

Rupture of Intracranial Aneurysms during Endovascular Coiling: Management and Outcomes

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OBJECTIVE: In this study, the incidence, etiologies, and management with respect to clinical outcome of patients with iatrogenic aneurysmal rupture during attempted coil embolization of intracranial aneurysms are reviewed.

METHODS: A retrospective analysis was conducted of 274 patients with intracranial aneurysms treated with Guglielmi detachable coils over a 6-year period from 1994 to 2000. Patient medical records were examined for demographic data, aneurysm location, the number of coils deployed preceding and after aneurysmal rupture, the etiology of the rupture, and the clinical status on admission and at the time of discharge.

RESULTS: Of 274 patients with intracranial aneurysms treated with coil embolization, six (2%) had an intraprocedural rupture. Of these six, two were women and four were men. The mean age was 67 years (range, 52–85 yr). Mean follow-up time was 8 months (range, 0–25 mo). Aneurysmal rupture resulted from detachment of the last coil in three patients, detachment of the third coil (of four) in one patient, and insertion of the first coil in another patient. In one patient, the aneurysmal rupture was a result of catheter advancement before detachment of the last coil. The Glasgow Outcome Scale score at last follow-up examination was 1 in two patients, 2 in two patients, and 5 in two patients.

CONCLUSION: The rate of rupture of aneurysms during coil embolization is approximately 2 to 4%. The clinical outcome may be related to the timing of the rupture and the number of coils placed before rupture. If extravasation of contrast agent is seen, which suggests intraprocedural rupture, further coil deposition should be attempted if safely possible. (*Neurosurgery* 49:807–813, 2001)

Key words: Aneurysm, Coil embolization, Endovascular, Guglielmi detachable coils

The use of Guglielmi detachable coils (GDCs) continues to play an increasing role in the treatment of intracranial aneurysms. Since approval of the coils by the Food and Drug Administration in 1995, the number of aneurysms coiled has markedly increased. With the evolution of softer, more pliable stents and balloons, stent-assisted and balloon-assisted coiling of irregular and wide-necked aneurysms has become possible.

Although questions remain concerning the long-term efficacy and safety of endovascular surgery, one of the most feared complications is an intraprocedural ruptured aneurysm. In several large surgical series, the estimated rate of intraoperative aneurysmal rupture was between 18 and 26%

(1, 5). In other studies, the routine use of temporary clipping with etomidate burst suppression has been shown to possibly prevent this complication (9). In one series, the majority of ruptures occurred either during dissection of the aneurysm or during clip application, with 62% of patients doing well after intraoperative rupture (1). It is clear that an advantage to surgical clipping is direct access to proximal and distal vessels for control should intraoperative aneurysmal rupture occur. The purpose of this review is to investigate the incidence, etiology, and management of patients with iatrogenic aneurysmal rupture, with respect to the clinical outcome, during attempted coil embolization of intracranial aneurysms.

PATIENTS AND METHODS

Between 1994 and 2000, 274 patients with intracranial aneurysms underwent GDC embolization at the University of Pittsburgh Medical Center or the University of Texas Southwestern Medical Center at Dallas. A retrospective review of medical records and outpatient charts for demographic data, location of aneurysm, etiology of rupture, management, and clinical outcome was conducted. Data concerning coil deposition preceding and after aneurysmal rupture were examined.

All patients in this study were taken to the angiography suite. Procedures were performed either with the patient under general endotracheal anesthesia or with intravenous sedation only. Primary coiling of the aneurysm was accomplished with a variety of GDCs, including two-dimensional and three-dimensional coils. All coils used were manufactured by Target Therapeutics (Fremont, CA). Both hard and soft T18 and T10 one-dimensional and two-dimensional coils were utilized. A record of the type or size of the coils used at the moment of intraprocedural rupture is not available. No three-dimensional Target coils were used in this series of ruptured aneurysms. Aneurysm size was determined by the largest distance from the neck to the dome. The diagnosis of rupture was made on the angiographic visualization of contrast extravasation from the intravascular compartment.

RESULTS

After review of medical records from 274 patients with intracranial aneurysms treated with GDCs, six (2%) were determined to have had aneurysmal rupture during the procedure (Tables 1 and 2, Figs. 1–4). Of these six patients, two were women and four were men. The mean age was 67 years (range, 52–85 yr), and the mean follow-up time was 8 months (range, 0–25 mo). Aneurysmal rupture resulted from detachment of the last coil in three patients, detachment of the third coil (of four) in one patient, and during insertion of the first coil in one patient. Microcatheter advancement immediately before detachment of the last coil caused aneurysmal rupture in the sixth patient. The Glasgow Outcome Scale score (GOS) at the time of discharge was 1 in one patient, 3 in three patients, and 4 and 5 in the remaining two patients (mean score, 3). The GOS score at the last follow-up examination improved to 1 in two patients, 2 in two patients,

and 5 in the remaining two patients (mean score, 2.5). We assigned the GOS score as follows: 1 = good recovery to normal life; 2 = moderate disability but independent; 3 = severe disability requiring daily support; 4 = vegetative state; and 5 = death.

Aneurysmal rupture because of microcatheter use resulted in death, whereas rupture because of coil herniation outside the aneurysm dome (as demonstrated by extravasation of dye) resulted in a GOS score of 1 or 2). The one exception is a patient who presented with a Hunt and Hess score of V and progressed to brain death after iatrogenic rupture of the aneurysm. The high prevalence of ruptures in posterior fossa aneurysms, although not statistically significant, reflects the fact that more posterior circulation aneurysms than anterior circulation aneurysms were selected for endovascular surgery.

DISCUSSION

Endovascular therapies continue to play increasing roles in the management of cerebrovascular diseases. With the advancement of stent, balloon, and coil technologies, clinicians are able to treat increasing numbers of aneurysms, including those previously amenable only to surgical clipping. As with surgical clipping, intraprocedural rupture remains a significant concern. With conventional surgery, immediate access to proximal and distal vasculature is usually available. Additionally, blood can be removed from the operative bed after intraoperative rupture. It is obvious that endovascular surgery lacks the aforementioned advantages that conventional surgery offers during situations of intraoperative rupture. It is important to note that the incidence of aneurysmal rupture in the published literature during endovascular surgery is between 2 and 4% (4, 7, 12). Our incidence is similar at 2%. The published incidence of aneurysmal rupture during conventional surgery seems to be greater at approximately 20% (2); however, with the more widespread use of temporary clips, the intraoperative rupture rate is substantially lower (8).

Some have suggested that aneurysmal rupture during endovascular surgery may result from blood pressure fluctuations, increased intraluminal pressure after contrast injection into the aneurysm, or perforation of the aneurysm by coils and/or guidewire (6, 7, 10). Other postulated etiologies for intraprocedural ruptured aneurysms include the diversion of blood flow by coils toward weaker portions of the aneurysm wall and the small dome size (<4 mm) (8). Other risk factors for intraprocedural rupture include recent rupture and the presence of a daughter aneurysm (8). We believe that previously ruptured aneurysms are more fragile and may be more likely to rupture, irrespective of the type of intervention. Although our series suggests that the rate of intraprocedural rupture is higher in previously unruptured aneurysms, we have no evidence that this difference is statistically significant.

We are not convinced that aneurysm size is related to the incidence of intraprocedural rupture. We do think, however, that smaller aneurysms may be at higher risk for rupture during initial catheter placement because the margin of error for catheter tip positioning relative to the aneurysm wall is smaller than with larger lesions. The catheter tip can be placed through the aneurysm fundus either during initial positioning

TABLE 1. Patient Characteristics at Time of Presentation^a

Patient No.	Age (yr)/Sex	Aneurysm Location
1	85/M	PICA
2	69/F	PICA
3	52/F	BA-SCA
4	61/M	ACoMA
5	75/F	PICA
6	61/F	VB junction

^a PICA, posteroinferior cerebellar artery; BA-SCA, basilar artery-superior cerebellar artery; ACoMA, anterior communicating artery; VB, vertebrobasilar artery.

TABLE 2. Patient Management and Clinical Outcomes^a

Patient No.	Coiling (Postbleed Day)	Rupture Etiology	Management	Hunt-Hess Grade	GOS at Discharge	GOS at Last Follow-up	Follow-up (mo)
1	3	Catheter before detachment of last coil	Detach last coil, supportive care	II	4	5	1
2	1	Last coil	Reposition, detach last coil	IV	3	2	25
3	Unruptured	First coil	Reverse heparin, clipping 10 d later	0	1	1	12
4	1	Last coil	Reposition, detach last coil	V	5	5	0
5	0	Last coil	Right vertebral artery sacrifice	IV	3	2	2
6	0	3rd of 4 coils	Insert 1 more coil	III	3	1	7

^a GOS, Glasgow Outcome Scale score.



FIGURE 1. Right vertebral artery angiograms (A, anteroposterior; B, lateral), demonstrating a right posteroinferior cerebral artery aneurysm (arrows).

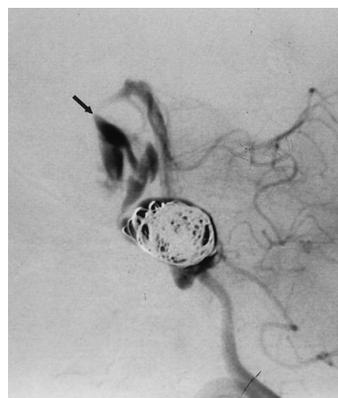


FIGURE 2. Right vertebral artery angiogram demonstrating contrast extravasation (arrow).

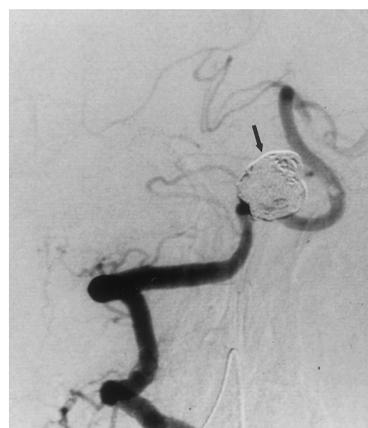


FIGURE 3. Right vertebral artery angiogram demonstrating final aneurysm status with GDC embolization. Extravasation has stopped (arrow).



FIGURE 4. Left vertebral artery angiogram after right vertebral artery sacrifice proximal to the aneurysm. The right posteroinferior cerebral artery continues to fill from distal right vertebral artery. The right vertebral artery was sacrificed to further protect the breached aneurysm (arrow).

or when the wire is removed from the catheter and potential energy within the catheter's loops inadvertently propels the catheter tip forward. With smaller aneurysms, it is more difficult to deploy early coils without directly impinging on the

aneurysm wall. This impingement can result in early aneurysmal rupture. Larger aneurysms tended to rupture when numerous coils were placed, resulting in catheter wedging between deposited coils and the aneurysm wall. Rupture in these larger lesions, however, could also occur from careless handling of the catheter or from potential energy of the catheter tip as the microwire is removed.

As stated earlier, there are many potential technical causes for iatrogenic intraprocedural rupture of an aneurysm. Among these are careless handling of the wire or catheter

such that the catheter builds potential energy when negotiating tortuous vasculature. When the wire is removed under such conditions, the catheter may spring forward and perforate the aneurysm. Other technical errors include wedging of the catheter between deposited coils and/or the aneurysm wall such that new coils cannot be deployed into a free space. Overpacking the aneurysm, oversizing the coils, or the liberal use of stiffer three-dimensional GDCs increases intraluminal pressure against the aneurysm wall, resulting in an increased risk of rupture. Although balloon-assisted coiling is often helpful for wide-necked aneurysms, inflation of a balloon across an aneurysm neck may cause rupture.

In this series, most of the intraprocedural ruptures resulted from attempted placement of the final coil. Often, it is difficult to visualize the catheter tip or the coil during later depositions as the aneurysm fills with platinum. Later deposition risks having the catheter tip become wedged between deposited coils and the aneurysm wall, potentially resulting in depositing a coil in a small space that cannot accommodate the coil, thus leading to wall rupture. These ruptures are often not deleterious because the aneurysm is no longer filling under high pressure. Computed tomographic scans obtained after the procedure often look unfavorable, however, because of the large amount of contrast medium in the subarachnoid space.

Most iatrogenic ruptures reported in the literature are because of coils or guidewires. Cognard et al. (3) reported a series of 182 patients with six intraprocedural ruptures. Of these, two ruptures occurred when the initial coil was placed in the dome of the aneurysm. The other four ruptures occurred in coils placed after the first coil was successfully detached. Those patients in whom the aneurysm ruptured during the initial coil deposition died, whereas the others were asymptomatic. In a prospective trial of 52 patients by Vanninen et al. (11), the three intraprocedural ruptures were all a result of coil placement. Similarly, of 57 matched patients in the same study, 3 had aneurysmal rupture during surgical clipping. There was no significant difference in the GOS score of the two treatment groups at 3 months. In a report by Casasco and George (2), 2 of 71 aneurysms ruptured during endovascular treatment; 1 rupture was caused by the guidewire, and the other resulted from initial coil detachment. In a recent report by McDougall et al. (7), 4 of 200 aneurysms ruptured during coil embolization. Interestingly, one rupture was a result of the catheter, one resulted from the guidewire, the third was caused by contrast injection preceding placement of the last coil, and the fourth was caused by the delivery wire of the final coil. The patient with the catheter-induced rupture died, whereas the others remained asymptomatic.

Several techniques are available to endovascular surgeons when attempting to gain control of an intraprocedural rupture. If the rupture occurs early during the coiling, further coil embolization should be attempted rapidly, safely, and precisely. Further coil packing of the aneurysm usually stops hemorrhage from the aneurysm, assuming that the rupture was a result of coil herniation. Heparin therapy should also be actively reversed with protamine sulfate. Hemorrhage is difficult to control if the rupture is caused by microcatheter perforation of the dome as a result of the increased size of the defect. As reported in the series by McDougall et al. (7),

the catheter-induced intraprocedural rupture resulted in the death of one patient. In a recent case described by Willinsky and terBrugge (13), aneurysm perforation by the microcatheter was treated by leaving the catheter in place and introducing a second microcatheter. This allowed the aneurysm defect to stay plugged while GDCs were detached through a second microcatheter, resulting in a good clinical outcome.

In our series, rupture caused by the last anticipated coil placement and subsequent coil herniation was managed by withdrawing the catheter back into the dome of the aneurysm and then repositioning and deploying the last coil. In one case, the vessel was sacrificed because of the inability to satisfactorily deploy the final coil. In no case was a second microcatheter introduced into the aneurysm for additional simultaneous coil deployment before withdrawal of the first catheter. Although heparin was routinely initiated before aneurysm catheterization in both ruptured and unruptured cases, it was immediately reversed (with protamine sulfate) in all cases after iatrogenic rupture.

Vessel sacrifice is another technique that can be used to safely control aneurysmal hemorrhage after endovascular-related rupture. As demonstrated by one of the patients in this series, right vertebral artery sacrifice was rapidly and safely accomplished in a patient with a posteroinferior cerebral artery aneurysm. Although the Hunt and Hess grade at the time of presentation was IV, the patient was functioning at a near independent level (GOS score of 2) at the last follow-up examination. It is clear that a patient's vascular anatomy and aneurysm location will dictate whether vessel sacrifice is safely possible.

An elevation in intracranial pressure immediately after aneurysmal rupture may be catastrophic, as it is often accompanied by a transient arrest in cerebral blood flow. Although we do not recommend placement of external ventricular drains for all patients undergoing endovascular treatment of aneurysms, in high-risk lesions (daughter aneurysm, small size, tortuous anatomy), it may be useful to have an external ventricular drain in place or rapidly available before coiling. Placement of external ventricular drainage after the iatrogenic rupture of an aneurysm, however, may not be sufficient to prevent a poor clinical outcome (8). All six patients with intraprocedural ruptured aneurysms described in this report underwent external ventricular drainage immediately after rupture. Interestingly, it remains unclear whether patients with intraprocedural ruptures have a higher incidence of vasospasm. Patients were uniformly treated with hypertensive, hypervolemic, hemodilution therapy once the diagnosis of vasospasm was established.

The only intraprocedural death in our series was in a patient treated without general anesthesia and endotracheal intubation. Once the aneurysm ruptured, this patient had a grand mal seizure and the airway became difficult to control. During this time, no coils could be deposited safely and the patient died. On the basis of this experience and the potential risks of the procedure, we think that general endotracheal anesthesia during coil embolization of intracranial aneurysms should be used whenever possible.

Some suggest that microcatheter perforations of aneurysms portend poorer prognoses than ruptures that are a result of coil herniations. Currently, there is insufficient evidence to

support such statements. Nevertheless, awareness of the etiologies responsible for iatrogenic aneurysmal rupture during endovascular treatment may reduce the incidence. Several large series previously reported in the literature mention intraprocedural rupture in the section on complications, but few provide details concerning location, timing, outcome, or suspected etiology of these ruptures. When provided in large numbers, these data may provide insight into those factors that predict clinical outcome after aneurysmal rupture during endovascular surgery.

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COMMENTS

In a retrospective case series, this article addresses two busy endovascular centers' experience with patients with aneurysm rupture during coil embolization. This topic is of considerable interest to endovascular neurosurgeons because of the difficulty in managing hemorrhagic complications during endovascular procedures. Factors such as anticoagulation and lack of direct visualization complicate endovascular management. The principles of management of intraoperative rupture during surgical clip ligation, securing the site of bleeding (with suction or temporary clip application), proximal control (temporary parent vessel occlusion), then permanent clip application may serve as a guide for endovascular management as well. For instance, when coil protrusion is identified, we prefer to leave the coil in place across the breach in the aneurysm wall while repositioning the catheter to deliver the remaining coil. Proximal control may be obtained with balloon occlusion when necessary, such as during balloon-assisted coiling. Final permanent control is obtained after completing endosaccular obliteration with additional coil delivery. Alternatively, especially if rupture occurs early, a second microcatheter can be placed in the aneurysm without moving the first, so that safe coiling can be carried out without disturbing the "plug in the dike" (i.e., the first catheter).

The authors' experience differs from ours in more than one respect. For example, why did four of the six patients experience aneurysm rupture during delivery of the last coil? The authors' explanation is that the microcatheter was trapped between the coil mass and the aneurysm, a situation that should be avoided. Ideally, the later coil should be placed in the center of the "basket" created by the initial coils. Our approach is to first form a basket or shell with three-dimensional coils sized to match the aneurysm dome as closely as possible. We feel that this step not only protects against aneurysm rupture with subsequent coils but also reduces the risk of coil prolapse from the aneurysm neck. The authors indicate that they did not use three-dimensional coils during their procedures. Perhaps this increases the risk of microcatheter trapping during the late phase of coil delivery. Another difference in protocol seems to be the routine withdrawal and repositioning of coils after herniation. Although we think that this procedure may open a space previously occluded by the coil and permit hemorrhage, occurrence late in the procedure is unlikely to result in significant bleeding.

Other aspects of the authors' surgical management are identical to ours. We, too, reverse heparin on the first recognition of hemorrhage or extravasation, particularly if profound neurological deterioration is encountered in an awake patient. In such a case, insertion of an external ventricular drain is often necessary. The authors report that five of their six patients presented with acute subarachnoid hemorrhage. We also have found that previously ruptured aneurysms were more likely to be complicated by intraoperative rupture during coiling, similarly to findings in the literature on surgical ligation of aneurysms.

Despite considerable variations in technique, the authors' rates of intraoperative rupture and clinical deterioration after rupture do not differ significantly from our own or from the rates reported in the literature. This similarity in outcomes seems to indicate that no single technique for coil emboliza-

tion is correct and that more than one method for complication management exists.

Andrew J. Ringer
L. Nelson Hopkins
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The authors report a retrospective review of cases of intraprocedural aneurysm rupture in 274 patients with intracranial aneurysms treated with Guglielmi detachable coils (GDCs). These data were collected from two neurointerventional centers between 1994 and 2000.

The authors did not identify the sizes of the aneurysms that ruptured during embolization. I agree with their statement that no definitive proof exists that small aneurysms rupture more easily than large ones, but the overall experience reported in the neurointerventional literature emphasizes the concept that small, previously ruptured aneurysms are more prone to intraprocedural rupture than large, previously unruptured aneurysms.

The possibility of rupturing a large aneurysm with a microcatheter, microguidewire, or GDC is very rare in the early phases of embolization. Rupturing of large or giant aneurysms tends to occur in those aneurysms that are incompletely embolized or in those that have recanalization of the inflow zone. The exposure of the residual aneurysm to the water hammer effect of the blood circulation may rerupture the aneurysm or produce a rupture in incidental aneurysms.

In the late phase of embolization, when the aneurysm is almost completely occluded, the possibility of aneurysm rupture is higher at the junction of the neck of the aneurysm with the parent artery. This higher risk is particularly true with regard to anterior choroidal, anterior communicating arterial, and superior cerebellar arterial aneurysms because the aneurysms are located at an acute angle to the parent artery. In my neurosurgical experience, the microcatheter elbows the superior aspect of the neck of the aneurysm and exerts great pressure while I attempt to deliver the last GDC coil.

Aneurysm rupture in this location tends to produce a severe subarachnoid hemorrhage that may not be stopped by continuing embolization unless the parent artery is occluded. The authors provide an appropriate discussion of the therapeutic steps to be followed in the acute phase of aneurysm rupture or rerupture during GDC embolization. Fortunately, this technical complication is seen with increasing rarity in clinical practice with the addition of softer GDCs and increased experience of interventional neuroradiologists.

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Levy et al. present a retrospective review of 274 patients treated at two separate institutions during a 6-year period. Six patients experienced intraoperative ruptures, and two died (mortality rate, 33%). The authors conclude, on the basis of their own surgical experience and a review of the literature, that the intraoperative rupture rate for aneurysms treated with GDC embolization is approximately 2 to 4%. Several details concerning this cohort of patients are not fully examined. What

percentage of the 274 patients presented with subarachnoid hemorrhage? Were the patients heparinized, and if so, at which point in the procedure? How much protamine sulfate was administered to reverse heparin-induced anticoagulation, and how long was the delay in its administration?

In a total of 122 GDC cases during the past year, patients at my institution have experienced two intraoperative ruptures during GDC embolization of ruptured aneurysms. Both intraoperative ruptures were controlled with rapid placement of additional GDCs and control of intracranial pressure with previously placed ventriculostomies. At my institution, all patients with ruptured aneurysms who undergo GDC embolization have ventriculostomies placed before coiling, and all embolizations are conducted with the patient under general endotracheal anesthesia. Currently, GDC patients at my institution are managed with electrophysiological monitoring and somatosensory evoked potentials in all cases, as well as with brainstem auditory evoked responses for patients with posterior circulation aneurysms. In patients with intraprocedural rupture, an attempt is made to control intracranial pressure with ventricular drainage and burst suppression with pentobarbital-induced coma to control intracranial pressure and to prevent secondary injury. The latest generation of GDCs have extremely rapid detachment times (often 10–30 s), and this technical advance allows for rapid deployment of additional coils in the face of intraoperative ruptures.

The authors quote an 18 to 26% rate of intraoperative rupture for aneurysms treated with microsurgical clip ligation. I suspect that this percentage is drastically overestimated and based on literature that is 15 to 25 years old. With the use of liberal temporary clipping at my institution, our patients' intraoperative rupture rate is 2.4%, or 4 ruptures in the most recent 166 consecutive cases.

Robert H. Rosenwasser
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Levy et al. describe their experience with the management of ruptured aneurysms during coil embolization. As part of their retrospective analysis of 274 patients treated with GDCs during a 6-year period, they analyzed clinical details pertinent to six patients with intraprocedural ruptures (2%). One of their conclusions is that smaller aneurysms may pose a higher risk of rupture because there is less margin for safety should inadvertent microcatheter movement propel the catheter through the fundus. My colleagues and I share these concerns and agree with the authors.

It is unfortunate, however, that the authors were not able to report details regarding the type of coil implicated in their patients' aneurysm ruptures. Although they do state that they used a variety of coils, they are not able to report which type of coil caused the rupture in each case. It would be very useful to know whether a particular coil type or dimension is more likely to cause a rupture. The authors did not use the Target Therapeutics three-dimensional coils (Target Therapeutics, Fremont, CA) in this series; however, they state that liberal use of the three-dimensional coil increases the risk of rupture. The authors do not state how they reached this conclusion, and no references are cited.

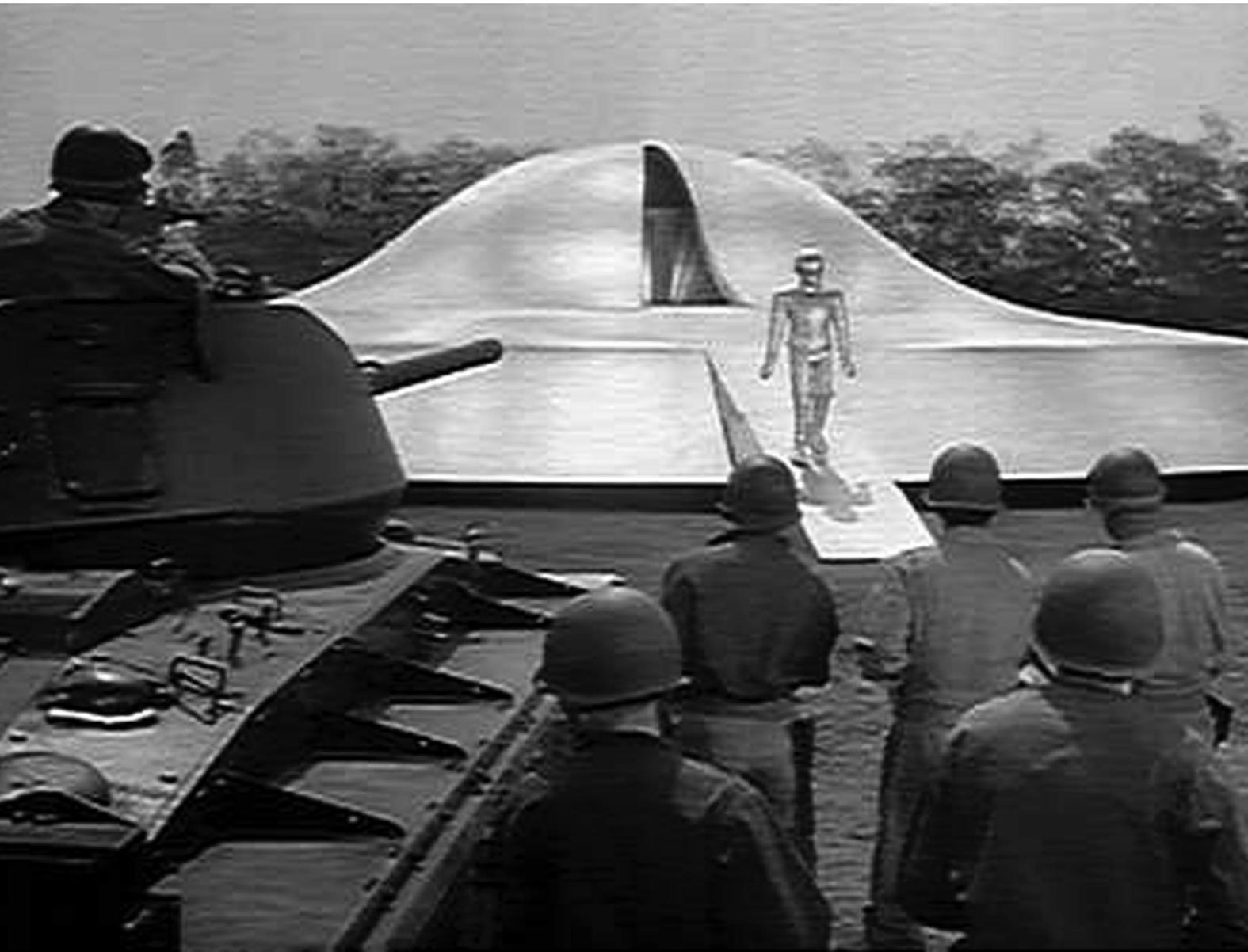
The authors do not describe the method by which they chose the size and type of coil used in each case. They state that aneurysm size was determined by the largest distance from the neck to the dome of the aneurysm. If they chose coils on the basis of this measurement, they potentially could have been choosing coils that were too large for the shorter dimension in oval or elongated aneurysms. It would be useful to know whether this was a factor in the iatrogenic ruptures of this series.

Although this series lacks significant detail in Patients and Methods, it is useful in that it reveals a relatively low incidence of rupture (2%). At my institution, my colleagues and I have had a similar experience; however, when a rupture occurs, it usually happens during placement of the first or second coil and is controlled rapidly by reversing heparin and

continuing to coil. None of our patients has died, nor has any of them experienced fixed deficits, as a result of iatrogenic endovascular rupture.

With the advent of an ever-larger variety of aneurysm coils, microcatheters, and microguidewires, it is imperative that the tools and techniques that work well and those that do not be accurately recorded and reported. There is no other way to realistically learn from the experiences of others, apply those lessons to one's own clinical practice, and effect an improvement in patients' clinical outcomes.

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The alien robot Gort descending from the spaceship in a scene from Robert Wise's classic film *The Day the Earth Stood Still* (1956). The alien android, humanoid only in gross shape, was perceived as a hostile, invading presence completely "other"; the confrontational response to the robot indicated societal mistrust of and resistance to such machines.