type of endoleak and is observed in up to 15% to 20% of cases at the first checkup following prosthesis implantation. Type II endoleaks initially require only monitoring but must be treated if checkups reveal an increase in aneurysm diameter. In many cases, the arteries close spontaneously.

Type III: The aneurysm sac is further perfused by the overlap zones of individual stent prosthesis components. This can be closed using balloon angioplasty or stent angioplasty of the docking zone.

Type IV: Blood can escape into the aneurysm sac through stent material. This type of endoleak is now rare as a result of improved stent prostheses.

Type V: Checkups reveal an increase in aneurysm diameter, but no contrast substance can be detected outside the stent prosthesis. This is thought to be caused by a remaining increase in pressure following endovascular aneurysm repair.

Conclusion

The introduction of endovascular treatment of aortic aneurysms has led to a reduction in perioperative mortality and morbidity and is possible even in cases in which open surgery is not suitable as a result of concomitant illnesses. Although in randomized trials comparing it to open surgery the difference in survival rate can no longer be identified after two years, its high levels of acceptance by patients and physicians are

leading to increasing use of endovascular treatment. In the long term, however, endovascular aortic prostheses are associated with a higher rate of complications, whereas open aortic surgery seems to cause fewer complications. Regular checkups are therefore currently recommended following EVAR, in order to identify complications early.

Conflict of interest statement

Dr. Grommes has received reimbursement of conference fees and travel expenses from Cook Medical. Prof. Greiner and Prof. Jacobs declare that no conflict of interest exists.

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KEY MESSAGES

- Endovascular treatment of abdominal aortic aneurysms reduces perioperative morbidity and mortality.
- Endovascular surgery can be used to treat high-risk patients who are ineligible for open aortic replacement.
- The high levels of acceptance of endovascular treatment by patients and physicians are leading to increasing use.
- In the long term, endovascular treatment leads to more frequent complications in the form of endoleaks or stent migration than open surgery.
- Regular monitoring of stent prostheses is recommended, in order to identify and treat complications early.

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Corresponding author:

Prof. Dr. med. Michael J. Jacobs
Aachen–Maastricht European Vascular Center
Vascular Surgery Facility, University Hospital of Rhine–Westphalia Institute of Technology, Aachen
Pauwelsstr. 30, 52074 Aachen, Germany
mjacobs@ukaachen.de