Incidence and risk factors of late rupture, conversion, and death after endovascular repair of infrarenal aortic aneurysms: The EUROSTAR experience

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Objective: **The EUROSTAR (European Collaborators on Stent/graft techniques for aortic aneurysm repair) Registry was established in 1996 to collect data on the outcome of treatment of patients with infrarenal aortic aneurysms with endovascular repair. To date, 88 European centers of vascular surgery have contributed. The purpose of the study was to evaluate the results of this treatment in the medium term (up to 4 years) according to the analysis of "hard" or primary end points of rupture, late conversion, and death.**

Patients and Methods: **Patients with aortic aneurysms suitable for endovascular aneurysm repair were notified to the EUROSTAR Data Registry Centre before treatment to eliminate bias due to selective reporting. The following information was collected on all patients: (1) demographic details and the anatomic characteristics of their aneurysms, (2) details of the endovascular device used, (3) complications encountered during the procedure and the immediate outcome, (4) results of contrast enhanced computed tomographic imaging at 3, 6, 12, and 18 months after operation and at yearly intervals thereafter, and (5) all adverse events. Life table analysis was performed to determine the cumulative rates of (1) death from all causes, (2) rupture, and (3) late conversion to open repair. Risk factors for rupture and late conversion were identified through regression analysis.**

Results: **By March 2000, 2464 patients had been registered, and their mean duration of follow-up was 12.19 months (SD, 12.3 months). There were 14 patients with confirmed rupture of their aneurysms. The cumulative rate (risk) of rupture was approximately 1% per year. Emergency surgery was undertaken in 12 (86%) patients, of whom five (41.6%) survived. Two patients who were not treated surgically also died, which resulted in an overall death rate of 64.5% (9/14) of the patients. Significant risk factors for rupture were proximal type I endoleak ($P = .001$), midgraft (type III) endoleak ($P = .001$), graft migration ($P = .001$), and postoperative kinking of the endograft ($P = .001$). Forty-one patients underwent late conversion to open repair with a perioperative mortality rate of**

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24.4% (10/41). The cumulative rate (risk) of late conversion was approximately 2.1% per year. Risk factors (indications) for late conversion were proximal type I endoleak (*P* = .001), midgraft (type III) endoleak (*P* = .001), type II endoleak (*P* = .003), graft migration (*P* = .001), graft kinking (*P* = .001), and distal type I endoleak (*P* = .001).
Conclusions: **Endovascular repair of infrarenal aortic aneurysms with the first- and second-generation devices that predominated in this study was associated with a risk of late failure, according to an analysis of observed hard end points of 3% per year. Action taken to address the risk factors identified by the study may improve results in the future. (J Vasc Surg 2000;32:739-49.)**

The feasibility of endovascular repair of abdominal aortic aneurysms and the short-term benefits of this approach, in comparison to conventional open surgery, are no longer in doubt. Subject to the vascular anatomy being favorable, successful deployment of the endograft can be achieved in more than 97% of the patients with a 30-day death rate below 3% (operative death has been low despite a tendency to select patients with a relatively high incidence of major comorbidities for this treatment).

The crucial and as yet unresolved issue with respect to endovascular aneurysm repair is its efficacy in the long term. The primary objective of treatment is to prevent the death of the patient from rupture of the aneurysm. Therefore, rupture and death from rupture are noncontentious primary or "hard" end points for the evaluation of long-term results. A requirement to undertake open surgery to replace the endoluminal device with a conventionally sutured graft, for whatever reason, is also unequivocal evidence of failure of the endovascular procedure and therefore a valid primary end point.

Analysis of the long-term results of endovascular repair on the basis of these primary or hard end points has not been possible previously because the total number of patients available for study has been relatively small and their duration of follow-up short. Worldwide experience spans less than one decade, and most patients with endografts have been treated within the last year or two. For this reason, considerable attention has been focused on secondary, surrogate, or "soft" end points, including endoleak, persistent endoleak, secondary intervention, and endotension as evidenced by postoperative change in the size of the aneurysm sac.[1-4] However, evidence to confirm that any of these represents a reliable indicator of the eventual outcome of treatment is lacking.

This report from the EUROSTAR Organisation has two important objectives: first, to present, for the first time, an assessment of the results of endovascular repair of abdominal aortic aneurysms according to the analysis of hard end points and second, to identify from the database significant risk factors for the occurrence of these end points. It is anticipated that these data together will provide a valuable guide to actions that need to be taken to secure improved results from endovascular treatment of abdominal aortic aneurysms in the future.

METHODS

The EUROSTAR Project. The EUROSTAR Project was launched in 1996 with the objective of collating information on the results of endovascular treatment of abdominal aortic aneurysms. Because the efficacy of the new technology of intra-aortic stent grafting was and remains unproved, it was considered essential to recruit as many patients as possible as quickly as possible to develop a database large enough to allow conclusions to be drawn within the shortest time possible. Achievement of this objective necessitated a large-scale multicentered international study. In most European countries, access to endovascular devices has been less restricted than in other parts of the world, most notably the United States, and for this reason Europe represented a very suitable setting for such a study. By March 2000, physicians from 88 centers in 16 European countries had registered 2464 patients. There is an expectation that participating centers will include all eligible patients. For any bias due to selective reporting to be eliminated, the study protocol requires that patients should be notified to the Data Registry Centre at least 24 hours before their operation. This ensures that the decision to register a patient is not influenced by the outcome of the procedure itself. A policy of excluding from the Registry all patients from centers who consistently fail to deliver follow-up data according to minimum standards of timing and quality has resulted in near complete submission of follow-up information. The number of censored observations provided in Tables II and IV includes

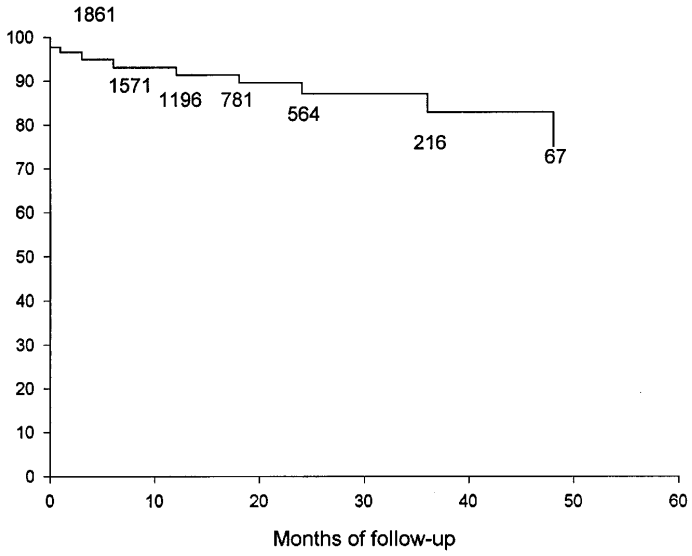

Fig 1. Life table analysis of overall survival.

all the patients whose data have not been entered onto the database at the time of analysis because of an inevitable lag in collection and entry. Eventual data collection is nearly complete.

Patients. At the end of March 2000, the total cohort of 2464 patients included 2267 men and 197 women (male-female ratio, 11.5:1). Their mean age was 70.5 years (range, 37-93 years). The operative risk profile of the patients according to the American Society of Anesthesiologists (ASA) classification included ASA 1 in 203 patients (8.2%); ASA 2 in 875 (35.5%); ASA 3 in 1083 (43.9%), and ASA 4 in 170 (6.9%). The ASA grade was not recorded in 133 patients (5.3%). The risk scores of The Society for Vascular Surgery and The International Society for Cardiovascular Surgery,[5] identified smoking, hypertension, and cardiac disease as the most prevalent risk factors. Six hundred fifty-two patients had undergone previous laparotomy, and 320 patients were considered to be unfit for conventional open surgery, of whom 98 were considered to be unfit for general anaesthesia. Cardiorespiratory compromise has been the most frequently stated reason for unfitness.

Aneurysms. Contrast enhanced computed tomographic (CT) scanning (2207 patients) combined with calibrated angiography (2081 patients) was the method of choice for preoperative assessment in most centers. Preoperative intravascular ultrasound scan examination was performed in 10 patients. The mean maximal transverse diameter of the aneurysms was 56.53 mm (range, 18-150 mm). The mean of the aneurysms' neck diameters was 22.45 mm (range, 11-35 mm), and the mean neck length was 27.7 mm (range, 5-110 mm). There were associated aneurysms of the common iliac arteries in 35% of the patients.

Endovascular devices. Only devices with European regulatory approval (CE mark) were eligible for inclusion in the study. Bifurcated endovascular stent-grafts were used in 2261 patients (92%). The make and manufacturer of each device in patients who survived more than 30 days are shown in Table I. This table also shows the mean duration of follow-up of each device. The mean duration was determined by the date of introduction of the product into the EUROSTAR study, and that was determined by the date that it received regulatory approval for use in European hospitals.

Patient follow-up. Patients were assessed through clinical observation and with contrast-enhanced CT scans at 1, 3, 6, 12, and 18 months after the operation and at yearly intervals thereafter. Color duplex ultrasound scan examination with or without contrast enhancement was also undertaken in a number of centers. According to the original study protocol, aortography was mandatory at 12 months, but subsequently, this investigation was undertaken only when indicated by the results of CT imaging, at the discretion of the responsible physician. Data reported to the Data Registry Centre included all adverse events. An indication of the completeness of the data can be obtained from the number of censored observations in the graph show-

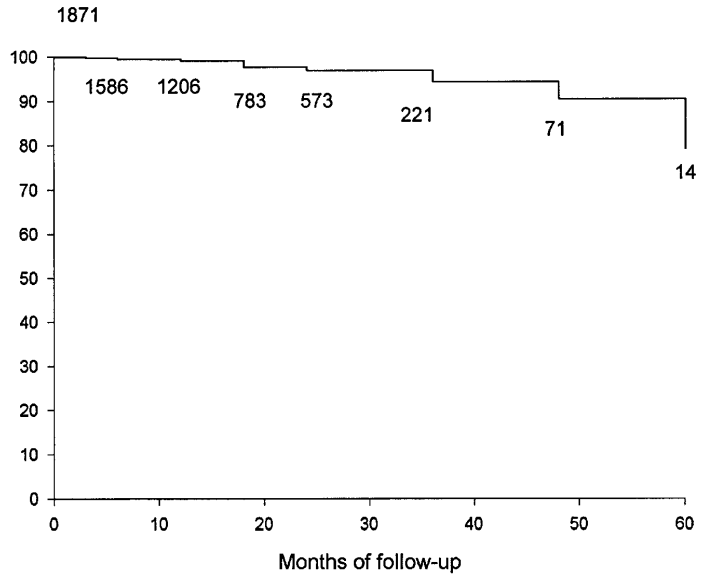

Fig 2. Life table analysis of freedom from late conversion among survivors.

ing overall survival (eg, at 1 year the ratio of actual to expected observations was 77.2% [1196/1549] and at 2 years 73.7% (564/765]). The purpose here is to report the incidence of the following: (1) the results of treatment to 30 days, (2) death from all causes and sudden death of unknown cause that occurred more than 30 days after operation, (3) rupture of the aneurysm and the outcome from this event, (4) risk factors for late rupture of the aneurysm, (5) conversion to open repair of the aneurysm undertaken more than 30 days after operation and the outcome, and (6) risk factors for late conversion to open repair.

Statistical analysis. Crude risk ratios with 95% CIs were calculated to quantify the correlation between procedural complications and potential risk factors. A regression analysis that was based on the Cox proportional hazards model was constructed with factors known to be associated with the occurrence of conversion and rupture. The patients with endovascular stent-grafts who survived 30 days were included in the risk factor analysis. Because of the small number of patients with a rupture and late conversion, only a univariate regression analysis was performed. The potential risk factors that we assessed were stent-graft kinking, migration, stenosis, thrombosis, and all types of endoleak. No other risk factors were analyzed. Survival analysis was calculated with Kaplan-Meier testing. All statistical analyses were performed with SAS software (version 6.12; SAS Institute, Inc, Cary, NY).

RESULTS

Outcome of operative procedures: results to 30 days

Deployment of the endoluminal device was achieved successfully in all but 60 of 2464 patients (97.6%). Conversion to open repair was undertaken at the time of the initial procedure in 34 patients (1.3%). There was one rupture within the first 30 days. This patient immediately underwent an open repair. However, the patient died. There were 79 deaths in the first postoperative month, which resulted in a 30-day death rate of 3.2%. The operative death rate for patients in ASA class 4 was 11.8% (20/170), compared with 3.4% for ASA class 3 patients (37/1083), 1.7% for ASA class 2 patients (15/875), and 1.5% for ASA class 1 patients (3/203) ($P < .001$), which indicated that death was related primarily to comorbidity. An endoleak was identified on the completion angiogram in 419 of 2404 of the patients who underwent a successful deployment. At 1 month, an endoleak was present in 140 (8.3%) of 1688 patients.

Follow-up: outcome events occurring more than 30 days after operation

Death from all causes and sudden death of unknown cause. After endovascular repair of their aneurysms, 136 patients died between 1 and 48 months. Life table analysis of survival for the whole cohort of EUROSTAR patients is shown in Fig 1.

Table I. Endovascular devices and their duration of follow-up

Device	*No. of patients*	*Mean follow-up (mo)*	*SD of follow-up*
Stentor (Mintec, La Ciotat, France)	293	27.93	17.15
Vanguard (Boston Scientific/Meadox Medical Oakland, NJ)	857	14.82	9.84
AneuRx (Medtronic, Sunnyvale, Calif)	430	8.60	7.87
Talent (World Medical, Sunrise, Fla)	308	7.63	8.10
Zenith (Cook, Indianapolis, Ind)	192	3.53	3.93
Ancure (Endovascular Technologies, Menlo Park, Calif)	106	15.42	13.08
Excluder (WL Gore, Flagstaff, Ariz)	88	2.40	2.60
Other	51		

Table II. Data of life table analysis of overall survival

Time (mo)	*Censored observations*	*No. of patients at risk*	*Total no. of deaths*	*Survival (%)*	*SE*
0		2464			
1	337	2048	79	96.6	0.00374
3	155	1861	111	95.0	0.00466
6	258	1571	143	93.10	0.0690
12	353	1196	165	91.42	0.00658
18	399	781	181	89.58	0.00789
24	201	564	197	87.11	0.00980
36	337	216	208	82.89	0.0155
48	142	67	215	75.05	0.0315

The number of patients expected at each follow-up, the number of censored observations, and the SEs at each point are shown in Table II. It was possible to attribute a precise cause of death in 113 patients. In 13 patients the cause of death was unrecorded. This group includes 10 patients in whom sudden death from rupture of their aneurysms cannot be excluded.

Rupture of the aneurysm. Thirteen patients had rupture of a treated aneurysm 30 days or more after operation. Only those patients with unequivocal evidence of rupture that was based on the findings at operation, CT images, or the results of postmortem examination have been included in this analysis. Patients who collapsed and died suddenly without a precise diagnosis having been confirmed (10 patients) were not included. Details of the patients with proved rupture are shown in Table III. The peak incidence of rupture occurred 18 months after operation (range, 0-24 months). The annual cumulative rate approximates to 1% (1.4% in the first year, 0.6% in the second year). Emergency open surgery was undertaken in 12 patients (85.7%); five patients (41.6%) survived. There were no survivors among the patients who were not subjected to an emergency operation. The overall death rate due to late rupture (> 30 days) of the aneurysm after endovascular repair was 69.2% (9/13) of the patients.

Risk factors for aneurysm rupture. Significant risk factors for postoperative late rupture (> 30 days) as obtained with univariate analysis of the data are shown in Table IV. Primary data on the incidence of the risk factors are also included in this table.

Conversion to open repair. During follow-up, the decision to remove and replace an endovascular device with a conventionally sutured graft was made at the discretion of the responsible physician. To date, 41 of these procedures have been undertaken within the EUROSTAR cohort of patients (Table V). Conversion has never been undertaken solely at a patient's request in the absence of an evidence of failure of treatment. The peak incidence of conversion, at the time of analysis, occurred at 18 months (range, 1-48 months). Life table analysis of the rate of late conversion to open repair is shown in Fig 2. The number of patients expected, the SE, and the number of censored observations are shown in Table VI. The average annual risk of conversion approximates 2.1%. The risk increased with time after operation (1% in the first year, 3.7% in the second year). There were 10 deaths within 30 days of the procedure, which resulted in a death rate of 24.4%.

Risk factors (indications) for conversion to open repair. Risk factors for late conversion to open repair that were revealed through univariate analysis are shown in Table VII. These may be considered

Table III. Details of patients with a proved rupture of the treated aneurysm

Serial no.	*Time since operation (mo)*	*Intervention on rupture*	*Device*	*Outcome (at 30 d)*
1	18	Conversion	Vanguard*	Death
2	24	Conversion	Vanguard*	Death
3	3	Conversion	AneuRx	Death
4	12	Conversion	Stentor*	Survived
5	18	Conversion	Stentor*	Survived
6	6	Conversion	Vanguard*	Death
7	18	Conversion	Vanguard*	Survived
8	18	Nil	Vanguard*	Death
9	6	Conversion	Vanguard*	Survived
10	24	Conversion	Vanguard*	Death
11	3	Nil	Talent	Death
12	18	Conversion	Vanguard*	Death
13	24	Conversion	Vanguard*	Survived
14†	0	Conversion	Talent	Death

*Discontinued model devices.
†One rupture within 30 days of endovascular repair.

Table IV. Risk factors for late rupture and their incidence after endovascular repair

Adverse factor	*Free from rupture and adverse factor (n)*	*Rupture with adverse factor (n)*	*Rupture free from adverse factor (n)*	*Adverse factor free from rupture (n)*	P *value*	*Relative hazard ratio (95% CI)*
Proximal type I endoleak	2250	3	10	62	.001	7.59 (2.09-27.62)
Midgraft (type III) endoleak	2224	5	8	88	.001	8.95 (2.92-27.52)
Stent-graft migration	2248	3	10	64	.001	4.53 (1.24-16.66)
Kinked endograft	2216	3	10	96	.001	3.13 (1.40-11.49)
Type II endoleak*	2106	2	11	206	.415*	
Distal type I endoleak*	2177	1	12	135	.776*	
Endograft stenosis*	2275	0	13	37	.646*	
Thrombosed endograft*	2235	0	13	77	.503*	

*Statistically not significant.

indications for conversion rather than risk factors. Data of the incidence of the risk factors are also shown in this table.

DISCUSSION

The first successful procedure[6] established the feasibility of endovascular aneurysm repair and, given the associated advantages of minimally invasive surgery over the conventional operation for this condition, ignited considerable enthusiasm for it among vascular physicians, the vascular devices industry, and patients. In recognition of the need to temper enthusiasm for this exciting new technology with responsible evaluation of the risks, as well as the benefits, the EUROSTAR Registry program was launched in 1996. The objective was to establish a database of sufficient size and quality to allow scientifically valid evaluation not only of the procedures themselves,[7] but also of the long-term risks and durability of aneurysm repair by this method. The early results of treatment in the EUROSTAR cohort of patients have been reported previously[1] and are presented here in summary only. In common with other similar reports, successful deployment of the endovascular device was achieved with a very high degree of consistency (in 97.6% of patients) and a low incidence of serious complications. The perioperative death rate was 3.2% (79/2464), and this compares well with the reported results of open surgery. The cumulative survival rate at 48 months for the whole cohort of patients was 75%. In most cases, death was not directly related to the aneurysm, and as an outcome measure of treatment for this condition, death from all causes is clearly too crude to be of any value, especially without reference to a scientifically valid comparator.

Previous reports on the longer-term results of treatment of infrarenal aortic aneurysms with intraluminal endografts have been based on relatively small numbers of patients with a short duration of follow-

up.[8-11] This reflects the limited total world experience of these techniques spanning less than one decade, the last few years of which have accounted for most of the operations. In the absence of sufficient data on primary or hard end points for meaningful analysis of results beyond the immediate postoperative period, attempts have been made to predict the eventual outcome of the procedures through extrapolation from surrogate or soft end points.

Attention has been focused mainly on endoleak as an indicator of an unsuccessful operation.[12] The EUROSTAR Organisation itself has proposed survival free from persistent endoleak as a possible outcome measure.[1] The rationale for using endoleak as an indicator of failure of treatment is based on an assumption that in the presence of endoleak, aneurysms will continue to expand and eventually rupture. However, recent studies have shown that the correlation between the presence or absence of endoleak and postoperative change in the morphology of the aneurysm sac is poor.[13] Furthermore, there are anecdotal reports of rupture of aneurysms after endovascular repair without detectable endoleak. The Laplace principle tells us that it is pressure or "endotension",[14,15] rather than flow within the aneurysm sac, that causes it to expand and rupture. Endotension may be present in the absence of detectable flow.[16] Unfortunately, direct measurement of endotension is not yet possible. However, continued expansion or reexpansion of the sac postoperatively is a sure indication of its presence and, therefore, a strong indication for secondary intervention.

Secondary intervention has also been proposed as an outcome measure. It is suggested that results should be reported in terms of both survival and survival free from secondary intervention in a way that is analogous to primary and secondary patency of arterial bypass grafts for occlusive arterial disease. Although this idea clearly has considerable merit, its value as an indicator of the final or definitive outcome of operation is undermined by a lack of consensus on the question of what constitutes an appropriate indication for secondary intervention. It cannot be assumed that failure to achieve the primary objective of treatment (ie, prevention of death from rupture of the aneurysm) would have resulted in every case if secondary intervention had not been undertaken.

Rupture of the aneurysm, death from rupture, and conversion to open repair are unequivocal indicators of failure of treatment. With 2464 patients entered on the database and a follow-up period extending to 4 years, for the first time, the EUROSTAR collaborators are in a position to report on the medium- to late-term results of endovascular aneurysm repair that are based on the analysis of these hard end points. Because the aim of the study was to present intermediate- to late-term results, the risk factor analyses presented here have included only those patients who were alive free from conversion at 30 days after endovascular repair. However, an analysis (not presented here) that included all patients on the "intention-to-treat" principle revealed the same factors to be significant. Multivariate analysis that could confirm independence of the risk factors is not yet possible because the number of ruptures is too small. However, uni-

Table V. Details of patients who underwent late conversion after endovascular aneurysm repair

Serial no.	*Time since operation (mo)*	*Indication for conversion*	*Outcome (at 30 d)*
1	24	Limbs occluded	Survived
2	18	Rupture	Death
3	36	Migration	Survived
4	36	Graft dislocation	Survived
5	24	Rupture	Death
6	12	Endoleak + graft stenosis	Survived
7	3	Rupture	Death
8	36	Painful enlarging aneurysm	Death
9	36	Endoleak + migration	Survived
10	24	Endoleak	Survived
11	36	Increasing endoleak	Survived
12	12	Rupture	Survived
13	18	Rupture	Survived
14	6	Rupture	Death
15	36	Graft thrombosis	Survived
16	48	Graft thrombosis	Death
17	36	Endoleak	Survived
18	6	Persistent endoleak	Survived
19	18	Migration + graft stenosis	Survived
20	24	Kinking + graft migration	Survived
21	18	Rupture	Survived
22	18	Stent breakage	Survived
23	6	Rupture	Survived
24	18	Prosthesis tear + endoleak	Survived
25	24	Rupture	Death
26	18	Migration	Survived
27	6	Endoleak + graft thrombosis	Survived
28	3	Painful aneurysm	Survived
29	18	Rupture	Death
30	3	Suspected rupture	Death
31	48	Migration	Survived
32	18	Migration	Survived
33	24	Rupture	Survived
34	36	Endoleak	Death
35	60	Endoleak	Survived
36	60	Migration	Survived
37	12	Increasing endoleak	Survived
38	3	Endoleak	Survived
39	6	Endoleak	Survived
40	2	Endoleak	Survived
41	6	Endoleak	Survived

Table VI. Life table data of late conversion

Time (mo)	*Censored observations*	*No. of patients at risk*	*Total no. of late conversion*	*Freedom from late conversion among survivors*	*SE*
1		2325			
3	339	1871	4	99.79	0.001
6	248	1586	9	99.47	0.001
12	353	1206	14	99.06	0.002
18	396	783	25	97.69	0.004
24	189	573	30	96.84	0.006
36	335	221	36	94.29	0.01
48	140	71	39	90.46	0.02
60		14	41	79.15	0.07

Table VII. Risk factors (indications) for late conversion and their incidence after endovascular repair

Adverse factor	*Free from late conversion and adverse factor (n)*	*Late conversion with adverse factor (n)*	*Late conversion from free adverse factor (n)*	*Adverse factor free from late conversion*	P *value*	*Relative hazard ratio (95% CI)*
Proximal type I endoleak	2231	12	29	53	.001	19.39 (4.78-18.48)
Midgraft (type III) endoleak	2204	13	28	80	.001	4.87 (2.49-9.6)
Type II endoleak	2085	9	32	199	.003	2.63 (1.25-5.54)
Distal type I endoleak	2159	11	30	125	.001	2.61 (1.29-5.28)
Stent-graft migration	2229	12	29	55	.001	5.09 (2.54-10.11)
Kinked endograft	2194	9	32	90	.001	2.97 (1.4-6.28)
Thrombosed endograft*	2210	3	38	74	.148*	
Stenosed endograft*	2248	1	36	40	.662*	

*Statistically not significant.

variate analysis was used to confirm statistically significant association. When these results are evaluated, it is important to take account of the fact that, inevitably, they mainly reflect the outcome of treatment with the earliest generations of endovascular device and especially those associated with Vanguard I and II (Boston Scientific Corporation/Meadox Medical, Oakland, NJ). It is possible that the newer generations of endograft will perform differently, but this remains to be proved.

Lumsden et al[17] first reported that some risk of rupture may persist after endovascular aneurysm repair. It is now possible, for the first time, to quantify this risk. Fourteen patients who registered with EUROSTAR had unequivocal evidence of rupture of their aneurysm at intervals from 1 to 24 months after operation (mean, 14 months). Another 10 patients died suddenly of unknown causes. At least three of these patients had aneurysms with a maximal diameter in excess of 6 cm shortly before their death. Although cardiac malfunction and other causes are possible, rupture of the aneurysm is likely to account for some of these 10 deaths. If only those patients in whom the diagnosis was confirmed are taken into account, the cumulative rupture rate, calculated with life table analysis, approximates to 1.0% per year. However, should one also speculatively take into account those patients who died suddenly of unconfirmed causes in whom rupture is a possibility, the risk of rupture increases to 1.7% per year.

It has been previously reported that rupture after endovascular aneurysm repair is associated with a lower death risk than might be expected otherwise.[18] In the current small series of 12 patients who underwent emergency open repair after rupture, five (41.6%) survived. Another two patients who were not operated on died, which resulted in an overall death rate of 64.3% (9/14), which is in line with usual expectations after rupture of an abdominal aortic aneurysm.[19] The reasons for the two patients not receiving an operation in the presence of known rupture were not included in the database.

The numbers of different makes of stent-grafts associated with rupture (Table III) reflect their relative proportion of use and the duration of follow-up. It is not possible to draw any conclusions or comparisons regarding the performance of different makes of devices in relation to rupture from this study.

The analysis of risk factors for postoperative rupture, in this series, confirms the major importance of proximal fixation site endoleak and the imperative of secondary intervention, either endovascular or open, to correct this problem. By contrast, distal fixation site endoleak did not have a significant impact on the risk of rupture. It is possible that distal endoleaks are inherently less dangerous, perhaps because they tend to be associated with lower pressure or endotension within the sac of the aneurysm. A more likely explanation is that most of the endoleaks that develop at this site are resolved, soon after detection, with relatively minor secondary endovascular procedures. On the other hand, proximal fixation site endoleaks are comparatively difficult to treat.

From the inception of endovascular aneurysm repair there has been controversy about the management of patent lumbar and inferior mesenteric arteries arising from the sac. Oversewing of these vessels is an integral part of conventional open surgery for this condition, but most physicians have chosen not to attempt intraluminal coiling or other techniques to occlude them as a routine part of endovascular treatment. Although type II endoleaks[20] due to perfusion of the sac from these vessels are seen in 10% to 20% of patients, most resolve spontaneously, and many physicians do not consider them to be of critical importance. In this study there was a trend toward an association between type II endoleak and rupture of the aneurysm, although this just failed to reach statistical significance. These results would seem to confirm that type II endoleaks are less important than type I. However, in this study, reliance on these data should be tempered with a degree of uncertainty regarding the accuracy of diagnosis of type II endoleak, in the absence of verification by a "core laboratory." One intriguing possibility is that a persistent type II endoleak may be a "marker" for a concealed type I endoleak. Kinking of intra-aneurysmal stent-grafts results from contraction of the sac in its longitudinal dimension after its effective exclusion from arterial pressure[21] and radial forces generated by blood flowing through curved or angulated grafts. Distal fixation site endoleak and midgraft endoleak due to disassociation of the components of modular devices may arise because of this phenomenon. The direct relationship between kinking of the device and the risk of eventual rupture of the aneurysm reported here emphasizes the importance of this problem. Future generations of endovascular stent-grafts for aneurysm repair should be kink resistant. Stent migration is also a device-related issue that has been shown in this study to be significantly associated with rupture of the aneurysm and which similarly requires to be addressed by appropriate improvements in the design of endoluminal stent-grafts.

The conversion to open repair of an aneurysm previously treated with endovascular repair is a serious undertaking. In the EUROSTAR series, this procedure was undertaken in 41 patients. The peak incidence of this event occurred at 18 months. The average cumulative rate of conversion was 2.1% per year. Because conversion to open repair is undertaken as a result of a decision made by the responsible physician, risk factors in this case may be regarded as *indications.* Endoleak of all types, including sac perfusion from patent aortic side branches, was the main indication for conversion. Proximal fixation site endoleak that cannot be resolved by other means is universally acknowledged to be a compelling indication for conversion. Its strong association with rupture and conversion in this study confirms the appropriateness of this approach. However, it is not universally accepted that endoleak from other sites necessarily warrants conversion. Conventional wisdom currently dictates that type II endoleaks, in particular, do not justify conversion unless there also is evidence of continuing expansion of the aneurysm sac, although in this study, there was a significant association between type II endoleak and conversion. Recognition of the importance of endotension has convinced many physicians that continuing or renewed expansion of the aneurysm mandates conversion regardless of the presence or absence of a detectable endoleak. Unfortunately, it has not been possible to assess this as a risk factor in the current study. Another indication for conversion to open repair was the migration of the stent, an important cause of proximal fixation site endoleak. Surprisingly, thrombosis of one or both limbs of the endograft was not significantly associated with late conversion. Common sense would suggest that graft thrombosis should be a risk factor for conversion, but it is possible that more often it has been dealt with by other means, such as crossover bypass graft. Twelve of the operations were undertaken for established rupture of the aneurysm, with a successful outcome in five.

The death rate associated with all operations for conversion to open repair was 24.4%. This is approximately six times higher than that associated with primary open repair of an abdominal aortic aneurysm. Therefore, it is not a procedure to be undertaken lightly. The responsible physician must be convinced that the risk of rupture of the aneurysm or other life- or limb-threatening disaster, is substantially greater

than the risk of conversion before recommending this course of action to his patient.

Recently, the Food and Drug Administration has approved two endovascular devices intended for aortic aneurysm repair for general use in the United States: Ancure (Endovascular Technologies, Menlo Park, Calif) and AneuRx (Medtronic, Sunnyvale, Calif). This decision was based on convincing evidence of acceptable short-term efficacy. However, the long-term benefits and durability of the generic endovascular approach for the treatment of aortic aneurysms have yet to be proved. The current results show that the combined cumulative risk of potentially fatal adverse events associated with early generations of commercially available endovascular devices approximates to 3% per year. Properly structured randomized trials are needed to determine how this compares with the outcome after conventional open repair. However, experience and published results have shown that most physicians would probably anticipate a lower rate of delayed life-threatening complications related directly to the open operation.[22] It is acknowledged that the results of endovascular aneurysm repair may improve as the relevant endovascular technologies evolve in the light of experience. Until the long-term efficacy of this approach has been established through further analysis of reliable hard end points, caution should be exercised with respect to its application in routine clinical practice.

REFERENCES

1. Cuypers P, Buth J, Gevers E, Laheij R, et al. Realistic expectations for patiems with stem-graft treatment of abdominal aortic aneurysms: results of a European multicentre registry. Eur J Vasc Endovasc Surg 1999;17:507-16.
2. Cuypers P, Buth J, Tielbeek A, Gardien M, Idu M. Endovascular abdominal aortic aneurysm repair: first experiences regarding 20 patients in Eindhoven. Ned Tijdschr Geneeskd 1997;141:1385-90.
3. May J, White GH, Waugh R, Stephen MS, Chaufour X, Yu W, et al. Adverse events after endoluminal repair of abdominal aortic aneurysms: a comparison during two successive periods of time. J Vasc Surg 1999;29:32-9.
4. May J, White G, Yu W, Waugh R, Stephen M, Harris J. A prospective study of anatomico-pathological changes in abdominal aortic aneurysms following endoluminal repair: is the aneurysmal process reversed? Eur J Vasc Endovasc Surg 1996;12:11-7.
5. Ahn SS, Rutherford RB, Johnston KW, May J, Veith FJ, Baker JD et al. Reporting standards for infrarenal endovascular aneurysm repair. J Vasc Surg 1997;25:405-10.
6. Parodi JC, Palmaz JC, Barone HD. Transfemoral intraluminal graft implantation for abdominal aortic aneurysms. Ann Vasc Surg 1991;5:491-9.
7. 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;4:72-9.
8. Matsumara JS, Pearce WH. Early clinical results and studies of aortic aneurysm morphology after endovascular repair. Surg Clin North Am 1999;79:529-40.
9. Chuter TA, Gordon RL, Reilly LM, Kerlan RK, Sawhney R, Jean-Claude J, et al. Abdominal aortic aneurysm in high-risk patients: short- to intermediate-term results of endovascular repair. Radiology 1999;210:361-5.
10. Zarins CK, White RA, Schwarten D, Kinney E, Diethrich EB, Hodgson KJ, et al for the investigators of the Medtronic AneuRx Multicenter Clinical trial. AneuRx stent graft versus open surgical repair of abdominal aortic aneurysms: multicenter prospective clinical trial. J Vasc Surg 1999;29:292-308.
11. Becquemin J-P, Lapie V, Favre J-P, Rousseau H for the French Vanguard study group. Mid-term results of a second generation bifurcated endovascular graft for abdominal aortic aneurysm repair: the French Vanguard trial. J Vasc Surg 1999;30:209-18.
12. Matsumara JS, Moore WS. Clinical consequences of periprosthetic leak after endovascular repair of abdominal aortic aneurysm: endovascular technologies investigators. J Vasc Surg 1998;27:606-13.
13. Gilling-Smith GL, Martin J, Sudhindran S, Gould DA, McWilliams RG, Brennan JA, et al. Freedom from endoleak after endovascular aneurysm repair does not equal treatment success. Eur J Vasc Endovasc Surg 2000;19:621-5.
14. Gilling-Smith G, Brennan J, Harris P, et al. Endotension after endovascular aneurysm repair: definition, classification and strategies for surveillance and intervention. J Endovasc Surg 1999;6:305-7.
15. White GH, May J, Petrasek P, Waugh R, Stephen M, Harris J. Endotension: an explanation for continued AAA growth after successful endoluminal repair. J Endovasc Surg 1999;6:308-15.
16. Clement Darling R III, Ozsvath K, Chang BB, Kreienberg PB, Paty PSK, Lloyd WE, et al. The incidence, natural history, and outcome of secondary intervention for persistent collateral flow in the excluded abdominal aortic aneurysm. J Vasc Surg 1999;30:968-76.
17. Lumsden AB, Allen RC, Chaikof EL, et al. Delayed rupture of aortic aneurysms following endovascular stent grafting. Am J Surg 1995;170:174-8.
18. May J, White GH, Waugh R, Chafour X, Stephen MS, Yu W, et al. Rupture of abdominal aortic aneurysms: a concurrent comparison of outcome of those occurring after endoluminal repair versus those occurring de novo. Eur J Vasc Endovasc Surg 1999;18:344-8.
19. Kantonen I, Lepäntalo M, Brommels M, Luther M, Salenius J-P, Ylönen. Mortality in ruptured abdominal aortic aneurysms. The Finnvasc Study Group. Eur J Vasc Endovasc Surg 1999;17:208-12.
20. White GH, Yu W, May J, et al. Endoleak as a complication of endoluminal grafting of abdominal aortic aneurysms: classification, incidence, diagnosis and management. J Endovasc Surg 1997;4:152-68.
21. Harris P, Brennan J, Martin J, Gould D, Bakran A, Gilling-Smith G, et al. Longitudinal aneurysm shrinkage following endovascular aortic aneurysm repair: a source of intermediate and late complications. J Endovasc Surg 1999;6:11-6.
22. Johnston KW. Nonruptured abdominal aortic aneurysm: six-year follow-up results from the multicentre prospective Canadian aneurysm study. J Vasc Surg 1994;20:163-70.

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