Endovascular repair of abdominal aortic aneurysms (EVAR) has enjoyed a quick and widespread growth over the last 15 years. Both clinicians and patients have embraced the minimal invasive alternative to open surgery. Although early benefits of EVAR have been confirmed in two randomized trials, the number of late complications and re-interventions remains an issue for debate.\(^1,2\) However, the trials failed to demonstrate a late overall survival gain. This opened the way for some epidemiologists and other financial decision makers to question the technique or even worse, to qualify the technique as a failed experiment.\(^3\) Despite this, this important surgical innovation has continued to evolve with expansion into the treatment of acute aneurysms and the development of fenestrated and branched grafts. This paper discusses the ongoing evolution of EVAR with respect to the available literature and our personal experience.

**Elective Evar**

As mentioned, the short-term benefits have undoubtedly been demonstrated by two randomized trials. In summary, EVAR presents with a threefold lower mortality than open repair (\(P = 0.009\), EVAR trial) and almost a twofold lower aneurysm related mortality at four years (4\% versus 7\%, \(P = 0.04\) EVAR trial). In addition, the health related quality of life, often regarded as non-different due to similar results after one year, demonstrated a better outcome from 3 to 12 months.\(^2\) Costs were higher in the trial setting, but the difference was marginal, and there are no post-trial comparisons available. The flip side was that the two randomized trials demonstrated a higher late complication rate which resulted in a higher reintervention rate of EVAR compared to open repair.

Since the trials, the technique has matured and devices have undergone further development. This has widely resulted in better results especially with regard to durability and reintervention rate. Many reports were published on these changes in outcome with maturation of the technique with the lifeline Registry and Eurostar Registry reporting a decrease in secondary interventions over time.\(^4,5\) With increased experience it is also became clear that Type II endoleaks were not presenting with increased risk of rupture as initially thought. Silverberg et al. reported an incidence of Type II endoleaks of 16\% (154/946), but 35\% of these Type II endoleaks resolved spontaneously during a mean follow-up of 14.5 months.\(^6\) A Kaplan Meier analysis suggested spontaneous seal of Type II endoleak of 75\% within 5 years. Franks et al. reported in a systematic review a decreasing trend over time in operative mortality, endoleak rate and post-operative rupture.\(^7\)

Our personal results show a mortality below 1\% which includes all patients, both low- and high risk, and difficult anatomy. The overall reintervention rate dropped from 15\% to below 10\% with 75\% of all reinterventions performed by endovascular means. Furthermore reinterventions were not associated with mortality.\(^8,9\)

Patient fitness and response to treatment are important
aspects of the success of new technologies. A number of issues need to be taken into account with respect to patient fitness. First, open surgical repair might be preferable in younger and fitter patients. Second, patients with multiple cardiac risk factors are at increased risk of perioperative cardiac events. Third, the high operative mortality rate (9-14%) associated with EVAR in the highest risk patients in both registry data and the EVAR II trial suggests that patient selection and management of co-morbidities needs to be improved. Risk assessment can be achieved by using several risk scoring models, including the Goldman Cardiac index, the Leiden Risk score, the Customized Probability Index, and the Glasgow Aneurysm Score. Data from EVAR I and II were analyzed and the Customized Probability Index was assessed for all patients.\(^{10}\) One of the remarkable findings was that there was considerable overlap of the scores between EVAR I and EVAR II, suggesting that a number of other factors, not accounted for in the risk model, contributed to a patient being considered fit or unfit for open repair. This study concluded that in patients considered fit for open repair EVAR provided a benefit in terms of 30-day operative mortality. This was especially true in the fittest patients. Nevertheless, it would be wrong to conclude that high-risk patients do NOT benefit from EVAR. Several studies have investigated the outcome of EVAR and open surgical repair of AAA in high risk patients. On the basis of EUROSTAR data analyzing outcome of EVAR in 2887 high risk patients it was suggested that high-risk patients in particular attain important advantages from minimal invasive anesthetic techniques. Mortality and morbidity rates were significantly lower for (loco)-regional versus general anesthesia.\(^{11}\) A study from Rotterdam compared the outcome of 77 high-risk patients with ≥3 cardiac risk factors undergoing EVAR (n = 39) or open surgery (n = 38).\(^{12}\)

Myocardial damage, i.e. a rise in serum levels of cardiac troponin T, was found in 18 (47%) patients undergoing open repair and in 5 (13%) patients undergoing EVAR (p = 0.001). Five patients (13%) in the open group experienced a myocardial infarction versus none in the endovascular group (p = 0.02). Three (8%) patients in the open repair group died within 30 days after surgery whereas in the endovascular group all patients survived. The incidence of the combined endpoint of cardiovascular death or nonfatal MI for patients in the open group was 13% versus 0% in the endovascular group (p = 0.02). These results are in concordance with several other comparative studies. Therefore it can be concluded that endovascular therapy seems to be associated with less perioperative adverse cardiac events compared to open surgery, especially in high-risk patients with 3 or more cardiac risk factors.

**EVAR for Ruptured Aneurysms**

A meta-analysis of open repair of ruptured aortic abdominal aneurysms (RAAAA) demonstrated a 30-day mortality of 48%. There was a constant reduction of mortality of approximately 3.5% per decade (1954-1997), with an estimated operative mortality rate for the year 2000 of 41%.\(^{13}\) These poor results with open surgery triggered the development of EVAR for RAAA. The potential benefits of EVAR for RAAA were demonstrated by several cohort studies and confirmed by two systemic reviews.\(^{14, 15}\) Nevertheless, it is difficult to interpret current results from the literature due to patients selection criteria, and the definition of anatomic suitability and hemodynamic stability. In Groningen, we adopted a protocol of selective use of EVAR for RAAA in 2002 after encouraging initial results with EVAR (1998-2001).\(^{16}\) Since then, we have offered both modalities of treatment to the patients.\(^{17}\) Although our EVAR results show excellent results, in accordance with the literature, we were not able to scientifically prove superiority of EVAR above open repair in view of the same confounding factors as mentioned above. Nevertheless, overall mortality of RAAA in our institution over the last five years decreased to 24%.\(^{18}\) Clinically, it seems obvious that (suitable) patients who are treated by EVAR do make a quicker recovery, and that the risk of iatrogenous injury is far lower than in open surgery. In addition, a cost-analysis study demonstrated that EVAR in RAAA may be cheaper than open repair because the costs of the prosthesis are more than compensated by the lower costs of blood transfusion, procedure time, intensive care unit and hospital stay.\(^{19}\)

With regard to graft selection, we have always opted for a bifurcated stent-graft and not an aorto-uni-iliac (AUI) stent-graft.\(^{16, 17}\) In our opinion, the advantages are clear: the bifurcated stent-graft represents the most physiological solution, and is also used in elective EVAR. Disadvantages of the AUI system include the higher risk of infection of the femoro-femoral cross-over bypass, prolonged ischemia of one limb intra-operatively, ischemic problems in the longer term in case of occlusion, and the risk of anastomotic aneurysms at the level of the femoral arteries. Advantages of AUI in terms of quicker exclusion of the aneurysm are non-significant as the catheterization...
and insertion of the second limb in bifurcated stent-grafts did not delay the exclusion of the aneurysm (less than five minutes in more than 90% of the patients). However, the use of a bifurcated stent-graft (in our centre the Cook Zenith Tri-Fab™ or the Gore Excluder™) requires a larger stock of devices. This, however, could be used as an argument for centralisation of acute vascular surgery. Another argument is given by the fact that higher volumes correlate with better patient outcomes in aortic surgery.20, 21

FENESTRATED AND BRANCHED EVAR

Feasibility of fenestrated endovascular stent-grafting has been established.22-24 CE mark for the fenestrated stent-graft has been obtained by William Cook Europe, and a FDA study in the USA has been carried out. In our opinion, fenestrated stent-grafting will become the primary treatment option in many patients with complex aneurysms that are not suitable for standard endovascular aortic repair. Nevertheless, it is important to consider the alternative options: open repair and standard endovascular repair. Standard endovascular repair in short neck aneurysms is and will remain a discussion point for some time. As discussed in the introduction, there is still controversy about EVAR with regard to longer term efficacy. On the other side, manufacturers and users are eager to treat patients with aortic aneurysms including necks between 10-15 mm, and even 5-10 mm. This raises questions, as some publications demonstrated a significant increase of proximal type I endoleaks in short-neck EVAR.25 More importantly, there are no publications regarding mid-term outcome of standard EVAR for necks shorter than 15 mm. Open surgery in short-neck/juxtarenal aneurysms is not extensively described in the literature, but several reports do specify the greater risks of mortality and morbidity.26-28 Mortality rates vary between 5.8 and 9%. Renal function deterioration is not infrequent and has been reported in up to 40.5% of the cases, with 7.0% of patients requiring dialysis. A recent report from the Mayo Clinic, however, demonstrated that open surgery of juxtarenal aneurysms can be achieved with excellent results, including a mortality of only 0.8%.29 Although their results are undeniable, one has to consider that most patients who were treated with fenestrated grafts were at high-risk for open surgery or even denied open treatment. A special subgroup includes the patients who had previous open aortic repair and present with a pararenal or anastomotic aneurysm, or the patients with type I endoleaks after previous EVAR, with a neck too short for proximal extension with a standard cuff. It is clear that open redo surgery in these cases is technically challenging, and associated with significant mortality and morbidity. Our first published data in this subgroup demonstrate a mortality of 0% and a cumulative branch patency of 96% at 42 months, in a group of 11 patients.30 In gaining further experience we were able to study each subgroup, demonstrating that fenestrated EVAR after previous open surgery (N = 18) gives excellent results,31 whereas fenestrated stent-grafting after EVAR (N = 9) is technically more demanding and carries a higher risk of complications.32

The fenestrated technique also provided a useful platform in the development of branched grafts to treat thoraco-abdominal aneurysms (TAAA). At this moment several centres have built up experience with this technique with good preliminary results.33, 34 Our own experience now includes 30 patients with a TAAA, with acceptable results (mortality n = 2, no paraplegia, dialysis n = 2) especially if one considers that 75% of the patients were regarded inoperable by open means.

FUTURE CONSIDERATIONS AND CONCLUSIONS

Endovascular techniques will undoubtedly continue to evolve. In view of the major impact of open surgery for TAAA, we presume that most patients who are suitable for endovascular repair with branched grafts will not be treated by open means in the future. However, the technique still needs further improvements. The connection between main graft and bridging stent-grafts and the development of dedicated bridging stent-grafts need to be addressed. The current bridging stent-grafts are too stiff to withstand the prolonged vector forces of the blood pressure. To a certain extent, the same goes for suprarenal, juxtarenal, and short necked aneurysms. Available techniques with fenestrated grafts have matured for some time now, and published results continue to be excellent with these technically difficult aneurysms in high risk surgical patients.

In standard EVAR, it has been difficult to demonstrate differences between individual grafts, as published recently by Abbruzzese et al.35 Nevertheless, if one looks at current developments in the industry, it gives a better insight into the current flaws of the different devices. It is no surprise that W.L. Gore & associates are working on a more controlled and repositionable proximal deploying system of the Excluder™. Medtronic has developed the
Endurant™ with a more controlled proximal deployment system, and provided the bare stent with hooks and barbs. Cook is now offering a new range of limbs for the Zenith™ device that are more flexible and kink resistant. Finally, Cook is also taking up the challenge to develop a system that is meant to be inserted percutaneously (14F-16F). Patients with suitable anatomy should be informed about both treatment options and offered an endovascular procedure if they agree with the more rigorous follow-up scheme and a higher risk of (endovascular) reintervention. At this moment, there is no literature to support standard EVAR for proximal necks shorter than 15mm!

In acute EVAR, both treatment options will co-exist, but in our mind every suitable (anatomic and hemodynamic) patient should be offered EVAR in centers who are equipped for it (logistics including materials and personnel). Although randomized trials are underway we should not expect too much from them, and develop a sound clinical judgment in order to decrease the overall mortality of the disease. 36-41

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