Aneurysms of the Ophthalmic (C6) Segment of the Internal Carotid Artery

Clinical Experience, Treatment Options, and Strategies (Part 2)

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Abstract: Treatment of ophthalmic (C6) segment aneurysms continues to be challenging and technically demanding for neurosurgeons, resulting in high rates of morbidity and mortality. In part 2, we provide a contemporary review of recent clinical series and assess the advantages and limitations of surgical and endovascular treatments relative to published series as well as our own. In part 1, we detailed the key embryologic, anatomical, and radiologic points that now provide the foundation for our critical discussion of such management strategies. We report the results of our 78 patients with 88 C6 segment aneurysms, including 43 with unruptured aneurysms and 35 with subarachnoid hemorrhage (SAH), 9 of which were giant and 25 of which were large. Management strategies included surgical clipping alone in 53 patients, clipping and hemicraniectomy in 2, coiling in 17, extracranial-to-intracranial bypass in 2, and coil occlusion of the internal carotid artery in 2. Of 2 patients who underwent no treatment, 1 had a myocardial infarction after diagnostic angiography and 1 declined treatment. Overall mortality was 6.4% (5 patients with SAH). At discharge, Glasgow Outcome Scale (GOS) scores were good (GOS score of 1 or 2) in 63 (80.8%) patients and poor (GOS score of 3 or 4) in 10 (12.8%) patients. In this review, we describe how the synergistic use of surgical and endovascular procedures seems to offer the best approach to these aneurysms to minimize morbidity associated with treatment and to achieve outstanding outcomes, highlighting the treatment strategies used by the senior surgeon.

Key Words: artery, treatment, opthalmic segment, internal carotid

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Aneurysms of the ophthalmic (C6) segment of the internal carotid artery (ICA) account for 5% to 11% of all intracranial aneurysms and can be large or giant, be associated with other aneurysms in 50% of cases, and develop bilaterally in 7% of patients.[1–3] C6 segment aneurysms typically present during the fifth and sixth decades of life and more often in women than in men (4:1 ratio). Similar to other intracranial aneurysms, those originating from the C6 segment present with subarachnoid hemorrhage (SAH) in 20% to 70% of patients. In addition, neurologic deficits occur because of compression of surrounding structures such as the visual system. Presentation includes visual symptoms (in one third of patients), ischemic symptoms from partially thrombosed aneurysms, and related embolic phenomena in some patients. Other cases are incidentally diagnosed.[1–3] Presentation can be divided into acute, subacute, chronic, and incidental forms (Table 1).

The presenting symptoms and behavior of these aneurysms are explained by their location and complex surgical anatomy. This complexity and the difficulty in categorizing these aneurysms have led to a myriad of different classifications and variant locations as presented in the literature.[4–21] When considering the proximal part of the C6 segment, most classifications relate to anatomical structures that are immediately involved with the aneurysm, in particular, vascular branching points like the ophthalmic artery. In contrast, aneurysms on the distal portion of the C6 segment are not usually associated with branching points; thus, the terminology is vague (Tables 2 and 3). Therefore, we adopt a simple classification based on the proximity of the aneurysm to the ophthalmic artery or the superior hypophyseal artery and the direction of the aneurysm (Fig. 1).

Treatment of C6 segment aneurysms is challenging and technically demanding for neurosurgeons; the related morbidity and mortality have been relatively high. Although indirect methods of treatment and alternative options have been developed consequently, including endovascular procedures and carotid occlusion, outcomes are often poor. Refinement of cranial base approaches and techniques along with endovascular procedures has greatly improved the outcome in treating these lesions through a combination of direct and indirect procedures in select cases.

In part 2, we review our recent experience with these aneurysms and discuss options regarding the optimal treatment plan. The key embryologic, anatomical, and radiologic points discussed in part 1 provide the foundation for our critical discussion of management strategies in our clinical series.

CLINICAL SERIES

From January 1997 to June 2003, 78 patients (70 women and 8 men, mean age = 51 years, age range: 27–77 years) with

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TABLE 1. Clinical Presentation of Ophthalmic Aneurysms

Type	Symptoms
Acute	SAH, epistaxis, transient ischemic attack/embolic stroke, acute monocular blindness (thrombosis), acute visual field cut, oculomotor deficit, seizures, headache
Subacute/chronic	Visual deficits, including ipsilateral optic nerve (inferior nasal cut, nasal hemianopia, nasal hemisnopia + superior temporal cut, and monocular blindness), chiasmal (bitemporal hemianopia), and combined (chiasmal + ipsilateral optic nerve compression)
	Additional visual deficits include hypothalamic/pituitary dysfunction, diplopia/oculomotor deficit, headache, retro-orbital pain, facial numbers (cranial nerve V, frontal division distribution), upper brainstem compression, seizures
Incidental	SAH from distant aneurysm, brain imaging for unrelated causes (eg, trauma, stroke), screening (eg, family history)

Courtesy at the Mayfield Clinic, Cincinnati, OH.

88 C6 segment aneurysms were admitted to our service. Patients with cavernous and transitional aneurysms were excluded from this analysis.

Total Series

Of 78 patients, 43 presented with unruptured aneurysms and 35 presented with SAH. There were 9 giant (diameter > 25 mm) and 25 large (diameter: 11–25 mm) aneurysms. Aneurysm size ranged from 3 mm to 27 mm (mean diameter = 10.26 mm). Of 28 patients (35.9%) who had multiple aneurysms, 9 (11.5%) had bilateral ophthalmic aneurysms and 1 (1.2%) had 2 distinct aneurysms on the same ICA C6 segment. A history of familial intracranial aneurysms was present in 12 (15.4%) patients. Management strategies included surgical clipping alone in 53 patients, clipping and hemicraniectomy in 2, coiling in 17, extracranial-to-intracranial (EC-IC) bypass in 2, and coil occlusion of the ICA in 2. Of 2 patients who underwent no treatment, 1 had a myocardial infarction after diagnostic angiography and 1 declined treatment. Overall mortality was 6.4% (5 patients with SAH). At discharge, Glasgow Outcome Scale (GOS) scores were good (GOS score of 1 or 2) in 63 (80.8%) patients and poor (GOS score of 3 or 4) in 10 (12.8%) patients. Presentation, demographic data, aneurysm location, and outcomes are summarized in Tables 4 through 6.

Unruptured Aneurysms

Forty-three patients (38 women and 5 men) had 49 unruptured ophthalmic aneurysms (see Tables 4, 6), including 5 patients with bilateral ophthalmic aneurysms and 1 patient

TABLE 2. Summary of Classifications of C6 Segment Aneurysms

Author, Year (Reference)	Classification
Kothandaram et al, 1971 (13)	Subchiasmatic, suprachiasmatic, and anterior wall
Thurel et al, 1974 (21)	Latero-optochiasmatic, suboptochiasmatic, suprachiasmatic, and global
Almeida et al, 1776 (4)	Latero-optochiasmatic and suboptochiasmatic
Pia, 1978 (19)	carotid-opthalmic (ventromedial, ventrocraniomedial), infraopthalmic that includes large (suprachiasmatic, infrachiasmatic) and nonlarge (supraoptic, infraoptic, paraoptic), and supraopthalmic
Day, 1990 (8)	Opthalmic artery and superior hypophyseal (paraclinoid and suprasellar)
Al-Rodhan and Piepgras, 1993 (5)	Supraopthalmic (superior hypophyseal and ventral paraclinoid), ophthalmic, infraopthalmic supracavernous (cave), transitional, and cavernous
Batjer et al, 1994 (7)	Carotid-opthalmic, superior hypophyseal, proximal posterior carotid, and giant paraclinoidal
Fries et al, 1997 (10)	Opthalmic, superior hypophyseal, proximal posterior wall, and partially intracavernous
Kumon et al, 1997 (14)	Subchiasmatic, lateral chiasmatic, suprachiasmatic, carotid cave, and paraclinoid
De Jesus et al, 1999 (9)	Clinoid (media [cave], lateral, anterior, posterior [not observed]), paraclinoid (medial, anterior, posterior, lateral [not observed]), and superior hypophyseal
Tanaka et al, 2002 (20)	Supraclinoidal, clinoidal, and infraclinoidal
Barami et al, 2003 (6)	Opthalmic artery, dorsal ICA, ventral ICA, supradiaphragmatic, infradiaphragmatic, clinoid segment of ICA

Courtesy of the Mayfield Clinic, Cincinnati, OH.

TABLE 3. Special Locations of Opthalmic Aneurysms

Author, Year (Reference)	Classification
Nutik, 1988 (16)	Ventral paraclinoid
Kobayashi et al, 1989 (12)	Carotid cave
Nakagawa et al, 1986 (15)	Dorsal ICA
Ishikawa et al, 1997 (11)	Blood blister-like
Ogawa et al, 2000 (18)	ICA trunk (anterior, medial, lateral, posterior)
Nutik, 2003 (17)	Subclinoid

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with 2 aneurysms on the same C6 segment. Patient age ranged from 33 to 77 years (mean age = 52.4 years). In these 43 patients with 49 aneurysms, 38 aneurysms underwent surgical clipping (3 patients with bilateral aneurysms had 2 separate operations), 12 had endovascular coil occlusion (1 patient with bilateral aneurysms had coil occlusion at a separate session), 1 underwent EC-IC bypass and cervical carotid ligation, and 2 underwent no treatment (previously described). Forty-six aneurysms were treated in 41 patients, including 1 patient who underwent clipping of 2 aneurysms on the same ICA C6 segment and 4 patients who had clipping of bilateral C6 segments. Treatment failures included 1 surgical exploration of a calcified aneurysm that could not be clipped and was eventually coiled, and 4 failed coiling attempts in 3 patients. Two of these aneurysms were ultimately successfully clipped, and 1 (which had 2 failed coiling attempts) was wrapped after surgical exploration.

Procedure-related morbidity was 15.7% (8 of 51 procedures), and permanent morbidity was 9.75% (4 of 41 patients). Morbidity in surgical patients was caused by a postoperative visual field defect in 3 patients, cerebrospinal fluid (CSF) leak in 2 patients (1 required 2 surgical explorations), transient cranial nerve III palsy in 1 patient, and stroke in 1 patient (posterior parietal middle cerebral artery [MCA] stroke after bypass). In the 2 coiling-related morbidities, 1 patient had a postprocedural groin hematoma that was medically treated and 1 had an acute visual loss after endovascular thrombosis that required surgical decompression of the optic nerve. At discharge after 51 procedures for 46 aneurysms in 41 patients, GOS scores were good (GOS score of 1 or 2) in 40 patients (97.6%) and poor (GOS score of 3) in 1 patient (see Table 6).

Ruptured Aneurysms

Thirty-five patients (32 women and 3 men) presented with SAH. Patient age ranged from 27 to 67 years (mean = 49.3 years). Four patients had bilateral ophthalmic aneurysms (see Tables 5, 6). Of 35 patients, 27 underwent surgical clipping (2 also had a hemicraniectomy), 5 underwent endovascular coil occlusion, 2 underwent ICA coil occlusion, and 1 underwent EC-IC bypass. The 1 treatment failure involved a coiling attempt in a patient who later underwent successful aneurysm clipping.

In 35 SAH patients, mortality was 14.3% (5 patients), which included 1 patient who had fatal rebleeding after coil occlusion, 3 who died as a result of refractory vasospasm, and 1 who died as a result of intractable intracranial hypertension. Of 12 (34.3%) patients affected by clinical vasospasm, 3 (25%) required endovascular vasospasm treatment with transluminal balloon angioplasty and/or intra-arterial papaverine. Procedure-related morbidity was 11.1% (4 of 36 procedures). In 27 patients who underwent clipping, 1 experienced a postoperative visual field defect and 1 had a silent postoperative perforator infarction. One patient experienced

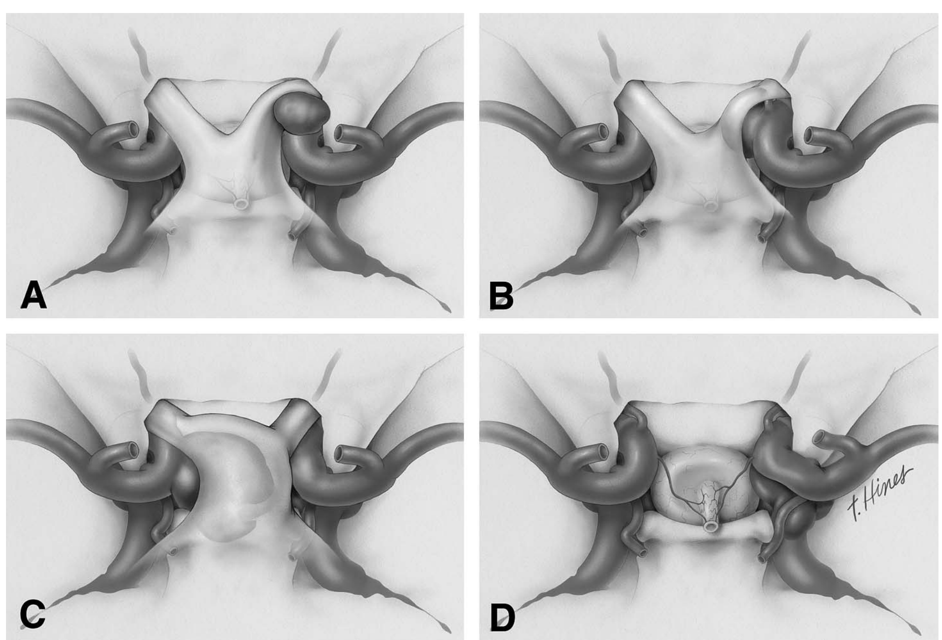

FIGURE 1. Four types of ophthalmic (C6) segment aneurysms. A, Type I, ophthalmic artery aneurysm with dorsal projection. B, Type II, ophthalmic artery aneurysm with medial projection. C, Type III, superior hypophyseal artery aneurysm with suprasellar projection. D, Type IV, superior hypophyseal artery aneurysm (paraclinoid projection). (Courtesy of the Mayfield Clinic, Cincinnati, OH.)

TABLE 4. Our Clinical Series of Presenting Symptoms in 43 Patients with Unruptured Aneurysms of the C6 Segment

Presenting Symptom	No. Patients (%)
Headache	17 (39.6)
SAH, other location	10 (23.2)
Mass effect	7 (16.3)
TIA	4 (9.3)
Prior SAH from ophthalmic aneurysm	3 (7)
Posttreatment aneurysmal regrowth	2 (4.6)
Total	43 (100)

TIA indicates transient ischemic attack.
Courtesy of the Mayfield Clinic, Cincinnati, OH.

an intraoperative aneurysmal rupture during an extradural anterior clinoidectomy, which was successfully controlled. In 5 patients who underwent coiling, 1 experienced a postprocedural groin hematoma that was treated medically, and 1 patient suffered intraprocedural thrombosis of the MCA, which recanalized after mechanical thrombolysis and abciximab infusion. At discharge, 21 patients (60%) had good (GOS scores of 1 or 2) outcomes and 9 (25.7%) had poor (GOS score of 3) outcomes (see Table 6).

TREATMENT OPTIONS

Treatment of aneurysms of the C6 segment of the ICA remains challenging and technically demanding for a number of reasons. First, the anatomy of this region is complex. These aneurysms are closely related to bony structures (eg, anterior clinoid process [ACP], sphenoid body), vascular structures (ICA and its branches), the visual system, the distal dural ring (DDR), the cavernous sinus and extradural compartment, and the pituitary complex. Second, aneurysm size is an important consideration in planning appropriate treatment. Many of these aneurysms are diagnosed when they are large (10–25 mm) or giant (>25 mm), when they are more often associated with thrombi or calcifications that pose hazardous management.

TABLE 5. Distribution of Clinical (Hunt and Hess) and Tomographic (Fisher grade) Scores in Our 35 Patients With SAH From Ruptured C6 Segment Aneurysms

Score/Grade	No. Patients
Hunt-Hess score	
1	4
2	19
3	6
4	5
5	1
Fisher grade	
1	5
2	4
3	25
4	1

Courtesy of the Mayfield Clinic, Cincinnati, OH.

TABLE 6. Demographic Data Distribution of Locations and Outcome in Our 78 Patients With C6 Segment Aneurysms

Variable	SAH	Unruptured	Total
Mean age (y)	49.34	52.41	51
Male/Female ratio	1:10.6	1:7.6	1:8.75
Mean aneurysm size (mm)	11.1	9.59	10.26
Aneurysm location			
Opthalmic	30	37	67
Carotid cave	2	4	6
Superior hypophyseal	4	3	7
Dorsomedial wall ICA	3	2	5
Subclinoid	—	2	2
Ventral paraclinoid	—	1	1
Total	39	49	88
GOS score*			
1–2	21 (60%)	42 (97.6%)	63 (80.8%)
3–4	9 (26.7%)	1 (2.4%)	10 (12.8%)
5	5 (14.3%)	—	5 (6.4%)

*Percentages are related to each group in the series for SAH and unruptured aneurysms. The final column reflects overall outcome.
Courtesy of the Mayfield Clinic, Cincinnati, OH.

Third, the occurrence of multiple aneurysms in approximately 50% of cases complicates identification of the bleeding source in cases of SAH presentation, and thus the decision for treatment.

Direct surgical therapy has been associated with high rates of morbidity and mortality.[4,13,22–25] Alternative and indirect methods of treatment were developed consequently, including endovascular procedures (ie, coiling, balloon exclusion of the aneurysm, coiling plus stent) and carotid occlusion (ie, ligation in the neck, permanent balloon occlusion [PBO], trapping of the aneurysm) with or without the need for bypass procedures. Treatment goals always include complete exclusion of the lesion and preservation of the parent vessel as well as its branches and perforators. A direct approach to the aneurysm still represents the preferred method for complete and permanent obliteration of the lesion, especially because refinements in microsurgical techniques have improved morbidity and mortality rates. Advances in indirect procedures offer suitable alternative solutions, however. The synergistic use of surgical and endovascular procedures seems to offer the best approach to these aneurysms.

Direct Treatment: Surgery

The first objective of direct treatment is the establishment of proximal artery control with surgical or endovascular procedures. During surgical treatment, the ICA is exposed at the neck (at the level of the petrous segment) or at the clinoid segment, as suggested by Dolenc.[26,27] Endovascular control is achieved by means of an intravascular balloon. The second objective is adequate exposure of the proximal neck of the lesion. Maneuvers such as removal of the ACP help to attain exposure for proper application of the clip. The third key objective, minimal manipulation of the optic nerve to avoid mechanical injury, is accomplished by unroofing the optic canal, sectioning the falciform ligament, and opening the dural sheath of the optic nerve. The final objective is decompression, especially for a large or giant aneurysm, so as to allow adequate dissection around it, proper clip application, and relief of mass effect. Understanding the relevant anatomy of this region, the presence of anatomical variations, and the radiologic features of the lesion is requisite for pursuing these goals (described in part 1).

Direct Treatment: Surgical Steps

We describe the surgical steps that we apply in the treatment of C6 segment aneurysms.

Operative Positioning

After the patient is positioned supine, the head is placed in a radiolucent Mayfield headholder for intraoperative angiography and is turned between 30° and 35° toward the opposite side. We always prepare the ipsilateral cervical carotid region, which is prepared and draped for proximal control in case external carotid artery–to–middle cerebral artery (ECA-MCA) bypass becomes necessary.

Anesthesia

We routinely administer prophylactic antibiotics, steroids, and mannitol after the patient is anesthetized in the operating room. Intraoperative monitoring, an electroencephalogram (EEG) or somatosensory-evoked potentials, is used for large or giant aneurysms when barbiturate or etomidate-induced metabolic depression is planned. Mild hypothermia (34°C) is maintained throughout the procedure. The neuroradiologist inserts a femoral artery catheter for intraoperative angiography. Spinal drainage is not routinely used.

Exposure of Cervical Carotid Artery

An incision along the border of the sternocleidomastoid muscle is marked. In all cases, we expose the cervical carotid bifurcation. Vessel loops are passed around the common carotid artery (CCA) and ECA. For temporary clipping, a Fogarty clamp is placed on the CCA and a 7-mm or 9-mm temporary clip is placed on the ECA.

Craniotomy

The scalp incision extends from 1 cm crossing the midline to the zygomatic arch using a hair-sparing technique in most cases. Care is taken to preserve the branches of the superficial temporal artery. The skin flap is reflected anteriorly along with the pericranium. Dissection of the temporalis muscle is performed in a subfascial manner to preserve the frontalis nerve. A frontotemporal craniotomy extends up to the supraorbital notch. The sphenoid ridge is flattened, followed by an orbital osteotomy. The superior orbital fissure is unroofed extradurally by removal of the lesser and greater wings of the sphenoid bone. A decision then is made whether to proceed with removal of the ACP extradurally or to perform an intradural bony resection.

Clinoidectomy

We prefer to perform a clinoidectomy and extradural decompression of the optic nerve canal in most patients. With the aneurysm protected by the dura, drilling is usually safe. When compared with an intradural clinoidectomy, the extradural procedure is quicker because the subarachnoid spaces are not contaminated with bony dust and it does not demand such great delicacy for its safe performance. Furthermore, an extradural clinoidectomy facilitates anatomical orientation and extensive removal of the optic canal.

We reserve the use of intradural clinoidectomy for cases in which aneurysms have eroded the ACP, for especially large aneurysms lying just beneath the ACP, and in the presence of a carotico-clinoid foramen, which forms from the bony fusion of the middle clinoid process (MCP) with the ACP. We strongly recommend the use of preoperative computed tomography (CT) scanning to diagnose this anatomical variant of bony fusion, which may also include a pneumatized clinoid process.

Extradural Clinoidectomy

After removal of the orbit, elevation of the dura from the floor of the anterior fossa exposes the planum sphenoidale and the entrance of the optic nerve into the optic canal (Fig. 2). The dura is then separated from the sphenoid ridge and superior orbital fissure. The dura folds are cut, and the dura is peeled off the lateral wall of the cavernous sinus. With gentle retraction of the dura and the underlying frontal and temporal lobes, the ACP can be drilled, beginning in its inferolateral aspect and proceeding in the posteromedial direction. A Midas Rex drill (AM-8 diamond bit) is used under continuous irrigation and with the aid of the operating microscope. The optic strut is then removed. The optic canal is opened on the lateral and superior aspects; after removal of the optic strut, the canal is opened in the inferior aspect. The bone is thinned until a thin rim remains. We always use a microcurette (never micropunches) to remove it. The ACP is cored out while still remaining within the cortical bone. A plane of dissection is created to separate the dura from the ACP and is removed en bloc using a microrongeur. If venous bleeding occurs from the cavernous sinus, oxycellulose with cotton sponge compression is used to achieve hemostasis.

Drilling the ACP presents a number of pitfalls. First, care is taken to avoid injury (ie, thermal injury) of the optic nerve by use of continuous irrigation and to avoid mechanical injury by use of microcurettes to unroof the optic canal. Second, unroofing the optic canal does not extend beyond the medial border so as to avoid the ethmoid sinus. Third, care must be taken not to open the sphenoid sinus during drilling of the optic strut. Finally, the walls of the hollowed ACP are checked after each drilling period to preserve the surrounding structures (ie, ICA). After the ACP is removed, the dura is incised in a direction parallel to the ACP.

Intradural Clinoidectomy

If the aneurysm is in direct contact with the ACP, an intradural clinoidectomy is selected (Fig. 3A–C). The dura is

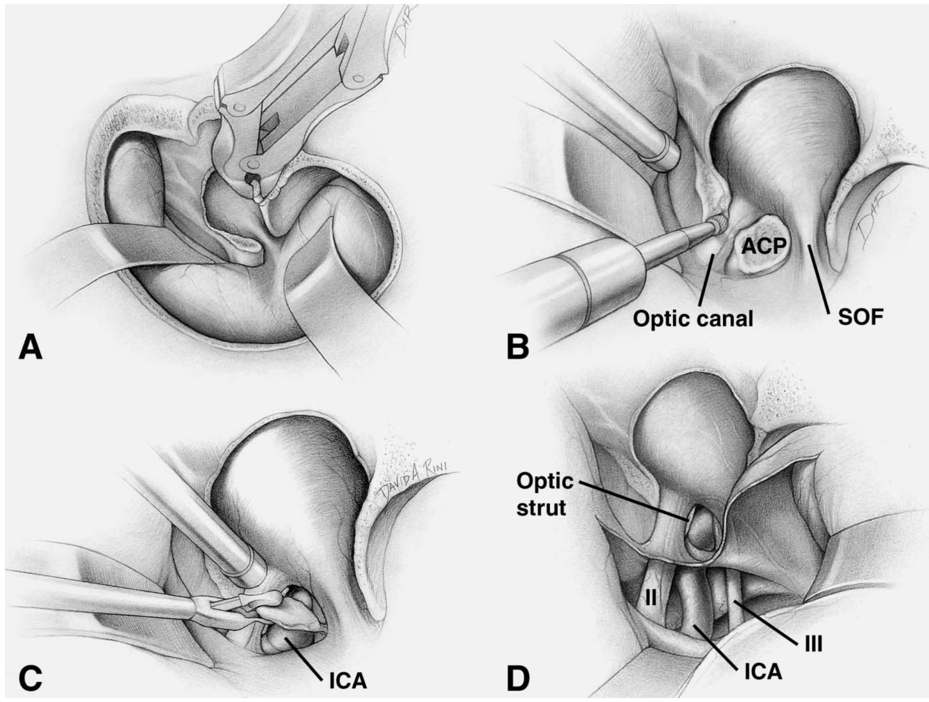

FIGURE 2. Operative steps for extradural clinoidectomy. A, Dura is retracted to expose the orbital roof, which is entered with a high-speed drill. The posterior half of the orbital roof is removed with a punch. B, Diamond burr is used to remove the bony roof of the optic canal and to hollow out the anterior clinoid process (ACP). C, ACP is hollowed out to separate it from the optic strut. D, T-shaped dura incision provides access to the floor of the frontal and middle fossae. ICA indicates internal carotid artery; II, optic nerve; III, oculomotor nerve; SOF, superior orbital fissure. (*From* Tew JM, Jr, van Loveren HR. *Atlas of Operative Microneurosurgery*, vol. 1. Philadelphia: WB Saunders; 1994:86–87; with permission.)

opened in a C-shaped manner and is anchored with stay sutures. Under the operating microscope, the Sylvian fissure is split. The frontal and temporal lobes are gently retracted, and the cisterns are widely opened. The dura over the ACP is incised in a T-shaped manner. The dura is stripped away from the ACP using a microcurette and the AM-8 bit of the Midas Rex drill. The clinoid is drilled away under direct vision of the optic nerve and carotid artery. The optic strut is resected, and the optic canal is opened.

Clipping Technique

After completion of the clinoidectomy, the falciform ligament is sectioned for optic nerve mobilization, followed by sectioning of the DDR circumferentially around the ICA. These maneuvers allow complete visualization of any aneurysm located in the C6 segment of the ICA with perfect visualization of the ophthalmic artery. By lifting the optic nerve, the surgeon is able to see the ophthalmic artery and its relation to small aneurysms. Clip blades can be applied parallel to the artery in most small aneurysms. A fenestrated clip encircling the ICA may work better in aneurysms in a ventral location (see Fig. 3D).

Temporary trapping with suction and collapse of the aneurysm is often required for large or giant aneurysms (see section on combination techniques and suction-decompression methods). We prefer to puncture the aneurysm fundus directly for its deflation and facilitation of clipping. A variety of clips, including fenestrated clips, are used for these types of aneurysms. If the aneurysm is thrombosed, a thrombectomy is required and an endarterectomy is sometimes needed.

When an aneurysm is unclippable because of calcification of the aneurysm neck or incorporation of the aneurysm by the ICA, a bypass with a vein graft or radial artery is performed. We prefer to use the ECA as the proximal end of the anastomosis and the M2 segment of the MCA as the distal end of the anastomosis. Intraoperative angiography is always performed to confirm the occlusion of the aneurysm and the patency of the carotid artery.

Combination Techniques and Suction-Decompression Methods

The combination of surgical and endovascular techniques allows surgeons to solve problematic issues, such as large or giant aneurysms, intraluminal thrombus, a broad neck, plaque at the neck, and potential compromise of branches at the aneurysm base. Important adjuncts in the treatment of difficult aneurysms are intravascular and intraluminal surgical maneuvers that facilitate the definitive surgical clipping of these lesions.[28]

Complete and permanent exclusion of the lesion is made possible by the combination of a direct surgical approach and an intravascular neuroradiologic procedure for temporary occlusion of the ICA proximal to the aneurysm, especially for large or giant aneurysms. Additionally, distal surgical control affords occlusion of the ICA just proximal to the origin of the posterior communicating artery, and safe proximal control can be achieved when bleeding occurs during dissection.[29] Furthermore, these maneuvers can be combined with a suction-decompression technique. During a trapping maneuver to empty the aneurysm sac and facilitate dissection and clipping, the suction-decompression technique allows

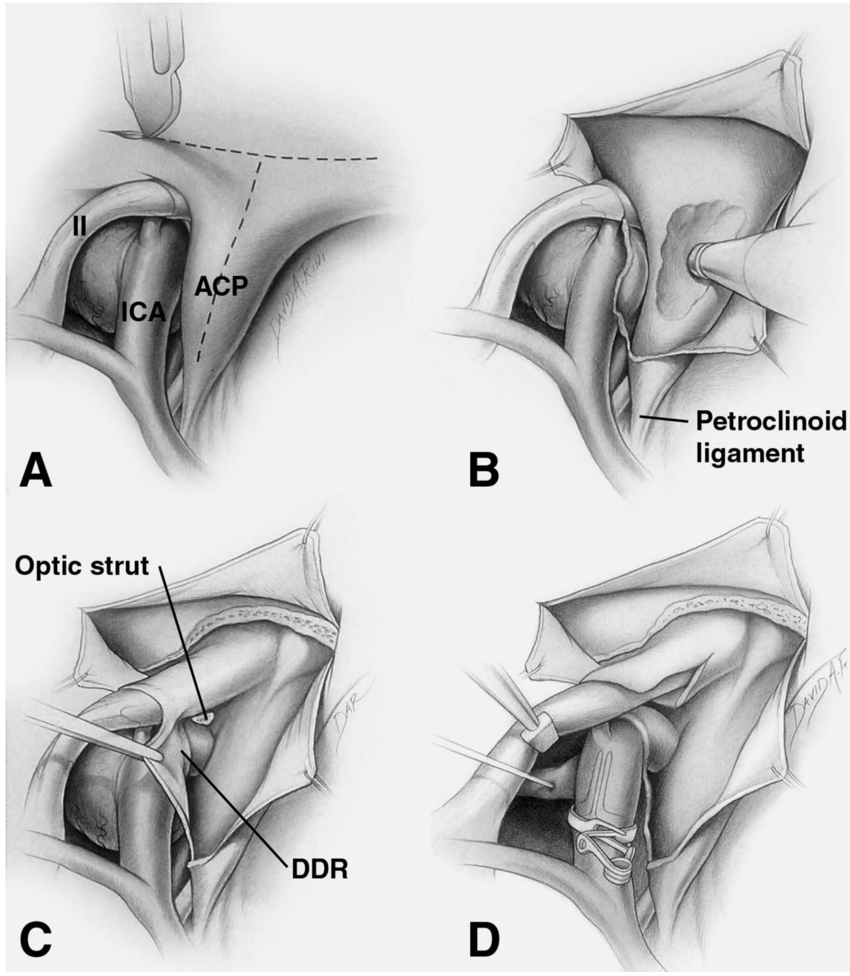

FIGURE 3. Operative steps for intradural clinoidectomy. A, T-shaped dura incision is made over the anterior clinoid process (ACP). B, Drill is used to remove the ACP; the tip of the clinoid is disarticulated from the clinoid ligament. C, Medial dura flap is reflected to expose the distal dural ring (DDR). D, Optic nerve is retracted, and a right-angle fenestrated clip closes the aneurysm base. ICA indicates internal carotid artery; II, optic nerve. (*From* Tew JM, Jr, van Loveren HR. *Atlas of Operative Microneurosurgery*, vol. 1. Philadelphia: WB Saunders; 1994:96–98; with permission.)

evacuation of retrograde blood flow through the ophthalmic artery from the ECA and the cavernous ICA branches.[28–32]

Different techniques are used for suction and decompression of the aneurysm during its dissection.[33–35] We use the following technique, which is similar to that described by Sinson et al.[28] After temporary trapping or occlusion of the ICA in the neck and distal to the lesion, the aneurysm is directly aspirated with a needle and/or is decompressed from a thrombus or calcification after its incision and evacuation by suction or ultrasonic aspiration. This technique requires exposure of the ICA in the neck or ICA control proximal to the aneurysm, which is not always feasible.

Batjer et al[7] first described a retrograde suction method of collateral blood aspiration through an intravenous catheter surgically placed in the cervical ICA. Fan et al.[34] proposed a variation of this technique in which the CCA and ECA (rather than the cervical ICA) were clamped. Aspiration of blood proximal to the ECA clamp then avoids arterial dissection and distal embolization from an atheromatous ICA.

Shucart et al[29] described temporary PBO of the parent vessel during aneurysm clipping using a percutaneous femoral approach and sparing the vessel exposure in the neck. Scott et al[35] combined the last 2 techniques, thus avoiding the need for surgical exposure of the cervical ICA. They used a double-lumen occlusion balloon catheter whose tip was positioned in the distal cervical segment of the ICA, applying occlusion of the vessel and suction to collapse the aneurysm with the same device. This technique was subsequently and successfully applied by several authors.[30–32] Disadvantages of the combined technique relate to its rate of complications, which is estimated as 1.5% because of stroke primarily from embolism and arterial dissection.[30]

Closure

The dura defect around the ACP is covered with a piece of muscle and a small pericranial flap to prevent any CSF leak through the sphenoid sinus. The dura is then sutured and reinforced with fibrin glue because it cannot be closed in a watertight manner. Replacement of the bone flap and closure of the temporalis muscle are followed by subgaleal drain placement and skin closure.

Direct Treatment: Other Approaches

Aneurysms located in the C6 segment of the ICA can be clipped from the contralateral side, particularly in patients with bilateral aneurysms or carotid cave aneurysms. The aneurysms

TABLE 7. Summary of Clinical Series of Aneurysms on C6 Segment of the ICA

Author, Year (Reference)	No. Patients	Treatment Modality	Percentage		
			Good Outcomes	Morbidity	Mortality
Drake et al, 1968 (22)	14	Surgery	40	N/A	60
Kothandaram et al, 1971 (13)	19	Surgery	68	16	16
Guidetti and La Torre, 1975 (23)	26	Surgery	58	15	27
Almeida et al, 1976 (4)	8	Surgery	75	25	0
Sengupta et al, 1976 (24)	32	Surgery	35	37	28
Yasargil, 1984 (52)	25	Surgery	88	12	0
Fox, 1988 (39)	8	Surgery	75	25	0
Day, 1990 (8)	54	Surgery	87	7	6
Mizoi et al, 1993 (31)	8	Combined	100	33	0
Batjer et al, 1994 (7)	89	Surgery	87	12	1
Kumon et al, 1997 (14)	15	Surgery	67	33	0
De Jesus et al, 1999 (9)	35	Surgery	88	8	4
Dolenc, 1999 (27)	143	Surgery	95	3	2
Hoh et al, 2001 (40)	145	Surgery	89	8	3
Hoh et al, 2001 (40)	38	Endovascular	74	22	4
Barami et al, 2003 (6)	61	Surgery	93	2	5
This series, 2004	78	Surgery and endovascular	81	13	6

N/A indicates not applicable.
Courtesy of the Mayfield Clinic, Cincinnati, OH.

should be less than 15 mm; have a small neck; and project medially, ventromedially, or ventrosuperiorly. Proximal control is usually achieved endovascularly by placing a temporary balloon into the cervical ICA. It is important to have a slack brain and to create a more medial extension of the craniotomy and orbital osteotomy.[36,37] The position of the optic chiasm may be a limiting factor, particularly if it is prefixed. The use of long aneurysm clips is frequently necessary. The bifrontal interhemispheric approach, which allows minimal retraction of the frontal lobes, has been proposed for bilateral, small, and medially projecting aneurysms when the chiasm is prefixed and the contralateral approach is thus unfeasible. When associated with the unroofing of the optic canal, the bifrontal interhemispheric approach allows wide and safe mobilization of the optic nerve on the medial and lateral aspects. Therefore, it provides a wide surgical field for aneurysms that lie beneath the optic nerve and chiasm. Proximal control is achieved by exposure of the cervical ICA or by temporary balloon occlusion (TBO) endovascularly.[38]

Surgical Outcome

In 1968, Drake et al[22] presented 14 paraclinoid aneurysms, including small ones, in which 40% of patients achieved good outcomes and 60% died. Clinical series published within the past 25 years have shown substantial improvement of the results (Table 7).[4,6–9,13,14,22–25,27,31,39,40] In a 1990 review of 54 patients with C6 segment aneurysms, Day[8] reported good outcomes in 87%. In a 1994 study of a surgical series of 89 paraclinoid aneurysms, Batjer et al[7] reported good outcomes in 87% of patients and 12% morbidity. In 2001, Hoh et al[40] reported on the surgical and endovascular treatment of paraclinoid aneurysms in which 90% of the 145 surgically treated aneurysms had good outcomes (GOS score of 4 or 5). Our surgical series compares favorably with these published results. Some studies focused on large or giant aneurysms only (Table 8).[7,30,41–52]

Although the population characteristics may differ and the outcome measures vary, the overall analysis of these results shows a marked decrease over time in postoperative mortality and morbidity. The numbers of patients with good outcomes continue to increase, whereas the numbers of those with poor and fair outcomes continue to decrease. This positive trend can be explained by the combination of better patient selection, preoperative planning of appropriate treatment, and refinements in surgical and endovascular procedures. An analysis of the published clinical series shows higher morbidity and mortality for large and giant aneurysms when compared with smaller C6 segment lesions, however. Nevertheless, there is also a trend toward better outcomes for aneurysms exceeding 10 mm because of the introduction of endovascular techniques alone or in combination with surgery.

Indirect Treatment: Carotid Occlusion With or Without Bypass

Carotid occlusion continues to play an important role in certain giant and complex carotid aneurysms when the lesion is judged to be unclippable. Occlusion can be accomplished by trapping the aneurysm during endovascular techniques (eg, PBO, coiling the parent vessel) or surgical ligation of the ICA. Proximal or Hunterian ligation of the ICA in the neck for the treatment of unclippable carotid aneurysms was reported more than 100 years ago. Drake et al[43] reported the results of Hunterian proximal arterial occlusion for giant aneurysms of the carotid circulation, including trapping the aneurysm, Selverstone clamps placed on the proximal cervical ICA, microtourniquet, and balloon occlusion. Complete thrombosis

TABLE 8. Clinical Series of Large and Giant C6 Segment ICA Aneurysms

			Percentage		
Author, Year (Reference)	**No. Patients**	**Treatment Modality**	**Good Outcomes**	**Morbidity**	**Mortality**
Hosobuchi, 1979 (45)	19	Surgery	71	N/A	29
Sundt and piepgras, 1979 (50)	20	Surgery	91	8	1
Heros et al, 1983 (44)	33	Surgery	50	37	13
Yasargil, 1984 (52)	17	Surgery	75	6	19
Symon and Vajda, 1984 (51)	6	Surgery	67	16	17
Perneczky et al, 1987 (48)	12	Surgery	75	N/A	25
Ausman et al, 1990 (41)	14	Surgery	92	N/A	8
Dolenc, 1994 (42)	29	Surgery	N/A	N/A	7
Drake et al, 1994 (43)	110	Surgery	88	6	6
Batjer et al, 1994 (7)	22	Surgery	59	N/A	5
Levy et al, 1995 (47)	44	Surgery	92	N/A	8
Shibuya and Sugita, 1996 (49)	19	Surgery	84	N/A	8
Arnautovic et al, 1998 (30)	16	Surgery	88	6	6
Kattner et al, 1998 (46)	29	Surgery	N/A	20	3
This series, 2004	33	Surgery and endovascular	76	12	12

N/A indicates not applicable.
Courtesy of the Mayfield Clinic, Cincinnati, OH.

of the aneurysm was obtained in most instances, but thromboembolism was reported as a complication of the carotid occlusion. The risk of thromboembolism was reduced by the use of abrupt rather than gradual occlusion of the proximal vessel by clamping the carotid as close to the origin of the sac as possible and with administration of heparin. They reported an 84% of success of proximal Hunterian ligation of the ICA, which was performed in 21% of their patients with giant paraclinoid aneurysms. Trapping of the aneurysm was recommended when feasible, because the risk of embolism was higher when the ICA segment distal to the aneurysm was not occluded.

Endovascular PBO represents an alternative treatment of unclippable aneurysms that is less invasive but is associated with a consistent risk of embolism. Serbinenko et al.[53] reported on 9 patients with giant ICA aneurysms and insufficient collateral circulation who underwent a single-stage procedure for EC-IC bypass and endovascular ICA occlusion. They advocated transcranial exposure of the lesion and trapping in cases of persistent filling of the lesion after the endovascular procedure.

One major source of complication is that the brain cannot tolerate permanent occlusion. If cerebral blood flow (CBF) studies are not performed, Nishioka[54] reported that ischemic complication rates can be as high as 41%. Thus, the risk of hemodynamic stroke should also be minimized by preoperative evaluation of the collateral circulation. Whatever the method, carotid occlusion needs to be planned before surgery. A test balloon occlusion, with or without CBF studies, is always required to ascertain the blood reserve through collateral flow and thus the need for bypass surgery.

At the University of Cincinnati, a test protocol for TBO has been developed (Fig. 4).[55] Collateral flow is evaluated by selective angiography and by reduction of the mean arterial pressure by 25% to 30%, with the patient undergoing continuous clinical neurologic testing. Technetium hexylmethylpropylene amineoxine (TcHMPAO) single-photon emission computed tomography (SPECT) imaging or xenon-enhanced CT is performed to assess asymmetry in CBF during TBO. An EC-IC arterial bypass is recommended for patients in whom TBO fails, those with asymmetry on the SPECT scan, or those with CBF less than 30 cm^3/100 g/min. We prefer to perform a saphenous vein bypass graft, followed by permanent vessel occlusion. We prefer to use the ECA as the bypass pedicle and an M2 branch of the MCA as the bypass recipient. These indirect approaches are associated with the risk of ischemic complications, however, mostly from embolism. Rates of embolic complications after EC-IC bypass surgery and ICA occlusion are approximately 8%.[50,56,57]

Indirect Treatment: Endovascular Procedures

The endovascular treatment of intracranial aneurysms began with the use of detachable latex balloons by Serbinenko et al[53] in 1973. These balloons were used primarily for parent artery occlusion and for selective aneurysm occlusion with preservation of the parent artery in select cases. The success of this technique for selective occlusion of intracranial aneurysms that were neither large, giant, nor broad-necked was limited, however, because the balloons did not conform to the shape of the aneurysmal lumen and exerted forces on the lesion wall. The development of electrolytically detachable coils (Guglielmi detachable coils [GDCs]) enabled significant advances for the selective endovascular occlusion of intracranial aneurysms. The goal of this technique is to fill the lumen as completely as possible with coils, resulting in thrombosis of the aneurysm by disruption of the flow pattern within it. The most successful aneurysmal occlusions are achieved in small aneurysms with small necks and in lesions located within the concavity of a vessel curvature in which the catheter tends to follow the curve. In contrast to terminal aneurysms, lateral wall aneurysms have a higher probability of achieving immediate thrombosis and less chance of recanalizing. Two studies[58,59] reported excellent results in

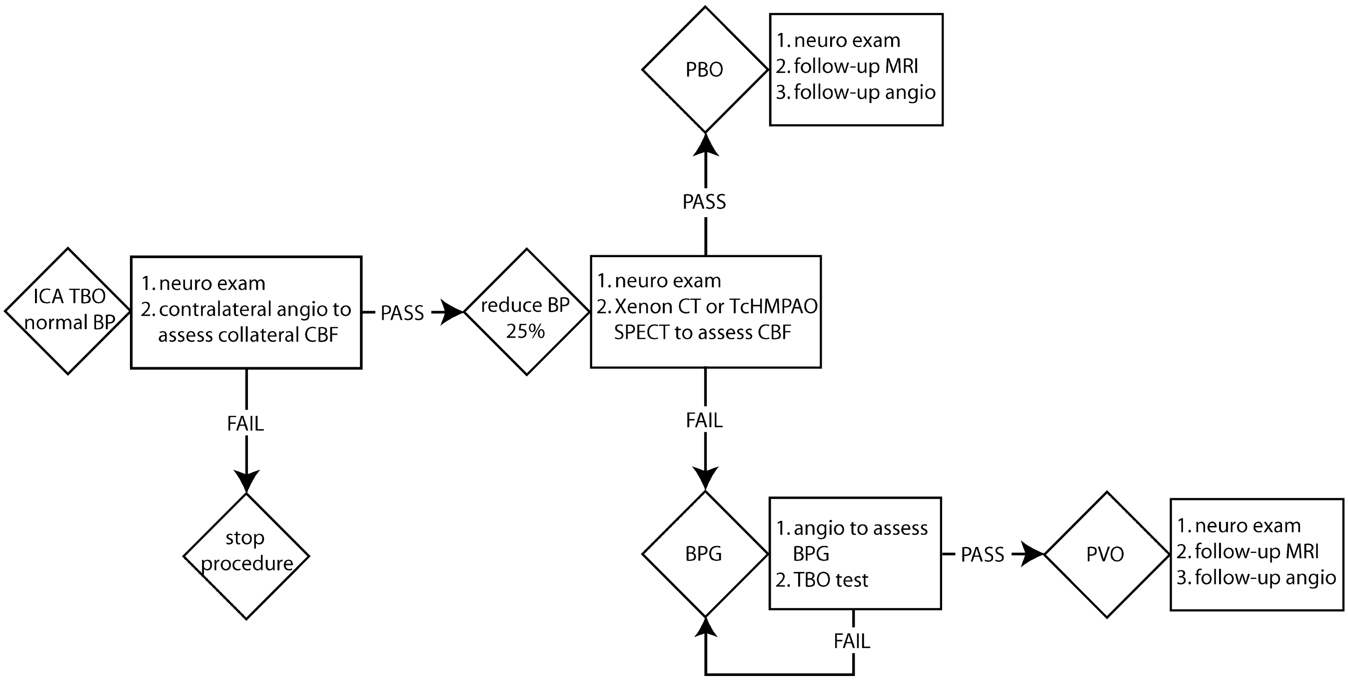

FIGURE 4. Temporary balloon occlusion (TBO) test protocol for treatment of large and giant unclippable aneurysms. BP indicates blood pressure; BPG, bypass graft; PBO, permanent balloon occlusion; CBF, cerebral blood flow; CT, computed tomography; ICA, internal carotid artery; MRI, magnetic resonance imaging; PVO, parent vessel; SPECT, single-photon emission computed tomography; TcHMPAO, technetium hexylmethylpropylene amineoxine. (Courtesy of the Mayfield Clinic, Cincinnati, OH.)

coiling aneurysms of the superior hypophyseal arteries, which usually have a small neck.

The most problematic area in the embolization of aneurysms is giant lesions. Because the size of the aneurysmal neck is the best predictor of the anatomical results, large or giant lesions, which are usually broad-necked, pose a high risk of coil protrusion into the parent vessel. The recanalization rate for giant aneurysms exceeds that of smaller ones; complete thrombosis using coils is difficult to obtain without sacrificing the ICA. Furthermore, these lesions often present with mass effect, which can worsen by packing the coils. Cerebral embolism represents the main device-related morbidity. Other complications include parent vessel thrombosis and aneurysm perforation.[59–62]

Endovascular Outcome

The North American experience in the first 735 patients treated with GDCs reported an 8.7% overall morbidity and 0.9% mortality in unruptured aneurysms.[27]

The percentage of incomplete occlusion of the lesion with subsequent refilling on angiograms is higher after coiling than after surgical procedures. Some aneurysms not only regrow, but the coils more often undergo compaction because of blood pressure. For these reasons, risks of rebleeding still exist with coiling treatment.[58]

In clinical series (Table 9),[40,59,61,62] the outcomes and the morbidity and mortality rates in the treatment of intracranial and carotid-ophthalmic aneurysms are similar for endovascular and surgical treatments. The angiographic efficacy of aneurysm obliteration and long-term rates of complete occlusion seem to be higher with surgery, however.[40] In addition, the long-term effectiveness of endovascular treatment is yet unproven.[61] For these reasons, the actual indications for endovascular occlusion of aneurysms are the following: failure of surgical exploration, patients with high surgical risk, and anatomical risk factors of the lesion (ie, aneurysm shape and neck size, relation to bony architecture).[59–62] Endovascular treatment of large and giant lesions is also restricted to patients who are elderly or have a poor clinical grade.[59] In addition, a staged approach with stabilization of the patient's condition by endovascular coiling, followed by surgical clipping, may be beneficial in some circumstances (eg, SAH).[60]

TABLE 9. Summary of Clinical Series of C6 Segment Aneurysms Treated With Endovascular Procedures

Author	No. Patients	Percentages		
		Good outcomes	Morbidity	Mortality
Roy et al, 1997 (59)	26	85	4	11
Thornton et al, 2000 (62)	66	94.3	3.3	2.2
Hoh et al, 2001 (40)	38	74	22	4
Park et al, 2003 (61)	70	88.9	4.8	6.3

Courtesy of the Mayfield Clinic, Cincinnati, off.

Endovascular Treatment: Other Techniques

Refinements and advances in endovascular techniques offer new solutions and helpful devices. The neck remodeling or balloon-assisted embolization techniques are helpful in the endovascular treatment of wide-necked aneurysms, because an inflated balloon prevents coil herniation into the parent artery and allows coil packing. Potential complications of this technique include rupture of the parent artery or aneurysmal sac, however.[63]

The possibility of aneurysm treatment using stents has also been explored, especially with regard to sidewall lesions.[64,65] Endoluminal stents have been used alone (with high rates of failed obliteration) or in combination with coils, especially in wide-necked aneurysms, to retain the coils in the sac.[65] The 2 most important factors for the success of a stent are its flexibility and size of its interstices.

Mawad et al[64] reported that some cases of large and giant aneurysms treated with a combination of stent placement and liquid polymer injection resulted in complete obliteration of the sac. Development of the newer types of coated stents provides the greatest hope for future progress of this technique, offering the possibility of occlusion of the aneurysmal neck without the additional need for coiling.[64,66,67]

STRATEGIES AND CONCLUSIONS

The treatment of aneurysms that arise from the C6 segment of the ICA represents a challenge for cerebrovascular surgeons, including preoperative localization of the aneurysm in relation to the DDR (see part 1). After the determination that the aneurysm is located intradurally, preoperative planning includes CT scanning, digital cerebral angiography, and, more recently, CT angiography. The decision to coil or clip a C6 segment aneurysm remains controversial and cannot be made solely on scientific grounds. When possible, direct obliteration of the aneurysm is our preferred treatment. The development of cranial base approaches has improved surgical outcomes in this anatomically complex region. As described in part 1, removal of the ACP intradurally or extradurally is an essential surgical step that allows the necessary exposure of the proximal ICA, ophthalmic artery, and DDR. By circumferentially cutting the DDR, clip placement is always possible and safe. We routinely use intraoperative angiography to rule out the presence of any residual portion of the aneurysm or compromise of the patency of the ICA.

In cases of large or giant aneurysms that are considered unclippable, surgical or endovascular occlusion of the proximal ICA is considered. A test balloon occlusion protocol indicates whether the patient needs an ECA-MCA bypass before the ICA occlusion. Along with advances in surgical techniques, endovascular procedures are continually evolving. Although GDCs offer an alternative treatment of these aneurysms, ongoing issues concern the recanalization and incompleteness of aneurysm obliteration, particularly in aneurysms with a wider neck. Use of a balloon to remodel coils at the aneurysm neck and intravascular stents may increase the utilization of endovascular techniques.

With the evolution of surgical and endovascular techniques in the treatment of aneurysms of the C6 segment of the ICA, a skilled team that includes a cerebrovascular surgeon and an endovascular surgeon is essential to minimize morbidity associated with treatment and to achieve outstanding outcomes.

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