Aneurysm rupture after endovascular repair using the AneuRx stent graft

Christopher K. Zarins, MD, Rodney A. White, MD, and Thomas J. Fogarty, MD, Stanford and Los Angeles, Calif

Objective. The purpose of this study was to determine the cause and frequency of aneurysm rupture after endovascular aneurysm repair.

Methods. We reviewed each patient who sustained aneurysm rupture among all patients enrolled for endovascular aortic aneurysm repair in phases I, II, and III of the U.S. AneuRx Multicenter Clinical Trial from June 1996 through October 1999.

Results. A total of 1067 patients were enrolled for endovascular aneurysm repair. The AneuRx stent graft was successfully implanted in 1046 patients (98%). Endovascular repair was unsuccessful in 21 patients (2%); 13 patients (1%) were converted to open aneurysm repair. Among these, two patients (0.2%) sustained aneurysm rupture due to procedure-related instrumentation and underwent open surgical conversion. Aneurysm rupture has occurred in seven patients (0.7%) 3 weeks to 24 months (mean, 16 months) after successful endovascular repair. Four patients survived open surgical repair, and three patients died within 30 days. Overall rupture-related mortality was 0.5% and included late deaths after rupture. Before rupture, two patients had endoleak and aneurysm enlargement, and five patients had no endoleak and no aneurysm enlargement. After aneurysm rupture, all seven patients had evidence suggesting that there was poor fixation of the stent graft at the proximal distal, or iliac junction fixation sites. The two patients with endoleak declined recommended open surgical or endovascular repair, which could have prevented aneurysm rupture. In retrospect, the five patients without endoleak could potentially have avoided rupture with better patient selection, better stent graft positioning, or reinforcement of fixation points with stent graft extenders. The probability of no aneurysm rupture for all patients undergoing endovascular repair is 0.996 ± 0.002 at 1 year and 0.974 ± 0.011 at 2 years by life table analysis with the longest follow-up of 41 months.

Conclusion. The early risk of aneurysm rupture after endovascular aneurysm repair is low. However, the possibility of rupture persists even in patients with no endoleak after the procedure. Therefore, all patients treated with endovascular aneurysm repair should continue to be monitored after the procedure. Patients with evidence suggesting insecure stent graft fixation should undergo further endovascular treatment or open surgical repair. (J Vasc Surg 2000;31:960-70.)

The natural history of abdominal aortic aneurysms (AAAs) is to enlarge and rupture. The risk of rupture of untreated aortic aneurysms is a continuous function of aneurysm size, with an annu-

From the Division of Vascular Surgery, Stanford University Medical Center, and the Division of Vascular Surgery, Harbor-UCLA Medical Center.

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Reprint requests: Christopher K. Zarins, MD, Chief, Division of Vascular Surgery, Stanford University Medical Center, 300 Pasteur Drive, H 3600, Stanford, CA 94305.


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al rupture rate of 0% for aneurysms less than 4 cm, 1% for aneurysms from 4 to 4.9 cm, 11% for aneurysms 5 to 5.9 cm, and 25% or more for aneurysms greater than 6 cm.1-4 The major objective in treating aortic aneurysms is to prevent aneurysm rupture and death from such rupture. Although direct aneurysm repair using a prosthetic graft is effective in preventing aneurysm rupture, it requires major abdominal surgery with significant morbidity and mortality.5,6 Transluminal endovascular aneurysm repair has been shown to significantly reduce patient morbidity with rapid patient recovery and comparable mortality.7-12 However, the long-term effectiveness in preventing aneurysm rupture is not yet known. A number of investigators have reported aneurysm ruptures after endovascular
The purpose of this report is to provide information on aneurysm rupture rate after endovascular aneurysm repair using a single endovascular device in a controlled multicenter clinical trial.

The AneuRx Stent Graft (Medtronic AVE, Inc) was evaluated in the United States in three phases of a prospective multicenter clinical trial in accord with FDA guidelines. Phase I was a feasibility study of the stent graft involving four study sites. Phase II was a controlled clinical investigation comparing endovascular repair using the AneuRx stent graft with standard surgical repair and included 13 study sites. Phases I and II of the study (June 3, 1996 and ending with the close of phase III) of the study at the time the Food and Drug Administration (FDA) granted market approval for the device (September 28, 1999). Follow-up information on all patients in the clinical database as of November 1, 1999, was reviewed. The clinical data, operative report, and pathology reports and preoperative and postoperative computed tomography (CT) scans on all patients experiencing aneurysm rupture were reviewed to determine the cause of rupture. The success of endovascular repair in preventing aneurysm rupture was evaluated using Kaplan-Meier life table analysis to determine the probability of no aneurysm rupture.

RESULTS

A total of 1067 patients were treated with the AneuRx Stent Graft in phases I, II, and III of the clinical trial (Table I). The stent graft was successfully implanted in 1046 (98%) of the 1067 patients. In 21 patients (2%), implantation was not successful. The causes for lack of success included two patients

METHODS

All patients entered into the endovascular treatment arm of the US Multicenter AneuRx Clinical Trial were reviewed. The review included all patients treated with the AneuRx Stent Graft (Medtronic AVE, Inc, Santa Rosa, Calif) beginning with the first patient in phase I of the study (June 3, 1996) and ending with the close of phase III of the study at the time the Food and Drug Administration (FDA) granted market approval for the device (September 28, 1999). Follow-up information on all patients in the clinical database as of November 1, 1999, was reviewed. The clinical data, operative report, and pathology reports and preoperative and postoperative computed tomography (CT) scans on all patients experiencing aneurysm rupture were reviewed to determine the cause of rupture. The success of endovascular repair in preventing aneurysm rupture was evaluated using Kaplan-Meier life table analysis to determine the probability of no aneurysm rupture.

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with procedure-induced aneurysm rupture who underwent surgical conversion within 18 hours, eight patients with inadequate sealing of the stent graft who underwent surgical conversion, eight patients in whom access to the aneurysm through the iliac arteries was not possible (three patients had surgical conversions), and three patients who were entered into the trial but had no procedure performed. The surgical conversion rate at implantation was 13 (1.2%) of 1067 patients. In addition, 10 patients have undergone late surgical conversions (3 weeks–25 months), three for endoleak and seven for aneurysm rupture, for an overall surgical conversion rate of 2.2%.

**Aneurysm rupture during implantation.** Aneurysm rupture was induced by the implantation procedure in two patients (0.2%). One patient experienced abdominal pain, chest pain, and hypotension shortly after stent graft implantation and had cardiac arrest. After resuscitation, an inferior myocardial infarction was diagnosed, and a CT scan demonstrated a retroperitoneal hematoma. The patient underwent surgical conversion with aortobifemoral bypass grafting 18 hours after stent graft implantation. At operation the stent graft was found to be intact, but a perforation of the anterior wall of the aneurysm was demonstrated. The surgeon believed that instrumentation during the procedure might have caused the rupture. The patient had a prolonged hospital course requiring dialysis and ventilator support and was discharged to a rehabilitation center where she died 3½ months after the rupture.

The second patient had evidence of a proximal endoleak on angiography in the operating room after placement of a 24 × 14-mm stent graft. A 25-mm balloon was inflated in the infrarenal neck in an attempt to seal the endoleak. A retroperitoneal hematoma was demonstrated on CT scan immediately after the procedure, and the patient was hemodynamically unstable. The patient was returned to the operating room where he underwent a successful open surgical repair with an aorto-biiliac graft. A tear in the aortic neck at the level of the renal artery where the balloon was inflated was demonstrated. The patient was discharged after 15 days and is alive and well 9 months later.

**Aneurysm rupture after implantation.** Among the 1046 patients with successful stent graft implantation, seven patients (0.7%) experienced aneurysm rupture 3 weeks to 24 months after stent graft repair (Table II). The seven patients were the following:

Patient 1 was a 70-year-old man from the phase I trial with a 5.5-cm aortic aneurysm. The infrarenal aortic neck was short and angulated, and there was placement of a proximal extender cuff at the time of endovascular repair. The main bifurcation used in this patient was the early stiff body design, which is no longer manufactured (manufacturing change from stiff to segmented [more flexible] bifurcation body design was approved by the FDA in April 1998).

The patient had no endoleak at hospital discharge, at 1 month, at 6 months, or at 12 months, and the aneurysm size was unchanged measuring 5.5 cm at 12 months. At 23 months, the patient had an acute onset of abdominal and back pain and was brought to the operating room with a suspected rupture. At operation, a retroperitoneal hematoma and ruptured aneurysm were found, and the patient underwent open aneurysm repair with an aorto-biiliac graft. The operating surgeon noted separation of the proximal extender cuff from the main body of the device in the area of the angulation. The patient was discharged 13 days after rupture and is alive and well 10 months later.

Patient 2 was an 80-year-old man from early in phase II of the study with a 6.8-cm aneurysm. The aneurysm neck was short and angulated, and the device used was the early stiff body stent graft design, which is no longer manufactured (manufacturing change from stiff to segmented [more flexible] bifurcation body design was approved by the FDA in April 1998). The patient had a minor endoleak on predischarge CT but had no endoleak at 1 month, 6 months, or 12 months. Aneurysm size at 12 months was unchanged. After 14 months the patient collapsed at home and was resuscitated, intubated, and brought to the hospital by paramedics. A CT scan demonstrated a new endoleak and a retroperitoneal hematoma. The patient underwent open surgical repair with an aorto-biiliac graft. At operation, the stent graft was found to have lost its seal proximally. Pathologic evaluation of the explanted device revealed an intact stent graft with good incorporation and fibrous tissue ingrowth surrounding most of the stent graft. There was evidence of soft thrombus proximally consistent with the surgeon’s findings and CT evidence of poor proximal fixation at this site as the cause of aneurysm rupture (Fig 1). The patient was discharged from the hospital after 30 days and died of pneumonia 2 months after rupture.

Patient 3 was a 65-year-old woman from phase II of the trial with a tortuous 6.7-cm aneurysm with significant anterior angulation of the neck and aortic bifurcation. A 26 × 15-mm bifurcation module, 13.5
Fig 1. Patient 2. Explanted stent graft from aortic aneurysm, which ruptured 14 months after implantation. A. The specimen reveals tortuosity of the iliac limbs and no curvature of the stiff proximal bifurcation body. There is evidence of soft thrombus and poor stent graft incorporation at the proximal attachment site (arrow). B. Cross sections of stent graft demonstrate that the iliac limbs and most of the bifurcation are well encased in fibrous tissue. Poor tissue ingrowth with soft thrombus is seen in the area of angulation of the neck (arrows). This is consistent with poor proximal fixation as the cause of rupture C. Photomicrograph demonstrating the stent graft bifurcation. The nitinol stents are visible and external to the polyester graft fabric, which is well incorporated by fibrous tissue. The iliac limb is well fixed in the bifurcation gate.
cm in length (short bifurcation module), was placed through the right iliac artery and joined to a long (11.5 cm) left iliac limb. This resulted in a bifurcated stent graft with a short right limb and a long left limb (Fig 2). Abdominal radiographs and a CT scan performed one day after endovascular repair revealed that the right limb of the stent graft barely reached the right common iliac artery, and there was a large endoleak at this site. Note the proximal curvature of the bifurcation module with the segmented stent graft design of the AneuRx stent graft currently in use. The right limb barely reached the right iliac artery, and there was a large endoleak at this site. Note the proximal curvature of the bifurcation module with the segmented stent graft design of the AneuRx stent graft currently in use.

Fig 2. Patient 3. Abdominal radiograph demonstrating a bifurcation stent graft with a short right limb and a long left limb. The right limb barely reached the right iliac artery, and there was a large endoleak at this site. Note the proximal curvature of the bifurcation module with the segmented stent graft design of the AneuRx stent graft currently in use.

Patient 4 was a 65-year-old man from phase II of the trial with a 9.0-cm aneurysm with anterior angulation and tortuosity of the neck and iliac arteries (Fig 3). After stent graft repair, there was no endoleak at 1 month, 6 months, or 12 months. Aneurysm size decreased markedly, measuring 7.5 cm at 6 months and 5.9 cm at 12 months (Fig 4). There was no radiographic evidence of kinking of the stent graft at 12 months although it was bowed anteriorly. At 23 months the patient had abdominal and back pain. A CT scan demonstrated a retroperitoneal hematoma, and the patient underwent complex open aneurysm repair requiring supraceliac crossclamp and an aorto-bifiliac graft. During the operation, the surgeon found that the stent graft was well incorporated and encased in firm thrombus, except at the iliac junction gate where there was soft, fresh thrombus and evidence of hemorrhage and separation of the iliac limb from the junction gate. Review of the abdominal radiograph after implantation revealed that the iliac limb had been positioned at the bottom of the junction gate (Fig 5). It appears that progressive anterior angulation of the stent graft associated with shrinkage of the aneurysm resulted in the iliac limb becoming dislodged from the bifurcation channel with loss of fixation. Initial placement of the iliac limb at the top of the junction or later placement of an extender to secure iliac limb fixation in the junction may have avoided this separation. The patient died 9 days after open surgical repair of multisystem organ failure.

Patient 5 was an 81-year-old man from phase II with a 5.9-cm aortic aneurysm with an accessory left renal artery. A CT scan 2 days after endovascular repair demonstrated an endoleak that was also present at 1 month. The endoleak was shown to originate from a lumbar artery and exit through the left accessory renal artery. The endoleak persisted at 6 months and 12 months. At 16 months the aneurysm had enlarged to 6.3 cm, and the endoleak now communicated with the left iliac artery attachment site (Fig 6). Open surgical repair was recommended, but the patient declined. At 22 months an abdominal radiograph demonstrated an intact stent graft, and the endoleak persisted. The patient continued to decline recommended surgical repair. After 24 months the patient presented to the emergency department with a 24-hour history of back and flank pain in the operating room. During the operation a large retroperitoneal hematoma was found, and the patient’s aneurysm was repaired with a tube graft. The patient is alive and well 5 months after rupture.
pain and hypotension. A CT scan and abdominal radiograph immediately performed before emergency surgery revealed a ruptured aneurysm, which measured 6.5 cm; an intact stent graft; and an endoleak that communicated with the left iliac artery attachment site (Fig 6). The patient was hemodynamically unstable and underwent emergent aneurysm repair with an aorto-biiliac graft. Although he survived the operation, he died 3 days later of cardiopulmonary failure.

Patient 6 was a 75-year-old man from phase III with a 5.9-cm aneurysm and a poorly defined, calcified infrarenal neck on preoperative imaging. An immediate angiogram in the endovascular suite after deployment revealed no endoleak, but the device was noted to be low in the aneurysm neck. An extender cuff was not placed at that time because of difficult iliac access and severe neck angulation and calcification. Follow-up CT scanning was planned at 1 month after the procedure, but the aneurysm ruptured 3 weeks later. A CT scan performed before emergent operation revealed the stent graft to be below the angulated neck with a large proximal endoleak (Fig 7). The patient was hemodynamically unstable and died during emergency surgery, which was complicated by extensive aortic calcification, making it difficult to clamp the aorta.

Patient 7 was a 65-year-old man from phase III
with a 6.0-cm aneurysm who underwent successful stent graft repair. Postoperative imaging was carried out with duplex ultrasound scanning rather than CT. There was no endoleak at the time of hospital discharge or at 1 month or 6 months. The aneurysm size was unchanged at 6.0 cm at 1 month and 6 months. Nine months after stent graft repair the patient had a syncopal episode while driving his car and was involved in a motor vehicle crash. The patient was hemodynamically stable but was noted to have a retroperitoneal hematoma on CT scan performed in the emergency department. The patient was brought to the operating room where he underwent open surgical repair of the ruptured aneurysm using an aorto-biiliac graft. During the operation the surgeon described poor proximal fixation of the stent graft with firm fixation of the iliac limbs. The stent graft was noted to be low in a severely angulated neck at the time of renal angioplasty and stenting 5 months earlier, 4 months after stent graft implantation. There was no endoleak at that time. The patient is alive and well 8 months after rupture.

**DISCUSSION**

The objective of aortic aneurysm repair is to prevent aneurysm rupture. This objective has been achieved in 99.2% of the 1067 patients with infrarenal AAAs enrolled in the AneuRx trial over a period of 3 years and 4 months. Aneurysm ruptures have occurred in nine patients (0.8%) during the course of the study. The 1-year risk of rupture by life table analysis was 0.4%, and the 2-year risk of rupture was 2.6%. This compares favorably with the expected aneurysm rupture rate of 11% per year for untreated 5.5-cm aneurysms.\(^1,4\) The mean size for all aneurysms treated in three phases of the AneuRx Trial was 5.7 ± 1.0 (SD) cm (median, 5.5 cm). It appears that there is an approximate 90% reduction in the risk of aneurysm rupture with endovascular repair compared with similar size untreated aneurysms. The risk of aneurysm rupture is virtually eliminated after successful open surgical repair.

May et al\(^18\) have shown a significant improvement in mortality of patients undergoing operation for aneurysm rupture after endovascular repair compared with patients who rupture de novo. May et al suggest that this is because patients with endografts are less likely to present with hypotension. In this series, the three rupture patients presenting with symptoms but no hypotension survived open surgical repair, whereas all four patients presenting with
hypotension died. Although overall rupture-related mortality was low (0.5%), there is a continuing potential for death from aneurysm rupture after endovascular repair that must be considered against the risk of open surgical repair.

There appear to be four mechanisms that can lead to aneurysm rupture in association with endovascular aneurysm repair with the use of the AneuRx stent graft. The first is aneurysm rupture due to instrumentation during the stent graft implantation procedure. This occurred in two patients in this experience. Aneurysm rupture must be recognized as a potential risk of the procedure. Although the occurrence rate is low, the consequences of rupture are life threatening. Therefore, performing the procedure in the operating room or having immediate availability of an operating room and surgeons experienced in open surgical repair is required.

The second mechanism involves ongoing endoleak and aneurysm enlargement. Aneurysm enlargement with continuing flow in the aneurysm sac is a clear indication that further treatment with either open surgical repair or endovascular repair is needed to prevent aneurysm rupture. The two patients with these findings in this study were strongly advised to undergo open surgical repair on several occasions, but both steadfastly refused. Aneurysm rupture occurred 15 and 24 months after stent graft implantation. These ruptures would likely not have occurred had the patients agreed to undergo elective surgical repair. Aneurysm enlargement, even without documentation of endoleak, should prompt further evaluation and treatment.

The third mechanism involves inadequate or insecure fixation without endoleak. There have been five such patients in this series. All five had angulated infrarenal aortic necks with or without significant iliac tortuosity. Insecure proximal fixation due either to a short neck or low placement in the neck occurred in four patients. Two patients were early in the series and were treated with the original stiff bifurcation stent graft design, which is no longer available. Two were treated with the more flexible bifurcation stent graft currently in use, but placement was low in the infrarenal neck. Although loss of proximal stent graft fixation is a rare event, it is a potentially avoidable complication. Better preoperative imaging and patient selection with avoidance of patients with excess neck angulation and tortuosity will reduce the potential of insecure proximal fixation. Even though low positioning of the stent graft in the neck may successfully exclude the aneurysm, the long-term security of such fixation is uncertain, especially when there is neck angulation. Adding proximal extender cuffs in such cases may significantly buttress proximal fixation and may have avoided

![Fig 6. Patient 5. Three-dimensional reconstruction of spiral CT scans demonstrating (A) an accessory left renal artery arising from a 5.9-cm AAA. B, After endovascular aneurysm repair, an endoleak originating from a lumbar artery and exiting through the left accessory renal artery was demonstrated at 1 month. C, At 16 months the aneurysm had enlarged to 6.3 cm, and the endoleak now communicated with the left iliac artery attachment site. The patient refused recommended surgical repair. D, The aneurysm ruptured at 24 months, at which time the endoleak was larger at the iliac artery attachment.](image)
rupture in each of these cases. The fifth patient who had a rupture without a preexisting endoleak experienced separation of the iliac limb in the junction gate in association with marked aneurysm shrinkage and angulation of the stent graft. The iliac limb had been placed at the bottom of the junction gate, and progressive angulation with iliac tortuosity caused it to separate. Placement of the iliac limb at the top of the bifurcation gate would likely have eliminated the risk of separation of the iliac limb. Alternatively, an extension cuff could have been placed when aneurysm shrinkage and increased stent graft angulation were apparent. Therefore, close monitoring and follow-up of patients with CT scanning, ultrasound scanning, and abdominal radiograph with careful attention to proximal, distal, and junctional fixation sites should be carried out. Early treatment of patients who have no endoleak but in whom insecure fixation is suspected may prevent the development of acute new onset endoleaks and aneurysm rupture.

A fourth possible cause of aneurysm rupture is device, fabric, or stent graft failure. This has not been observed in this patient series, although it has been reported with other devices.19-21 Although endoleak has been considered to be a prime indicator of success or failure of endovascular aneurysm repair,13,22,23 endoleak was detected in only two of the seven patients who sustained aneurysm rupture. In both of these patients, there was evidence of poor distal fixation of the stent graft.

Fig 7. Patient 6. Three-dimensional reconstruction of contrast CT scan at time of aneurysm rupture 3 weeks after stent graft placement low in angulated infrarenal neck. A large proximal endoleak is demonstrated with poor fixation to the infrarenal neck.
Most patients with rupture had no evidence of endoleak on follow-up imaging studies before rupture. Although this does not rule out the possibility of intermittent or undetected endoleak, most patients had evidence of insecure stent graft fixation with new onset, acute endoleak at the time of rupture. Poor fixation of the stent graft, rather than evidence of ongoing endoleak, was the most common predisposing factor for aneurysm rupture in this group of patients. Indeed, the presence or absence of endoleak after endovascular aneurysm repair is a poor predictor of subsequent patient outcome.\(^9\)

It appears that the AneuRx stent graft greatly reduces, but does not eliminate, the risk of aneurysm rupture. This reduced but ongoing risk of rupture is not reliably predicted by the presence or absence of an endoleak. Therefore, all patients with endovascular aneurysm repair should undergo periodic imaging to evaluate the stent graft position and aneurysm size regardless of whether an endoleak is present. Significant aneurysm enlargement; image evidence suggesting insecure proximal, distal, or junctional fixation; or the appearance of a new endoleak should prompt further investigation and treatment with either endovascular or open surgical means. Although the risk of aneurysm rupture is low in the short term, longer follow-up periods are needed before the true long-term benefit of endovascular repair in preventing rupture is known. This closely monitored cohort of patients will hopefully be able to shed light on this important question in the years to come. Until long-term follow-up data become available, patients undergoing endovascular aortic aneurysm repair should be followed up indefinitely with at least a yearly imaging study.

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Adverse events involving the AneuRx Stent Graft should be reported to Mary Robinson, Clinical Research Coordinator, Medtronic AVE, 2170A Northpoint Parkway, Santa Rosa, CA 95407; telephone (707) 591-7417; e-mail mary.robinson@medtronic.com.
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