Surgical Management of Intracranial Aneurysms in the Endovascular Era: Review Article

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The advent of endovascular therapy for intracranial aneurysms and the rapid advances in that field have supplanted microsurgical treatment for many intracranial aneurysms. Applying current outcome data and other parameters, nuances of selecting the modality of treatment for intracranial aneurysms are reviewed. Patient factors, such as age, comorbidities, vasospasm and other medical conditions, are addressed. A custom-tailored multimodality treatment paradigm for the management of ruptured and unruptured aneurysms will maximize the favorable results seen in this difficult patient population.

KEY WORDS: Aneurysm · Subarachnoid hemorrhage · Aneurysm clip · Endovascular treatment.

INTRODUCTION

The advent of endovascular therapy for intracranial aneurysms, and the rapid advances in that field have supplanted microsurgical treatment for many intracranial aneurysms. The less invasive nature of endovascular therapy is quite appealing to patients as well as practitioners.

These endovascular advances have led to a sharp decline in the use of microsurgical techniques for many aneurysms without clear scientific evidence of superiority of endovascular techniques.

Microsurgical clipping has the advantage of being a time-honored, durable and versatile method for treating most intracranial aneurysms. It is rare for an intracranial aneurysm to recur once it has been properly clipped, and there are very few aneurysms that are not amenable to some microsurgical repair technique. The primary disadvantage of surgery is the fact that it requires an open operation and some manipulation of the brain.

Endovascular therapy has the advantage of being less invasive and multiple aneurysms at distant sites can be treated. There are, however, some important disadvantages of endovascular therapy. Like surgery, endovascular therapy has risks. As with surgery, if endovascular therapy is provided by individuals with significant experience, those risks are relatively small, but not eliminated. The primary disadvantage of endovascular therapy is its inferior durability.

Endovascular treatment requires routine maintenance in the form of follow-up imaging because of the higher likelihood of recurrence of the aneurysm and the potential need for additional treatment. Another disadvantage of endovascular therapy is the fact that it simply is not suitable for all aneurysms. There remain a large number of aneurysms whose angioarchitectural features make them unsuitable for current endovascular techniques, as suggested in the International Subarachnoid Aneurysm Trial (ISAT), where only 22% of the 9,559 patients were randomized into the trial for either endovascular or open surgical treatment. The majority of those not randomized underwent surgical management of their aneurysms. Finally, endovascular coiling does not have the ability to remove intracerebral hemorrhages or necessarily eliminate mass effect from large or giant aneurysms that present as an intracranial mass. In some rare instances, endovascular treatment can occasionally exacerbate the condition.

With a rapid shift in the philosophy concerning the treatment of intracranial aneurysms, it is important to periodically review the role of therapeutic options, as well as the
scientific evidence supporting the shift. In this review article, we will assess the current role of microsurgical clip ligation of selected intracranial aneurysms based upon available evidence supporting its use. It is our opinion that the best results in the management of intracranial aneurysms will occur in high-volume institutions that utilize a truly multidisciplinary approach to the management of patients harboring these lesions. Many aneurysms are amenable to both microsurgical or endovascular therapies. There remain, however, some aneurysms that are not ideal for microsurgical clip ligation and a number of aneurysms which are currently not suitable for available endovascular techniques.

**ANEURYSMS NOT IDEAL FOR MICROSURGICAL CLIP LIGATION**

A number of characteristics of either the patient and/or the aneurysm can make them undesirable for surgical management. In these situations, an available endovascular option may be a much more appropriate choice because of the known increased risks of surgical management in such situations, including aneurysms in elderly patients, patients in very poor medical condition or who present with cerebral vasospasm, or aneurysms that have calcified necks or unfavorable surgical anatomy.

**Elderly patients**

It is well-recognized that surgical treatment of aneurysms, whether ruptured or unruptured, carries increased morbidity in the elderly population. These patients simply do not tolerate intracranial surgery as well as their younger counterparts. As older patients do not have as long a life expectancy as younger individuals, the marginally inferior durability of endovascular techniques is less of a concern in this population. Most institutions utilize general anesthesia for endovascular procedures, so this aspect of treatment and its attendant risks not eliminated by endovascular therapy. However, though it has not been clearly demonstrated that endovascular therapy in the elderly population is associated with less risk than an open procedure, intuition would certainly suggest that this is the case.

**Patients in poor neurological or medical condition**

The advantages of early elimination of a ruptured aneurysm from the intracranial circulation have been addressed in the literature. Early removal eliminates the risk of re-hemorrhage, which is most likely to occur during the first six to twenty four hours after the initial rupture. Furthermore, if the patient develops vasospasm in the days to come, it can be treated more aggressively without fear of causing a re-hemorrhage form the aneurysm. These observations of the advantages of early surgical management of the aneurysms led to a shift in the mid-1980s and early 1990s to earlier surgery for ruptured intracranial aneurysms. In many institutions, early surgery was withheld from patients in poor neurological or medical condition for fear of unacceptable morbidity in operating on patients with attendant medical or neurological co-morbidities. Although several authors have demonstrated that acceptable outcomes can occur with early surgery in patients who are initially in poor neurological condition, there certainly is additional morbidity of early manipulation of a severely injured and edematous brain. The advent of endovascular techniques has provided an alternative to early surgery and remains a very appealing option for patients in poor medical or neurological condition.

**Patients presenting with cerebral vasospasm**

With increasing regionalization of aneurysm care, many patients presenting with aneurysmal subarachnoid hemorrhage are transferred to regional facilities; it has been shown that patients that receive care at high-volume centers have statistically better outcomes. However, the delays inherent in such transfers, and the attendant delays in resuscitation and work-up may result in a patient presenting to the treating institution in angiographic and/or clinical vasospasm. In such a situation, neurovascular surgeons may be concerned about operating in the face of significant vasospasm for fear of exacerbating the underlying condition or increasing the risks of intraoperative ischemic injuries because of poor perfusion. If the ruptured intracranial aneurysm is appropriate for endovascular therapy, an endovascular approach to eliminate the aneurysm from the circulation and treat the vasospasm during the same procedure is a very appealing and likely superior option for these patients.

**Difficult location**

Although virtually any aneurysm can be addressed by some microsurgical treatment, it is clear that some aneurysms carry a greater risk of exposure and treatment than others. Even within the same anatomic location, local factors of the aneurysm can influence the risks of microsurgical clip ligation. While most neurovascular surgeons agree that basilar apex aneurysms are particularly treacherous due to the surrounding perforating vessels, those lesions with a very high or low bifurcation can make microsurgical treatment even more difficult than if the aneurysm arises at the level of the posterior clinoid processes. The orientation of a basilar apex aneurysm should also be considered, as
anteriorly-pointing domes allow easier visualization and dissection of the thalamoperforating vessels. Anterior communicating artery aneurysms pointing anteriorly are very straightforward to treat surgically, while those that point superiorly between the A2 segments present a greater challenge to the neurovascular surgeon, and often require some degree of gyrus rectus resection, which may have subtle influences on future neuropsychiatric performance. Those aneurysms that arise in difficult locations or have anatomic variations that increase the degree of surgical difficulty are often more ideal for endovascular therapy if their angioarchitecture is suitable for an endovascular option. In general, basilar trunk or apex aneurysms, high-riding and posterior-pointing anterior communicating aneurysms, or aneurysms of the very proximal internal carotid artery with a partially extradural neck are often at least considered for endovascular therapy.

Calcified neck

Intracranial aneurysms associated with any degree of calcification, particularly if the calcification involves the neck, present significant difficulties for the neurovascular surgeon. Thin-slice CT through the aneurysm and its neck can identify area of calcification, allowing the neurovascular team to anticipate significant difficulty in securing the aneurysm by clip ligation (Fig. 1). If these lesions are suitable for endovascular therapy, this will often be a far superior option than attempts at reconstructing the calcified neck by clipping.

Multiple aneurysms requiring multiple operations

Approximately 20% to 30% of patients who harbor an intracranial aneurysm will have multiple aneurysms43). This can vary from two to several aneurysms. Ideally, one would wish to choose a therapeutic option that allows the largest number of aneurysms to be eliminated from the circulation. Although a number of aneurysm locations can be exposed through the standard surgical approaches, with some aneurysms, there are limitations to those surgical exposures. For example, a right-sided pterional approach will allow one to clip aneurysms throughout most of the anterior circulation, as well as proximal aneurysms on the left carotid circulation and aneurysms of rostral basilar artery. This approach, however, may not allow adequate exposure of a left middle cerebral artery aneurysm or aneurysms of the vertebral artery. Endovascular therapy, however, is not limited by these anatomic constraints. Multiple aneurysms at multiple sites can potentially be treated at the same endovascular setting. However, in the setting of subarachnoid hemorrhage, whichever modality is chosen should, of course, focus foremost on the ruptured aneurysm.

ANEURYSMS NOT IDEAL FOR ENDOVASCULAR COILING

Despite the many advances in endovascular therapy and the appeal of this less invasive technique, there remain a significant number of aneurysms which are simply unsuitable or not ideal for endovascular therapy. Advances in endovascular technology may address many of these shortcomings in the foreseeable future but, for the present time, microsurgical clip ligation remains a better option in many of these situations. The ISAT trial has shown that complete aneurysm obliteration was only seen in 66% of those coiled at one year, as compared with more than 80% of the surgically ligated aneurysms, suggesting that many aneurysms that were treated by endovascular means are not ideally suited to be treated as such37). In the literature, angiographically demonstrated recurrences of aneurysms during follow-up ranged from 17-50%, depending on the aneurysm neck size, and most studies include relatively short-term follow-up11,44,52).

Fusiform aneurysms

With some rare exceptions, fusiform aneurysms, particularly those on the distal aspects of intracranial arteries, are not amenable to endovascular therapy without sacrificing the parent artery (Fig. 2). There are reports of an endovascular ‘bypass’ with a combination of stent and possible coiling, however the long-term stent patency and recurrence rates are unclear10,22). If it is important to maintain patency of the distal vessel, as is usually the case for many intracranial aneurysms may be challenging and may require use of extracranial to intracranial bypass, intracranial to intracranial bypass, flow reversal, clip wrapping techniques or other innovative means to eliminate the aneurysm (Fig. 3).
Blister-like aneurysms

“Blister-like” aneurysms at non-branching points, most commonly occur on the dorsal proximal internal carotid artery, although these may also occur in other locations on the intracranial circulation\(^4,46\) and are often misclassified initially with a negative angiogram. These aneurysms are relatively rare, comprising less than 1% of cerebral aneurysms\(^1,45\). They are characterized as very small, broad-based aneurysms without a neck that are extremely thin-walled and may be seen in association with other aneurysms. Pathologically, they lack an internal elastic lamina and media, and are covered only by adventitia and fibrinous tissue\(^25\). Currently, there is no appropriate endovascular option for managing these nefarious lesions. Perhaps, in the future, covered stents may provide an alternative to microvascular repair when needed. Even surgical repair of these lesions is challenging, with a high intraoperative rupture rate. Often times, management requires considerable creativity, utilizing such techniques as clip wrapping or even a sacrifice with extracranial to intracranial bypass\(^6,45\).

Wide-necked aneurysms

With the advent of endovascular adjuncts, such as balloon-remodeling and stent-coiling, many wide-necked aneurysms previously deemed unsuitable for endovascular coiling are now able to be treated by endovascular techniques. For many wide-necked aneurysms, however, microsurgical clip ligation remains a better option, as it allows for complete, immediate and permanent clip ligation of the aneurysm with a very low chance of recurrence (Fig. 4). Although the current literature regarding wide-necked aneurysm treatment and recurrence varies tremendously, there is little doubt that wide-necked aneurysm, often defined as 4 mm or greater, have a higher recurrence rate\(^23,39\). We are very hesitant to use stents in treating recently ruptured aneurysms because the need for use of powerful antiplatelet agents that may increase the risks of patient management, particularly in the setting of hydrocephalus requiring ventricular drainage or additional surgical procedures\(^51\). Additionally, the long term efficacy of intracranial stents is unknown but significant morbidity in this population.

Complex aneurysm configuration

Aneurysms with highly complex anatomy are oftentimes unsuitable for endovascular treatment. If endovascular therapy is used, a variety of adjuncts, including balloon-remodeling and the use of stents, may be necessary, and may increase the risk of the endovascular procedure. Oftentimes, these complex aneurysms can be best treated by microsurgical clip ligation.
with reconstruction of the parent artery, utilizing a variety of clipping strategies (Fig. 5).

**Thrombotic aneurysms**

It is well-recognized that aneurysms with a significant amount of intraluminal thrombus are poor candidates for endovascular therapy, although they are poorly described in the literature because they are often included into larger endovascular therapy databases. Most of the thrombotic aneurysms reported in the literature are large or giant aneurysms. There are rare case reports suggesting that endovascularly-treated thrombotic aneurysms behave differently, with less thrombus organization and deposition of fibrous connective tissue. In addition to the delayed or altered healing, endovascular coils rapidly migrate into the adjacent thrombus, leading to early recurrence of these aneurysms. On the other hand, microsurgical treatment, including aneurysmorraphy, the evacuation of the intraluminal thrombus, and clip reconstruction are more durable options for managing these complicated aneurysms (Fig. 6).

**Giant aneurysms**

Many large and giant aneurysms have been demonstrated to be associated with significantly lower rates of obliteration and significantly higher recurrence rates following endovascular therapy, with recurrence rates higher than 50% in some larger studies.

Furthermore, the mass effect of these aneurysms often present with is not reliably eliminated by filling the aneurysm with endovascular devices, with some studies suggesting up to 25% of patients experiencing no improvement or worsening of their neurologic symptoms (Fig. 6B, C).

**Very small aneurysms**

Small aneurysms, such as those that are less than 3 mm in size, are likely treated by routine surveillance in most patients. However, in those patients presenting with subarachnoid hemorrhage, or unruptured aneurysms in patients that are young, have other intracranial aneurysms or a personal or medical or social reasons that necessitate treatment of these very small aneurysms, open surgical management remains the standard. Aneurysms of this size are very difficult or impossible to treat by endovascular means. Currently, there are few endovascular coils small enough to treat these very small aneurysms adequately. Endovascular treatment of such small lesions also presents significant technical challenges, including more difficult and unstable catheter positioning and a higher risk of coil migration and aneurysm perforation. In contrast, however, small aneurysms are much more readily amenable to microsurgical clip ligation and do not typically lesions more suitable for microsurgical clip ligation at the present time.

**Failed endovascular treatment**

Aneurysms that have undergone endovascular therapy and present with recurrence should be strongly considered for microsurgical treatment. Although the data available varies considerably, the ISAT treatment rate was 6.9 times more likely in the endovascular therapy group than in the open surgical group. Most experienced centers now report a 3-6% endovascular re-treatment rate, compared to...
a historical surgical recurrence rate of approximately 1% (though the true rate is unknown, as most surgeons do not routinely perform surveillance of clipped aneurysms). If an initial endovascular procedure has failed, questions regarding the cause of failure and what new endovascular options can be brought to bear must be answered. If the initial endovascular treatment did not utilize all current technology and a suitable endovascular option exists that will likely eliminate the aneurysm on a permanent basis, endovascular therapy is still the primary option. However, if the new endovascular option carries a significant risk of another recurrence, future microsurgical treatment may be rendered much more complicated and dangerous; clearly, in such a situation, a definitive surgical treatment strategy is preferred over a second failed endovascular attempt. With every retreatment, one also has additive medical and procedural-related risks associated with additional procedures. In a

Fig. 6. Sagittal magnetic resonance image (A) reveals a partially thrombosed distal MCA aneurysm. Antero-posterior (B), lateral (C) and 3D (D) right ICA angiograms demonstrate the aneurysm. Postoperative ICA (E) and ECA (F) angiograms document successful trapping of the aneurysm and patency of the superficial temporal artery bypass to the distal MCA.

Fig. 7. Anterior-posterior angiogram (A) and 3-D angiogram (B) of a patient with subarachnoid hemorrhage demonstrating a tiny basilar tip aneurysm. This was treated with microsurgical clip ligation.
recent report of 350 endovascular-retreated aneurysms, there was a 2.2% morbidity-mortality rate associated with retreatment, although with subsequent retreatment sessions, the authors did note a decreased complication rate as compared with the initial treatment session\textsuperscript{19}. It must also be remembered that surgical treatment of previously coiled aneurysms is also associated with challenges\textsuperscript{55}.

**Intracerebral hemorrhage**

Those aneurysms presenting with an intracerebral hemorrhage with mass effect should be strongly considered for microsurgical repair at the time of clot evacuation (Fig. 9)\textsuperscript{1}. Currently, there is no endovascular means for the removal of an intracerebral hemorrhage and, if an operation is to be performed to evacuate the hematoma, one should treat the aneurysm by a more durable microsurgical procedure during the same operation\textsuperscript{18,42}.

**Multiple aneurysms not amenable to endovascular therapy**

If a patient presents with multiple aneurysms that are not all amenable to endovascular therapy, one should strongly consider microsurgical clip ligation if this is a viable option for treating all of the aneurysms. To treat one or more aneurysms by endovascular therapy when the patient will have to be subjected to an intracranial operation at a later time is an illogical choice, since surgery is not avoided. The obvious exception is if endovascular therapy can be provided for an aneurysm that would not be able to be addressed during a single microsurgical procedure.

**Subarachnoid hemorrhage with high-risk of vasospasm**

Vasospasm is a common complication, identified angiographically in 40-70% of patients and causing delayed ischemic neurological deficits (DIND) in 17-40% of patients with subarachnoid hemorrhage\textsuperscript{2,13-15,29}. Of this population with DIND, approximately 50% will develop an ischemic infarction\textsuperscript{35}. Although a recent review suggested there was no statistical difference between coiling vs. clipping of aneurysms with regard to vasospasm, there have been several smaller studies examining pharmacological or technical nuances suggesting that surgical management may
provide decreased vasospasm risk that were not addressed in the review which bear discussion and consideration\(^3\). Andaluz et al.\(^3\) prospectively examined the effect of microsurgical opening of the lamina terminals in ruptured anterior communicating artery patients and found that there was as statistically significant decrease in vasospasm and hydrocephalus requiring a shunt. Another group has shown that placement of nicardipine prolonged-release pellets into the surgical bed and cisterns significantly reduced the incidence of vasospasm in their patient population\(^8\). Although reports suggest that microsurgical management of ruptured intracranial aneurysms is far from a mature art, it is also clear that we as physicians are far from solving many of the vexing problems that our patients experience.

**CONCLUSION**

Endovascular therapy for the treatment of intracranial aneurysms represents an innovative and welcome addition to the armamentarium for management of these challenging lesions.

Currently, there is a paucity of definitive scientific evidence to support the superiority of endovascular or microsurgical treatment in the management of the vast majority of aneurysms. Undeniably, the International Subarachnoid Aneurysm Trial (ISAT) published in 2002 has changed the practice patterns of many referring physicians and neurosurgeons. However, many experts in the field have pointed out significant design and implementation flaws within the study\(^5\). In such an environment, individualized clinical decision-making for each aneurysm and each patient is undoubtedly best accomplished by a truly multidisciplinary group with both endovascular and microsurgical skills. Despite the substantial advances in endovascular therapy, microsurgery also is not a static field and a number of advances have been made in the past several years. These include advances in skull-base surgery to minimize brain retraction and injury, three-dimensional rotational, intraoperative and indocyanine green videoangiography, advanced pharmacologic mechanisms for brain protection, improved temporary and permanent aneurysm clips, and the increasing use and refinement of cerebral bypass techniques.

As endovascular therapy has become more popular and been utilized for an increasing number of intracranial aneurysms, those aneurysms requiring surgical treatment have become increasingly complex and this trend will continue for the foreseeable future. These more challenging aneurysms will tax the skills of the neurovascular surgeons and require increasingly innovative and challenging microsurgical solutions.

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