REVIEW

Endovascular management of unruptured intracranial aneurysms

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Endovascular coil embolisation is increasingly used to treat unruptured intracranial aneurysms (UIA). Endovascular coil embolisation of UIA is associated with a 5–10% risk of morbidity and nearly zero mortality from the procedure. Complete or near complete occlusion is usually achieved in >90% of cases, and endovascular therapy seems to reduce the risk of future rupture significantly. Specific selection criteria for endovascular embolisation and novel approaches to endovascular treatment of aneurysms are discussed. Endovascular therapy appears to be a safe and effective treatment for selected UIA. Treatment failure rates will probably decrease with greater experience and advances in techniques and devices. Further study with long term follow up, however, is still necessary to characterise the efficacy, durability, and cost efficiency of endovascular treatment of UIA.

factors—for example, aneurysm size and morphology (including whether an aneurysm is symptomatic), location, and patient age. It is therefore difficult to accumulate enough statistical power to draw robust scientific and quantitative conclusions for each specific subset of aneurysms. Nonetheless, this discussion provides background and highlights areas for improvement as we continue to accumulate data regarding the best management options for UIA.

NATURAL HISTORY OF UNRUPTURED ANEURYSMS

The preliminary report from the International Study of Unruptured Intracranial Aneurysms (ISUIA) represented the largest study of the natural history of UIA to date, including 2621 patients in 53 participating centres.¹ In patients without a history of SAH, aneurysms <10 mm, >10 mm, and >25 mm ruptured at a rate of 0.05%, ~1%, and ~6% annually, respectively. In contrast, in patients with an SAH history from a different aneurysm, aneurysms <10 mm and >10 mm ruptured at a rate 0.5% and ~1% annually, respectively. The authors report an overall mortality rate of 66% when UIAs rupture. Despite the large sample studied and the extensive patient follow up, this report has been received with some scepticism because of the unexpectedly low rupture rates reported for some subgroups. Critics most often attribute this to surgical selection bias.²

In 2003, the prospective arm of ISUIA confirmed that aneurysm size and location were important predictors of rupture risk.³ The investigators reported 51 aneurysmal ruptures in 6544 patient-years of follow up, corresponding to an overall 0.8% annual risk of rupture and a rate of between 0% and 10% per year, depending on the size, location, and history of the SAH. There was an overall mortality of 65% with aneurysmal rupture. This second study has also been criticised for intervention selection bias and short follow up (<5 years) in over half the patients studied. Follow up is ongoing.

Juvela and colleagues followed 142 patients with 181 unruptured aneurysms for a total of 1944 patient-years and reported a nearly constant rupture rate of 1.3% annually over three decades of follow-up. Importantly, they also report a 52% mortality rate with aneurysmal rupture.^{4 5} Surgery was never offered to patients

Imaging advances have significantly increased the detection of incidental unruptured intracranial aneurysms (UIA). The management of UIA may include observation, microsurgery, endovascular embolisation, or combinations of these. When recommending management, in addition to considering each patient's preferences and personal philosophy, the treating physician must compare the natural history of aneurysms and the potential consequences of subarachnoid haemorrhage (SAH) with the efficacy, morbidity, and mortality of intervention.

To clarify the role of endovascular embolisation in the management of UIA, we have reviewed published reports on this subject and our own experiences. Occlusion rates using endovascular techniques, the stability and significance of these occlusion rates, the impact of endovascular therapy on spontaneous SAH rates, and the morbidity and mortality of endovascular procedures are critically reviewed. Interventions for UIA should carry less risk than the lifetime accumulated risk of leaving an aneurysm untreated. Therefore we briefly review the natural history of UIA to provide a framework for interpreting the utility of endovascular therapy.

Drawing conclusions about endovascular treatment of unruptured aneurysms can be challenging. Because of evolving technology and the rapid advances made in endovascular therapy, discussions of efficacy, morbidity, and mortality are necessarily dated. Furthermore, both the treatment and natural history of UIA are affected by multiple

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Abbreviations: ISUIA, International Study of Unruptured Intracranial Aneurysms; MCA, middle cerebral artery; SAH, subarachnoid haemorrhage; UIA, unruptured intracranial aneurysm

with unruptured aneurysms during the period studied; no surgical selection was introduced into this study. The study's weaknesses include its small sample size and the lack of truly incidental aneurysms; 92% of subjects had a history of SAH from a different aneurysm.

Tsutsumi and colleagues, who studied 62 patients, confirmed the importance of aneurysm size in predicting rupture.⁶ They report a five and 10 year cumulative rate of rupture of 4.5% and 19%, respectively, for aneurysms <10 mm and 33.5% and 55.9%, respectively, for aneurysms >10 mm. Moreover, they reported that all patients experiencing SAH had poor outcomes, with an 86% mortality rate. Although the profile of the studied population (elderly, Asian, and co-morbid cerebrovascular disease) may not resemble all populations, this study highlights the fact that SAH rates and mortality may be considerably higher in selected populations.⁶

Although each study has its weaknesses, taken together, they suggest that the rupture rate across all aneurysms is ~1–2% per year and that certain aneurysms are at greater rupture risk, including those with increasing diameters and in certain anatomical distributions (for example, basilar tip aneurysms). Studies also indicate a relatively constant rupture risk over time. The decision to intervene will therefore have to account for patient age and life expectancy in order to accurately compare the risk of “conservative observation” with that of intervention. Using the results of the ISUIA, Vindlacheruvu and colleagues confirmed the importance of age and life expectancy.⁷ They concluded that aneurysms should not be treated in patients with a life expectancy less than 15–35 years (depending on aneurysm size and other patient characteristics) or in any patients with anterior circulation aneurysms less than 7 mm.⁷ The thresholds for intervention may change if increasing experience and advancing technology decreases the morbidity and mortality of intervention.

ENDOVASCULAR OCCLUSION OF ANEURYSMS: EFFICACY AND NEED FOR FOLLOW UP

Surgical management of aneurysms represents the traditional gold standard intervention because it “completely excludes aneurysms from the circulation” without the possibility of recurrence or future SAH (although some studies indicate otherwise, see “Surgical perspective” below). Occlusion rates have therefore become a central debate in the risks and benefits of aneurysm treatment.⁸

Evaluating the efficacy and utility of endovascular treatments for unruptured aneurysms is particularly challenging because of the inherent selection bias in nearly all the reports of endovascular aneurysm management, and differing management philosophies across institutions. With the exception of randomised trials, physicians and investigators have a preconceived notion of the risks and benefits of either endovascular or surgical treatment, and therefore self select patients to undergo a certain treatment. As a result, in many studies aneurysm profiles do not reflect the natural occurrence of UIAs. For example, in a study by Roy *et al*, the investigators excluded very small aneurysms (<3 mm) and were reluctant to treat middle cerebral artery (MCA) aneurysms because they are prone to branch occlusion after coiling and are readily accessible surgically.⁹ Consequently, their series contained a relative overabundance of ophthalmic (40%) and basilar bifurcation aneurysms (14.4%) and a paucity of anterior communicating, posterior communicating, and middle cerebral artery aneurysms (8.0%, 9.6%, and 11.2%, respectively) relative to the natural incidence of these aneurysms.⁹ Occlusion rates therefore represent outcomes for a selected population; whether they can be extrapolated to the general population remains unclear.

Most studies evaluating endovascular occlusion rates report complete aneurysmal obliteration in approximately 50–70% of aneurysms and near complete occlusion (>90% occlusion) in approximately 90% of aneurysms immediately after embolisation.^{9–14} At the University of Virginia, between 2000 and 2004 we treated 105 aneurysms endovascularly and achieved similar occlusion rates: near complete or complete occlusion was observed in 91% of aneurysms immediately after embolisation. Our occlusion rates were not size or location dependent. In a meta-analysis of 48 studies with 1383 patients, Brilstra *et al* reported that occlusion rates were independent of aneurysm size, location, neck configuration, and mode of presentation.¹⁰

One must also consider how aneurysm occlusion evolves with time, presumably because of thrombosis, coil compaction, coil prolapse, angiogenetic phenomena resulting in new aneurysm growth, or a combination of these. Roy and colleagues reported that 7.8% of aneurysms that were initially deemed to be completely occluded had neck remnants on follow up, and 12% of aneurysms that initially had neck remnants had aneurysmal recurrence on follow up.⁹ Goddard and colleagues similarly reported that around 6% of patients required retreatment after initial successful treatment (median follow up eight months) but also reported improved occlusion grades in 10.5% of patients on follow up.¹¹ Ng and colleagues noted that 23% of initially completely occluded aneurysms showed recanalisation at six to 12 months and 14% showed recanalisation at two years.¹² On the other hand, 44% of aneurysms that initially had residual body filling showed improved occlusion grades on follow up.¹² Our institutional experience is similar: 8% of endovascularly treated aneurysms required re-embolisation (sometimes two or three sessions) on follow up between six and 36 months after initial embolisation. Interestingly, aneurysms that were angiographically stable on follow up were statistically smaller (mean (SD), 8.6 (5.4) mm) than those requiring re-embolisation (14.0 (5.9) mm) ($p = 0.005$).

The literature supports a size dependent evolution of occlusion rates. In a series of 73 aneurysms, long term follow up showed recanalisation in 17% of small aneurysms with small necks, 42% of small aneurysms with wide necks, 87% of large aneurysms, and 90% of giant aneurysms.¹⁵ In a prospective trial of 100 consecutive patients with 104 endovascularly treated aneurysms (not all unruptured), mid-term clinical outcome (average 3.5 years post-embolisation) in 94 patients revealed 0% recanalisation for small aneurysms, 4% for large ones, and 33% for giant lesions.¹⁶ The long term failure in large and giant aneurysms may be due to a different pattern of clot organisation in these aneurysms, the persistence of openings between coils or incomplete membranous coverings.¹⁷

While it is often assumed that aneurysm recurrence is due to coil compaction, physical and angiogenetic events also probably contribute to new aneurysm growth after initial treatment. Aneurysm regrowth has been reported and explained in previous surgical lesions arising from untreated postoperative aneurysm rests.^{18, 19} This is analogous to de novo aneurysm formation from “blebs” on blood vessels.²⁰ This may in part account for why occlusion rates evolve at a much higher rate in endovascularly treated aneurysms (20–30%) than reported for aneurysms after surgical clipping. While surgery physically excludes an aneurysm, preventing aneurysm regrowth from the excluded part of the aneurysm, endovascularly treated aneurysms could theoretically grow and recur from any part of the aneurysm wall as the aneurysm is not physically excluded from the circulation upon treatment. Although some studies recommend angiographic surveillance of surgically treated aneurysms as well,^{21, 22} the unpredictability of occlusion rates over time in endovascularly

treated aneurysms mandates angiographic surveillance for long term post-embolisation management. The need for long term follow up, probability of patient compliance, and cost must therefore be considered in patients before recommending endovascular embolisation.

Although occlusion rates have become a central debate, their significance remains unclear. While most agree that safely maximising aneurysmal occlusion is beneficial, "complete exclusion"—as deemed necessary by surgical criteria—may only be a theoretical advantage and not required for adequate aneurysm treatment. Neck remnants of <1 mm are often considered complete obliterations in surgical series and, although there have been reports of aneurysm recurrence and subsequent SAH from small residual necks (1–2 mm),²² such necks are usually not considered to pose any risk of SAH. Moreover, complete obliteration rates may be overreported (and therefore overvalued) in surgical series owing to the presence of a metal clip obscuring the visualisation of the aneurysm neck–parent artery interface.

POST-EMBOLISATION RUPTURE RATES

Owing to the relative novelty of endovascular treatment and the evolving technology, long term outcomes of endovascularly treated UIA are not readily available. Although it is generally accepted that endovascular treatment reduces the risk of SAH, aneurysms can still rupture after coiling.^{10 23 24} Brilstra and colleagues reported that three of 90 endovascularly treated unruptured aneurysms bled (no time frame given). In all three cases, there was angiographic evidence of incomplete aneurysmal occlusion.¹⁰ Roy and colleagues, on the other hand, reported no post-treatment SAH in patients with an average follow up of 32.1 months, even though only ~50% of the patients had complete occlusion (~90% had either complete occlusion or only neck remnants).⁹ At our institution, we have not observed any incidence of SAH from a previously treated aneurysm.

Data on the rate of SAH after endovascular treatment are indeed sparse. Studies such as the CARAT (Cerebral Aneurysm Re-rupture After Treatment) study—which is currently under way—that characterise SAH rates after treatment are critical for evaluating the relative risk and benefits of therapy. Such studies should help elucidate how SAH rates change as a function of occlusion rate.

ENDOVASCULAR OCCLUSION OF ANEURYSMS: SAFETY

Although endovascular aneurysm treatment was designed to reduce the risk of intervention, the treatment still has significant risks. Perhaps the most important complication of endovascular therapy is technical failure, exposing patients to the risks of the procedure without offering any benefit of aneurysmal occlusion. Technical failure rates are often greater than 10%,^{9 12 13} but have been reported as low as 5.7%.¹⁴ At our institution, we have observed a 4.8% technical failure rate (5/105) and, in one additional case, a patient required surgery after three embolisations and repeated coil compaction on angiographic follow up. No morbidity was associated with these technical failures. These failure rates necessitate the careful evaluation of each patient, based on vascular anatomy and aneurysmal configuration, to ensure that the patient is not subjected to risks of a procedure without any benefits.

Complications other than technical failures occur in between 5% and 10% of cases.^{10 11 14 25 26} Complications include thromboembolic stroke (including silent infarcts), vessel perforation, vasospasm, coil prolapse, and internal carotid artery dissection.¹¹ In the largest study of complication rates in aneurysm management, Johnston *et al* reviewed 2069 patients treated for unruptured aneurysms and reported adverse results (defined as death or discharge to nursing home or rehabilitation hospital) in 10% of endovascular treatments, and mortality in 0.5%.^{25 26} Brilstra and colleagues similarly reported a 6.7% rate of permanent complications from endovascular therapy (in a meta-analysis of 48 studies over a seven year period).¹⁰ The ISUIA study reported a 9.5% overall rate of morbidity and mortality at one year after endovascular treatment of unruptured aneurysms.³ In our experience, at three months post-embolisation, we have observed an overall morbidity of 8.6% and no mortalities (table 1). All morbidity was attributable to thromboembolic strokes except for one case of intraprocedural rupture. Increased endovascular morbidity in more recent years (2003–2004) compared with earlier periods (2000–2001, see table 1) is likely because endovascular embolisation is being used to treat a larger volume of aneurysms and more complex aneurysms that previously may have been treated surgically.

Table 1 Treatment of unruptured intracranial aneurysms at the University of Virginia

	2000–2004		2000–2001		2003–2004	
	Endovascular	Surgery	Endovascular	Surgery	Endovascular	Surgery
Number of patients	105	121	17	36	70	53
Age (years)	57.2	53.8	54.6	52.0	57.8	53.3
Location						
Posterior circulation	33.3%	14.9%	29.4%	19.4%	27.1%	7.5%
Anterior circulation	66.7%	85.1%	70.6%	80.6%	72.9%	92.5%
Size						
<7 mm	36.2%	24.0%	52.9%	38.9%	38.6%	18.9%
7–12 mm	46.7%	52.9%	41.2%	41.7%	41.4%	52.8%
13–24 mm	12.4%	16.5%	0.0%	16.7%	14.3%	22.6%
>25 mm	4.8%	4.1%	5.9%	2.8%	5.7%	5.7%
Complications						
MRS						
0	91.4%	71.9%	100.0%	69.4%	91.4%	83.0%
1	2.9%	8.3%	0.0%	5.6%	1.4%	7.5%
2	1.0%	4.1%	0.0%	8.3%	0.0%	1.9%
3	2.9%	5.8%	0.0%	5.6%	4.3%	3.8%
4	1.9%	4.1%	0.0%	5.6%	2.9%	1.9%
5	0.0%	4.1%	0.0%	2.8%	0.0%	0.0%
Death	0.0%	1.7%	0.0%	2.8%	0.0%	1.9%

MRS, modified Rankin scale.

One of the most feared complications of endovascular embolisation is aneurysmal rupture during the procedure. Previously ruptured aneurysms, however, seem to be at much greater risk of intraprocedural rupture than unruptured aneurysms. In a series of 734 aneurysms, Tummala *et al* reported a total of 10 intraprocedural ruptures, all of which occurred in aneurysms that had ruptured previously.²⁷ Of the 105 UIA treated endovascularly at the University of Virginia between 2000 and 2004, we have observed a single case of intraprocedural aneurysmal rupture while treating an unruptured aneurysm (corresponding to a rate of <1%), resulting in significant post-procedural morbidity. If perforation does occur during embolisation, the best intervention is to reverse anticoagulation and complete the GDC embolisation.²⁷

Failure to treat aneurysms definitively is another potential complication of endovascular therapy. Intra-aneurysmal coils can complicate surgical attempts to treat aneurysms.^{28, 29} The need for further treatment and associated challenges is highlighted by a study in which 15 of 59 endovascularly treated aneurysms required further treatment. Seven of these were referred for surgery because they could not be treated with further embolisation. Clipping was impossible in three (20% of the aneurysms requiring further treatment) owing to partial filling of the aneurysm neck by coils.²⁸ Thornton and associates also noted increased surgical difficulty in nine out of 11 patients requiring surgical treatment of unruptured aneurysms after initial coiling; additional measures had to be taken to remove the coils intraoperatively before clipping the aneurysms.²⁹

Despite these complications, most investigators conclude that endovascular management is a relatively safe procedure for aneurysm treatment.²⁵ With increasing experience and improving technology, we can expect that the risk of technical failures, complications, morbidity, and mortality will decrease.²⁵ It is critical to continue to assess complication rates as this will affect the decision about when to treat unruptured aneurysms. Although Vindlacheruvu *et al* recently concluded that patients with less than 15 to 35 years of life expectancy should not undergo treatment of unruptured aneurysms, this conclusion may change if the morbidity of treatment declines with advancing technology.⁷

VARIABLES THAT ALTER SUCCESS

Certain aneurysm and patient characteristics are significantly associated with poor outcomes. Johnston and associates reported the following to be significant independent risk factors for poor prognosis in treatment of unruptured aneurysms (across all treatment modes): posterior circulation aneurysms (odds ratio (OR) for poor outcome = 3.8), symptomatic aneurysms (OR = 5.3), and age per decade (OR = 1.7).³⁰ Aneurysm size has also been implicated in poor outcomes. In one report, poor outcomes were reported in as many as 26% of endovascularly treated giant unruptured aneurysms.³¹ In addition to aneurysm sac size, neck size is also an important consideration. The dramatic effect of neck size on obliteration success is evident in an 85% complete occlusion rate in aneurysms with necks of less than 4 mm yet only a 15% complete occlusion rate in aneurysms with necks of more than 4 mm.³² Similarly, another study indicated 68.8% complete occlusion of aneurysms with a neck to sac ratio of less than 1:3.¹³ As with large and giant aneurysms, recanalisation rates are higher in aneurysms with wide necks; in one study, 42% of small aneurysms with wide necks showed recanalisation on follow up.¹⁵ More success is expected in treating wide necked aneurysms as newer technologies and approaches are developed, including balloon assisted and stent assisted embolisation (see below, "Novel endovascular embolisation approaches").

Aneurysm location is also a critical consideration; physicians must consider both endovascular and surgical accessibility. For example, endovascular embolisation of MCA aneurysms is considered challenging because of anatomical constraints. The anatomy in the region of the MCA bifurcation can be complex; M2 branches often overlie and obscure the relation of the aneurysm neck to the parent artery on cross sectional angiographic images. Moreover, MCA aneurysms have a higher likelihood of incorporating a branch vessel into the aneurysm base, making them less suitable for endovascular treatment. Accordingly, Regli and colleagues report an 85% endovascular failure rate for MCA aneurysms and relatively low morbidity and mortality for surgical interventions, concluding that surgery is the most successful treatment of aneurysms in this location.³³

Endovascular treatment of symptomatic aneurysms deserves special discussion as it presents a seemingly paradoxical scenario. Many aneurysms become symptomatic because of mass effect (for example, impinging on cranial nerves). It seems counterintuitive that occluding an aneurysm with coils (another mass) could effectively treat the mass effect symptomatology. Yet endovascular embolisation often provides symptomatic relief. Wanke and colleagues report that of seven patients treated in a series of 39 consecutive aneurysms, four with preprocedural neurological symptoms had complete resolution of the symptoms, two had improvement, and one had no change.³⁴ Hallbach reported complete resolution of cranial nerve symptoms in 58% and dramatic improvement in 38% of endovascularly treated symptomatic aneurysms.³⁵ One patient in that series worsened. Malisch *et al* reported that after embolisation, 32% of patients had complete resolution of neurological symptoms, 42% had significant improvement, 21% reported no change in symptoms, and one patient (5%) had worsening symptoms.³⁶ The probability of improvement is seemingly increased with shorter durations of symptoms. Despite the neurological benefits, treatment of symptomatic aneurysms is associated with a slightly increased rate of morbidity and mortality than treatment of asymptomatic aneurysms (16% of the total).³¹

NOVEL ENDOVASCULAR EMBOLISATION APPROACHES

New techniques, manipulations, and instruments are constantly being designed to improve the rate of treatment success. The major challenges that endovascular therapy faces are coiling wide neck aneurysms and ensuring the stability of coil emboli over time.

Two distinct methodologies have been proposed for coiling aneurysms with wide necks: balloon assisted coiling and stent assisted coiling. Balloon assisted coiling was first described by Moret *et al*, who proposed inflating a temporary non-detachable balloon to occlude both the parent artery and the aneurysm before coil embolisation, to achieve a denser and more secure packing of coils in wide necked and complex aneurysms.³⁷ On angiographic follow up, these investigators reported a 77% complete occlusion rate and a 17% subtotal occlusion rate, values that clearly rival that of unassisted coil embolisation, with a 0.5% morbidity and 0% mortality.³⁷ Cottier *et al* reported on their experience in 44 patients with 49 aneurysms treated with balloon assisted coiling. They found that 90% of completely occluded aneurysms were stable over time and that 85% of initially subtotally occluded aneurysms were stable or progressed to complete occlusion on follow up.³⁸ However, they also reported that 15% of initially subtotally occluded aneurysms recanalised.³⁸

Stent assisted coiling is similar in concept to balloon assisted coiling except that it offers a permanent means of preventing coil prolapse (that is, the stent remains in place after the procedure, whereas the balloon is removed at the

end of the procedure).^{39, 40} The major limitation of stent assistant embolisation, however, is that deploying stents in tortuous vessels is technically challenging. Moreover, stent deployment may cause intimal hyperplasia, resulting in physiologically significant stenosis.⁴¹ Based on the limited sample and follow up, stent assisted coiling seemingly yields stable embolisation of aneurysms, but its efficacy and widespread applicability remain to be determined.

Other technologies have also been developed to produce more stable aneurysmal occlusion on follow up, including biologically active coils and coils treated with angiogenic factors and radioisotopes.⁴² Originally, coils were composed of inert metals that induced thrombosis by interrupting normal flow through the aneurysm. Coated, biologically active coils, on the other hand, are intended to enhance cell proliferation and adhesion by having stimulant proteins on the surface of the coil to promote clot formation and stability. The theoretical limitation of such devices is related to overstimulation of cellular proliferation and clotting pathways, possibly resulting in parent artery stenosis. Kallmes and Fujiwara have recently proposed an alternative modified coil.⁴³ This hybrid coil made of the “normal” platinum material and an expandable hydrogel material expands up to ninefold to fill the aneurysm cavity.⁴³ This approach may be able to achieve a higher occlusion rates than unassisted coiling but also presents the potential complication of increased prolapse into the parent artery.

These new techniques offer exciting opportunities for advancing the endovascular management of unruptured aneurysms and ensuring a more complete and permanent treatment of aneurysms. All these methods involve broadening the technical expertise of the interventionalists. Some of these techniques have been verified clinically and carry only slightly increased, if not decreased, morbidity relative to traditional coil embolisation. However, some techniques are still conceptual and are not yet ready for practical implementation.

SURGICAL PERSPECTIVE

Microsurgery is the traditional treatment method for aneurysms. Like endovascular therapy, surgical intervention can also be technically unsuccessful, either because of inaccessibility of the aneurysm or because of incomplete aneurysm obliteration. Although surgery claims to exclude aneurysms completely from the circulation, rates of aneurysm residuals after clipping are not negligible, ranging from 3.8% to 8%.^{19, 21} Perhaps more important is the rate of SAH after surgical intervention. Considering all aneurysms (completely occluded and those with remnants), Feuerberg reported a rate of rupture of 0.8% per year after surgical clipping, all from aneurysms that were originally incompletely treated.¹⁹ Tsutsumi *et al* also reported that two of 115 treated aneurysms ruptured because of aneurysm regrowth, one occurring seven years and the other 11 years after the treatment.⁴⁴ Although SAH rates are significantly decreased after surgery relative to the natural history of the lesions, a risk of rupture is still present even after surgical clipping. At our institution, we have not observed any cases of aneurysmal rupture from a previously clipped aneurysm.

Surgical procedures carry a significant risk of both intraoperative and immediately postoperative complications. In the largest meta-analysis of complications of surgical clipping of intracranial aneurysms, including 61 reports involving 2460 patients and 2568 aneurysms, the investigators reported an overall mortality of 2.6% and a permanent morbidity of 10.6%. Notably, the mortality of surgical intervention was significantly lower in more recent reports of anterior circulation aneurysms and aneurysms that were not “giant” in character.⁴⁵ Particular factors that predispose

patients to greater risk with surgical treatment of unruptured aneurysms include increasing age (more than 50 years old), aneurysm size greater than 12–25 mm, and a complex posterior circulation location and anatomy.^{3, 46, 47}

In direct comparisons of surgical and endovascular treatment of unruptured aneurysms, some studies indicate that surgical intervention is associated with a greater morbidity and mortality. In their review of 2069 aneurysms treated either endovascularly or surgically, Johnston *et al* reported a 25% rate of adverse effects from surgical treatment of unruptured aneurysms—an adverse outcome being considered death or discharge to a nursing home or rehabilitation hospital.²⁵ They also specifically found that death rates were higher in the surgical cohort (3.5%) than in the endovascular group (0.5%).²⁶ Johnston *et al* also reported that 25% of patients undergoing surgical intervention had a change in Rankin scale score of 2 or more, whereas only 8% of endovascularly treated patients had such a change.³⁰ Moreover, the average length of stay was longer in surgically treated patients than in endovascularly treated patients (7.7 v 5.0 days). Finally, surgical patients were more likely to report persistent new symptoms or disability since treatment (34% v 8%) and a longer period of recovery. Using multivariate analysis, these investigators found that surgery instead of endovascular intervention was an independent predictor of worse outcome, with an odds ratio of 9.0 (95% confidence interval, 2.5 to 32.9).³⁰

The ISUIA trial also compared the morbidity and mortality of endovascular and surgical intervention. At one year, surgical treatment of unruptured aneurysms was associated with a combined morbidity and mortality of 12.2% (2.3% mortality) and endovascular therapy was associated with a combined morbidity and mortality of 9.5% (3.1% mortality), again suggesting the risks of endovascular therapy are less than those of surgical intervention.³

In our experience at the University of Virginia, we have also seen a significant difference in the morbidity and mortality of surgical and endovascular treatment of UIA (table 1). While the morbidity (defined as modified Rankin scale greater than 0) and mortality of endovascular treatment between 2000 and 2004 were 8.6% and 0%, respectively, the morbidity and mortality of surgical intervention were 26.4% and 1.7%, respectively. Increased use of endovascular therapy over the years has decreased the morbidity of surgery from 30.6% in 2000–2001 to 17.0% in 2003–2004. Simultaneously, the morbidity of endovascular therapy has increased from 0% in 2000–2001 to 8.6% in 2003–2004. The shift in morbidity probably represents an increasing number of complex aneurysms being treated endovascularly rather than surgically, as well as a willingness to treat an increasing number of aneurysms that might not have been treated just a few years ago.

These studies present intriguing results with respect to the expected morbidity in patients who are eligible for either intervention. Unfortunately, all studies and our own institutional experience are likely to be biased (in particular, to show selection bias) and the true difference cannot yet be fully appreciated.

SUMMARY AND CONCLUSIONS

Endovascular therapy is an attractive option for treatment of unruptured aneurysms because its mortality approaches zero and the risk of permanent morbidity is approximately 5–10% (most often related to thromboembolic phenomena). Importantly, clinical experiences and reports indicate that endovascular intervention significantly reduces the risk of future SAH, although a formal study needs to be done characterise the true relation between occlusion rates and the risk of future SAH. As technology and experience advances,

the risks, complications, and rates of technical failure will probably decrease.

Appropriate management of unruptured aneurysm requires a multidisciplinary approach that relies on a close and honest collaboration of interventional neuroradiologists and neurosurgeons, both of whom have extensive experience in aneurysm treatment. The physician must consider multiple factors including aneurysm characteristics, the patient's general medical condition and age, and their personal philosophies. This collaboration is not only important when first evaluating patients for possible intervention, but also when aneurysm residuals or recanalisation are noted on follow up examinations. It is important to consider specific characteristics of both the aneurysm and the patient in recommending the best management of UIA. Three dimensional angiography is the best method for thorough evaluation of aneurysms, providing detailed information about aneurysmal anatomy (neck and sac characteristics) as well as the aneurysm's relations to parent and branching arteries. Unfortunately, many of the characteristics that make patients ideal for surgical management overlap with those that are considered advantageous for endovascular management. Each patient is therefore best managed on an individual basis, taking into consideration their general health, life expectancy, the likelihood of compliance with respect to follow up, and the opinions of both neurointerventionalists and neurosurgeons.

The significant limitation of endovascular treatment remains the possibility of embolised aneurysms evolving over time, in some cases improving but also often worsening the occlusion rate, and the consequent need for meticulous follow up. Long term follow up should be scheduled for all patients, not only for appropriate management, but also to increase the data on the evolution of endovascularly treated aneurysms and on the risk of future SAH after endovascular treatment. Formal studies still need to be completed to characterise how endovascular treatment truly alters SAH rates.

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