Elective Endovascular versus Open Surgical Repair of Abdominal Aortic Aneurysms: Systematic Review of Short-term Results[1]

Miraude E. A. P. M. Adriaensen, MSc
Johanna L. Bosch, PhD
Elkan F. Halpern, PhD
M. G. Myriam Hunink, MD, PhD
G. Scott Gazelle, MD, MPH, PhD

Index terms:
Aneurysm, abdominal, 943.73
Aneurysm, aortic, 943.73
Aneurysm, surgery, 943.1268, 943.73
Data, analysis
Grafts, interventional procedures, 943.1268

Published online before print
10.1148/radiol.2243011675
Radiology 2002; 224:739–747

[1] From the Dept of Radiology, Massachusetts General Hospital, Harvard Medical School, Zero Emerson Pl, Ste 2H, Boston, MA 02114 (M.E.A.P.M.A., J.L.B., E.F.H., G.S.G.); Depts of Radiology (M.E.A.P.M.A., M.G.M.H.) and Epidemiology and Biostatistics (M.E.A.P.M.A., J.L.B., M.G.M.H.), Erasmus Univ Med Ctr, Rotterdam, the Netherlands; and Dept of Health Policy and Management, Harvard School of Public Health, Boston, Mass (M.G.M.H., G.S.G.). From the 2001 RSNA scientific assembly. Received Oct 12, 2001; revision requested Dec 26; revision received Jan 15, 2002; accepted Mar 12. M.E.A.P.M.A. supported by grants from Foundation Fundatie van de Vrijvrouwe van Renswoude, Foundation Gerrit Jan Mulder Stichting, Netherland-America Foundation, Netherlands Heart Foundation, Foundation Stichting Dr Hendrik Muller's Vaderlandsch Fonds, Foundation Stichting Jo Kolk Studiefonds, Talentenprogramma Award for Talented Students by the Dutch Ministry of Education, Foundation Van Walree Fonds of the Royal Netherlands Academy of Arts and Sciences, Foundation Vereniging Trustfonds Erasmus Univ Rotterdam, and VSB Foundation. J.L.B., E.F.H., G.S.G. supported in part by the U.S. Dept of the Army under DAMD 17-99-2-9001. The information presented does not necessarily represent the position of the government, and no official endorsement should be inferred.
Address correspondence to G.S.G.
Author contributions:
Guarantors of integrity of entire study, M.E.A.P.M.A., J.L.B., G.S.G.; study concepts, M.E.A.P.M.A., J.L.B., G.S.G.; study design, all authors; literature research, M.E.A.P.M.A., J.L.B.; data acquisition, M.E.A.P.M.A., J.L.B.; data analysis/interpretation, all authors; statistical analysis, M.E.A.P.M.A., J.L.B., E.F.H.; manuscript preparation, M.E.A.P.M.A.; manuscript definition of intellectual content, all authors; manuscript editing, M.E.A.P.M.A.; manuscript revision/review and final version approval, all authors.

PURPOSE: To summarize and compare published short-term results of elective endovascular and open surgical repair of abdominal aortic aneurysms.

MATERIALS AND METHODS: A MEDLINE search of the English literature was performed. Studies with at least 10 patients in each treatment group were included if they reported patient characteristics, complications, and mortality. Two reviewers independently extracted the data. A random-effects model was used to pool the data and calculate pooled odds ratios (endovascular vs open surgical repair).

RESULTS: Nine studies were included, reporting results of 1,318 procedures (687 endovascular repair and 631 open surgical repair). Mean blood loss was 456 mL for endovascular repair and 1,202 mL for open surgical repair ($P = .003$). On average, patients undergoing endovascular repair spent 0.5 days in the intensive care unit and 3.9 days in the hospital, and patients undergoing open surgical repair spent 2.2 days ($P = .04$) in the intensive care unit and 10.3 days ($P = .02$) in the hospital. The pooled 30-day-mortality was 0.03 for endovascular repair (95% CI: 0.02, 0.04) and 0.04 for open surgical repair (95% CI: 0.00, 0.07) ($P = .03$), and the odds ratio was 0.55 (95% CI: 0.33, 0.92). The pooled local and/or vascular complication rate was 0.16 for endovascular repair (95% CI: 0.06, 0.25) and 0.12 for open surgical repair (95% CI: 0.06, 0.18) ($P = .46$), and the odds ratio was 0.97 (95% CI: 0.62, 1.54). The pooled systemic and/or remote complication rate was 0.17 for endovascular repair (95% CI: 0.09, 0.25) and 0.44 for open surgical repair (95% CI: 0.21, 0.66) ($P < .001$), and the odds ratio was 0.22 (95% CI: 0.11, 0.45).

CONCLUSION: On the basis of this systematic review, endovascular repair results in less blood loss, shorter intensive care unit and hospital stays, lower 30-day mortality, and lower systemic and/or remote complication rates than those of open surgical repair.

Asymptomatic abdominal aortic aneurysms can be life threatening, since they may rupture with no prior warning (1). Currently, almost half of the patients with a ruptured abdominal aortic aneurysm who reach the hospital die (2). The risk of rupture is related to aneurysm size. Therefore, elective repair of abdominal aortic aneurysms is generally recommended for patients whose aneurysms are larger than 5.0 cm in diameter to avoid morbidity and mortality associated with rupture and emergency repair (3). The goal of elective repair of abdominal aortic aneurysms is to exclude the aneurysm from the circulation to avert rupture and death.

Open surgical repair was the first method used to treat abdominal aortic aneurysms electively. Since 1991, an alternative method—endovascular repair—has become available (4). Endovascular repair is less invasive and does not require abdominal laparotomy and long periods of aortic clamping. It has the potential to reduce procedure-related morbidity and mortality rates from those associated with open surgical repair and shorten the postprocedural recovery period.

Investigators in several reports have described short-term results for endovascular repair of abdominal aortic aneurysms. These reports provide a wide range of estimates for short-term morbidity and mortality. For example, estimates for the systemic and/or remote complication rate for endovascular repair varied between 0% and 39% (5,6), and estimates for the 30-day mortality rate for endovascular repair varied between 0% and 6.1% (7,8). To better understand the appropriate use of this new technology, it is important to evaluate these short-term results. Moreover, a published cost-effectiveness analysis comparing elective endovascular and open surgical repair of abdominal aortic aneurysms showed that the cost-effectiveness of endovascular repair is critically dependent on its potential to reduce morbidity and mortality rates from those associated with open surgical repair (9). That same analysis showed that varying the costs or incidence of repeat interventions for either endovascular repair (for graft thrombosis or endoleak) or open surgical repair (for graft thrombosis or hemorrhage) had no influence on the cost-effectiveness of endovascular repair (9). Furthermore, it was suggested that investigators should place primary focus on morbidity and mortality rates when considering the effectiveness of endovascular repair (9). So far, to our knowledge, no randomized controlled trial comparing elective endovascular and open surgical repair has been published. The purpose of this study was to summarize and compare published short-term results of elective endovascular and open surgical repair of abdominal aortic aneurysms.

MATERIALS AND METHODS

Data Sources

A MEDLINE search of the literature in the English language was performed for articles on elective endovascular and open surgical repair of infrarenal abdominal aortic aneurysm. We used key words describing infrarenal abdominal aortic aneurysm, elective endovascular repair, and outcome (eg, "complication," "morbidity," "mortality," and "success rate"). We limited our search to reports on human subjects published in the English language, and we excluded case reports and reviews. We searched MEDLINE for articles published from 1991 onward, since Parodi et al (4) published their article on the first clinical application of elective endovascular repair for abdominal aortic aneurysm in 1991. In addition, bibliographies of identified articles were checked to obtain additional references. Prospective and retrospective studies were included if they met all of the following criteria: *(a)* Patients undergoing elective endovascular repair were compared with patients undergoing elective open surgical repair, *(b)* each treatment group included at least 10 patients, and *(c)* patient characteristics, complications, and mortality were reported for both groups. In the event of multiple reports from a single institution, we included only the most recently published report to avoid double counting.

Nine studies (5–8,10–14) met our inclusion criteria, in which the results of 1,318 procedures were reported. The total number of patients undergoing endovascular repair (n = 687) was higher than the total number of patients undergoing open surgical repair (n = 631). In Table 1, the characteristics of the included studies are given. The publication dates of the studies varied from June 1998 to February 2001. Patients were enrolled in these studies from 1992 to 1999. All studies were observational. Various strategies were used to enroll patients in the endovascular and open surgical groups (Appendix). In most studies, one or two institutions were involved, with the exception of the study by Zarins et al (14), in which 12 institutions were involved. In six of the nine studies, the first endovascular procedures performed at the institution were included in the endovascular repair group (5,8,10,11,13,14). May et al (12) performed their first endovascular procedure in 1992, but their study period started in May 1995. It is unclear if the other investigators (6,7) had performed any endovascular procedures before the start of their study periods.

Data Extraction

Two authors (M.E.A.P.M.A., J.L.B.) independently extracted data on study design, patient characteristics, lesion characteristics, procedural techniques, and short-term results by using standardized forms. Discrepancies were resolved by means of consensus. If a discrepancy existed in the numbers in the text or between text and tables, we chose the most frequently reported number.

Short-term results were defined as all measurable results within 30 days of the procedure, including duration of the procedure, blood loss during the procedure, number of days in the intensive care unit, number of days in the hospital, and 30-day mortality and complication rates. Complications were extracted as they were described in the studies. We made a distinction between complications and outcomes related to the aneurysm or to the graft. Complications included, for example, wound infection, postoperative hemorrhage, myocardial infarction, pneumonia, and sepsis. The existence of an endoleak, graft thrombosis, or graft occlusion; increasing aneurysm size over time; aneurysm rupture; and conversion to open surgical repair were considered treatment outcomes—that is to say, they were considered to be potential aneurysm- and graft-related failures rather than complications.

Data Synthesis

To assess the possibility of publication bias (ie, bias resulting from more studies with a desirable result being published than those with an undesirable result), we constructed a funnel plot (15). In a funnel plot, an estimate of the precision of the effect size for each study (in our study, the reciprocal of the standard error of the 30-day mortality odds ratio) is plotted as a function of the corresponding effect-size estimate (in our study, the natural logarithm of the odds ratio). In the absence of publication bias, the data points from all studies (one point for each study) should take the shape of a symmetrical inverted funnel-shaped distribution (inverted V shape); the effect-size estimates from larger, more precise studies will converge; and the effect-size estimates from smaller, less precise studies will be scattered symmetrically at the bottom of the funnel plot. If publication bias is present, the data points will be distributed in an asymmetrical fashion. For example, one side of the funnel shape can be missing. We used 30-day mortality as effect size, since it was the most robust, most standardized outcome presented in the studies.

In our meta-analysis, we assumed that the individual studies were a random sample of a hypothetical population of studies comparing elective endovascular and open surgical repair of abdominal aortic aneurysms (16). Therefore, we used a random-effects model, which takes into account the between-study variance (derived from the sampling of studies) and the within-study variance (derived from the limited sample size of each study), to

TABLE 1
Characteristics of Studies Comparing Endovascular and Open Surgical Repair for Abdominal Aortic Aneurysm

Study	Year of Publication	Study Location	No. of Institutions	Study Period	Initial Experience Included*	Patients Matched†	EVR Data Collection	OSR Data Collection
Becquemin et al (10)	2000	France	1	1995–1999	Yes	Yes‡	Pros§	Pros§
Birch et al (11)	2000	Australia	1	1996–1999	Yes	No	Retro	Retro
Brewster et al (8)‖	1998	USA	1	1994–1997	Yes	Yes#	NR	NR
Cohnert et al (5)	2000	Germany	2	1996–1998	Yes	Yes**	Retro	Retro
May et al (12)	1998	Australia	1	1995–1998	No††	No	Pros	NR
Moore et al (13)	1999	USA	1	1992–1998	Yes	Yes‡‡	Pros	NR
Scharrer-Palmer et al (6)	1999	Germany	1	1996–1997	NR	No	Pros	Pros
Treharne et al (7)	1999	UK	1	1994–1997	NR	No	Pros	Pros
Zarins et al (14)	1999	USA	12	1996–1997	Yes	Yes‡	Pros	Pros

Note.—EVR = elective endovascular repair, OSR = elective open surgical repair, Pros = prospective data collection, Retro = retrospective data collection, NR = not reported.
* First endovascular procedure performed at institution was included in the study.
† EVR patients and OSR patients matched by study design.
‡ Patients were not matched, but same entry criteria were used for EVR and OSR patients. All included patients were potential candidates for EVR.
§ Prospective except that missing data were entered retrospectively.
‖ Not analyzed by intention to treat. EVR patients converted to OSR during the initial procedure were excluded from the analysis.
\# Matched for age, risk factor status, abdominal aortic aneurysm size, and aneurysm extent and morphologic features.
** Matched for age, sex, and body mass index.
†† First EVR performed in 1992.
‡‡ Matched for age, risk factors, and anatomic considerations.

pool discrete variables throughout our study (16).

From the data provided in the individual studies, we calculated weighted means for patient age and abdominal aortic diameter. The estimates were weighted for sample size. For patient sex and preoperative risk factors, we calculated pooled estimates and their 95% CIs by using the random-effects model described by Laird and Mosteller (16).

To summarize the short-term results of both treatment groups, we calculated weighted means for duration of the procedure, blood loss during the procedure, days in the intensive care unit after the procedure, and total length of stay in the hospital. For the overall 30-day mortality and complication rates, we calculated pooled estimates and their 95% CIs by using the random-effects model described by Laird and Mosteller (16). In addition to reporting the total complication rate of endovascular and open surgical repair, we divided the total complication rate into a local and/or vascular complication rate and a systemic and/or remote complication rate, as has been suggested by several investigators in articles about reporting standards (17–21). We also reported complications according to type (ie, arterial injury, embolization and/or occlusion, limb ischemia, wound, bleeding, renal sepsis, and cardiac, neurologic, pulmonary, gastrointestinal, and other complications). The word *occlusion* was used to refer to coverage of renal arteries and unintentional branch occlusion.

All pooled estimates were compared between treatment groups by using the Student *t* test and the χ^2 test as appropriate. Two-sided *P* values of .05 or less were considered to indicate a statistically significant difference.

To compare 30-day mortality, total complication rates, local and/or vascular complication rates, and systemic and/or remote complication rates between the two treatment groups, we also calculated pooled odds ratios (endovascular vs open surgical repair). Pooled odds ratios and their 95% CIs were calculated by using the random-effects model described by DerSimonian and Laird (22,23).

To test for heterogeneity in patient characteristics and short-term results across the studies, we used the χ^2 test, and to test for heterogeneity in the odds ratios across the studies, we used the Cochran-Mantel-Haenszel test.

Most analyses were performed with Microsoft Excel software (Redmond, Wash). Only the Cochran-Mantel-Haenszel test was performed with SAS version 7 software (Statistical Analysis Systems, Cary, NC).

RESULTS

Publication bias may have affected our results. The Figure shows that the funnel plot did not have a symmetrical appearance. In the lower left-hand corner, studies appear to be missing. This suggests that small studies with a low mortality rate for endovascular repair compared with that for open surgical repair were underrepresented.

Table 2 presents the demographic and clinical characteristics of the patients included in this systematic review by study and by treatment group. Most of the characteristics were not significantly different between the endovascular and open surgical repair groups. A significant difference was present in the proportion of male patients (P = .002), the proportion of patients with cardiac morbidity ($P < .001$), and the proportion of patients who did not smoke (P = .04); all of these proportions were higher in the endovascular repair group than in the open surgical repair group.

The endovascular procedures were performed in operating rooms in two studies (8,12) and in angiographic suites in two studies (5,11), and the site of performance was not reported in five studies (6,7,10,13,14). General anesthesia was used during endovascular repair in four studies (5,6,8,11), either general or epidural anesthesia was used in one study (14), and the type of anesthesia was not reported in four studies (7,10,12,13). A variety of endografts were implanted, including AneuRx (Medtronic AVE, Santa Rosa, Calif), Bard (Haverhill, Mass), Baxter (Irvine, Calif), EVT (Endo Vascular Technologies, Menlo Park, Calif), Gore (Flagstaff, Ariz), Stentor (Mintec, Free-

TABLE 2
Characteristics of Patients Undergoing Endovascular or Open Surgical Repair for Abdominal Aortic Aneurysm

Study	No. of Patients	Male (%)	Mean Age (y)	Mean Aneurysm Diameter (cm)	Preoperative Risk Factors: Cardiac (%)[*]	Cerebral (%)[†]	DM (%)	HL (%)	HT (%)	Pulm (%)[‡]	PAD (%)	Renal (%)[§]	Smoking (%)[‖]
Endovascular repair													
Becquemin et al (10)	73	90	70	5.0	56	NR	11	30	53	25	NR	11	34
Birch et al (11)	31	87	73	5.7	68	6	3	29	48	42	23	6	NR
Brewster et al (8)	28	86	76	5.5	61	18	11	32	57	43	18	14	11
Cohnert et al (5)	37	97	68	5.7	68	5	5	11	70	NR	NR	5	NR
May et al (12)	148	93	72	NA	56	NR	7	NR	35	7[#]	NR	8	18
Moore et al (13)	100	94	75	5.6[**]	70	24	7	NR	56	28	NR	4	80
Scharrer-Palmer et al (6)	31	94	66	5.2	NR	NR	NR	NR	NR	NR	NR	NR	NR
Treharne et al (7)	49	86	68[**]	5.7[**]	16	4	2	NR	31	NR	18	NR	37
Zarins et al (14)	190	90	73	5.6	84	19	7	NR	69	23	18	4	85
Mean[††]	687[‡‡]	91 (89, 93)[§§]	72[‖‖]	5.5[‖‖]	60 (46, 74)[§§]	14 (7, 20)	7 (5, 9)	26 (16, 35)	52 (43, 62)	30 (22, 38)	19 (17, 20)	7 (4, 9)	44 (19, 70)[§§]
Open surgical repair													
Becquemin et al (10)	107	93	69	5.1	43	NR	10	21	51	22	NR	13	36
Birch et al (11)	31	81	71	6.2	55	23	10	35	55	42	19	6	NR
Brewster et al (8)	28	71	74	5.5	54	14	7	29	46	29	21	11	18
Cohnert et al (5)	37	97	68	6.0	62	8	3	19	59	NR	NR	5	NR
May et al (12)	135	83	69	NA	51	NR	8	NR	33	0[#]	NR	4	23
Moore et al (13)	100	86	73	5.9[**]	59	23	10	NR	66	18	NR	10	79
Scharrer-Palmer et al (6)	29	83	70	6.5	NR	NR	NR	NR	NR	NR	NR	NR	NR
Treharne et al (7)	104	83	72[**]	5.9[**]	23	5	3	NR	42	NR	9	NR	47
Zarins et al (14)	60	85	69	5.6	87	15	10	NR	60	33	25	5	83
Mean[††]	631[‡‡]	85 (81, 90)[§§]	70[‖‖]	5.7[‖‖]	54 (41, 66)[§§]	14 (9, 20)	8 (6, 10)	24 (17, 31)	51 (44, 58)	27 (19, 35)	17 (11, 23)	8 (6, 10)	48 (26, 70)[§§]

Note.—DM = diabetes mellitus, HL = hyperlipemia, HT = hypertension, Pulm = pulmonary, PAD = peripheral arterial disease, NR = not reported, NA = not available or the numbers in the article were not interpretable.

[*] Reported in studies as cardiac disease, coronary artery disease, and ischaemic heart disease.

[†] Reported in studies as cerebrovascular disease, stroke, and transient ischemic attack.

[‡] Reported in studies as chronic obstructive airways disease, chronic obstructive pulmonary disease, and pulmonary disease.

[§] Reported in studies as creatinine levels greater than 1.7 mg/dl, renal dysfunction, renal failure, renal impairment, and renal insufficiency.

[‖] Reported in studies as history of smoking or current smoking.

[#] Defined as severe respiratory disease and Boushy category III. Only reported in the subgroup of patients who had a comorbidity sufficiently severe to preclude open surgical repair. Therefore, these numbers were excluded when calculating the pooled mean for pulmonary preoperative risk factor.

[**] Median.

[††] Mean based on random-effects model, unless indicated otherwise. Numbers in parentheses are 95% CIs.

[‡‡] Total.

[§§] Statistically significant difference ($P < .05$) between pooled mean of endovascular repair and pooled mean of open surgical repair.

[‖‖] Weighted mean.

port, Bahamas), Stenway (Stenford, Paris, France), Talent (Medtronic AVE), Vanguard (Boston Scientific, Natick, Mass), Zenith (Cook Australia, Brisbane, Australia), and custom-made and in-house designs. The configurations of the endografts used, listed according to decreasing frequency of use, were bifurcated (408 of 539; 76%), aortouniiliac combined with contralateral iliac occlusion and femorofemoral bypass (79 of 539; 15%), and tubular (52 of 539; 9%) (Table 3).

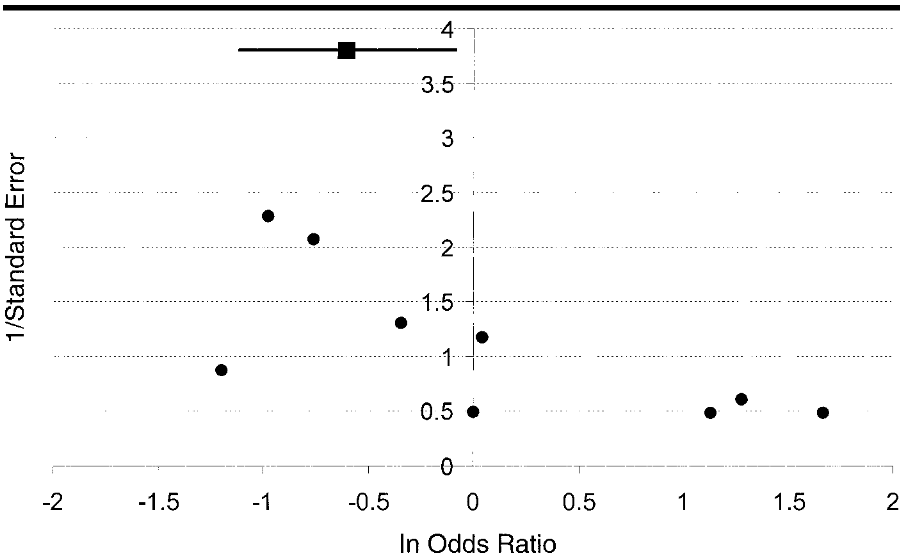
Open surgical repair was performed according to common surgical practice. Tubular and bifurcated grafts were used in 51% and 49% of cases, respectively (Table 3).

Conversion to open surgical repair during the initial procedure or within 30 days after endovascular repair was seen in 0%–10% of patients treated with endovascular repair, with a pooled estimate of 0.03 (95% CI: 0.00, 0.05). In four additional patients in whom iliac arterial access was impossible, the endovascular procedure was abandoned, and no open surgical repair was performed (14). Early endoleak was seen in 7%–29% of patients in the individual studies. The pooled estimate of early endoleak after endovascular repair was 0.20 (95% CI: 0.15, 0.24).

The duration of an endovascular procedure (mean, 192 minutes) was not significantly different from the duration of an open surgical procedure (mean, 200 minutes) ($P = .79$) (Table 3). Blood loss during the procedure was significantly less for endovascular repair (mean, 456 mL) than for open surgical repair (mean, 1,202 mL) ($P = .003$) (Table 3). The number of days spent in the intensive care unit after the procedure and the number of days spent in the hospital were both significantly less for endovascular repair (mean, 0.5 and 3.9 days, respectively) than for open surgical repair (mean, 2.2 and 10.3 days, respectively) ($P = .04$ and $P = .02$, respectively) (Table 3).

The 30-day mortality ranged from 0.00 to 0.06 for endovascular repair and from 0.00 to 0.16 for open surgical repair. The pooled estimate of 30-day mortality for endovascular repair (0.03; 95% CI: 0.02, 0.04) was significantly lower than that for open surgical repair (0.04; 95% CI: 0.00, 0.07) ($P = .03$) (Table 3). The likelihood of dying within 30 days after elective repair of an abdominal aortic aneurysm was reduced by undergoing an endovascular procedure (pooled odds ratio, 0.55; 95% CI: 0.18, 0.71).

The pooled estimate of total complication rate for endovascular repair (0.30; 95% CI: 0.20, 0.40) was significantly lower than that for open surgical repair (0.53; 95% CI: 0.30, 0.75) ($P < .001$) (Ta-



Funnel plot shows the reciprocal of the standard error of the 30-day mortality odds ratio, endovascular repair versus open surgical repair, as a function of the natural logarithm of the 30-day mortality odds ratio. The natural logarithm of the pooled 30-day mortality odds ratio is indicated by the square. Horizontal error bars represent 95% CIs. The funnel plot does not demonstrate a funnel-shaped distribution (inverted V shape). Studies with a low reciprocal of the standard error and with a low 30-day mortality odds ratio appear to be missing (lower left-hand corner). This implies that studies with a low mortality for endovascular repair compared with that of open surgical repair are underrepresented, suggesting that there may be publication bias. ● = studies.

ble 3). The likelihood of experiencing a complication after elective repair of an abdominal aortic aneurysm was reduced by undergoing an endovascular procedure (pooled odds ratio, 0.26; 95% CI: 0.09, 0.78).

For local and/or vascular complication rates, the pooled estimate was 0.16 (95% CI: 0.06, 0.25) for endovascular repair and 0.12 (95% CI: 0.06, 0.18) for open surgical repair (P = .46) (Table 3). No significant difference was found in the likelihood of experiencing a local and/or vascular complication after endovascular or open surgical repair (pooled odds ratio, 0.97; 95% CI: 0.62, 1.54).

The pooled estimate of systemic and/or remote complication rates for endovascular repair (0.17; 95% CI: 0.09, 0.25) was significantly lower than that for open surgical repair (0.44; 95% CI: 0.21, 0.66) ($P < .001$) (Table 3). The likelihood of experiencing a systemic and/or remote complication after elective repair of an abdominal aortic aneurysm was reduced by undergoing an endovascular procedure (pooled odds ratio, 0.22; 95% CI: 0.11, 0.45).

Variation in the presence of risk factors and reported short-term results across the studies included in this systematic review was present, as shown by results of tests for heterogeneity. However, no relationship between the presence of risk factors and worse short-term results could be detected by eyeballing the data. Variations in odds ratios across the studies were demonstrated for total complication rate and systemic and/or remote complication rate.

Table 4 presents a more detailed overview of the reported complications. Significant differences were found in the proportion of arterial injury, bleeding, and cardiac, pulmonary, renal, and gastrointestinal complications. With the exception of arterial injury, the proportions were higher for open surgical repair. Arterial injury was observed more often after endovascular repair than after open surgical repair ($P < .001$). Cardiac, pulmonary, renal, and gastrointestinal complications, as well as bleeding, were observed more often after open surgical repair than after endovascular repair ($P < .001$, $P < .001$, $P = .02$, $P = .002$, and $P = .04$, respectively).

DISCUSSION

In this systematic review, we have summarized and compared the short-term results of elective endovascular and open surgical repair of abdominal aortic aneurysms. We found less blood loss, shorter intensive care unit and hospital stays, lower 30-day mortality, and lower systemic and/or remote complication rates for endovascular repair than those for open surgical repair on the basis of data reported in the nine studies that met our inclusion criteria.

The pooled 30-day mortality of 3% for endovascular repair in this systematic review was in agreement with the 30-day mortality for endovascular repair in the EUROSTAR registry, in which 40 of 1,554 patients (2.6%) died (24). Data from the EUROSTAR registry were not included in this systematic review because a control group of patients treated with open surgical repair was not reported. Two other studies with a large cohort of patients treated with endovascular repair reported a lower 30-day mortality. Twenty-three of 1,192 patients (2.0%) treated within the first 4 years of the U.S. AneuRx clinical trial died within 30 days of the procedure, and 10 of 669 patients (1.5%) treated worldwide with an EVT tube or bifurcated graft between February 1993 and October 1997 died within 30 days of the procedure (25,26). Less blood loss, fewer blood transfusions, and shorter intensive care unit and hospital stays with endovascular repair than those associated with open surgical repair have also been reported in other studies (27–31).

We found that the duration of an endovascular procedure (mean, 192 minutes) was not significantly different from the duration of an open surgical procedure (mean, 200 minutes). Other studies (27–31) reporting procedure times for both treatment options also found a slightly shorter procedure time for endovascular repair than that for open surgical repair, but the difference was only significant in three of five of these studies (27,28,31). It should be noted, however, that endovascular repair was a new procedure, and most of the studies in this systematic review included consecutive endovascular repairs starting from the first endovascular procedure performed at their institution.

Results of a previous study demonstrated that the cost-effectiveness of endovascular repair was critically dependent on its potential to reduce morbidity and mortality rates from those associated with open surgical repair (9). If the mortality rate for endovascular repair increased from 1.2% to greater than 4.4% or if the mortality rate for open surgical repair decreased from 4.4% to less than 1.7%, endovascular repair was no longer cost-effective (9). Endovascular repair will be a cost-effective alternative if it can produce a substantial decrease in morbidity and mortality rates, which is most likely to occur in patients at

TABLE 3
Procedure Results of Endovascular Repair and Open Surgical Repair for Abdominal Aortic Aneurysm

Study	No. of Tubular/ Bifurcated/ Aortouniiliac Grafts*	Procedure Duration (min)	Blood Loss (mL)	ICU Stay (d)	Hospital Stay (d)	30-day Mortality (%)	Total Complications (%)†	Local and/or Vascular Complications (%)‡	Systemic and/ or Remote Complications (%)§
Endovascular repair									
Becquemin et al (10)	3/67/3	149‖	96‖	NR	7	2.7	16.4	1.4	15.1
Birch et al (11)	0/30/1	205	545	0.07	6	3.2	48.4#	45.2#	25.8#
Brewster et al (8)	8/8/12	211	498	0.1	3.9	0	50.0	35.7	14.3
Cohnert et al (5)	0/37/0	233	NR	1.5**	10**	5.4	13.5	13.5	0
May et al (12)	NR	NR	NR	NR	NR	2.7	20.9	11.5	9.5
Moore et al (13)	39/45/16	211	326	0‖	2‖	2.0	21.0	8.0	13.0
Scharrer-Palmer et al (6)	2/29/0	NR	NR	1.5**	10**	0	45.2	6.5	38.7
Treharne et al (7)	0/2/47	NR	. . .††	NR	NR	6.1	44.9	12.2	32.7
Zarins et al (14)	0/190/0	186	641	0.9	3.4	2.6	17.4	10.5	6.8
Mean‡‡	. . .	192§§	456§§‖‖	0.5§§‖‖	3.9§§‖‖	3 (2, 4)‖‖	30 (20, 40)‖‖	16 (6, 25)	17 (9, 25)‖‖
Open surgical repair									
Becquemin et al (10)	37/70/0	133‖	985‖	NR	13	2.8	32.7	6.5	26.2
Birch et al (11)	19/12/0	224	1,735	2.9	13.4	0	83.9#	35.5#	71.0#
Brewster et al (8)	14/14/0	195	1,287	1.75	10.3	0	71.4	7.1	64.3
Cohnert et al (5)	20/17/0	198	NR	1.4**	10.4**	0	10.8	8.1	2.7
May et al (12)	NR	NR	NR	NR	NR	5.9	25.9	6.7	19.3
Moore et al (13)	NR	256	1,010	2‖	7‖	3.0	27.0	11.0	16.0
Scharrer-Palmer et al (6)	20/9/0	NR	NR	3.2**	13**	3.4	103.5##	6.9	96.6
Treharne et al (7)	61/43/0	NR	. . .***	NR	NR	16.3	96.2	15.4	80.8
Zarins et al (14)	y/y/n†††	216	1,596	2.5	9.4	0	28.3	11.7	16.7
Mean‡‡	. . .	200§§	1,202§§‖‖	2.2§§‖‖	10.3§§‖‖	4 (0, 7)‖‖	53 (30, 75)‖‖	12 (6, 18)	44 (21, 66)‖‖

Note.—ICU = intensive care unit, NR = not reported.

* Aortouniiliac grafts combined with contralateral iliac occlusion and femorofemoral bypass.

† Total complications reported, divided by total number of patients per treatment group per study.

‡ Reported in studies as arterial injury, common femoral artery dissection, iliac artery dissection, perforation of iliac artery, spurious aneurysm, abdominal wound dehiscence, groin infection, groin wound problem, hematoma, lymphatic drainage, subcutaneous wound separation, wound complications, wound infection, wound infection necessitating repeat surgery, bleeding, bleeding necessitating repeat surgery, deep hemorrhage, hemorrhage, postoperative hemorrhage, retroperitoneal hemorrhage, wound hemorrhage, acute lower-limb ischemia, chronic lower-limb ischemia, femoral neuropathy, leg ischemia, limb ischemia, renal arteries covered, unintentional branch occlusion, intraoperative embolization of both legs, major embolization, massive microembolization, minor embolization, peripheral embolization, unilateral ureteral obstruction, bowel obstruction, colonic ischemia, and mesenteric infarct.

§ Reported in studies as deep venous thrombosis, cardiac complications, cardiac arrhythmia, cardiac failure, congestive heart failure, hypotension, mild congestive heart failure, myocardial infarction, subendocardial infarction, transient arrhythmia, cerebrovascular accident, encephalopathy, neurologic complications, organic brain dysfunction, paraplegia, seizure, stroke, transient ischemic attack, chest infection, pneumonia, pulmonary complications, pulmonary edema, pulmonary embolism, pulmonary infiltrate, respiratory failure, acute renal failure, creatinine level greater than 2.0 (no dialysis), impaired renal function, renal insufficiency (with dialysis), renal insufficiency (no dialysis), transient acute tubular necrosis, infection, urinary infection, sepsis, septicaemia, urinary sepsis, wound sepsis, clostridium difficile colitis, ileus, prolonged ileus, and sigmoid volvulus.

‖ Median.

\# Proportion of patients with a complication was reported, not total number of complications.

** Duration of intensive care unit and hospital stay were regulated in Germany and do not necessarily reflect a patient's clinical condition. Therefore, we excluded these studies when calculating the pooled mean.

†† 21 of 29 patients had blood loss of more than 1,000 mL.

‡‡ Mean based on random-effects model, unless indicated otherwise. Numbers in parentheses are 95% CIs.

§§ Weighted mean.

‖‖ Statistically significant difference ($P < .05$) between pooled mean of endovascular repair and pooled mean of open surgical repair.

\## Because probability cannot exceed 100% in the analysis, we assumed 100% when calculating the pooled total complication rate for open surgical repair.

*** 81 of 104 patients had a blood loss of more than 1,000 mL.

††† Exact numbers were not reported. y = yes, n = no.

high risk (9). On the basis of our results, endovascular repair does indeed seem to reduce short-term morbidity and mortality rates. There is still uncertainty, however, regarding the long-term effectiveness of endovascular repair. Threats to the long-term effectiveness of endovascular repair could include endoleaks, graft distortion, limb graft occlusion, and material fatigue (32). The consequences of having an endoleak are still unclear. Different consequences have been published, varying from a decreased maximum transverse diameter in patients with temporary endoleak and no change in patients with persistent endoleak to no statistically significant diameter changes between patients with and patients without endoleak and an increased diameter in patients with persistent endoleak (33–35). Furthermore, aneurysm rupture occurred in patients with and patients without endoleak (36). Threats to the long-term effectiveness of open surgical repair include pseudoaneurysm rupture, suprarenal and iliac aneurysm formation, graft infection, aortoenteric fistula, and graft thrombosis (25,26). Also, endoleaks have been reported after open surgical repair (37). The same cost-effectiveness analysis showed, however, that varying the costs or incidence of repeat interventions for either endovascular repair (for graft thrombosis or endoleak) or open surgical repair (for graft thrombosis or hemorrhage) had no influence on the cost-effectiveness of endovascular repair (9). Before a final comparison between endovascular and open surgical repair can be made and a definite conclusion reached,

TABLE 4
Complications after Endovascular or Open Surgical Repair for Abdominal Aortic Aneurysm

Study	Arterial Injury (%)*	Embolization and/or Occlusion (%)†	Limb Ischemia (%)‡	Wound (%)§	Bleeding (%)‖	Cardiac (%)#	Neuro (%)**	Pulm (%)††	Renal (%)‡‡	Sepsis (%)§§	Gastro (%)‖‖	Other (%)##
Endovascular repair												
Becquemin et al (10)	0	0	0	1	0	3	0	4	4	4	0	0
Birch et al (11)***	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Brewster et al (8)	7	4	11	14	0	11	0	4	0	0	0	0
Cohnert et al (5)	0	0	0	14	3	0	0	0	0	0	0	0
May et al (12)	3	3	3	3	0	6	1	0	3	0	0	0
Moore et al (13)	0	0	3	5	0	1	3	2	7	0	0	0
Scharrer-Palmer et al (6)	6	0	0	0	3	3	6	10	19	0	0	0
Treharne et al (7)	0	0	0	12	6	4	0	18	8	2	0	0
Zarins et al (14)	3	5	0	1	1	2	1	0	4	0	1	1
Mean†††	2 (0, 4)‡‡‡	2 (0, 3)	2 (0, 4)	6 (2, 10)	1 (0, 3)‡‡‡	3 (1, 6)‡‡‡	1 (0, 3)	4 (0, 9)‡‡‡	5 (1, 10)‡‡‡	1 (0, 2)	0 (0, 0)‡‡‡	0 (0, 0)
Open surgical repair												
Becquemin et al (10)	0	0	0	4	2	7	2	13	3	2	1	0
Birch et al (11)***	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Brewster et al (8)	0	0	0	7	0	21	11	14	4	4	11	0
Cohnert et al (5)	0	0	0	3	3	0	0	3	3	0	0	0
May et al (12)	0	1	0	4	0	13	1	0	4	0	1	0
Moore et al (13)	0	0	5	1	3	5	0	5	6	0	2	0
Scharrer-Palmer et al (6)	0	7	0	0	0	17	14	38	21	0	7	0
Treharne et al (7)	0	4	2	8	6	18	0	35	23	1	0	0
Zarins et al (14)	0	0	0	2	3	5	3	2	2	0	3	5
Mean†††	0 (0, 0)‡‡‡	1 (0, 0)	1 (0, 2)	4 (2, 6)	2 (0, 4)‡‡‡	11 (5, 16)‡‡‡	3 (0, 7)	13 (3, 24)‡‡‡	8 (2, 14)‡‡‡	1 (0, 0)	2 (0, 5)‡‡‡	1 (0, 2)

Note.—Neuro = neurologic, Pulm = pulmonary, Gastro = gastrointestinal, NR = not reported.

* Includes (as reported in the various studies) arterial injury, common femoral artery dissection, iliac artery dissection, perforation of iliac artery, and spurious aneurysm.

† Includes (as reported in the various studies) deep venous thrombosis, intraoperative embolization of both legs, major embolization, massive microembolization, minor embolization, peripheral embolization, renal arteries covered, and unintentional branch occlusion.

‡ Includes (as reported in the various studies) acute lower limb ischemia, chronic lower limb ischemia, leg ischemia, and limb ischemia.

§ Includes (as reported in the various studies) abdominal wound dehiscence, groin infection, groin wound problem, hematoma, lymphatic drainage, subcutaneous wound separation, wound complications, wound infection, and wound infection necessitating repeat operation.

‖ Includes (as reported in the various studies) bleeding, bleeding necessitating repeat operation, deep hemorrhage, hemorrhage, postoperative hemorrhage, retroperitoneal hemorrhage, and wound hemorrhage.

Includes (as reported in the various studies) cardiac complications, cardiac arrhythmia, cardiac failure, congestive heart failure, hypotension, mild congestive heart failure, myocardial infarction, subendocardial infarction, and transient arrhythmia.

** Includes (as reported in the various studies) cerebrovascular accident, encephalopathy, neurologic complications, organic brain dysfunction, paraplegia, seizure, stroke, and transient ischemic attack.

†† Includes (as reported in the various studies) chest infection, pneumonia, pulmonary complications, pulmonary edema, pulmonary embolism, pulmonary infiltrate, and respiratory failure.

‡‡ Includes (as reported in the various studies) acute renal failure, creatinine level greater than 2.0 mg/dl (no dialysis), impaired renal function, renal insufficiency (dialysis), renal insufficiency (no dialysis), and transient acute tubular necrosis.

§§ Includes (as reported in the various studies) sepsis, septicemia, urinary sepsis, and wound sepsis.

‖‖ Includes (as reported in the various studies) bowel obstruction, clostridium difficile colitis, colon ischemia, ileus, mesenteric infarct, prolonged ileus, and sigmoid volvulus.

Includes (as reported in the various studies) infection and medical complications.

*** Birch et al (11) reported total number of patients with local and/or vascular complications and total number of patients with remote and/or systemic complications. No further details were reported.

††† Mean based on random-effects model. Numbers in parentheses are 95% CIs.

‡‡‡ Statistically significant difference ($P < .05$) between pooled mean of endovascular repair and pooled mean of open surgical repair.

Radiology

however, long-term mortality rates should be taken into account, as well.

The principal limitation of our study was that the individual studies included in our systematic review were not based on randomized controlled clinical trials. Various strategies were used to enroll patients in the endovascular and open surgical repair groups (Appendix). Demographic and clinical characteristics were not significantly different between groups, however, with the exception of male sex and the presence of cardiac comorbidities, which were more common in the endovascular group, and smoking, which was more common in the open surgical group. Of course, we could not compare unknown confounders and unpublished characteristics between the treatment groups. For example, the average number of risk factors per patient was not reported. Only Becquemin et al (10) reported that the percentage of patients with two or more risk factors was higher in the endovascular repair group than in the open surgical repair group (P = .01). In a cohort study of endovascular repair in 116 high-risk patients, the 30-day mortality and total complication rate were 2% and 20%, respectively (38), which is lower than the 3% and 30% found in our systematic review.

Publication bias may have affected our results. To assess publication bias, we constructed a funnel plot. The funnel plot suggested that small studies with a low mortality in the endovascular repair group when compared with that in the open surgical repair group may have been underrepresented. Therefore, if present, any publication bias worked against endovascular repair. In spite of this bias, the pooled estimate was still in favor of endovascular repair.

Data collection within the individual studies may also have been a source of bias, especially when data were collected retrospectively in one treatment group and prospectively in the other. In three studies, it was not clear how the open surgical repair data were collected (8,12,13), but the endovascular repair data were collected prospectively. The other studies used the same method for both groups. Because prospectively collected data are likely to be more carefully scrutinized, this potential bias would be expected to work against endovascular repair.

Our study was limited by the originally reported data and the lack of standardization. To reduce the effect of differing interpretations of reported data, two authors independently extracted the data. Lack of standardization was most apparent while dealing with morbidity. Each study defined morbidity differently or did not define it at all, resulting in heterogeneity in the total complication rate and systemic and/or remote complication rate across the studies. To present a complete overview of all complications, we reported all complications as described in the individual studies. Furthermore, we classified complications into local and/or vascular and systemic and/or remote groups, as has been suggested by several authors who were trying to improve reporting standards (17–21). Fatal complications were excluded from the complication rate and were included in the 30-day mortality rate, according to common practice. Events related to the aneurysm and the patency of the graft were excluded from the complication rate, since the reporting of these events is dependent on the available follow-up in the individual studies, which was generally not performed for patients who underwent open surgical repair, and would thus have introduced uncertainty and potential bias into the analysis.

Unfortunately, incorporation of the severity of the complications into our analysis was not possible, because severity was not reported consistently in the included studies. Two European cohort studies, one on endovascular repair and one on open surgical repair, graded complications as mild, moderate, and severe, following the recommendations of the Ad Hoc Committee on Reporting Standards (39,40). The distribution of complications was 24% mild, 55% moderate, and 21% severe for endovascular repair (40) and 29% mild, 36% moderate, and 34% severe for open surgical repair (39). It was not possible to incorporate the actual number of patients with a complication into our analysis, since only Birch et al (11) and Brewster et al (8) reported those numbers. Since one patient could experience more than one complication, the number of patients with complications need not equal the number of complications. We extracted the total number of complications reported in each study. Brewster et al (8) reported a total of 14 complications in 13 patients who had at least one complication after endovascular repair and a total of 20 complications in 14 patients who had at least one complication after open surgical repair. The EUROSTAR registry reported a total of 369 systemic complications in 279 of 1,554 patients who underwent endovascular repair (24).

In conclusion, our results suggest that elective endovascular repair for abdominal aortic aneurysms results in less blood loss, shorter intensive care unit and hospital stays, lower 30-day mortality, and lower systemic and/or remote complication rates than those of elective open surgical repair for abdominal aortic aneurysms. These favorable short-term results add further support to prior studies citing the benefits of endovascular repair.

APPENDIX

Various strategies were used in the included studies to enroll patients in the endovascular and open surgical repair groups. In three studies, the patients in the open surgical repair group were matched with the patients in the endovascular repair group by study design (5,8,13). Brewster et al (8) matched for age, sex, risk factor status, aneurysm size, and aneurysm extent and morphologic features. It should be noted that Brewster et al (8) excluded two of 30 patients from their analysis. These two patients were converted to open surgical repair during the endovascular procedure. Cohnert et al (5) matched for age, sex, and body mass index. Moore et al (13) matched for age, risk factors, and anatomic considerations. In the remaining articles, the authors used other means of defining the two treatment groups. Becquemin et al included patients in both treatment groups who were potential candidates for endovascular repair. The criteria used to decide between performing endovascular or open surgical repair varied during the study period. Birch et al (11) included all patients who underwent endovascular repair and designated the patients who underwent the most recently performed open surgical repairs as an unmatched control group. May et al (12) included all patients who underwent elective repair during the study period, resulting in an endovascular repair group that had 46 high-risk patients who were considered to be unfit for open surgery and an open surgical repair group that had 19 high-risk patients who were considered to be anatomically unsuitable for endovascular repair. Scharrer-Palmer et al (6) included all patients who underwent elective repair during the study period. Patients underwent endovascular repair if they fulfilled the anatomic requirements. Treharne et al (7) included all patients who underwent elective repair during the study period. Patients underwent open surgical repair if they were aged 65 years or younger and had no specific indications for endovascular repair (eg, hostile abdomen) or had unsuitable arterial anatomy for endovascular repair. Zarins et al (14) included only patients who were potential candidates for endovascular repair. The open surgical repair group was created by allowing the institutions to perform endovascular repair only after they had enrolled five control subjects who were treated with open surgical repair.

References

1. Kaufman JA, Geller SC, Brewster DC, et al. Endovascular repair of abdominal aortic

aneurysms: current status and future directions. AJR Am J Roentgenol 2000; 175:289–302.
2. Dardik A, Burleyson GP, Bowman H, et al. Surgical repair of ruptured abdominal aortic aneurysms in the state of Maryland: factors influencing outcome among 527 recent cases. J Vasc Surg 1998; 28:413–421.
3. Ernst CB. Abdominal aortic aneurysm. N Engl J Med 1993; 328:1167–1172.
4. Parodi JC, Palmaz JC, Barone HD. Transfemoral intraluminal graft implantation for abdominal aortic aneurysms. Ann Vasc Surg 1991; 5:491–499.
5. Cohnert TU, Oelert F, Wahlers T, et al. Matched-pair analysis of conventional versus endoluminal AAA treatment outcomes during the initial phase of an aortic endografting program. J Endovasc Ther 2000; 7:94–100.
6. Scharrer-Palmer R, Kapfer X, Orend KH, Sunder-Plassmann L. Endoluminal grafting of infrarenal aortic aneurysms. Thorac Cardiovasc Surg 1999; 47:119–121.
7. Treharne GD, Thompson MM, Whiteley MS, Bell PR. Physiological comparison of open and endovascular aneurysm repair. Br J Surg 1999; 86:760–764.
8. Brewster DC, Geller SC, Kaufman JA, et al. Initial experience with endovascular aneurysm repair: comparison of early results with outcome of conventional open repair. J Vasc Surg 1998; 27:992–1005.
9. Patel ST, Haser PB, Bush HL Jr, Kent KC. The cost-effectiveness of endovascular repair versus open surgical repair of abdominal aortic aneurysms: a decision analysis model. J Vasc Surg 1999; 29:958–972.
10. Becquemin J, Bourriez A, D'Audiffret A, et al. Mid-term results of endovascular versus open repair for abdominal aortic aneurysm in patients anatomically suitable for endovascular repair. Eur J Vasc Endovasc Surg 2000; 19:656–661.
11. Birch SE, Stary DR, Scott AR. Cost of endovascular versus open surgical repair of abdominal aortic aneurysms. Aust N Z J Surg 2000; 70:660–666.
12. May J, White GH, Yu W, et al. Concurrent comparison of endoluminal versus open repair in the treatment of abdominal aortic aneurysms: analysis of 303 patients by life table method. J Vasc Surg 1998; 27:213–221.
13. Moore WS, Kashyap VS, Vescera CL, Quinones-Baldrich WJ. Abdominal aortic aneurysm: a 6-year comparison of endovascular versus transabdominal repair. Ann Surg 1999; 230:298–308.
14. Zarins CK, White RA, Schwarten D, et al. AneuRx stent graft versus open surgical repair of abdominal aortic aneurysms: multicenter prospective clinical trial. J Vasc Surg 1999; 29:292–308.
15. Begg CB, McNeil BJ. Publication bias: a problem in interpreting medical data. J R Stat Soc 1988; 419–463.
16. Laird NM, Mosteller F. Some statistical methods for combining experimental results. Int J Technol Assess Health Care 1990; 6:5–30.
17. Rutherford RB, Baker JD, Ernst C, et al. Recommended standards for reports dealing with lower extremity ischemia: revised version. J Vasc Surg 1997; 26:517–538.
18. Suggested standards for reports dealing with lower extremity ischemia. Prepared by the Ad Hoc Committee on Reporting Standards, Society for Vascular Surgery/North American Chapter, International Society for Cardiovascular Surgery. J Vasc Surg 1986; 4:80–94.
19. Ahn SS, Rutherford RB, Johnston KW, et al. Reporting standards for infrarenal endovascular abdominal aortic aneurysm repair. Ad Hoc Committee for Standardized Reporting Practices in Vascular Surgery of The Society for Vascular Surgery/International Society for Cardiovascular Surgery. J Vasc Surg 1997; 25:405–410.
20. Ahn SS, Rutherford RB, Becker GJ, et al. Reporting standards for lower extremity arterial endovascular procedures. Society for Vascular Surgery/International Society for Cardiovascular Surgery. J Vasc Surg 1993; 17:1103–1107.
21. Johnston KW, Rutherford RB, Tilson MD, Shah DM, Hollier L, Stanley JC. Suggested standards for reporting on arterial aneurysms. Subcommittee on Reporting Standards for Arterial Aneurysms, Ad Hoc Committee on Reporting Standards, Society for Vascular Surgery and North American Chapter, International Society for Cardiovascular Surgery. J Vasc Surg 1991; 13:452–458.
22. Fleiss JL, Gross AJ. Meta-analysis in epidemiology, with special reference to studies of the association between exposure to environmental tobacco smoke and lung cancer: a critique. J Clin Epidemiol 1991; 44:127–139.
23. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials 1986; 7:177–188.
24. Buth J, Laheij RJ. Early complications and endoleaks after endovascular abdominal aortic aneurysm repair: report of a multicenter study. J Vasc Surg 2000; 31:134–146.
25. Jacobowitz GR, Lee AM, Riles TS. Immediate and late explantation of endovascular aortic grafts: the endovascular technologies experience. J Vasc Surg 1999; 29:309–316.
26. Zarins CK, White RA, Moll FL, et al. The AneuRx stent graft: four-year results and worldwide experience 2000. J Vasc Surg 2001; 33:S135–S145.
27. Ceelen W, Sonneville T, Randon C, De Roose J, Vermassen F. Cost-benefit analysis of endovascular versus open abdominal aortic aneurysm treatment. Acta Chir Belg 1999; 99:64–67.
28. Clair DG, Gray B, O'Hara PJ, Ouriel K. An evaluation of the costs to health care institutions of endovascular aortic aneurysm repair. J Vasc Surg 2000; 32:148–152.
29. Holzenbein J, Kretschmer G, Glanzl R, et al. Endovascular AAA treatment: expensive prestige or economic alternative? Eur J Vasc Endovasc Surg 1997; 14:265–272.
30. Sternbergh WC III, Money SR. Hospital cost of endovascular versus open repair of abdominal aortic aneurysms: a multicenter study. J Vasc Surg 2000; 31:237–244.
31. Seiwert AJ, Wolfe J, Whalen RC, Pigott JP, Kritpracha B, Beebe HG. Cost comparison of aortic aneurysm endograft exclusion versus open surgical repair. Am J Surg 1999; 178:117–120.
32. Harris PL, Buth J, Mialhe C, Myhre HO, Norgren L. The need for clinical trials of endovascular abdominal aortic aneurysm stent-graft repair: the EUROSTAR Project. European collaborators on Stent-graft Techniques for abdominal aortic Aneurysm Repair. J Endovasc Surg 1997; 4:72–79.
33. Cuypers P, Buth J, Harris PL, Gevers E, Lahey R. Realistic expectations for patients with stent-graft treatment of abdominal aortic aneurysms: results of a European multicentre registry. Eur J Vasc Endovasc Surg 1999; 17:507–516.
34. Zarins CK, White RA, Hodgson KJ, Schwarten D, Fogarty TJ. Endoleak as a predictor of outcome after endovascular aneurysm repair: AneuRx multicenter clinical trial. J Vasc Surg 2000; 32:90–107.
35. Becquemin JP, Lapie V, Favre JP, Rousseau H. Mid-term results of a second generation bifurcated endovascular graft for abdominal aortic aneurysm repair: the French Vanguard trial. J Vasc Surg 1999; 30:209–218.
36. Harris PL, Vallabhaneni SR, Desgranges P, Becquemin JP, van Marrewijk C, Laheij RJ. Incidence and risk factors of late rupture, conversion, and death after endovascular repair of infrarenal aortic aneurysms: the EUROSTAR experience. European Collaborators on Stent/graft Techniques for aortic Aneurysm Repair. J Vasc Surg 2000; 32:739–749.
37. Chan CL, Ray SA, Taylor PR, Fraser SC, Giddings AE. Endoleaks following conventional open abdominal aortic aneurysm repair. Eur J Vasc Endovasc Surg 2000; 19:313–317.
38. Chuter TA, Reilly LM, Faruqi RM, et al. Endovascular aneurysm repair in high-risk patients. J Vasc Surg 2000; 31:122–133.
39. Akkersdijk GJ, van der Graaf Y, Moll FL, et al. Complications of standard elective abdominal aortic aneurysm repair. Eur J Vasc Endovasc Surg 1998; 15:505–510.
40. Cuypers P, Nevelsteen A, Buth J, et al. Complications in the endovascular repair of abdominal aortic aneurysms: a risk factor analysis. Eur J Vasc Endovasc Surg 1999; 18:245–252.