Elective Abdominal Aortic Aneurysm (AAA) repair: challenges remain

Bulder, R.M.A.

PART II

Aspects of medical decision-making

Chapter 6

A systemic evaluation of the costs of elective EVAR and open abdominal aortic aneurysm repair Implies cost equivalence

Ruth M.A. Bulder
Daniël Eefting
Patrick W.H.E. Vriens
Robert B. van Tongeren
Jon S. Matsumara
Wilbert B. van den Hout
Jaap F. Hamming
Jan H.N. Lindeman

European Journal of Vascular and Endovascular Surgery 2020

ABSRACT

Background

The suggested high costs of endovascular aneurysm repair (EVAR) hamper the choice of insurance companies and financial regulators for EVAR as the primary option for elective abdominal aortic aneurysm (AAA) repair. However, arguments used in this debate are impeded by time related aspects such as effect modification and the introduction of confounding by indication, and by asymmetric evaluation of outcomes. Therefore, a re-evaluation minimizing the impact of these interferences was considered.

Methods

A comparative analysis was performed evaluating a period of exclusive open repair (OR; 1998-2000) and a period of established EVAR (2010-2012). Data from four hospitals in The Netherlands were collected to estimate resource use. Actual costs were estimated by benchmark cost prices and a literature review. Costs are reported at 2019 prices. A break even approach, defining the costs for an endovascular device at which cost equivalence for EVAR and OR is achieved, was applied to cope with the large variation in endovascular device costs.

Results

One hundred and eighty-six patients who underwent elective AAA repair between 1998 and 2000 (OR period) and 195 patients between 2010 and 2012 (EVAR period) were compared. Cost equivalence for OR and EVAR was reached at a break even price for an endovascular device of €13.190. The main cost difference reflected the longer duration of hospital stay (ward and Intensive Care Unit) of OR (€11.644). Re-intervention rates were similar for OR (24.2%) and EVAR (24.6%) (P=0.92).

Conclusion

Cost equivalence for EVAR and OR occurs at a device cost of €13 000 for EVAR. Hence, for most routine repairs, EVAR is not costlier than OR until at least the five year follow up.

INTRODUCTION

Owing to its profoundly lower procedural morbidity and superior 30 day mortality, endovascular aneurysm repair (EVAR) has become the preferred strategy for elective abdominal aortic aneurysm (AAA) repair.[1] However, the literature suggests that EVAR comes with higher device costs and higher re-intervention rates.[2] As a consequence, the cost effectiveness of EVAR is being challenged and, on this basis, the preference for EVAR as the primary option for elective AAA repair is disputed.[3]

Yet, conclusions regarding the costs of EVAR vs. open repair (OR) are potentially affected by time related aspects, such as effect modification and the emergence of confounding by indication, and by an asymmetric evaluation of outcomes (see **Table 1** for definitions and examples). In fact, all prospective (trial based) cost (effectiveness) studies are based on devices and medical decision making from the early EVAR era.[4] Therefore the time related positive impact of procedural changes (i.e. improved devices and delivery systems, imaging modalities, and surgical experience), as well as changes in follow up, such as a more reticent attitude towards endoleaks are ignored. However, interpretation of more recent (retrospective) analyses is affected by decreasing OR volume, resulting in loss of surgical routine, and by the emergence of asymmetric medical decision making (confounding by indication, **Table 1**), in which the type of repair is essentially dictated by the patient's characteristics, for example EVAR is preferred in more frail patients.[5,6]

While time related aspects of effect modification and confounding by indication could be resolved in a randomised controlled trial, such a trial would most likely be considered unethical in the current timeframe with an established position and preference for EVAR. An alternative strategy is a comparative analysis of representative intervals. This analysis compares two periods: an open repair period (1998-2000) and EVAR period (2010-2012). The 1998-2000 period reflects a timeframe with standard OR and minimal interference of competitive medical decision making with EVAR. The 2010-2012 period reflects a timeframe with well established (and as first choice of repair) EVAR (i.e. established devices and surgical experience, and developed follow up policies). This period also allowed for a five year follow up.

Procedural costs were recalculated in order to reflect the actual (2019) costs. Device costs are the main determinant of the overall costs for EVAR, yet considering the broad spectrum of devices available, and the fact that actual per device costs are highly negotiable, it was difficult to assign a uniform per unit price.[7] To address these aspects, a break even approach was considered appropriate; therefore, the price for an EVAR device at which cost equivalence for EVAR and open repair was reached was estimated and reported.

Table 1. Explanation of terms used in the article

Term	Definition	Example
Time-dependent effect modification	The association between the exposure and outcome depends on a third variable i.e. alterations in care over time.	- Improved surgical experience with EVAR - Loss of surgical routine with open repair - Improvements of endovascular devices - Altered follow-up after EVAR (more reticent attitude towards endoleaks)
Confounding by indication	Asymmetrical decision-making i.e. the choice of repair (OR/EVAR) is based on and influenced by patient characteristics.	- The introduction of EVAR lowered the threshold for repair; as result more frail and older patients are being treated by EVAR, whereas some advise OR in younger/fit patients.
Asymmetrical evaluation of outcomes	Biased evaluation of outcomes in published studies.	- Strong focus on graft-related re-interventions in studies evaluating EVAR

EVAR, endovascular aneurysm repair; OR, open repair.

METHODS

Ethical approval

The medical ethical committee of Leiden University Medical Centre reviewed the study protocol (G18.126). The boards of the individual study centres all granted approval.

Data collection

This study includes all consecutive patients who underwent primary, elective AAA repair, in either the OR (1998-2000) or EVAR (2010-2012) period. Exclusion criteria were emergency repair, thoracic AAA, suprarenal AAA or need for suprarenal clamping, mycotic/inflammatory AAA, and previous aortic repair. Patients were identified from hospital registry data of four hospitals in the Netherlands (one university hospital and three non-academic teaching hospitals). Patient and procedural data were retrieved from medical records. Re-interventions were defined as any procedure related to the primary OR or EVAR.

Outcome

The aim of this study was to compare costs associated with OR and EVAR. Patient outcomes were not considered, as would be the case in a cost effectiveness analysis. Instead, a break even point for EVAR device costs was calculated as the point at which the costs of OR equalled those of EVAR. The primary end point was the break even point for OR and EVAR. This point reflects the costs of an endovascular device at which cost equivalence for EVAR and OR is reached.

Unit costs, viz. the total expenditure associated with the separate aspects of AAA repair, were defined on the basis of the registered benchmark costs for the Dutch hospitals, and a systematic literature search.[8,9,10] Procedural costs included operating room use, graft (OR), cell saver, and length of stay on the surgical ward and Intensive Care Unit (ICU). Operating room costs included all direct and indirect costs, calculated as costs per minute of operating time. Surgical ward and ICU costs reflected both direct and indirect costs and were calculated on a daily basis.

Follow up costs included both regular follow up (postoperative consultations and imaging) and follow up associated with complications. Regular follow up was based on the 2011 European Society for Vascular Surgery (ESVS) guidelines.[11] For patients who underwent EVAR, this included one computed tomography angiogram at 12 months, and yearly duplex ultrasounds and plain radiographs thereafter; for patients who underwent OR, it included a duplex ultrasound at three months, six months, one year, and optional at three years. Costs of complications included all costs related to reinterventions, which were defined as any procedure related to the primary EVAR or OR, including graft related reinterventions, abdominal wall hernias, bowel obstructions, wound dehiscences, thrombosis, and so on. Re-intervention costs were estimated in the same manner as the costs of the primary intervention. All costs were converted to the 2019 price level using the Consumer Price Index.[12] Costs per unit estimates are provided in **Table 2**.

Costs of AAA surveillance programmes or pre-operative screening were not included, as these are extremely heterogeneous owing to the timing of diagnosis and not influenced by the type of AAA repair.

Table 2. Composition of Dutch costs (in 2019 euros*) with the USA costs (in 2019 euros) as reference

	Netherlands	United States
Operating room/min	22 [11]	36 [26]
Ward/day	548 [12]	1012 [27]
ICU/day	1678 [12]	1988 [27]
Graft OR	663 [13]	1434 [28]
Graft EVAR	-	-
Cellsaver	172 [14]	232 [28]
CT Abdomen	171 [12]	574 [29]
CTA aorta	346 [12]	
Ultrasound Abdomen	86 [12]	121 [29]
X-Ray	46 [12]	28 [29]
Postoperative consult	96 [12]	105 [30]

ICU, intensive care unit; OR, open repair; EVAR, endovascular aneurysm repair; CT, computed tomography; CTA, computed tomography angiography.

* All costs were converted to the 2019 price level using the Consumer Price Index.[12]

Statistical analysis

The normality of data was assessed by histograms. Continuous variables were expressed as means ("standard deviation) or medians (interquartile range [IQR]) and compared using the Student's t test or the Mann-Whitney U test. Categorical data were analysed using the chi square test. A p value of $< .05$ was considered statistically significant. All analyses were conducted with SPSS version 26 (IBM, Armonk, NY, USA).

RESULTS

Study population

This study is based on an evaluation of all elective AAA repairs performed between 1998 and 2000 (OR) or between 2010 and 2012 (EVAR), with 186 patients having open repair and 195 patients EVAR in the respective periods. Baseline patient characteristics are shown in **Table 3**. The proportion of active smokers was higher in the OR group (P<0.001). The proportion of diabetic patients (P<0.001) and patients on statins (P<0.001) was higher in the EVAR group.

Primary AAA repair (OR e EVAR)

Table 4 shows that OR was associated with a slightly longer duration of surgery (P<0.001), a longer ICU stay (P<0.001), and a longer stay on the surgical ward (P<0.001). The number of post-operative consultations was similar for the two groups (P=0.32), but imaging was more common after EVAR (P<0.001). Primary repair related resource use is summarised in **Table 4**.

Re-interventions

The relative and absolute number of repair related reinterventions for the five year follow up period was similar. In fact, 24.2% (total re-interventions, n = 81) of the OR patients and 24.6% (total re-interventions, n = 85) of the EVAR patients underwent at least one repair related re- intervention (P=0.92). There was a clear difference in the nature and timing of re-interventions with a median reintervention time of one month (IQR 0-17 months) in the OR group and 23 months (IQR 4-37.5 months) in the EVAR group (P<0.001). Re-interventions in the EVAR group were mainly graft related (EVAR, n = 67 vs. n = 1 in the OR group; P<0.001). Surgery related re-interventions (including wound complications, incisional hernias, re-laparotomies, and gastro-intestinal complications) were more prevalent in the OR group (OR, n = 80 vs. EVAR, n = 18; P<0.001). A detailed overview of all repair related re-interventions is provided in **Table 5**.

Costs

Mean costs (2019 prices) of the initial hospital admission, graft, and follow up are presented in **Table 4**. Overall costs after five years for OR were €20.041 and for EVAR €6.576 (excluding the device costs). Mean costs of re-interventions for OR were €5.907 per re-intervention (€2.572 per elective OR); re-intervention costs for EVAR were €5.953 (€2.595 per elective EVAR) (P=1.00). **Table 6** provides a summary of the re-intervention costs.

Table 3. Characteristics of 381 patients treated by open (OR) vs. endovascular aneurysm repair (EVAR) in The Netherlands in 1998-2000 and 2010-2012, respectively

	Open repair n = 186	EVAR n = 195	P-value
Age - years	70.6 ± 7.6	72.1 ± 8.0	0.71
Gender			0.63
Male	158 (84.9)	169 (86.7)	
Female	28 (15.1)	26 (13.3)	
Diameter AAA (mm), median (IQR)	57.5 (52.0 – 65.0)	57.0 (55.0 – 61.0)	0.81
missing	16	5	
ASA classification			0.82
ASA 1	10 (5.4)	11 (5.6)	
ASA 2	108 (58.1)	120 (61.5)	
ASA 3	53 (28.5)	62 (31.8)	
ASA 4	0 (0)	1 (0.5)	
missing	15	1	
Smoking status			< 0.001
Yes	57 (30.6)	48 (24.6)	
No	66 (35.5)	128 (65.6)	
Not known	63 (33.9)	19 (9.7)	
Diabetes mellitus	11 (6.4)	31 (16.0)	0.004
missing	15	1	
COPD	41 (23.8)	46 (23.7)	0.98
missing	14	1	
Hypertension	111 (73.0)	129 (75.0)	0.61
missing	34	12	
Hyperlipidaemia	68 (47.6)	76 (44.2)	0.55
missing	43	23	
Medication use			
Statins	42 (38.2)	117 (68.8)	< 0.001
missing	76	25	
Antihypertensive	55 (50.5)	87 (50.9)	0.95
missing	77	24	

Data are presented as n (%) or mean ± standard deviation unless stated otherwise.
IQR, interquartile range; AAA, abdominal aortic aneurysm; ASA, American Society for Anesthesiologists; COPD, chronic obstructive pulmonary disease.

Table 4. Mean costs (in euros) of primary procedures for 186 open (OR) or 195 endovascular (EVAR) abdominal aortic aneurysm repairs in The Netherlands

		Open repair n = 186		EVAR n = 195		Difference OR - EVAR (€)
	Unit costs (€)	Resource use	Total costs (€)	Resource use	Total costs (€)	
Surgery						
OR time (min)	22	183	4026	127	2794	1232
Cell saver	172	1	172	0	0	172
Device *	663	1	663	0	0	663*
Hospital stay						
ICU (days)	1678	4.1	6880	0	0	6880
Ward (days)	548	13.8	7562	4.7	2576	4987
Follow-up						
CTA	346	0	0	1	346	- 346
Ultrasound	86	3	258	5	430	- 172
X-ray	46	0	0	1	46	- 46
Consult	96	5	480	4	384	96
Total*			20.041		6576	13.466*

Data are presented as mean costs in euros. There were no missing data regarding primary outcomes. ICU, intensive care unit.

* Costs of the EVAR device are not included here. Threshold costs are calculated in the break even point analysis.

Table 5. Re-interventions after 186 open repair (OR) and 195 EVAR for a five year follow up in The Netherlands

	OR (n = 186)	**EVAR** (n = 195)	**P-value**
Patients with reinterventions	45 (24.2)	48 (24.6)	0.92
Total number of reinterventions	81	85	
Total graft related	1	67	<0.001
Endoleak	0 (0)	39 (45.9)	
Migration	1 (1.2)	2 (2.4)	
Occlusion/stenosis	0 (0)	23 (27.1)	
Other	0 (0)	3 (3.5) *	
Total non graft related	80	18	<0.001
Relaparatomy	14 (17.3)	0 (0)	
Wound complication	17 (21.0)	8 (9.4)	
Incisional hernia	16 (19.8)	0 (0)	
RAAA	1 (1.2)	0 (0)	
AAA spurium	1 (1.2)	2 (2.4)	
Bleeding	1 (1.2)	1 (1.2)	
Embolism/thrombus	4 (4.9)	3 (3.5)	
Limb/amputation	7 (8.6)	1 (1.2)	
Gastro-intestinal	9 (11.1)	0 (0)	
Fistula	3 (3.7)	0 (0)	
Other **	7 (8.6) **	3 (3.5) ***	

Data are presented as n (%). RAAA, ruptured abdominal aortic aneurysm.

* Dissection stent graft, infection stent graft, proximal anastomotic abdominal aortic aneurysm.
** Infection, neurological complications, tracheotomy, inserting renal graft.
*** Removal peel away sheet, abscess, infection.

Table 6. Costs of the 166 re-interventions in the five years following 186 elective open repairs (OR) or 195 endovascular aneurysm repairs (EVAR) in The Netherlands

		Open repair n = 186		**EVAR n = 195**		**Difference OR - EVAR (€)**
	Unit costs (€)	Resource use	Total costs (€)	Resource use	Total costs (€)	
Surgery						
OR time (min)	22	73	1606	51	1122	484
Hospital stay						
ICU (days)	1678	0.8	1342	1.2	2014	- 672
Ward (days)	548	5.4	2959	4.7	2576	- 242
CTA	346	0	0	0.7	242	242
Total*			5907		5953	- 46

Data are presented as costs in euros. ICU, intensive care unit.
* The p value for total costs of open repair vs. EVAR re-intervention is 1.0.

Break even point and sensitivity analyses

Considering the costs of both primary repair and reinterventions after five years of follow up, the break even point for cost equivalence of OR and EVAR is established at €13.466. The impact of variations in ICU and hospital stay on the break even point were addressed in a sensitivity analysis (**Table 7**). Boundaries were based on different scenarios reflecting various days at the ICU and ward.

Table 7. Sensitivity analysis: impact of hospital and intensive care unit (ICU) stay on the break even point (device costs for endovascular aneurysm repair [EVAR] and open repair (OR) of abdominal aortic aneurysm)

ICU days (OR)	Ward days (OR)											
	3	4	5	6	7	8	9	10	11	12	13	14
EVAR one day admission ward												
1	4 320	4 868	5 416	5 964	6 512	7 060	7 608	8 156	8 704	9 252	9 800	10 348
2	5 998	6 546	7 094	7 642	8 190	8 738	9 286	9 834	10 382	10 930	11 478	12 026
3	7 676	8 224	8 772	9 320	9 868	1 0416	10 964	11 512	12 060	12 608	13 156	13 704
4	9 354	9 902	10 450	10 998	11 546	12 094	12 642	13 190	13 738	14 286	14 834	15 382
5	11 032	11 580	12 128	12 676	13 224	13 772	14 320	14 868	15 416	15 964	16 512	17 060
EVAR two days admission ward												
1	3 772	4 320	4 868	5 416	5 964	6 512	7 060	7 608	8 156	8 704	9 252	9 800
2	5 450	5 998	6 546	7 094	7 642	8 190	8 738	9 286	9 834	10 382	10 930	11 478
3	7 128	7 676	8 224	8 772	9 320	9 868	10 416	10 964	11 512	12 060	12 608	13 156
4	8 806	9 354	9 902	10 450	10 998	11 546	12 094	12 642	13 190	13 738	14 286	14 834
5	10 484	11 032	11 580	12 128	12 676	13 224	13 772	14 320	14 868	15 416	15 964	16 512
EVAR three days admission ward												
1	3 224	3 772	4 320	4 868	5 416	5 964	6 512	7 060	7 608	8 156	8 704	9 252
2	4 902	5 539	6 087	6 635	7 183	7 731	8 279	8 827	9 375	9 923	10 471	11 019
3	6 580	7 306	7 854	8 402	8 950	9 498	10 046	10 594	11 142	11 690	12 238	12 786
4	8 258	9 073	9 621	10 169	10 717	11 265	11 813	12 361	12 909	13 457	14 005	14 553
5	9 936	10 840	11 388	11 936	12 484	13 032	13 580	14 128	14 676	15 224	15 772	16 320
EVAR four days admission ward												
1	2 676	3 224	3 772	4 320	4 868	5 416	5 964	6 512	7 060	7 608	8 156	8 704
2	4 354	4 902	5 450	5 998	6 546	7 094	7 642	8 190	8 738	9 286	9 834	10 382
3	6 032	6 580	7 128	7 676	8 224	8 772	9 320	9 868	10 416	10 964	11 512	12 060
4	7 710	8 258	8 806	9 354	9 902	10 450	10 998	11 546	12 094	12 642	13 190	13 738
5	9 388	9 936	10 484	11 032	11 580	12 128	12 676	13 224	13 772	14 320	14 868	15 416
EVAR five days admission ward												
1	2 128	2 676	3 224	3 772	4 320	4 868	5 416	5 964	6 512	7 060	76 08	8 156
2	3 806	4 354	4 902	5 450	5 998	6 546	7 094	7 642	8 190	8 738	9 286	9 834
3	5 484	6 032	6 580	7 128	7 676	8 224	8 772	9 320	9 868	10 416	10 964	11 512
4	7 162	7 710	8 258	8 806	9 354	9 902	10 450*	10 998	11 546	12 094	12 642	13 190†
5	8 840	9 388	9 936	10 484	11 032	11 580	12 128	12 676	13 224	13 772	14 320	14 868

Each part of the table represents the subsequent number of days (1, 2, 3, 4, 5) on the ward for EVAR patients. The first column represents the number of days at the ward for OR patients. The following columns present the number of days on the ICU for OR patients. With these numbers, alterations in hospital stay can be simulated, i.e. if EVAR patients stay four days on the ward and OR patients three days on the ICU and 11 days on the ward, this is visualised in the "EVAR four days admission ward" part of the table, on the third row below and in the column for 11 ward days.

* Primary analysis break even point equals 13.466 (equals 13.190 when based on integer days on ward and ICU).

** Shorter ward stay (nine days) for OR = 10.450d (= adjusted decrease in hospital stay of open repair [factor 0.67] for the Dutch situation).

DISCUSSION

The total costs of EVAR remain a matter of debate. In fact, the presumed higher costs of EVAR are one of the mainstays of the current National Institute of Health and Care Excellence (NICE) guideline recommendation to refrain from EVAR for elective repair.[3] Specifically, the concept states that "the total cost per patient associated with EVAR is higher, and it is expected to generate fewer QALYs per patient".[3] However, these conclusions are based on the current literature, which is potentially prone to time related aspects such as effect modification and the introduction of confounding by indication, and asymmetric evaluation of outcomes (**Table 1**). In order to reduce these time related aspects a comparative analysis of two time periods, i.e., an open repair period (1998-2000) and an EVAR period (2010-2012), was performed. Conclusions from this analysis show that cost equivalence for OR and EVAR is established at an EVAR device cost level of approximately €13.000. This break even point reflects the mean of the reported prices for an endovascular device (€6.249-25.425).[7,13,14] As such, it is concluded that for device costs up to €13 000, the total costs per patient associated with EVAR are lower than for OR.

So far, several studies reviewed costs of OR vs. EVAR. A detailed evaluation based on the EndoVascular Aneurysm Repair (EVAR-1) trial data concluded that EVAR was not cost effective over the lifetime.[15] With the exception of the Anevrysme de l'aorte abdominale, Chirurgie vs. Endoprothese (ACE) trial, similar conclusions were reached by the other prospective (trial based) analyses, which all concluded that while initial hospitalisation costs with EVAR were lower, the costs significantly increased over time.[4,16] Conclusions from real world cost analyses, however, were less unanimous, and reported EVAR to be more costly, as well as cost effective.[9,17,18] In the light of the contrasting conclusions and the large variation in cohorts and outcomes, authors of a meta-analysis concluded that costs cannot be employed as an instrument to choose between the methods of AAA repair.[19]

Contrasting conclusions concerning the overall costs of EVAR and OR largely relate to the fact that the interpretation of available studies is interfered by time related aspects (i.e. effect modification, and the introduction of confounding), and by an asymmetric evaluation of outcomes (**Table 1**). So far, these aspects have not been addressed. Aspects of time related effect modification may profoundly impact any conclusions with respect to procedural costs. Since its introduction, the EVAR procedure has been thoroughly optimised. A new generation of devices and delivery systems, more experienced teams, a less intense follow up, and a more conservative approach towards type II endoleaks may all reduce the costs associated with of EVAR.[1,20] In parallel, the broad implementation of EVAR comes with a profound reduction in the number of, and thus experience with open procedures.[1] This may potentially negatively impact the efficacy and outcomes of OR (and consequently result in higher procedural costs). Further interference results from confounding by indication. The implementation of EVAR as an option for AAA repair introduced confounding by indication, in which the preferred choice of repair is dictated by patient characteristics. This is reflected in the preference for EVAR in older and frail patients. As a consequence, EVAR and OR groups are not comparable in the current timeframe.

A further, so far ignored, aspect in cost analyses is the asymmetric evaluation of outcomes. While OR is generally considered a final solution, there has always been awareness on the need for post-procedural surveillance with EVAR. This has resulted in an intensified follow up after EVAR, as well as awareness of re-interventions. These contrasting attitudes are reflected in an asymmetric evaluation of re-intervention costs after EVAR or OR. In fact, most studies fail to systematically include re-interventions related to OR.[21,22] As a consequence, the reported higher incidence of re-interventions after EVAR may reflect underestimation of the number of interventions following OR.

A final limitation of the available reports is that the included prices of an endovascular device in these studies reflect list prices, and not the actual, negotiated costs paid by individual hospitals. This latter aspect may greatly impact conclusions as device costs are the primary determinant of EVAR related costs.

In order to reduce the impact of time related aspects, it was decided to do a comparative cost analysis for elective infrarenal AAA repair based on a comparison of two representative intervals. A period of almost exclusive OR and a period of preferred and established EVAR. Complex EVAR procedures (suprarenal and pararenal AAAs) were excluded as these reflect an extremely heterogeneous group of patients and procedures. The two timeframes showed broadly similar baseline characteristics (American Society of Anesthesiologists' classification and age) for patients receiving OR or EVAR. Asymmetric evaluation of repair related re-interventions was avoided by a systematic evaluation of all re-interventions related to the primary procedure in the five years after the primary repair. Although the evaluation indicated clear differences in the type of re-intervention, it was concluded that the overall number of procedure related re-interventions was similar for EVAR and OR.

Performance and the interpretation of cost analyses are interfered by the complex cost structures of health systems and the lack of transparency. In order to minimise this interference, benchmark costs for Dutch hospital costs were applied, as these are probably the best reflection of the actual costs for the Netherlands.[8] As cost structures may not directly translate to other countries/health systems, reference costs for the USA are included in **Table 2**.[23-28]

Based on the data in this evaluation, cost equivalence for OR and EVAR is reached at approximately €13.000 for an endovascular device. This estimate reflects the mean of prices for endovascular devices reported in the literature (€6.249 - €25.425).[7,13,14] Yet, conclusions are obviously influenced by the devices used, individual pricing agreements between hospitals and suppliers, and days spent in the ICU and on the ward. The latter aspect was addressed in a sensitivity analysis (**Table 7**), which allows for an individualised estimation of the break even point for cost equivalence.

Note that conclusions regarding cost equivalence are exclusively based on actual procedural and re-intervention costs, and that aspects of formal cost effectiveness analysis, such as differences in procedural mortality and utility, are not included in the analysis. From the patient's perspective, EVAR comes with a number of advantages, including a substantially lower procedural morbidity and mortality, aspects that are of particular relevance for elderly patients, and should be taken into account in considerations of cost effectiveness.[29-32] Moreover, decisions regarding follow up in this evaluation reflected the 2011 ESVS guidelines. Implementation of the current guidelines, advising that patients with an adequate seal and no type II endoleaks (30% - 60% of patients) do not require imaging up to five years, would result in a break even point that further favours EVAR (€13.552 - €13.914).

Altogether, it could be argued that from a cost effectiveness perspective, the break even point for EVAR is well above €13.000 for an EVAR device. Consequently, in contrast to the conclusions of the NICE guidelines, most EVAR procedures will generate more quality adjusted life years per patient than OR.[3]

Limitations

As the OR period represents patients from 1998 to 2000 it is unclear to what extent the costs of OR (procedural costs, and ICU and ward stay) are influenced by current reductions in OR volume (and thus team skills) on one hand, and technical improvements on the other hand. Average ICU and ward times declined between 1998 and 2010.[33] Therefore, the cost of OR could be overestimated. The potential impact of these aspects is illustrated by a sensitivity analysis (**Table 7**). Note that this sensitivity analysis does not include underlying causes of altered hospital stay. This reflects a general model and should not be used for individual decision making. It is concluded that even with a shorter hospital stay of open repair, EVAR remains cost equivalent.

A further aspect not addressed in this study is that the lower threshold with EVAR may result in AAA repair in patients whose surgical treatment would have been withheld in the OR era.[20] This may result in the inclusion of more frail patients in the 2010-2012 period. Although it could be argued that this phenomenon would actually favour EVAR, it may also result in the treatment of patients who will not live long enough to benefit from the repair. This latter aspect will obviously negatively impact the cost effectiveness of EVAR.

Finally, the data were collected retrospectively. As a consequence, the analysis is influenced by time related aspects such as the organisation of patient records. Follow up in this study was limited to five years. Thus, reinterventions beyond five years are not included. However, it is considered unlikely that this affects the conclusions of this evaluation, the more so as a considerable number of complications of OR present more than five years after primary repair.

The data did not allow for specific subgroup analyses. Such an analysis would be particularly relevant for women as female patients have a higher 30 day mortality with OR than men (8.0% vs 4.3%).[34] As this sex specific mortality is not observed for EVAR it is highly unlikely that different conclusions would be reached for women.

CONCLUSION

Results from this cost analysis study show that cost equivalence for EVAR and OR occurs at a device costs of €13.000. Hence, for most routine repairs EVAR is not costlier than OR until at least five years of follow up.

REFERENCES

1. Arko FR, Murphy EH, Boyes C, Nussbaum T, Lalka SG, Holleman J, et al. Current status of endovascular aneurysm repair: 20 years of learning. Semin Vasc Surg 2012;25:131e5.
2. Paravastu SC, Jayarajasingam R, Cottam R, Palfreyman SJ, Michaels JA, Thomas SM. Endovascular repair of abdominal aortic aneurysm. Cochrane Database Syst Rev 2014;1:CD004178.
3. National Institute of Health and Care Excellence. Abdominal aortic aneurysm: diagnosis and management. Available at: https://www.nice. org.uk/guidance/ng156/chapter/Recommendations#monitoringand-reducing-the-risk-of-rupture. [Accessed 24 June 2020].
4. Epstein D, Sculpher MJ, Powell JT, Thompson SG, Brown LC, Greenhalgh RM. Long-term cost-effectiveness analysis of endovascular versus open repair for abdominal aortic aneurysm based on four randomized clinical trials. Br J Surg 2014;101:623e31.
5. Zettervall SL, Schermerhorn ML, Soden PA, McCallum JC, Shean KE, Deery SE, et al. The effect of surgeon and hospital volume on mortality after open and endovascular repair of abdominal aortic aneurysms. J Vasc Surg 2017;65:626e34.
6. Chaikof EL, Brewster DC, Dalman RL, Makaroun MS, Illig KA, Sicard GA, et al. SVS practice guidelines for the care of patients with an abdominal aortic aneurysm: executive summary. J Vasc Surg 2009;50:880e96.
7. Chambers D, Epstein D, Walker S, Fayter D, Paton F, Wright K, et al. Endovascular stents for abdominal aortic aneurysms: a systematic review and economic model. Health Technol Assess 2009;13:1e315.
8. Portal performation. Available at: https://portal.performation.com. [Accessed 13 February 2020].
9. Burgers LT, Vahl AC, Severens JL, Wiersema AM, Cuypers PW, Verhagen HJ, et al. Cost-effectiveness of elective endovascular aneurysm repair versus open surgical repair of abdominal aortic aneurysms. Eur J Vasc Endovasc Surg 2016;52:29e40.
10. So-Osman C, Nelissen RG, Koopman-van Gemert AW, Kluyver E, Pöll RG, Onstenk R, et al. Patient blood management in elective total hip- and knee-replacement surgery (Part 1): a randomized controlled trial on erythropoietin and blood salvage as transfusion alternatives using a restrictive transfusion policy in erythropoietin-eligible patients. Anesthesiology 2014;120:839e51.
11. Wanhainen A, Verzini F, Van Herzeele I, Allaire E, Bown M, Cohnert T, et al. Editor’s choice - European society for vascular surgery (ESVS) 2019 clinical practice guidelines on the management of abdominal aorto-iliac artery aneurysms. Eur J Vasc Endovasc Surg 2019;57:8e93.
12. CBS. StatLine e consumentenprijzen; Prijsindex. 2015. Available at: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83131ned/table?ts¼1560106575807. [Accessed 13 February 2019].
13. Berghmans JCH, Lübke T, Brunkwall JS. A cost calculation of EVAR and FEVAR procedures at a European academic hospital. Ann Vasc Surg 2019;54:205e14.
14. Lemmon GW, Neal D, DeMartino RR, Schneider JR, Singh T, Kraiss L, et al. Variation in hospital costs and reimbursement for endovascular aneurysm repair: a Vascular Quality Initiative pilot project. J Vasc Surg 2017;66:1073e82.
15. Patel R, Powell JT, Sweeting MJ, Epstein DM, Barrett JK, Greenhalgh RM. The UK EndoVascular Aneurysm Repair (EVAR) randomised controlled trials: long-term follow-up and costeffectiveness analysis. Health Technol Assess 2018;22:1e132.

16. Becquemin JP, Pillet JC, Lescalie F, Sapoval M, Goueffic Y, Lermusiaux P, et al. ACE trialists. A randomized controlled trial of endovascular aneurysm repair versus open surgery for abdominal aortic aneurysms in low- to moderate-risk patients. J Vasc Surg 2011;53:1167e73.
17. Dua A, Kuy S, Lee CJ, Upchurch Jr GR, Desai SS. Epidemiology of aortic aneurysm repair in the United States from 2000 to 2010. J Vasc Surg 2014;59:1512e7.
18. Gupta AK, Alshaikh HN, Dakour-Aridi H, King RW, Brothers TE, Malas MB. Real-world cost analysis of endovascular repair versus open repair in patients with nonruptured abdominal aortic aneurysms. J Vasc Surg 2020;7:432e43.
19. van Bochove CA, Burgers LT, Vahl AC, Birnie E, van Schothorst MG, Redekop WK. Cost-effectiveness of open versus endovascular repair of abdominal aortic aneurysm. J Vasc Surg 2016;63:827e38.
20. Tadros RO, Faries PL, Ellozy SH, Lookstein RA, Vouyouka AG, Schrier R, et al. The impact of stent graft evolution on the results of endovascular abdominal aortic aneurysm repair. J Vasc Surg 2014;59:1518e27.
21. Curl GR, Faggioli GL, Stella A, D'Addato M, Ricotta JJ. Aneurysmal change at or above the proximal anastomosis after infrarenal aortic grafting. J Vasc Surg 1992;16:855e9.
22. Hagino RT, Taylor SM, Fujitani RM, Mills JL. Proximal anastomotic failure following infrarenal aortic reconstruction: late development of true aneurysms, pseudoaneurysms, and occlusive disease. Ann Vasc Surg 1993;7:8e13.
23. Childers CP, Maggard-Gibbons M. Understanding costs of care in the operating room. JAMA Surg 2018;153:e176233.
24. Stroupe KT, Lederle FA, Matsumura JS, Kyriakides TC, Jonk YC, Ge L, et al. Cost-effectiveness of open versus endovascular repair of abdominal aortic aneurysm in the OVER trial. J Vasc Surg 2012;56:901e9.
25. Matsumura JS, Stroupe KT, Lederle FA, Kyriakides TC, Ge L, Freischlag JA, et al. Costs of repair of abdominal aortic aneurysm with different devices in a multicenter randomized trial. J Vasc Surg 2015;61:59e65.
26. Waters JR, Meier HH, Waters JH. An economic analysis of costs associated with development of a cell salvage program. Anesth Analg 2007;104:869e75.
27. Hengge UR, Wallerand A, Stutzki A, Kockel N. Cost-effectiveness of reduced follow-up in malignant melanoma. J Dtsch Dermatol Ges 2007;5:898e907.
28. Lubitz CC, Kong CY, McMahon PM, Daniels GH, Chen Y, Economopoulos KP, et al. Annual financial impact of welldifferentiated thyroid cancer care in the United States. Cancer 2014;120:1345e52.
29. Bulder RMA, Bastiaannet E, Hamming JF, Lindeman JHN. Metaanalysis of long-term survival after elective endovascular or open repair of abdominal aortic aneurysm. Br J Surg 2019;106: 523e33.
30. Arko FR, Hill BB, Reeves TR, Olcott C, Harris EJ, Fogarty TJ, et al. Early and late functional outcome assessments following endovascular and open aneurysm repair. J Endovasc Ther 2003;10:2e9.
31. Williamson WK, Nicoloff AD, Taylor Jr LM, Moneta GL, Landry GJ, Porter JM. Functional outcome after open repair of abdominal aortic aneurysm. J Vasc Surg 2001;33:913e20.
32. Lennings CJ. Optimism, satisfaction and time perspective in the elderly. Int J Aging Hum Dev 2000;51:167e81.
33. CBS. StatLine e gezondheid, leefstijl, zorggebruik eneaanbod, doodsoorzaken; vanaf 1900. Available at: https://opendata.cbs.nl/ statline/#/CBS/nl/dataset/37852/table?ts¼1581606736291. [Accessed 11 November 2019].
34. Tomee SM, Lijftogt N, Vahl A, Hamming JF, Lindeman JHN. A registry-based rationale for discrete intervention thresholds for open and endovascular elective abdominal aortic aneurysm repair in female patients. J Vasc Surg 2018;67:735e9.