Authors: Robert J Singer, MD, Christopher S Ogilvy, MD, Guy Rordorf, MD
Section Editor: Jose Biller, MD, FACP, FAAN, FAHA
Deputy Editor: Richard P Goddeau, Jr, DO, FAHA

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INTRODUCTION

Subarachnoid hemorrhage (SAH) is often a devastating event with a high mortality and morbidity. Most SAH are caused by ruptured intracranial saccular aneurysms. In most cases, the presence of the aneurysm is unsuspected until SAH occurs. After aneurysmal SAH, the patient is at substantial risk of rebleeding: 3 to 4 percent in the first 24 hours and 1 to 2 percent each day in the first month [1]. Rerupture is associated with a mortality that is estimated to be 70 percent. Aneurysm repair is the only effective treatment to prevent this occurrence [2].

Unruptured cerebral aneurysms may manifest clinically by their mass effect on adjacent neurologic structures, or they may be discovered incidentally when a patient has a neuroimaging study for another indication. Such aneurysms have a future risk of rupture and SAH that depends in part on their size and location.

The treatment of cerebral aneurysms is discussed in this topic. Other aspects of the clinical features, diagnosis, and management of cerebral aneurysms and aneurysmal SAH are discussed separately. (See "Unruptured intracranial aneurysms" and "Aneurysmal subarachnoid hemorrhage: Treatment and prognosis" and "Aneurysmal subarachnoid hemorrhage: Clinical manifestations and diagnosis".)

TECHNIQUES

Surgical and endovascular techniques are available for aneurysm treatment. In

many cases, anatomic considerations, such as size, location, along with other morphological features determine which treatment is most appropriate for the patient.

Surgery — Surgical management of cerebral aneurysms, in which a clip is placed across the neck of the aneurysm, is an effective and safe procedure with the evolution of microsurgical techniques in the hands of an experienced surgeon (image 1). This applies to patients with unruptured cerebral aneurysms and those with subarachnoid hemorrhage (SAH) [3].

Treatment at specialized neurosurgical centers performing high volumes of cerebral aneurysm procedures is associated with better outcome compared with treatment at lower-volume centers [4]. Temporary clip occlusion may be achieved via traditional extraluminal clip placement or with an intravascular balloon but does not clearly prevent complications [5]. Intraoperative angiography is useful to facilitate accurate clip placement, and to confirm parent vessel patency after clip occlusion and occlusion of the aneurysm; this allows immediate clip revision when necessary, which is estimated to occur in approximately 10 percent of patients [2,6-9]. Intraoperative hypothermia does not appear to improve neurologic outcome after surgery for intracranial aneurysm clipping [10-12]. Prolonged hypotension should be avoided during surgery [2].

Risks associated with surgical aneurysm treatment include new or worsened neurologic deficits caused by brain retraction, temporary arterial occlusion, and intraoperative hemorrhage [13-15]. Intraprocedural aneurysmal rupture occurred in 19 percent of 711 patients treated with surgical clipping in the Cerebral Aneurysm Rerupture After Treatment (CARAT) study and was associated with periprocedural death and disability [16]. Procedure-related surgical complications occurred in 29 (20 percent) of 143 patients in a retrospective series [17], although functional outcome was good in 22 (76 percent) of those patients.

Endovascular therapy

Coil embolism — The Guglielmi electrolytically detachable coil system was introduced in the early 1990s [18]. Platinum coils are inserted into the lumen of the aneurysm (image 2). A local thrombus then forms around the coils,

obliterating the aneurysmal sac [19]. The procedure is often, but not invariably performed under general anesthesia [2].

Complications of endovascular coiling include thromboembolism and intraprocedural aneurysm rupture. Both of these complications are somewhat more common in the setting of SAH than for unruptured aneurysms [20,21].

- Thromboembolism occurred in 12.5 percent of endovascularly-treated aneurysms in one series [22]. Aneurysm size >10 mm and neck size >4 mm were risk factors for this complication.

- While of unproven benefit, some combination of heparin and/or antiplatelet therapy is used in most centers to minimize sequelae [23]. In one large series, 9.3 percent of patients experienced a thromboembolic event during coiling despite use of heparin and aspirin [24]. In one series, GIIB/IIIa inhibitors appeared to be safer for this indication than thrombolytic agents [25].

- Intraprocedural aneurysmal rupture occurred in 5 percent of 299 patients with aneurysmal SAH treated with coil embolization in the CARAT study [16]. Periprocedural death or disability was more likely in those with this complication compared with those without rupture (34 versus 17 percent). Other studies have shown similar rates of intraprocedural rupture during endovascular coiling of 4 to 5 percent [21,22,26]. Among different series, risk factors for this complication have been variably noted to include small aneurysm size, middle cerebral artery location, ruptured versus unruptured status, and hypertension [22,27,28]. Patients treated with anticoagulation or antiplatelet therapy may require reversal of these therapies if intraprocedural rupture occurs [2].

Coiled aneurysms also appear to be more likely than clipped aneurysms to recur and require additional intervention. (See "Late recurrence of subarachnoid hemorrhage and intracranial aneurysms", section on 'Recurrence of the treated aneurysm'.)

Newer techniques — Endovascular therapy for cerebral aneurysms is evolving. New techniques under investigation include stent-assisted coiling, balloon-assisted coiling, flow diverters and disruptors, and new embolic material including

liquids offer promise that aneurysms previously considered not amenable to therapy will be treatable in the future [20,29].

Anatomic considerations — Aneurysms in distal arterial segments are often not amenable to endovascular therapy [30]; surgical therapy may preferred in these circumstances. Endovascular treatment is often the preferred technique for posterior circulation aneurysms which are accessible by angiogram but harder to get to surgically [31]. In contrast, aneurysms at the middle cerebral artery trifurcation are difficult to coil without complication and surgery may be preferred for these lesions.

Combined endovascular and surgical techniques may be required with some very large or complex aneurysms [32]. Some aneurysms remain challenging to treat by any technique; these include giant aneurysms, fusiform aneurysms, and those with very broad necks and a low neck-to-fundus ratio [20].

SUBARACHNOID HEMORRHAGE

Early rebleeding — Rebleeding occurs in 8 to 23 percent of patients with aneurysmal subarachnoid hemorrhage (SAH). Most studies have found that the risk of rebleeding is highest in the first 24 hours after SAH, particularly within six hours of the initial hemorrhage [33-36]. (See "Aneurysmal subarachnoid hemorrhage: Treatment and prognosis", section on 'Rebleeding'.)

Aneurysmal rebleeding is associated with a poor prognosis. In a prospective study involving 574 hospitalized patients admitted within 14 days of SAH, rebleeding was associated with a 12-fold reduction in the probability of survival with functional independence at three months (odds ratio [OR] 0.08, 95% CI 0.02-0.34) after correction for admission Hunt-Hess grade and aneurysm size [35]. Another prospective study found similar results [37]. In one case series, half of hemorrhage expansions were related to rerupture of the aneurysm [38]. Other mechanisms of hemorrhage expansion or rebleeding may be similar to those for intracerebral hemorrhage. (See "Spontaneous intracerebral hemorrhage: Treatment and prognosis".)

Only aneurysm treatment is effective in preventing rebleeding. In one analysis of

neurosurgical aneurysm clipping, the authors estimated the absolute reduction in the risk of a poor outcome was 10 percent (ie, 10 surgeries would prevent a poor outcome in one patient) [3]. Patients in whom aneurysm treatment is not possible or is unavoidably delayed may be candidates for antifibrinolytic therapy.

Timing and choice of therapy — Decisions regarding the timing and choice of therapy for a rupture intracranial aneurysm are ideally made by a team of experienced clinicians.

- The timing of surgery following intracranial aneurysm rupture is an area of controversy. The potential benefits of early surgery (within 24 to 72 hours of the hemorrhage) include prevention of rebleeding and management of vasospasm. In addition, the usual methods of treating vasospasm (hypervolemia, induced hypertension, intraarterial vasodilators, and balloon angioplasty) are dangerous in the presence of an untreated aneurysm. (See 'Early rebleeding' above and "Aneurysmal subarachnoid hemorrhage: Treatment and prognosis", section on 'Vasospasm and delayed cerebral ischemia'.)

- Decisions regarding the choice of therapy in the treatment of a ruptured intracranial aneurysm are made by a team of experienced surgeons and endovascular practitioners. Factors important to consider include the neurologic grade and clinical status of the patient, the availability of expertise in surgical and endovascular techniques, as well as the anatomic characteristics of the aneurysm, including the location and the size of the aneurysm and its neck [1,39]. (See 'Anatomic considerations' above.)

Good-grade SAH — Early aneurysm repair (within 24 to 72 hours) in patients with good-grade aneurysmal SAH (Hunt and Hess grades I to III) (table 1) is a generally accepted treatment with a satisfactory outcome in the large majority of patients. Approximately 70 to 90 percent of patients have a good neurologic recovery, with a mortality rate of 1.7 percent to 8 percent [40]. Limited clinical trial evidence suggests that early aneurysm surgery may be associated with a lower risk of rebleeding and better outcome than later surgery, but the results did not achieve statistical significance [41,42]. Observational studies, which are limited by selection bias, suggest that early intervention is associated with better outcomes

[43].

A subset of patients with good-grade aneurysmal SAH may do as well, or even better, with endovascular coiling [44,45]. In the largest of the randomized trials to examine this question, the International Subarachnoid Aneurysm Trial (ISAT), 2143 patients with ruptured intracranial aneurysms were randomly assigned to neurosurgical clipping or endovascular coiling [46,47]. The patients in this study represented a selected subgroup in which 88 percent were of good clinical status, aneurysms ≤3 mm were excluded; 90 percent of the target aneurysms were smaller than 10 mm in diameter, and 95 percent of aneurysms were in the anterior circulation [47]. Outcomes included:

- Lower rates of combined death and disability at one year in the endovascular group (23.5 versus 30.9 percent), with an absolute risk reduction of 7.4 percent (95% CI 3.6-11.2) [47]. At 10 years, the endovascular group continued to have somewhat lower rates of both mortality and combined death and dependency (OR 1.35, 95% CI 1.06-1.73, and OR 1.34, 95% CI 1.07-1.67, respectively) [48].

- Similar mortality at one year, 8.0 percent (95% CI 6.4-9.8) and 9.9 percent (95% CI 8.2-11.9), in the endovascular and neurosurgical groups, respectively [47].

- Higher rates of post-treatment rebleeding from the target aneurysm in the endovascular therapy group during the first year (2.6 versus 1.0 percent). Few rebleeding events occurred in either treatment group after one year, but again were more common in the endovascular therapy group [49]. However, within eight years rebleeding rates become similar [50]. (See "Late recurrence of subarachnoid hemorrhage and intracranial aneurysms".).

- Lower rates of post-treatment seizures in the endovascular group (relative risk 0.52, 95% CI 0.37-0.74) [47]. At one year, the prevalence of epilepsy and cognitive impairment were less common in patients treated by endovascular coiling than surgical clipping [51].

These results can only be applied to patients that fit the characteristics of patients selected to participate in the ISAT, which is a small percentage of patients presenting with SAH [46]. For such patients, endovascular coiling appears to have somewhat more favorable outcomes and is probably the favored treatment for

aneurysm repair if anatomic and morphologic features of the aneurysm are deemed appropriate for endovascular treatment.

Poor-grade SAH — The prognosis for patients with aneurysmal SAH and with poor clinical grade (Hunt and Hess IV and V) (table 1) is poor, particularly in those patients with a Glasgow coma scale motor score (table 2) less than 4 [52]. Treatment decisions need to be individualized with consultation with family members. Some data suggest that aneurysm occlusion in such patients (particularly if associated with advanced age and medical comorbidity) may not improve their overall prognosis [53]. Nonetheless, we favor early treatment, with endovascular therapy when possible for patients with poor-grade SAH.

Early surgery may be more complicated than a procedure delayed for 10 to 14 days in patients with poor clinical grade. The presence of cerebral edema (which may prevent brain retraction and relaxation) and clot around the aneurysm increases the technical difficulty of surgery. Early surgery may be associated with an increased risk of ischemic complications [54]. However, early rebleeding is also more common in patients with poor clinical grade [55]. One large retrospective study of 2106 patients found that delayed surgery was associated with a small, nonsignificant reduction in delayed cerebral ischemia, but a significant increase in poor outcomes [56].

Endovascular techniques also may offer a less invasive and often definitive mode of therapy for this group [57]; the concerns regarding the increased difficulty of early surgery do not apply to intraluminal therapy. In addition, although not substantiated by any large series, the use of intravascular embolization of aneurysms in the acute setting may facilitate aggressive medical management algorithms for proactive treatment of cerebral vasospasm.

A systematic review and meta-analysis that included the ISAT as well as other smaller randomized trials and observational studies, found that while outcomes at one-year were more favorable in patient treated with endovascular coiling, the choice of treatment modality did not seem to have a significant impact on outcome in patients with poor preoperative grade [58]. In a subsequently performed randomized trial of 571 patients with SAH that included patients with a broader spectrum of disease severity than were included in ISAT, patients assigned

to endovascular treatment were more likely to have a better outcome at one year as measured by the modified Rankin Scale; the difference no longer reached statistical significant at year three [59,60]. It is noteworthy that 38 percent of those assigned to endovascular treatment crossed over to surgical clipping (usually because the endovascular treatment was judged to be technically difficult); such patients had a worse outcome than those who received the assigned endovascular treatment and was similar to those who were assigned to and received clipping.

Post-treatment management — Patients are managed in the intensive care unit after aneurysm therapy. Continuous cardiodynamic and neurologic monitoring is critical. Postoperative angiography is used at the surgeons' discretion. Patients should have monitoring and treatment for vasospasm. (See "Aneurysmal subarachnoid hemorrhage: Treatment and prognosis", section on 'Vasospasm and delayed cerebral ischemia'.)

UNRUPTURED ANEURYSMS

The management of unruptured intracranial aneurysms is controversial [61]. There are no randomized trials on which to base recommendations. Decisions about therapy need to weigh the natural history of the aneurysm, the risks of intervention, and patient preferences. While these are discussed in detail separately, in general, asymptomatic aneurysms ≥7 to 10 mm in diameter warrant strong consideration for treatment, taking into account patient age, existing medical and neurologic conditions, and relative risks for treatment [62]. (See "Unruptured intracranial aneurysms", section on 'Risk factors for aneurysm rupture' and "Unruptured intracranial aneurysms", section on 'Risk of intervention'.)

Surgical treatment of unruptured aneurysms has been the most common procedure used in patients who undergo definitive therapy. In clinical studies, which are typically in centers with high case volumes, endovascular techniques appear to be associated with lower morbidity and mortality than surgical clipping and are playing an increasing role in the treatment of unruptured aneurysms [63-70]. New technologies, such as flow diversion, may advance the safety of endovascular treatment and allow aneurysms, previously considered to be

inaccessible or technologically difficult for such treatment [71]. (See 'Newer techniques' above.)

ANEURYSM RECURRENCE AND LATE REBLEEDING

Patients who survive aneurysmal subarachnoid hemorrhage (SAH) and those with unruptured intracranial aneurysms have a small but enduring risk of subsequent SAH which can occur despite successful endovascular or surgical treatment of the aneurysm.

SAH may result from recurrence of the treated aneurysm, rupture of another pre-existing aneurysm in a patient with multiple aneurysms, and de novo aneurysm formation. The risk of these events and recommendations for monitoring and treatment are discussed separately. (See "Late recurrence of subarachnoid hemorrhage and intracranial aneurysms".)

SOCIETY GUIDELINE LINKS

Links to society and government-sponsored guidelines from selected countries and regions around the world are provided separately. (See "Society guideline links: Stroke in adults".)

SUMMARY AND RECOMMENDATIONS

- Surgical clipping and endovascular coiling are the most commonly used techniques for aneurysm treatment. In many cases, anatomic considerations, such as size, location, other morphological features determine which treatment is most appropriate for the patient. (See 'Techniques' above.)
- Patients with ruptured cerebral aneurysms present with aneurysmal subarachnoid hemorrhage (SAH). Patients have a high risk of rebleeding in the first days and hours after SAH, and this complication is associated with increased mortality and morbidity. (See 'Early rebleeding' above.)
- Decisions regarding the timing and choice of therapy for a ruptured

intracranial aneurysms are ideally made by a team of experienced clinicians who consider the neurologic grade and clinical status of the patient, the availability of expertise in surgical and endovascular techniques, as well as the anatomic characteristics of the aneurysm. (See 'Timing and choice of therapy' above.)

  - For patients with good-grade aneurysmal SAH (Hunt and Hess grades I to III) (table 1), we suggest early aneurysm repair (within 24 to 72 hours) (**Grade 2C**). In centers with available expertise and in patients with endovascularly-accessible lesions, short-term outcomes appear to be improved with endovascular coiling compared with surgical clipping. (See 'Good-grade SAH' above.)

  - The optimal timing and choice of therapy in patients with more severe aneurysmal SAH (Hunt and Hess grades IV and V) is uncertain. Their overall prognosis is poor, particularly for older patients. Treatment decisions need to be individualized in consultation with family members. (See 'Poor-grade SAH' above.)

- Asymptomatic aneurysms ≥7 to 10 mm in diameter warrant strong consideration for treatment, taking into account patient age, existing medical and neurologic conditions, and relative risks for treatment. (See "Unruptured intracranial aneurysms".)

- Patients with aneurysmal SAH are at enduring risk of recurrent SAH despite aneurysm treatment and may require follow-up evaluations. (See "Late recurrence of subarachnoid hemorrhage and intracranial aneurysms".)

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