Available online at www.sciencedirect.com
ScienceDirect
Surgical Neurology 67 (2007) 457–466
SURGICAL NEUROLOGY
www.surgicalneurology-online.com

Aneurysm

Microsurgical treatment of unruptured intracranial aneurysms. A consecutive surgical experience consisting of 450 aneurysms treated in the endovascular era

Eric S. Nussbaum, MD*, Michael T. Madison, MD, Mark E. Myers, MD, James Goddard, MD
Healtheast Neurovascular Institute, St Joseph's Hospital, St Paul, MN 55102, USA
Received 28 February 2006; accepted 4 August 2006

Abstract

Background: With the progressive refinement of endovascular techniques, fewer IAs are being treated with open microsurgery. There is limited information regarding the impact of this trend on the ability of younger neurosurgeons to achieve proficiency in the surgical management of IAs. We describe a consecutive series of patients with unruptured IAs treated by a neurosurgeon initiating a dedicated cerebrovascular practice in the "endovascular era."
Methods: We retrospectively reviewed the records of all patients who had undergone surgical repair of a saccular IA by one neurosurgeon upon completion of neurosurgical training in July 1997 until April 2005. Patients with ruptured IAs were excluded from review.
Results: Of the 1450 patients with IAs treated during this period, 376 underwent microsurgical repair of 450 unruptured IAs. Microsurgical aneurysm neck clipping was possible in most cases, although distal revascularization with proximal occlusion was used in many of the more complicated aneurysms. Major complications occurred in 6 (1.60%) patients, and 1 (0.27%) patient died. At the time of 6-month follow-up, 4 (1.06%) patients were left with a new focal neurologic deficit related to surgery.
Conclusions: Despite the growing role of endovascular therapy in the management of IAs, it is possible for young neurovascular surgeons to achieve acceptable results with open microsurgical treatment of IAs. The factors that were deemed important in achieving success in this series included a collaborative approach with endovascular colleagues, careful surgical judgment, continual reanalysis of personal results, and early support from experienced mentors.

Keywords: Aneurysm; Brain; Microsurgery; Surgical outcome; Unruptured aneurysm

1. Introduction

Over the past decade, several major factors have reduced the number of IAs treated with open microsurgical repair. The progressive refinement of endovascular techniques, including the introduction of balloon-assisted and stent-supported coiling, has substantially increased the percentage of aneurysms treated with coil embolization rather than with open surgery [1,14,28,30,31,34,40]. In the presence of acute SAH, results from the ISAT suggested that endovascular therapy may be associated with a lower morbidity as compared with open surgery [33]. In addition, based on the results of the ISUIA, smaller unruptured aneurysms appear to carry a more benign natural history than previously appreciated, further tempering enthusiasm for open microsurgery in this setting [18].

As fewer surgeons perform fewer open microsurgical procedures for IAs, general competence and comfort levels with this operation decline. Within academic training programs, these procedures have become less common;

Abbreviations: CT, computed tomography; DVT, deep venous thrombosis; GOS, Glasgow Outcome Scale; IA, intracranial aneurysm; ISAT, International Subarachnoid Aneurysm Trial; ISUIA, International Study of Unruptured Intracranial Aneurysms; MCA, middle cerebral artery; MRI/MRA, magnetic resonance imaging/magnetic resonance angiography; SAH, subarachnoid hemorrhage; SF-12, Short Form 12; SF-36, Short Form 36; SVG, saphenous vein graft.

* Corresponding author. 3033 Excelsior Blvd, Suite 403, Minneapolis, MN 55416, USA. Tel.: +1 612 374 0177; fax: +1 612 374 0893.
E-mail address: lnussbaum@mn.rr.com (E.S. Nussbaum).

0090-3019/$ – see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.surneu.2006.08.069

as a result, resident experience has become more limited. In recent years, the neurosurgical job market has increasingly emphasized the importance of endovascular skills, driving neurosurgical trainees with an interest in cerebrovascular disease toward endovascular fellowships. It is difficult to assess the subtle but definite impact that this trend has had and will have on the ability of younger neurosurgeons to become proficient in the surgical management of IAs. At the present time, however, there are many IAs that cannot be treated satisfactorily using available endovascular techniques [14,27,30,43,46]. In addition, there are many lesions that are still best managed with open microsurgery, assuming that an acceptable risk profile can be achieved. This study was performed to evaluate the outcomes achieved by a neurosurgeon initiating a dedicated cerebrovascular practice in the "endovascular era" and to assess how this practice has been affected by the decreasing number of IAs treated with open surgery.

2. Materials and methods

From July 1997 through April 2005, our institute's neurovascular service treated a total of 1450 patients with IAs, including 760 unruptured IAs. During that period, a single neurosurgeon (ESN) repaired 450 unruptured IAs in 376 patients (140 men and 236 women). The patients' ages ranged from 22 to 84 years. Of all the patients, 290 had a single aneurysm whereas 86 had multiple lesions. There were 314 (70%) small (maximal diameter, <1 cm), 99 (22%) large (maximal diameter, 1–2.5 cm), and 37 (8%) giant (maximal diameter, >2.5 cm) aneurysms. Only patients with saccular IAs treated in the absence of acute SAH were included in this study. Most aneurysms in this series were identified incidentally on a CT or an MRI/MRA scan obtained for an unrelated reason. Many patients gave a history of headaches, and 54 patients had suffered a remote SAH from another previously treated aneurysm. Thirty patients presented with symptoms related to a mass effect resulting in either cranial neuropathy or cerebral dysfunction. All patients underwent a 4-vessel digital subtraction angiography as part of their diagnostic evaluation; patients managed after October 2003 were evaluated with 3-dimensional rotational angiography.

All patients were treated under general endotracheal anesthesia and secured in a radiolucent head frame. A standard pterional craniotomy was used for most anterior circulation lesions. An additional skull base dissection, including orbitocranial and modified orbitozygomatic approaches, was used liberally when additional exposure was considered to be important [29]. Distal anterior cerebral artery lesions were treated via parasagittal craniotomy. Basilar apex lesions were treated via a combined half-and-half approach with orbitozygomatic osteotomy in most cases. Posterior inferior cerebellar artery aneurysms generally underwent a far lateral suboccipital craniotomy [10,13]. All patients in this series underwent intraoperative angiography.

Neuroimaging studies, inpatient charts, operative reports as well as drawings, and follow-up clinical notes were available in each case. One-week and 1-month follow-ups were available for all patients. Six-month follow-up was available for 97% of the patients and for all patients who suffered an early complication. Outcome was graded based on the GOS [19]. Patients were further evaluated with the SF-12 and SF-36; in addition, at the 6-month follow-up, they were asked to assess their ability to return to work or to their previous lifestyle as follows: able to return with no modification; able to return with minor modification; able to return with major modification; or unable to return to previous lifestyle. The SF-12 and SF-36 have been used previously in the assessment of outcomes for patients who have had a stroke and with IAs [3,25]. Complications were defined as *major* if they resulted in a change in the GOS score or in a permanent medical disability; they were defined as *minor* otherwise.

3. Results

Aneurysm locations and sizes are summarized in Table 1. Microsurgical neck clipping was achieved in 381 (85%) cases. Thirty-three patients underwent distal revascularization with proximal occlusion, including superficial temporal artery–to-MCA bypass in 25, SVG in 6, and radial artery graft in 2. Proximal occlusion was performed surgically at the same setting as the bypass in 25 cases and endovascularly in a delayed fashion in 5. Five patients with complex aneurysms underwent preliminary extracranial-intracranial bypass to allow for prolonged temporary occlusion, in turn allowing for surgical clipping of the

Table 1
Aneurysm locations and size distribution

Aneurysm location	Small	Large	Giant	Total
All	314	99	37	450
Internal carotid artery	108	36	17	161
Petrous/Cavernous	0	1	3	4
Paraclinoid	31	17	8	56
PCOMMA/AchA	61	13	5	79
Carotid bifurcation	16	5	1	22
Anterior cerebral artery	59	29	2	90
ACOMMA	46	29	1	76
Distal anterior cerebral	11	–	1	12
A1 segment	2	–	–	2
MCA	127	28	14	169
MCA bifurcation	117	22	11	150
M1 segment	9	4	2	15
Distal MCA	1	2	1	4
Vertebrobasilar	20	6	4	30
PICA	10	–	3	13
Basilar apex	10	5	1	16
Basilar trunk	–	1	–	1

PCOMMA indicates posterior communicating artery; AchA, anterior choroidal artery; ACOMMA, anterior communicating artery; PICA, posterior inferior cerebellar artery.

Table 2
Serious complications in and associated outcomes of the 376 patients (450 unruptured aneurysms)

Age (y)/Sex	Aneurysm location	Aneurysm size	Complication	GOS score[a]
59/F	MCA	18 mm	Perforator injury; hemiparesis (severe)	2
41/F	Basilar apex	8 mm	Perforator injury; hemiparesis (mild)	1
65/M	MCA	4.8 cm	Posterior division MCA infarct; SVG thrombosis	3
51/F	MCA	7 mm	Retraction injury; transient dysphasia	1
68/F	Paraclinoid	8 mm	Subfrontal contusion	2
58/F	Paraclinoid	4.2 cm	Severe visual impairment	3
44/F	ACOMMA	6 mm	Systemic thromboemboli	5 (died)

F indicates female; M, male.
[a] Measured at the 6-month follow-up.

aneurysm. Bipolar electrocoagulation with gauze reinforcement was used in the treatment of 27 microaneurysms (maximal diameter, ≤3 mm), and 9 patients underwent gauze wrapping as a primary treatment [37,59]. Eighteen aneurysms were clipped after having been previously coiled, and 7 patients underwent clipping of previously operated aneurysms. Four patients underwent intentional subtotal clipping followed by subsequent endovascular coil obliteration of the residual aneurysm.

Major nonfatal surgical complications occurred in 6 (1.60%) patients and are detailed in Table 2. Major complications developed in 3 (0.96%) small aneurysms, 1 (1.01%) large aneurysm, and 2 (5.41%) giant aneurysms. At the 6-month follow-up, 4 (1.06%) patients were left with a new focal neurologic deficit related to surgery. The mortality rate was 0.27%. The single death in our series was that of a 44-year-old woman who underwent an uneventful repair of a small anterior communicating artery aneurysm. She woke up from surgery without deficit; however, 12 hours after the operation, she developed multiple cerebral, cerebellar, renal artery, and lower extremity arterial emboli from a previously unrecognized cardiac mural thrombus. In spite of attempted intra-arterial thrombolysis and systemic anticoagulation, the patient rapidly developed multisystem organ failure.

Symptomatic ischemic injury occurred in 3 (0.80%) patients. One patient with a basilar apex aneurysm suffered a nondominant thalamoperforator injury resulting in hemiparesis, although the patient had returned to her preoperative occupation as a hairdresser at the time of 6-month follow-up. Intraoperatively, no perforating vessel was obviously injured or occluded, but several perforators were dissected from the posterior aneurysm wall before clip application. A second patient (age, 59 years) with a large (1.8 cm) nondominant MCA aneurysm suffered a lenticulostriate injury with prolonged severe hemiparesis that was still problematic by the 6-month follow-up. The perforator was injured during the procedure while it was attempted to be dissected away sharply from the aneurysm neck. One patient with a giant (4.8 cm) MCA aneurysm suffered a nondominant posterior division MCA infarction when a long SVG to the posterior division M2 thrombosed on the second postoperative day. The patient had been in poor condition with hemiparesis, lethargy, and contusion preoperatively as a result of a severe mass effect and was left with significant disability requiring long-term nursing home care. In the absence of a new neurologic deficit, we did not perform routine postoperative CT or MRI; therefore, we cannot comment on the incidence of silent ischemic injury in our series.

Of the 30 patients who presented with a mass effect, 25 had cranial neuropathy resulting in varying degrees of diplopia and ptosis. At the 6-month follow-up, 18 patients had experienced complete resolution of symptoms, 3 patients were left with mild intermittent diplopia particularly with fatigue, and 4 patients had no improvement. Of 5 patients with giant aneurysms and cerebral edema, 1 patient had a poor outcome as described earlier and in Table 2. The remaining 4 patients demonstrated progressive improvement after aneurysm treatment.

Two patients suffered perioperative seizures and were treated with anticonvulsant therapy: 1 had undergone craniotomy years earlier and had a known seizure disorder, but the other had never had a prior seizure. Three patients suffered from complications presumably related to direct surgical trauma. One patient with a small dominant MCA aneurysm had a very adherent sylvian fissure and suffered from transient word-finding difficulty that began on the second postoperative day and lasted for several weeks. A second patient with a small carotid-ophthalmic aneurysm developed thrombocytopenia and a frontal contusion presumably from the overzealous use of a subfrontal retractor. One patient with a 4.2-cm carotid-ophthalmic aneurysm who presented with visual impairment underwent successful clip reconstruction of her aneurysm but woke up with severe visual impairment that had not recovered by the 6-month follow-up.

One patient developed a delayed wound infection that responded to removal of the bone flap, replacement with a

Table 3
Glasgow Outcome Scale scores of the patients at the 6-month follow-up

GOS score	No. of patients
1	371
2	2
3	2
4	0
5	1

titanium mesh cranioplasty, and prolonged intravenous antibiotics. Two patients were displeased with notable temporalis muscle atrophy and elected to undergo reconstructive surgery for cosmetic purposes. Two patients developed lower extremity DVT postoperatively. Both of them noticed unilateral lower extremity pain and swelling 2 weeks after surgery and were readmitted for evaluation and anticoagulation. There was no obvious long-term sequela or pulmonary thromboembolic complication in these cases.

Third nerve palsy not present preoperatively developed in 7 patients. These included 5 patients with basilar apex aneurysms, 1 patient with a large anterior choroidal artery aneurysm, and, for unexplained reasons, 1 patient with an anterior communicating artery aneurysm. The palsy recovered completely in all but 1 patient with a basilar apex aneurysm who was left with permanent ptosis but no diplopia. Two patients returned 2 and 6 months after surgery with headaches and a chronic subdural hematoma necessitating surgical evacuation.

Intraoperative rupture occurred in 3 patients. These were always well-controlled situations in which bleeding resulted from a sharp dissection attempting to free a perforator or an adherent branch from the aneurysm dome. The bleeding was controlled with bipolar electrocautery in 2 cases and with partial dome clipping in 1 case, and there was no adverse sequela in these cases. To date, no patient has experienced SAH after surgical treatment, with follow-up ranging from 6 months to 7 years.

Because neurosurgeons treating IAs have been criticized for inadequately assessing postoperative quality-of-life issues in patients who appear well on casual neurologic examinations, we attempted to more carefully evaluate our patients using the SF-12, the SF-36, and additional questions regarding functional outcome [3,25,39]. Using these scales, we identified 9 patients who would have been graded as normal (GOS score = 1) on the GOS but who felt that their quality of life was meaningfully worse postoperatively (Tables 3 and 4). This was a heterogeneous group of patients who complained of a combination of postoperative problems, including headaches, anxiety regarding potential aneurysm recurrence despite reassurance, intermittent facial swelling that could not be confirmed on examination, and attention difficulty that interfered with job performance or social activities. Two of these patients carried psychiatric diagnoses even before surgery and suffered from recurrent bouts of major depression. In all cases, these 9 patients felt that they were able to return to work or to their previous lifestyle with minor modifications. Interestingly, there was no relationship between this finding of mild postoperative difficulty and aneurysm size, location, or patient age.

Table 4
Ability to return to previous lifestyle or occupation at the 6-month follow-up

Status	No. of patients
Able to return to previous lifestyle or occupation	
Without modification	361
With minor modification	10
With major modification	1
Unable to return to previous lifestyle or occupation	4[a]

[a] Includes one death.

4. Discussion

4.1. Management philosophy

The appropriate management of unruptured IAs remains controversial. Although it appears that these lesions do not bleed often, when they do, the consequences are severe and potentially life-threatening [17,22,23,44,45,53,54,57,58]. Annual rupture rates ranging from 0.05% to 2.3% have been reported in contemporary series [18,23,35,36,52,58]. Presumably, the true incidence lies somewhere between these estimates, with most series suggesting a rupture rate approximating 0.5% to 1% per year [22,23,52,55]. Although earlier reports advocated treating most unruptured IAs, some more recent studies have recommended treating only larger or symptomatic aneurysms because of their more aggressive natural history [5,6,8,10,17,20,21,24,35,36,43,49,56]. Nevertheless, several investigators have described the rupture of small, asymptomatic, and previously unruptured IAs that were being followed without treatment [15,22,23,35,44,48,57,58]. Clearly, unruptured IAs should be treated only if surgical and endovascular complication rates can be kept at very low levels. Because these numbers may vary significantly based on surgical experience and treatment volume, it becomes critical for individual surgeons and centers to track their personal outcomes in such cases.

In our experience, a collaborative team approach is critical in the management of unruptured IAs. At our center, approximately 75% of ruptured IAs and 50% of unruptured IAs are treated endovascularly. With the perspective that open microsurgery and endovascular therapy are complementary rather than competitive, each patient is offered the option that the team feels will have the highest likelihood of yielding the optimal result, balancing morbidity with durability of repair. Although the superior durability of microsurgical clipping as opposed to coiling is an important consideration, there is little benefit to the patient of leaving the operating room with a well-clipped aneurysm if the cost is a permanent disabling deficit that could have been avoided by an alternative treatment option. In the setting of unruptured IAs, we have generally recommended open surgery only when we feel confident that our surgical risk is extremely low. When it has been our impression that an aneurysm should be treated but the surgical risk in our hands is unacceptably high, we typically recommend endovascular therapy or referral to a center with greater expertise.

In our practice, we have been diligent to treat each patient as an individual, carefully weighing the numerous factors that affect the decisions of whether and how to treat unruptured IAs. There is currently no available algorithm that can be used on a universal basis to answer these questions. At our center, every patient with an unruptured IA is evaluated by a combined neurovascular service, represented by a dedicated neurovascular surgeon and an interventional neuroradiologist. Each patient is assessed on an individual basis taking into account age, general medical condition, history of SAH, family history of SAH, aneurysm size as well as location, and anticipated difficulty associated with either open microsurgery or endovascular coiling.

In some cases, aneurysm location and anatomy are critical. For example, anterior communicating artery aneurysms directed posteriorly and superiorly or basilar apex aneurysms directed posteriorly or associated with a very high or very low basilar bifurcation are generally given endovascular preference. On the other hand, in our experience, MCA aneurysms are generally best treated surgically because these lesions often have a wide neck that incorporates a major arterial branch. Patient age may be an important factor, with older patients being treated endovascularly if possible to minimize treatment-related medical morbidity. We generally recommend conservative management without intervention in older patients with smaller aneurysms, although it is important to note that we do not have rigid age or aneurysm size limitations dictating treatment. Finally, in our opinion, the psychologic impact on the patient of leaving the aneurysm untreated has been underemphasized in the past [38]. In spite of careful counseling regarding the relatively benign natural history of unruptured IAs, many individuals experience an unacceptable deterioration in their quality of life once an IA is discovered. This is particularly true for patients who have a primary relative who has died or been left with a disability by rupture of an IA, and this emotional stress should be considered when making treatment decisions.

As endovascular techniques improve, those patients still referred for open microsurgery often harbor complex, large, or giant aneurysms that lack a distinct neck. This difficult subgroup of aneurysms is likely to constitute a progressively increasing percentage of those aneurysms requiring microsurgical clip reconstruction in the future. Microsurgery must often be combined with endovascular treatment in innovative ways to achieve successful results in these challenging cases, further underscoring the importance of a collaborative approach. In addition, these complicated lesions probably deserve the attention of a surgeon with a dedicated interest in cerebrovascular disease who is practicing at a center that manages a high volume of IAs [11,14,17,24,36,50]. In multiple series of unruptured IAs, including several meta-analyses, surgical mortality rates and major morbidity rates have generally varied from 0% to 3% and from 0% to 16%, respectively [4,5,8,10,17,18,24,32,36,42,43,49,56]. Our morbidity and mortality rates compare favorably with those achieved by other large centers that have developed a focused approach to the management of IAs. We suggest that we have been able to limit serious complications in the present series, at least in part, by offering a combined team approach using endovascular techniques when the risk of open microsurgery was deemed high.

4.2. Surgical judgment

A thoughtful approach is mandatory when deciding on whether to treat and how to treat unruptured IAs. An appreciation of the relatively benign natural history of unruptured IAs and detailed understanding of available alternative endovascular options must be incorporated into this decision-making process. It has also become increasingly important for surgeons managing unruptured IAs to maintain a high degree of flexibility in the operating room, continuously reassessing the planned course of treatment as the surgical procedure progresses. At times, the degree of difficulty associated with exposure, dissection, or clipping of the aneurysm proves to be greater than had been anticipated preoperatively. For example, the finding of heavy calcification at the aneurysm neck that repeatedly prevents a clip from closing mandates immediate reassessment of the risk-benefit profile of continued attempts to clip the aneurysm primarily. How difficult would it be to construct a bypass that would allow trapping of the lesion? Are safer endovascular options available? Does the natural history associated with aborting the procedure compare favorably with the risk of pushing forward? The option of backing out, although not often discussed, should always be viewed as a reasonable alternative [16,27].

In 9 (2%) cases in this series, we used gauze wrapping as the primary treatment modality. These were cases in which it was felt that proceeding with direct clipping posed an unacceptable risk to the patient (eg, in the case of a 58-year-old woman with a 5-mm basilar apex aneurysm that was found to be atheromatous and that was situated so high above the posterior clinoid process that we could not obtain a proper view of the posterior thalamoperforating arteries behind the aneurysm). Proper respect for the relatively benign natural history of the "enemy" mandates the occasional acceptance of a less-than-perfect angiographic result when the alternative carries an unacceptably high risk of disaster. In our experience, careful surgical judgment has often been proven to be the most critical factor in avoiding serious operative complications.

4.3. Surgical techniques

A number of surgical techniques have been found to be particularly important in our experience. Many of these have been emphasized previously by other surgeons. The use of sharp rather than blunt microsurgical dissection, especially when working immediately around an aneurysm, has been stressed repeatedly in the past [59]. Wider arachnoid opening with more liberal opening of the sylvian fissure as championed originally by Yasargil [59] has been very important as well. Over time, we have paid more attention to venous anatomy and have increasingly attempted to preserve bridging and sylvian veins whenever possible. With regard to the aneurysm itself, aggressive and complete aneurysm dissection, freeing perforators and looking "behind" the lesion, has minimized perforator injury and has facilitated proper clip placement. With increasing experience, we have developed greater comfort with more aggressive aneurysm dissections. We have also applied cerebral revascularization techniques liberally when primary clipping of a giant or fusiform aneurysm was difficult or when the need for prolonged temporary occlusion was anticipated.

We have used intraoperative angiography in every case and have been convinced repeatedly of its usefulness [26,51]. On multiple occasions, intraoperative angiography has resulted in the replacement of a clip that unexpectedly compromised a parent vessel or branch or, more commonly, in the placement of additional clips when a small amount of residual aneurysm filling was noted. At the same time, intraoperative angiography has been extremely helpful in confirming adequate obliteration of large and giant atheromatous lesions when clips must often be placed away from the true aneurysm neck to avoid narrowing the parent artery. In our experience, intraoperative angiography has been an important learning tool, giving essentially immediate feedback on the adequacy or inadequacy of clip placement and aneurysm reconstruction. We have not been able to uniformly predict in advance those cases in which intraoperative angiography results in clip readjustment; therefore, we continue to perform intraoperative angiography in every case. Although the intraoperative use of indocyanine green represents a promising new option, only vessels that are well visualized in the surgical field can be assessed and it may be difficult to identify mild or moderate clip-induced stenosis, representing potential limitations of this technique [41].

4.4. Subspecialization and the learning curve

An important factor influencing outcomes in many areas of medicine, including the management of IAs, appears to be the number of patients treated by a given surgeon and at a particular center [2,4,7,9,11,12,47,49]. Although there is an increasing trend toward subspecialization in the field of cerebrovascular neurosurgery, no clear set of guidelines regarding appropriate subspecialty training and minimum case volumes to establish and maintain competence in the treatment of IAs currently exists. Therefore, it is critical that individual surgeons track their own complication rates to ensure that these rates are at an acceptable level. Surgeons who operate on a limited number of patients with IAs must decide as to whether this represents an appropriate practice based on their personal results.

It would be disingenuous to suggest that IA surgery does not carry a significant learning curve. It is our contention that the neurosurgeon with a dedicated interest in aneurysm surgery who wishes to ascend this curve must take all possible measures to protect those patients who may be placed at risk during this process. The significance of working under the direction of highly skilled surgical mentors has been emphasized in the past [27]. Early on in our series, it was reassuring to have a senior experienced colleague present in the operating room for the final phases of aneurysm dissection and clipping even when that individual did not scrub in for the case. Importantly, we have never hesitated to refer selected difficult cases to more experienced surgeons when the problem at hand was felt to exceed our surgical skill level. Although operating on every patient would have more rapidly expanded our surgical experience, we considered it unethical to jeopardize patient safety when there was an obvious unacceptable disparity in patient risk comparing our level of experience with that available elsewhere.

There is no formula that determines when young surgeons are prepared to independently treat their first giant aneurysm or basilar apex aneurysm. With the decreasing number of aneurysms being managed with open microsurgery, this issue may well become more complex in the future. Nevertheless, in our experience, the surgeon initiating a dedicated neurovascular practice can treat increasingly complicated aneurysms by working in collaborative fashion with endovascular colleagues and more experienced surgeons and by carefully and continually analyzing personal results. Over time, a surgical maturity develops, allowing the neurovascular surgeon to tackle increasingly difficult lesions while maintaining acceptable complication rates develops.

4.5. Study limitations

The fact that this series was based on the retrospectively reviewed results of a single surgeon introduces bias and may limit the degree to which the results can be generalized. It should be noted that the recommendations set forth in this report were considered to be important in our experience but may not be applicable to or appropriate for others. Nevertheless, with progressively fewer aneurysms being treated with open microsurgery and with serious questions about surgical morbidity and mortality rates being raised in the literature, it becomes more important to carefully examine and report contemporary surgical results in a systematic fashion. When deciding on whether to recommend open surgery, endovascular coiling, or observation to a patient with an unruptured IA, it is critical that we have accurate and realistic assessments of the risks associated with each of the available options. In particular, are the results that can be achieved today by younger surgeons comparable with those that have been reported in the past by cerebrovascular experts who trained and honed their skills in a very different era?

5. Conclusions

We have presented a large consecutive series of patients with unruptured IAs treated by a single neurosurgeon. The acceptable morbidity and mortality rates in this complex group of patients support the idea that young neurosurgeons can become proficient in the surgical management of even very complicated IAs despite the decreasing percentage of aneurysms being treated with open surgery. Of equal importance is that it appears that this proficiency can be achieved without putting patients at undue risk if the young neurovascular surgeon exercises careful surgical judgment. It is suggested that younger neurosurgeons who wish to manage IAs will have to work closely with endovascular colleagues and demonstrate a dedicated interest in this area to treat an adequate number of patients and ascend the learning curve over a reasonable period.

Acknowledgments

We thank Jody Lowary, Nancy Mattsen, Jane Monita, Sandy Bartz, and Char Martins for their excellent nursing assistance in the management and follow-up evaluation of the study patients. We also thank Dr Donald Erickson for providing expert surgical assistance during our early experience and Dr Leslie Nussbaum for providing assistance with the preparation of this manuscript. Finally, we thank Dr Ira Kasoff for his invaluable surgical advice.

References

[1] Akpek S, Arat A, Morsi H, et al. Self-expandable stent-assisted coiling of wide-necked intracranial aneurysms: a single-center experience. AJNR Am J Neuroradiol 2005;26:1223-31.

[2] American Society of Bariatric Surgery. Guidelines for laparoscopic and open surgical treatment of morbid obesity. Obes Surg 2000;10:378-9.

[3] Anderson C, Laubscher S, Burns R. Validation of the Short Form 36 (SF-36) health survey questionnaire among stroke patients. Stroke 1996;27:1812-6.

[4] Bardach NS, Zhao S, Gress DR, et al. Association between subarachnoid hemorrhage outcomes and number of cases treated at California hospitals. Stroke 2002;33:1851-6.

[5] Batjer HH, Samson DS. Causes of morbidity and mortality from surgery of aneurysms of the distal basilar artery. Neurosurgery 1989;25:904-16.

[6] Bederson JB, Awad IA, Wiebers DO, et al. Recommendations for the management of patients with unruptured intracranial aneurysms. A statement for healthcare professionals from the Stroke Council of the American Heart Association. Stroke 2000;31:2742-50.

[7] Berman MF, Solomon RA, Mayer RA, et al. Impact of hospital related factors on outcome following treatment of cerebral aneurysms. Stroke 2003;34:2200-7.

[8] Brennan JW, Schwartz ML. Unruptured intracranial aneurysm: appraisal of the literature and suggested recommendations for surgery using evidence-based medicine criteria. Neurosurgery 2000; 47:1359-72.

[9] Cross DT, Tirschwell DL, Clark MA, et al. Mortality rates after subarachnoid hemorrhage: variations according to hospital case volume in 18 states. J Neurosurg 2003;99:810-7.

[10] Drake CG, Peerless SJ, Hernesniemi JA. Surgery of vertebrobasilar aneurysms: London, Ontario, experience on 1767 patients. Wien: Springer; 1996.

[11] Dudley RA, Johansen KL, Brand R, et al. Selective referral to high-volume hospitals: estimating potential avoidable deaths. JAMA 2000;283:1159-66.

[12] Hannan EL, Popp AJ, Tranmer B, et al. Relationship between provider volume and mortality for carotid endarterectomies in New York State. Stroke 1998;29:2292-7.

[13] Heros RC. Lateral suboccipital approach for vertebral and vertebro-basilar artery lesions. J Neurosurg 1986;64:559-62.

[14] Heros RC, Morcos JJ. Cerebrovascular surgery: past, present, and future. Neurosurgery 2000;47:1007-33.

[15] Ferguson GG. Physical factors in the initiation, growth, and rupture of human intracranial saccular aneurysms. J Neurosurg 1972;37:666-77.

[16] Giannota SL. Cerebrovascular surgical skills: learning them, teaching them. Donaghy LecturePresented at the 70th meeting of the American Association of Neurological Surgeons, Chicago, IL, April 6-11, 2002.

[17] Heiskanen O. Risks of surgery for unruptured intracranial aneurysms. J Neurosurg 1986;65:451-3.

[18] International Study of Unruptured Intracranial Aneurysms. Risk of rupture and risks of surgical intervention. N Engl J Med 1988; 339:1725-33.

[19] Jennett B, Bond M. Assessment of outcome after severe brain damage. Lancet 1975;1:480-4.

[20] Johnston SC, Gress DR, Kahn JG. Which unruptured cerebral aneurysms should be treated? A cost utility analysis. Neurology 1999;52:1806-15.

[21] Juvela S. Unruptured aneurysms. J Neurosurg 2002;96:58-60.

[22] Juvela S, Porras M, Heiskanen O. Natural history of unruptured intracranial aneurysms: a long-term follow-up study. J Neurosurg 1993;79:174-82.

[23] Juvela S, Porras M, Poussa K. Natural history of unruptured aneurysms: probability of and risk factors for aneurysm rupture. J Neurosurg 2000;93:379-87.

[24] King Jr JT, Berlin JA, Flamm ES. Morbidity and mortality from elective surgery for asymptomatic, unruptured, intracranial aneurysms. A meta-analysis. J Neurosurg 1994;81:837-42.

[25] King Jr JT, Horowitz MB, Kassam AB, et al. The Short Form–12 and the measurement of health status in patients with cerebral aneurysms: performance, validity, and reliability. J Neurosurg 2005;102:489-94.

[26] Klopfenstein JD, Spetzler RF, Kim LJ, et al. Comparison of routine and selective use of intraoperative angiography during aneurysm surgery: a prospective assessment. J Neurosurg 2004;100:230-5.

[27] Lawton MT. Basilar apex aneurysms: surgical results and perspectives from an initial clinical experience. Neurosurgery 2002;50:1-10.

[28] Lefkowitz MA, Gobin YP, Akiba Y, et al. Balloon-assist Guglielmi detachable coiling of wide-necked aneurysms: II. Clinical results. Neurosurgery 1999;45:531-8.

[29] Lemole Jr GM, Henn JS, Zabramski JM, et al. Modifications to the orbitozygomatic approach. Technical note. J Neurosurg 2003;99: 924-30.

[30] Malek AM, Halbach VV, Phatouros CC, et al. Balloon-assist technique for endovascular coil embolization of geometrically difficult intracranial aneurysms. Neurosurgery 2000;46:1397-406.

[31] Mericle RA, Wakhloo AK, Rodriguez R, et al. Temporary balloon protection as an adjunct to endosaccular coiling of wide-necked cerebral aneurysms: technical note. Neurosurgery 1997;41:975-8.

[32] Mizoi K, Yoshimoto T, Nagamine Y, et al. How to treat incidental cerebral aneurysms: a review of 139 consecutive cases. Surg Neurol 1995;44:114-20.

[33] Molyneaux A, Kerr R, Stratton I, Sandercock P, et al. International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms. Lancet 2002;360:1267-74.

[34] Moret J, Cognard C, Weill A, et al. The remodeling technique in the treatment of wide neck intracranial aneurysms. Interv Neuroradiol 1997;3:21-35.

[35] Morita A, Fujiwara S, Hashi K, et al. Risk of rupture associated with intact cerebral aneurysms in the Japanese population: a systematic review of the literature from Japan. J Neurosurg 2005;102:601-6.

[36] Moroi J, Hadeishi H, Suzuki A, et al. Morbidity and mortality from surgical treatment of unruptured cerebral aneurysms at Research Institute for Brain and Blood Vessels–Akita. Neurosurgery 2005; 56:224-31.

[37] Nussbaum ES, Erickson DL. The fate of intracranial microaneurysms treated with bipolar electrocoagulation and parent vessel reinforcement. Neurosurgery 1995;45:1172-5.

[38] Otawara Y, Ogasawara K, Kubo Y, et al. Anxiety before and after surgical repair in patients with asymptotic unruptured intracranial aneurysm. Surg Neurol 2004;62:28 - 31.
[39] Otawara Y, Ogasawara K, Ogawa A, et al. Cognitive function before and after surgery in patients with unruptured intracranial aneurysm. Stroke 2005;36:142 - 3.
[40] Phatouros CC, Sasaki TY, Higashida RT, et al. Stent-supported coil embolization: the treatment of fusiform and wide-neck aneurysms and pseudoaneurysms. Neurosurgery 2000;47:107 - 13.
[41] Raabe A, Nakaji P, Beck J, et al. Prospective evaluation of surgical microscope–integrated intraoperative near-infrared indocyanine green videoangiography during aneurysm surgery. J Neurosurg 2005; 103:982 - 9.
[42] Raaymakers TW, Rinkel GJ, Limburg M, et al. Mortality and morbidity of surgery for unruptured intracranial aneurysms: a meta-analysis. Stroke 1998;29:1531 - 8.
[43] Rice BJ, Peerless SJ, Drake CG. Surgical treatment of unruptured aneurysms of the posterior circulation. J Neurosurg 1990;73:165 - 73.
[44] Schievink WI, Piepgras DG, Wirth FP. Rupture of previously documented small asymptomatic saccular intracranial aneurysms. Report of three cases. J Neurosurg 1992;76:1019 - 24.
[45] Schievink WI, Widjicks EF, Parisi JE, et al. Sudden death from aneurysmal subarachnoid hemorrhage. Neurology 1995;45:871 - 4.
[46] Shanno GB, Armonda RA, Benitez RP, et al. Assessment of acutely unsuccessful attempts at detachable coiling in intracranial aneurysms. Neurosurgery 2001;48:1066 - 74.
[47] Showstack JA, Rosenfeld KE, Garnick DW, et al. Association of volume with outcome of coronary artery bypass graft surgery: scheduled vs. nonscheduled operations. JAMA 1987;257:785 - 9.
[48] Solomon RA, Correll JW. Rupture of a previously documented asymptomatic aneurysm enhances the argument for prophylactic surgical intervention. Surg Neurol 1988;30:321 - 3.
[49] Solomon RA, Fink ME, Pile-Spellman J. Surgical management of unruptured intracranial aneurysms. J Neurosurg 1994;80:440 - 6.
[50] Solomon RA, Mayer SA, Tarmey JJ. Relationship between the volume of craniotomies for aneurysm performed at New York State hospitals and in-hospital mortality. Stroke 1996;27:13 - 7.
[51] Tang G, Cawley CM, Dion JE, et al. Intraoperative angiography during aneurysm surgery: a prospective evaluation of efficacy. J Neurosurg 2002;96:993 - 9.
[52] Tsutsumi K, Ueki K, Morita A. Risk of rupture from incidental cerebral aneurysms. J Neurosurg 2000;93:550 - 3.
[53] Wiebers DO, Whisnant JP, O'Fallon WM. The natural history of unruptured intracranial aneurysms. N Engl J Med 1981;304:696 - 8.
[54] Wiebers DO, Whisnant JP, Sundt TM, et al. The significance of unruptured intracranial saccular aneurysms. J Neurosurg 1987;66: 23 - 9.
[55] Winn HR, Jane JA, Taylor J, et al. Prevalence of asymptomatic incidental aneurysms: review of 4568 arteriograms. J Neurosurg 2002; 96:43 - 9.
[56] Wirth FP, Laws Jr ER, Piepgras DG, et al. Surgical treatment of incidental intracranial aneurysms. Neurosurgery 1983;12:507 - 11.
[57] Yasui N, Magarisawa S, Suzuki A, et al. Subarachnoid hemorrhage caused by previously diagnosed, previously unruptured intracranial aneurysms: a retrospective analysis of 25 cases. Neurosurgery 1996; 39:1096 - 101.
[58] Yasui N, Suzuki A, Nishimura H, et al. Long-term follow-up study of unruptured intracranial aneurysms. Neurosurgery 1997;40:1155 - 60.
[59] Yasargil MG. Microneurosurgery, vol. 1. Stutgart: Thieme Verlag; 1984. p. 208 - 71.

Commentary

This report on 450 consecutive operations for unruptured IAs by a single neurosurgeon is unique and important for a number of reasons. The senior author has presented his entire operative experience with unruptured aneurysms rather than selecting cases performed after navigating through the learning curve. All the cases were managed in a multidisciplinary fashion, with endovascular options being considered and surgery being chosen through this multidisciplinary approach. The results are excellent, and most of the complications occurred in challenging aneurysms for which endovascular options may not have been appropriate and the natural history was presumably more aggressive. Each of the patients in this series was evaluated by the standard GOS and further evaluated by the SF-12 and SF-36 at a 6-month follow-up assessment. Although used commonly in the neurosurgical literature, the GOS alone may overlook subtle yet important neurologic deficits perceived by patients and/or their families. The use of a functional outcomes scale improves the validity of the outcome assessment.

The article emphasizes the continued role of neurovascular surgeons in the endovascular era. A large number of aneurysms for which endovascular therapy is either an inferior option or not appropriate remain. Because endovascular therapy has become more refined, the aneurysms presenting for microsurgical management have become increasingly more complex and challenge the skills of neurovascular surgeons.

As emphasized by the authors, I believe that the keys to success in the microsurgical management of IAs include a multidisciplinary and cooperative approach with endovascular experts; attention to microsurgical detail; inclusion of skull base exposures when appropriate; wide dissection of the arachnoid planes to minimize or eliminate the need for retraction; sharp dissection of the aneurysm with full visualization of the parent vessel, aneurysm neck, as well as adjacent neurovascular structures; and use of intraoperative angiography to confirm that the goals of surgery have been met before closure. Importantly, neurovascular surgeons must maintain an attitude of flexibility and creativity during surgery to alter their therapeutic plan when new information or observations indicate that the original plan places the patient at unnecessary risk.

It is obvious the authors have used all of these skills in the management of their group of patients and ought to be congratulated for their excellent results.

Despite the remarkable improvements in endovascular therapy, it should be emphasized that the field of microsurgery is not static. We continue to develop novel and innovative methods to deal with an increasingly complex group of patients who are presently still best managed by microsurgical techniques.

Daniel L. Barrow, MD
Atlanta, GA 30322, USA

Coiling of unruptured aneurysms is of questionable benefit because, according to the ISAT, it does not really protect patients from (re)bleeding as well as clipping does.