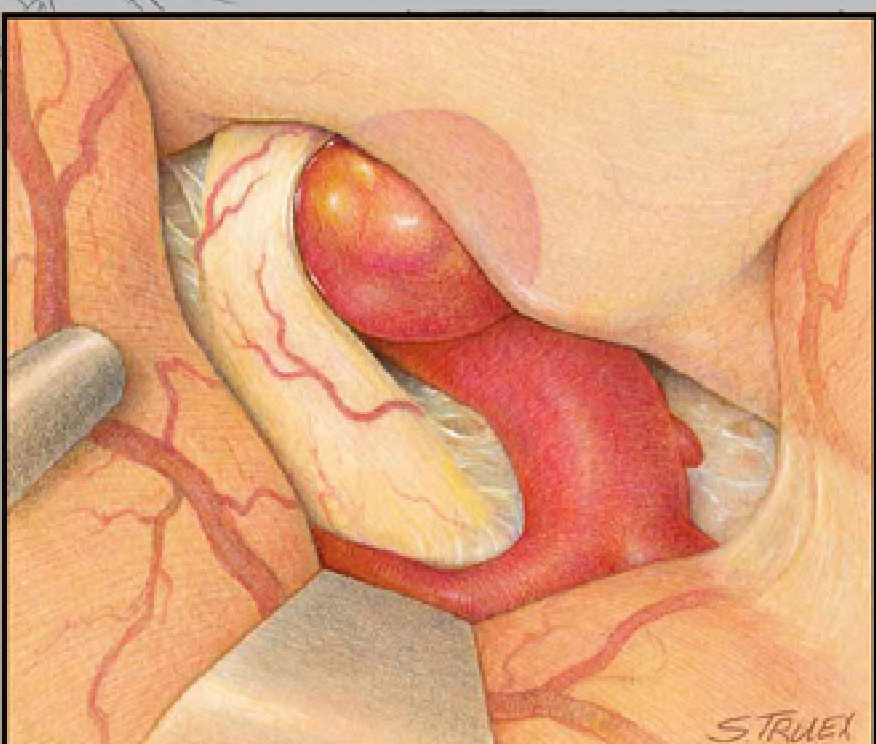
Intracranial Aneurysm Surgery: Basic Principles and Techniques

Duke S. Samson
H. Hunt Batjer
Jonathan White
J. Talmadge Trammell
Christopher S. Eddleman



Thieme

Intracranial Aneurysm Surgery: Basic Principles and Techniques

Thieme

Intracranial Aneurysm Surgery: Basic Principles and Techniques

Duke S. Samson, MD
Lois C. A. and Darwin E. Smith Distinguished Chairman in Neurological Surgery
Kimberly-Clark Distinguished Chairman in Mobility Research
Professor and Chairman
Department of Neurological Surgery
University of Texas–Southwestern Medical School
Dallas, Texas

H. Hunt Batjer, MD, FACS
Michael J. Marchese Professor of Neurosurgery
Professor and Chairman
Department of Neurological Surgery
Northwestern University Feinberg School of Medicine
Chicago, Illinois

Jonathan White, MD, FACS
Birsner Family Professorship in Neurological Surgery
Associate Professor and Program Director
Department of Neurological Surgery and Radiology
University of Texas–Southwestern Medical School
Dallas, Texas

J. Talmadge Trammell, MD
Neurosurgery Associates of West Texas
Hendrick Medical Center
Abilene, Texas

Christopher S. Eddleman, MD, PhD
Department of Neurological Surgery and Radiology
University of Texas–Southwestern Medical School
Dallas, Texas

Thieme
New York · Stuttgart

Thieme Medical Publishers, Inc.
333 Seventh Ave.
New York, NY 10001

Executive Editor: Kay Conerly
Managing Editor: Lauren Henry
Editorial Assistant: Judith Tomat
Editorial Director, Clinical Reference: Michael Wachinger
Production Editor: Kenneth L. Chumbley
Medical Illustrator: Suzanne Truex
International Production Director: Andreas Schabert
Vice President, International Marketing and Sales: Cornelia Schulze
Vice President, Finance and Accounts: Sarah Vanderbilt
President: Brian D. Scanlan
Compositor: Kenneth L. Chumbley, Publisher
Printer: Sheridan Press

Library of Congress Cataloging-in-Publication Data: Available from the publisher upon request.

Printed in the United States of America

5 4 3 2 1

ISBN 978-1-60406-693-7

Contents

Preface

In 1988 Hunt Batjer and I began to write a short text on basic operative techniques and approaches used in intracranial aneurysm surgery. The impetus for this shared effort was our mutual belief that there were no reliable, straightforward, "cut-on-the-dotted-line" sources available to help young, would-be aneurysm surgeons learn the tools of their trade. By that point in our own learning curves, we had individually and collectively committed enough serious mistakes to make us firm believers in the value of an "operation by the numbers" philosophy whenever possible—all that was missing was the instruction manual.

After the routine series of false starts (and a couple of divorces), *Intracranial Aneurysm Surgery Techniques* was published by Futura in 1990. For better or worse, we resisted our first impulse to title the book *Aneurysm Surgery for Dummies,* although when we later mentioned that lost opportunity to Dr. Charles Drake, he paused for a second then replied, "For . . . and by, eh?"

We all laughed so hard that Dr. Drake spilled his scotch.

Over the next several years, our text became gratifyingly popular with its intended audience, and Hunt and I both were the proud recipients of late night calls and quick thank-yous scribbled on progress note paper from surgeons who believed "the little aneurysm book" had helped them find an elusive contra-lateral A1 segment or finally close a broad-necked aneurysm that just refused to die.

Techniques went out of print in 1999. Subsequently, we resisted requests to reissue or revise the book, in part out of pure laziness, in part because of the large number of recently published volumes dedicated to cerebrovascular disease, and in part due to the increasing importance of endovascular techniques in the management of intracranial aneurysms.

Hunt and I contributed to many of those expansive textbooks and believed that, taken as a group, they offered more than adequate explanations of every surgical technique known to man, especially if the young surgeon was willing to pick and choose judiciously among the offerings. Additionally, faced with the rapid evolution of endovascular techniques, neither of us, frankly, wanted to invest large amounts of time and effort in the tedious description of technical exercises that, in the not-too-distant future, might well become as arcane as the art of pneumo-encephalography.

So what changed? All of us have other demands on our time, publishers continue to grind out impressive tomes devoted to operative techniques, and healthcare think tanks, such as the Advisory Group, predict that endovascular techniques, generally in the hands of neurosurgeons, will account for somewhere between 60–80 percent of all aneurysm treatment by 2020. In light of all this competition, what justifies a reexamination of the fundamental microsurgical techniques involved in aneurysm surgery?

First, even in the face of rapid development and impressive improvements in endovascular technology and techniques, there remain a large number of intracranial aneurysms for which microvascular surgery remains either the only or the preferable management option. Additionally, the complications of endovascular treatment have generated a unique subset of aneurysms requiring special surgical skills. Preparation to meet the challenges raised by all of these lesions begins with assimilation of basic aneurysm surgical techniques and the development of a conceptual framework for their use.

Second, we still believe the most reliable training ground for excellent microsurgical technique remains cerebrovascular disease in general and aneurysm surgery in specific. Realistically, if a surgeon has the requisite skills to deal successfully with the vagaries of aneurysm surgery, he or she has at least the technical abilities to deal with the breadth of neurosurgical pathology. Furthermore, despite the wide-spread availability of lengthy texts that address all aspects of intracranial vascular pathologies, there seems to remain a persistent demand, especially among young practioners, for nitty-gritty, “first-you-do-this-and-then-you-do-that” technical advice presented in a consistent, straight-forward, didactic format.

Third, over the past two decades, surgeons at our institution have treated almost 3,000 additional aneurysm patients, an experience that has significantly changed the technical nuts-and-bolts of my own practice. We don’t operate or teach using exactly the same principles as we did in 1989; I think (hope) that some of these changes help to make aneurysm surgery safer and simpler, and we’d like to share them with the next generation of cerebrovascular surgeons.

The volume is organized with general operating room principles first, followed by a sequential discussion of aneurysms of the carotid, middle cerebral, and anterior cerebral arteries. We then move to the posterior fossa, beginning proximally with lesions of the vertebral artery, then moving distally to the basilar apex. The book concludes with a discussion of the concepts and techniques we’ve found helpful in the surgical management of very large and giant aneurysms and a review of the unique problems posed by previously-coiled and /or stented aneurysms.

The five authors want to emphasize that the approaches, techniques, and tricks outlined in this brief volume represent only a single surgical philosophy in aneurysm management. As noted, all of us are aware of and in awe of the numerous other technical approaches described by the two master aneurysm surgeons, Drs. Drake and Yasargil, as well as more recent but equally inspired works by gifted vascular surgeons such as Bob Spetzler, Roberto Heros, Dick Winn, Art Day, and Mike Lawton. With appreciation—but no apologies—to these folks, this book is a “how-we-do-it-here-in-Dallas-and-Chicago” manual that is written for the express purpose of helping young aneurysm surgeons learn their craft.

Duke Samson
Dallas, Texas

Acknowledgments

As I've said many times, Hunt's move to Northwestern in 1996 dramatically lowered the mortality rates at both institutions, but he naturally remains a major part of the authorship of this "how to do it" manual. Tom Kopitnik, Bob Replogle, Mike Horowitz, and Babu Welch, all of whom have shared the burden of aneurysm surgery at Southwestern since 1990, have made major contributions to the thought process behind this text, and I sincerely appreciate their support and friendship.

One of my coauthors this time out is another University of Texas–Southwestern cerebrovascular disciple, Jonathan White, who actually bats from both sides of the vessel. After operating on over 600 aneurysms in his first five years of practice, Jon has now completed his formal endovascular training. He, and surgeons like him, are the bright future of our specialty, and I'm grateful for his unique perspective in this effort.

After some rumination, Hunt, Jon, and I felt that insights from another fresh viewpoint would offer a potentially important flavor to this educational endeavor. In consequence, we convinced an outstanding young neurosurgeon, Talmadge Trammell, to add his perspective in helping us translate our sometimes obtuse thought processes into legible diction. "T"—as he's known far and wide—has the unique viewpoint that comes only with the experience of carrying the gospel from the mother ship to a far planet. We are truly appreciative of his help.

Finally, we found the assistance of another dual-trained young neurosurgeon—Christopher Eddleman—to be an enormous help in bringing this project to successful completion. Chris, who has suffered under the tutelage of both senior authors, has not only patiently refined all of our initial offerings, but also provided valuable insights in his own chapter, "The Evolution of the Intracranial Aneurysm Surgeon."

The heart of this book is composed of illustrations that translate our barebones narrative into eloquent, anatomical fact. For this beautiful body of work, we're indebted to Suzanne Truex who devoted two years of her professional life to this effort and, consequently, has come to think of the basal cisterns as a second home.

No two individuals have contributed as much to the surgical management of intracranial aneurysms as Dr. Charles Drake and Dr. M. Gazi Yasargil. Their work, accomplishments, and friendship form the inspiration for this book.

Finally, one brief expression of personal gratitude to my wife, Dr. Patricia Bergen, and our fine sons, Daniel and Gabriel.

Abbreviations

A1—anterior cerebral artery (main trunk)

A2—anterior cerebral artery distal to anterior communicating artery and proximal to origin of frontopolar artery

A3—anterior cerebral artery between origins of frontopolar and callosomarginal

A4—anterior cerebral artery distal to callosomarginal, aka pericallosal

ACA—anterior cerebral artery

ACHRD—anterior choroidal artery

ACOMM—anterior communicating artery

AICA—anterior-inferior cerebellar artery

AVM—arteriovenous malformations

BIF—bifurcation

BA—basilar artery

CP—cerebellopontine

DACA—distal anterior cerebral artery

ICA—internal carotid artery

ICG—indocyanine green

M1 segment—main trunk of MCA

M2 segment—middle cerebral artery branches (emerging from bifurcation)

MCA—middle cerebral artery

OA—occipital artery

OPHT—ophthalmic artery
P1—posterior cerebral artery (P1 segment)
PCA—posterior cerebral artery
PCOMM—posterior communicating artery
PICA—posterior-inferior cerebellar artery
SAH—subarachnoid hemorrhage
SCA—superior cerebellar artery
SHA—superior hypophyseal artery
STA—superficial temporal artery
TBO—trial balloon occlusion
VA—vertebral artery
VBJ—vertebrobasilar junction
VLG—very large and giant

1

Operating Room Considerations: Equipment, Setup, and Culture

"Every journey begins with a single step."
Frodo Baggins, Esq.

The four of us agreed it might not be amiss to begin with the essentials of every operative procedure, the tools of our trade. We also surmised that a short section devoted to the OR team and OR culture might provide pioneering vascular neurosurgeons with some food for thought and a few negotiating chips as they look at a new job. The burden of our song here, as in the remainder of the book, is that the operative treatment of intracranial aneurysms has little margin for error; the better prepared the surgeon, the anesthesiologist, and the OR scrub team, the better the patient's chances of walking away from this encounter no worse off than when he walked in.

During the final years of training, a young neurosurgeon is up to her eyeballs in learning the techniques of microvascular surgery; consequently, during surgical procedures she is rightly focused on where and when to cut, coagulate, or clip. All of her concentration is centered on the physical process of exposure, dissection, and, ultimately, clip placement, which may render her oblivious to the surrounding supportive cocoon that is usually the result of someone's decades of surgical experience. That's the mentor's job: simplify the process, provide the guidance, and keep the patient safe while the younger surgeon finds her wings and ultimately develops her own style. But, unbeknownst to our young cerebrovascular surgeon, all components of this well-honed machine may not automatically transfer to a new region or hospital. A good time for a little forethought.

This chapter discusses some of the basic concepts essential to the establishment of a cerebrovascular OR and touches briefly on the critical operative culture we try to inculcate at our institution. Thus, in many ways, this will be a "how we do it" discussion, not aimed at changing the work patterns of well-established centers, but rather serving as a guide to the young neurosurgeon attempting to benefit from the experience gained by cerebrovascular teams routinely operating on 200+ aneurysms annually.

Equipment

The operating microscope has obviously been the cornerstone of microsurgery since Yasargil introduced it into routine use in Zurich in the late 1960s. There are currently several well-established international microscope vendors, each with multiple model lines, all of which cost exorbitant amounts of money. Microscope selection will naturally depend heavily on the young surgeon's prior experience, but there are several other significant issues that should figure into such an important purchase.

The first is adaptability—will this scope truly do every operation in every position you can imagine? Don't trust the rep—bottom line, the rep's job is to sell your hospital one very expensive piece of equipment. Regardless of the truth about the microscope's capabilities, do you think the rep might stretch it a little to make the sale? Hmmm.

Take the time to trial each of the microscopes under consideration, not just with a patient in the usual supine or prone positions, but in every imaginable posture—to include the sitting position and the lateral position for spine cases, even if you can't imagine being crazy enough to do a case either way. Your learning process won't stop (hopefully) just because you're out on your own; who knows what new approaches you'll be using in a year or two?

The second important issue is image quality: Is the image clear, concise, and reliable at every magnification, and can both magnification and focal length be changed without an advanced degree in bioengineering? How much light is in the wound, and is the periphery equally as bright as the center of focus? You'll be moving the scope constantly to remain in focus, but a full field of clarity is really critical to safe and efficient microsurgical technique.

The third criterion is reliability: Does the microscope work every time, night or day? Can more than one person in the OR be taught to fire it up and have it ready at any hour? Finally, on the rare occasion when it doesn't work, is the company rep available, competent, and as concerned as you are?

The last important consideration should be the special features of a model that potentially might allow you to deliver better-quality care. The incorporation of ultraviolet imaging capabilities is a striking new component of some modern scopes; intraoperative angiography is becoming the standard of aneurysm surgery practice, and microscopes capable of indocyanine green (ICG) videoangiography may greatly alter not only vascular but ultimately tumor surgery as well. If you plan to build a busy aneurysm practice that "takes all comers" the ICG videoangiography-capable microscope will be an investment that quickly pays off with increased patient safety and decreased morbidity.

Next in importance are adequate microsurgical instruments. Very often, recently graduated residents have horror stories about the instrumentation available on their first aneurysm cases "out in the real world." Typically, the microinstrument tray contained a giant set of bipolar forceps, one pair of microscissors equipped with a large burr, a few standard clips (each older than the scrub nurse), one microclip applier, and one 12 Frazier sucker tip. Now, exactly whose fault is this?

The time to get the correct tools for the job is *before* you come on as an attending surgeon, not when you're first threatened with audible two-sucker bleeding. There are a wide variety of good-quality microsurgical instruments on the market, and personal choices will have much to do with the tools favored at the individual's training institution. At Southwestern, for the past 2 decades we've relied primarily on Aesculap instruments (Aesculap, Inc., Center Valley, PA), with major emphasis on microscissors in sizes short (160 mm), bayonet medium (200 mm), and bayonet long (225 mm)—upturned and straight blades. The other primary tools of sharp dissection are an "arachnoid knife" or beaver blade no. 5910, a silver dagger dissector (PMT Silver Dagger U0795701, Mizuho, Union City, CA), and/or a Jannetta no. 6 dissector.

The varied scissor blade lengths enable sharp microdissection from the superficial sylvian fissure to deep in the interpeduncular cistern, but even the most expensive scissors are useless unless kept in pristine condition. The ease with which an entire set of microdissection tools can be destroyed by one crew of instrument cleaners can't be overestimated, so resist the temptation to buy only one scissor set—always have a complete backup—and don't neglect the weird-looking, very long, bayoneted scissors. When you need them, you really need them.

Another major expenditure will be the purchase of aneurysm clips. Again, there are multiple vendors, designs, and models readily available on the market. Our advice is to pick one—any one—and learn to use it well, rather than having four different styles, none of which you or your scrub tech really understands. If you want to stay with the design with which you trained, spend some time with your institution's lead scrub tech to identify which aneurysm clip shapes and numbers are most frequently used; generally she knows not only the appropriate models but also the ratio of clip configurations (ie, "you'll probably use one of these for every three of those"). Get a robust set of mini, standard, and fenestrated clips, and avoid choosing only the most commonly used clip shapes. Otherwise, without fail, your first case—the local banker's wife—will have a bizarre ruptured aneurysm that can only be clipped with a giant "7-shaped" clip. Without it, you're both hosed.

Buy clip appliers with the same approach you used for scissors—all lengths (90 to 225 mm) with both straight and upturned heads—mini and standard size. If you get two sets, then you can remove the ratchets from one, producing "ratchetless" appliers that cannot be surpassed for ease of gentle clip adjustment and removal.

For suction instrumentation, we use standard Frazier tips for opening/closing, then for all microsurgical work we switch to Fukushima malleable tips (B. Braun Medical, Inc., Bethlehem, PA)—usually no. 4, 5, 6, or 7. For opening of the superficial sylvian fissure, we have shortened a no. 6 for up-close ease of use. Three working suckers should be present, meaning on the field, at *all* times. The surgeon's sucker is adjusted to provide 80 to 100 mm suction; the assistant's is generally at full suction, and the third sucker is secured on the field for use in what can be delicately described as "emergencies." Your new OR crew may initially generate some whining about this compulsivity, but they ultimately will attribute exactly as much gravity to an aneurysm operation as you, the surgeon, demand. So you can either explain the rules of engagement from the get-go or wait until you're trying to control a ruptured proximal carotid aneurysm with one sucker plugged, the other overwhelmed, and the nursing crew frantically trying to assemble a third setup, to make the point. Both approaches will ultimately result in three suction setups being routinely available on the operative field; one is just a little easier on your gastric mucosa.

Doppler insonation is still a vital part of safe aneurysm repair. The micro-Doppler probe along with the appropriate speaker should be obtained, and the afferent and efferent arteries of the aneurysm-bearing vascular segment should be insonated routinely both prior to and following clip placement (assuming you don't know what they sounded like before you put the clip on, how will you know the difference between a stenotic and a normal artery?). If the nursing staff doesn't quickly develop the habit of bringing a micro-Doppler to the OR for every aneurysm operation, asking the circulator for a Doppler in the middle of a case may result in something the size of a cigar being handed to you. Again, planning is critical; the nurses should know how to turn the machine on, how to control the volume, and most importantly, where the disposable tips are kept.

Qualitative interpretation is key with the Doppler apparatus. Remember, very frequently alarming Doppler signals emanate from a malfunctioning head, rather than a stenotic artery. This problem can be avoided by routinely insonating the vessels prior to clip placement and can be corrected by first changing the disposable tip anytime the sounds are not right. Also remember it is important to distinguish the direction of flow when using the Doppler; a critical degree of arterial stenosis can be concealed by a retrograde flow signal, which itself is no guarantee of adequate collateral circulation.

Mayfield headrests (Budde Halo: Integra, Cincinatti, OH) are ubiquitous and Yasargil, Leyla (Aesculap, Center Valley, PA), or Budde halo retractor systems are in widespread use all over the world—just maybe not in your new hospital. Don't assume they are already in inventory or that anybody other than you knows how to put one together. At least once, check for every part during a dry run. A variety of length and width retractor blades are essential, and especially for minimalist exposures, the new, very flexible miniblades are extremely helpful.

Regardless of the availability of endovascular expertise, cervical carotid artery exposure/control is a routine part of a busy intracranial vascular practice, and on occasion can be a life-saving maneuver in the management of severe trauma. You'll need a complete but not expansive set of vascular surgery tools that your coordinator and/or scrub tech can successfully keep away from the vascular surgeons. This set will also come in handy for certain bypass procedures, which additionally require a dedicated set of microanastomotic instruments and the instant availability of special suture material. A small tear in an aneurysm neck is a minor problem if you have the appropriate tools to put a 10–0 stitch in; it rapidly becomes a major complication if nobody can find the Castroviejo needle driver and the only suture available is 4-0 Nurolon (Ethicon, Inc., Somerville, NJ).

Anesthesia

We won't attempt to cover neuroanesthetic issues here, with the exception of one very important technique. Anesthesia-induced burst-suppression is used in almost every major aneurysm operation at our institution, especially during local arterial circulatory arrest, because of its well-documented beneficial effects in neuronal protection from ischemia. Doing this the right way requires a minimum of preoperative planning and just a little anesthesia cooperation, although in general, anesthesiologists are very enthusiastic about adding this fillip to their armamentarium, and the concept is spreading to medical situations involving witnessed cardiac arrest outside the OR. A four-lead electroencephalographic (EEG) array placed prior to prepping but after the headrest is applied is perfectly adequate to monitor cortical activity during and after administration of the initial bolus of barbiturate, and to indicate when supplementation is necessary. If it turns out to be a struggle to get your new anesthesia department to incur this expense and responsibility, a standard neuromonitoring company can provide this service at a reasonable expense, but as mentioned, having your own anesthesia guy excited about brain protection is a real advantage.

Setup

As the newest surgeon at an established facility, the young, confident cerebrovascular stud may find himself low man on the OR priority list and consequently assigned to the smallest, oldest, and least comfortable room in the suite. This can be a bit of an ego bruise, but with a little thought, a very efficient OR can be developed in a relatively limited space. To that end, it is important from the get-go to establish a routine for utilizing the space you do have so that your team is not reinventing the wheel every time you roll a patient back. Yasargil's *Microneurosurgery Volume I* provides a good setup template and can help everyone find their own designated "zone" in what can become a pretty cramped space. The professor was the first surgeon to suggest the OR setup should be designed so that the microscope became the focal point, rather than an intrusive "add on," and his concepts have stood the test of time. It is also important to remember that not everybody bats from the right side of the plate; in a facility like ours, where unfortunately at least one of our neurosurgeons is always left-handed, the team gets pretty accomplished at "mirror image" setups, but the concept can be confusing to a virgin OR staff.

No matter how much or how little vascular or tumor surgery you think will come your way, don't let your hospital skimp on video monitors for your OR. One of these should be dedicated to your scrub nurse and is essential to allow her to follow the operative procedure, anticipate particular needs, and become an involved participant in the procedure. It's also of enormous benefit as she begins to teach other scrub techs what you do and how you do it. A second monitor dedicated to the anesthesiologist will pay great dividends in terms of interest and improved quality of your anesthesia.

Culture

Regardless of local custom, political correctness, and the ever-popular health care "team" concept, we believe neurosurgeons are morally and ethically responsible for the care patients receive in their operating room. It doesn't matter if you are a grizzled veteran doing your 4000th aneurysm or a green rookie fresh out of training with your hair on fire—if your name is on the board as the surgeon, you're "the Man." So, since like it or not you've got the responsibility, why not demand the operating room environment suited to producing your best work? Peace and quiet? High volume music? Ceaseless chatter? Telephones ringing? Beepers buzzing? Lots of folks coming and going? It's the surgeon's choice, and contrary to historical legend, a neurosurgical OR certainly doesn't have to be an armed camp.

That said, part of the surgeon's job is to create an atmosphere where everybody brings their "A" game, unencumbered by issues and interactions that may complicate situations that by definition are already complicated enough. For example, most aneurysm surgeons are familiar with the sudden switch from "Cruise" to "Full Military Power," a potentially critical transition that occurs not infrequently in aneurysm surgery. When that situation arises, if everyone in the OR—from orderly to anesthesiologist—has mimicked the surgeon's focus throughout the operative procedure, within seconds of the suctions' change in tune, the OR will be at maximum efficiency, and the lucky surgeon can then concentrate on doing his or her thing. On the other hand, if the music needs to be turned off, the circulating nurse summoned back from her smoke break, and the anesthesiologist convinced to hang up on his broker, even the slickest surgeon may find himself overwhelmed before he can retrieve the initiative.

This is just a common example of issues and occurrences that have convinced us that maintaining the appropriate global level of attention is less stressful than trying to get the genie back in the bottle; consequently, we recommend keeping the ambient noise, OR traffic, and idle (meaning not related to this operation) chatter to a minimum.

Staff

The finest cerebrovascular ORs are manned by scrubs and circulators who are Green Beret equivalents in their field. In a new operating room environment, this attitude and pride will take quite some time to establish. It is important to seek out smart, motivated people who want to learn and can take instruction well. Usually, these personnel will be flattered to be "called up to the big leagues," and will strive to overachieve. The time taken to teach the staff about aneurysm surgery fundamentals, including positioning, timing of treatment, and special circumstances will pay large dividends almost immediately. In a surprisingly short timeframe, the team will know that a posting of "Right Crani for Ophthalmic Aneurysm" means: possible cervical carotid exposure, *no* right IJV access, the skull base drill/ultrasonic bone aspirator is needed, and so forth, all without need of spelling out each step. It helps if along the way the surgeon is generous with “Atta-boys” and “Atta-girls” and if he or she is thoughtful enough to routinely provide the OR team with postop follow-ups on the patients undergoing surgery. At the end of the day, these folks really care about your (their) patients’ outcomes.

The transition from chief resident to attending surgeon can be challenging. In some large practices, the junior staff are mentored (and monitored) for a specific period of time, but quite often a young neurosurgeon is the only individual within 150 miles willing to deal with these lesions. In these situations, it is important to expand the preoperative checklist. Not only must preoperative planning include all of the worst-case scenarios involved in the pursuit of clipping the aneurysm, it must include the same thoughts about the function and flow of the OR. Every tool or service that could possibly be needed must be verified before the patient is asleep. With proper planning and diligent attention to detail, a cerebrovascular OR can come online in short order and bring a sorely needed resource to a new patient population.

However, all of the planning in the world, freshly laid smiles, warm handshakes, and advanced equipment cannot, have not, and will not alone make a good intracranial aneurysm surgeon. What is required in addition to all of the above is hands-on experience built upon a solid foundation of fundamental principles. Your office building certainly isn’t built on toothpicks and balsa wood. Without such a foundation, adequate and acceptable knowledge of the events going on in and around the neurosurgical operating room are certainly going to escape, which would be an incredible disservice to the hospital, the staff, and most importantly, the patient. What is the developmental process of the intracranial aneurysm surgeon? What are the required fundamental principles required to construct a good aneurysm surgeon? In the next chapter, we discuss this process, first by understanding the building blocks essential to becoming a good assistant surgeon.

2

The Evolution of the Intracranial Aneurysm Surgeon

It is unfortunate that you cannot just add water to each deer-in-the-headlights young neurosurgical resident and promptly grow a good aneurysm surgeon. To further complicate matters, progressive technology, portable electronic devices, and instant information access have made the ability to gain information without learning almost too easy for young neurosurgeons. Technical neurosurgery does not start and stop in the operating room, which, as most extraordinary surgeons will be quick to admit, is only the tip of the iceberg, whether you're floating on it or heading right for it. Becoming a good aneurysm surgeon requires more than just *knowing* the nuts and bolts of when to cut and when to clip; it demands the ability to integrate, modify, expand, anticipate, and react. This complex set of skills cannot be achieved just by reading (even a book of this caliber). Rather, its acquisition is a process; a gradual accumulation of knowledge, awareness, and technical facility continuously built upon layer after layer of experience. As surgical educators, we need to ask ourselves, what are the fundamental building blocks that budding aneurysm surgeons need to begin their quest?

The basics are pretty simple: a sound knowledge base of the operating room's physical layout and function, awareness of who on the staff does what, an understanding of the equipment involved, and an appreciation of the OR's culture. Equipped with that information, young surgeons can begin the interactive process that ideally will lead them first to become good assistants and ultimately competent aneurysm surgeons.

Viewed objectively, it might seem that an assistant surgeon during a craniotomy for aneurysm is at best a necessary evil. As is true with most neurosurgical procedures performed under the operating microscope, intracranial aneurysm surgery is primarily an Operator versus Pathology saga. Surgical exposures are small and deep; often even the surgeon has difficulty finding room for his own two hands in the limited operative field, not to mention that the narrow exposures are defined by a variety of neurologically essential and structurally fragile entities, none of which tolerate ham-handed retraction or manipulation. The surgeon himself almost always secures proximal and distal arterial control within the small operative exposure [a notable exception being internal carotid artery–ophthalmic artery (ICA-OPHT) aneurysms], and the "guts" of the procedure, namely aneurysm dissection and definitive clip application, are emphatically one-person operations. So, other than during routine opening and closing, and leaving out for the moment the dreaded intraoperative aneurysm rupture, what actual use can an assistant surgeon be in these complex, high-risk operations? Equally important, what can the assistant surgeon learn from sweating through these procedures that he or she couldn't have assimilated in much less time and in much greater comfort by watching a heavily edited operative video?

We strongly believe good assistants enhance the success rate of these operations and in so doing enhance their own chances of becoming not only good neurosurgeons but also accomplished aneurysm surgeons. These points, which are probably equally true for almost all microsurgical procedures, can be proven at each major step throughout the trajectory of every craniotomy for aneurysm (**Table 2.1**).

The Plan

Most accomplished aneurysm surgeons are notorious for their compulsivity in the preoperative analysis of each surgical patient's imaging studies. The reasons for this are legion, but suffice it to say that the patient advertised as having an anterior communicating artery (ACOMM) aneurysm will frequently have something entirely different, such as multiple aneurysms, an arteriovenous malformation (AVM)–aneurysm combination, two ACOMM lesions, and so forth. Furthermore, a multitude of other features beyond the general anatomical location of the aneurysm merit focus of the surgeon's attention (eg, the size

Table 2.1 Fundamental Knowledge of the Assistant Surgeon

Stage	Elements
The plan	Know the patient Know the lesion and surrounding anatomy Know the surgical approach
The warmup	Survey the operating room for necessary equipment Brief staff on exact procedure and patient position Microscope preparation
The procedure	Situational awareness (equipment, operative field, surgeon's movements) and anticipation (procedural flow and surgeon's needs)
The wrapup	Communication with intensive care unit nurses Communication with patient and family Debrief with surgeon

and location of the patient's frontal sinus; the nature of the bilateral A1 segments; the location and projection of the ACOMM itself; the size, morphology, and projection of the aneurysm; etc.). All of these parameters frequently play important roles in the surgeon's selection of operative procedure, head position, laterality, bony opening, and subarachnoid exposure.

The successful surgeon's preoperative flight plan actually encompasses not only the surgical checklist but also the "rescue" or "fall-back" options for the procedure. Assistant surgeons with the good fortune to hear Steve Gianotta or Robert Spetzler apply that checklist to an actual patient–aneurysm combination have a great opportunity to adopt a similar template and incorporate those critical planning processes into their own armamentarium. On the other hand, during his preop analysis, even Dr. Charles Drake would occasionally (but very rarely) overlook an important feature of an individual patient's anatomy, an oversight that one of his rapt assistants would be more than happy to point out, to the delight of both. In the optimal situation, this critical planning process is a dialogue that profits the surgeon, the assistant, and most importantly, the patient.

The Warmup

For all intents and purposes, an aneurysm case starts when the patient rolls through the operating room door; that's when the assistant surgeon should be standing tall near the head of the bed. The surgeon may be having a quick last cup of coffee, making rounds, or texting his ranch foreman, but the assistant has several jobs that won't get done in the OR lounge.

As a product of the planning session, the assistant knows whether special equipment will be needed (the Sonopet, Miwatec, Tokyo; Cavitron, Integra, Cincinatti, OH; bypass instruments; oscillating saw; etc.) and whether unusual problems or circumstances are to be anticipated. This is the time for the assistant to run through those anticipations with the scrub and circulating nurses. If a vein or artery harvest is planned, everyone must know how the patient will be positioned, prepped, and draped and in what sequence the procedures will be done. In order not to interfere with a graft harvest or exposure, the anesthesiologists must understand where their lines can and can't be inserted. If frontal sinus violation is anticipated, the abdomen must be prepped for a fat graft. If electroencephalography (EEG), somatosensory, motor-evoked potentials, or other monitoring is anticipated, the assistant must ensure that the essential equipment is not only present but also that the placement of the leads is consistent and does not interfere with the operative approach.

Not of least importance, the patient must be safely transferred from the gurney to the operating table; whose responsibility is it to ensure that the lumbar drain or ventricular drainage device won't be left behind on the floor? Lastly, in the unlikely event the gas passers can't get an arterial or central line, the surgical assistant must be ready, willing, and able to put on the gloves.

Once a patient is ready to be placed in pins and positioned for the procedure, aneurysm surgeons often differ about the assistant's role. Here at the University of Texas Southwestern (UTSW), we think it is important that the operating surgeon not only be present but also be an active part of this segment of the operation. Head-holder placement and subsequent head positioning both carry some risk, not only to the patient but also to the rhythm of the procedure itself. Most aneurysm surgeons are finicky about where the pins are inserted and especially about the exact position of the head. Even though these things are most commonly discussed in the planning session, this is a good time to review aloud the reasons for both and how they apply to the overall operative approach. Of equal importance, immediately prior to pin placement, comes our designated moment for the formal "Timeout"; our final chance to ensure we're operating on the correct patient, in the correct position, and on the correct side. Needless to say, the assistant can learn the fine points of positioning here—of which there are many—and also, with a gentle word of correction, the assistant can prevent the attending surgeon from making a major error. Believe us, it happens.

At our place, before the assistant surgeon runs off to scrub, there is one more job to be done; making certain the microscope is in working order. While scrub nurses often like to get the scope draped early and then put over in a corner, it's pretty embarrassing later in the day when the attending surgeon finds out he can't simultaneously focus on the carotid and get his instruments in the wound because he's got a 400 mm lens left over from yesterday's transsphenoidal procedure. As microscopes become more complicated, the understandable tendency is to have one or two staff members in the OR designated as the microscope jockeys; this has generally worked well—until you're doing a ruptured middle cerebral artery (MCA) aneurysm with a big temporal clot at 2:00 AM, or both jockeys are out sick with the flu. The preop period is a great time for young neurosurgeons to become comfortable with the working mechanics of today's microscopes, and the OR staff is usually more than happy to provide the instruction.

The Procedure

Although we won't spend much time discussing the general techniques of extradural exposure, it's worthwhile noting that most experienced surgeons have special little things they do during this part of the procedure, things they're convinced give them an extra edge later on. Whether it's how they reflect the temporalis muscle, remove the inner table, stop the condyle from bleeding, or open the dura, generally the only way to learn these tricks is to be there when they're done, and to have the guts to ask, "Why do you do it like that?" Left to their own devices, surgeons either forget to mention these small things when they're describing their personal preferences or mistakenly think they're so silly as to not be worth mention. Some of them may be, but don't be too quick to judge.

Once the dura has been opened, at UTSW we bring the microscope to the wound immediately. If the scope is then focused at a high power, generally on a vessel overlying the cortex, then both the surgeon and assistant can take a moment to get their images focused and eyepieces appropriately oriented. The importance of this banal step can't be overemphasized. If the assistant's eyepieces are not in focus, if their orientation is not correct, and if their position is not conducive to easy access to the surgical field, the assistant surgeon is not only worthless to himself and to the surgeon, he's a threat to the patient.

Most aneurysm surgeons will admit to the fantasy of having four hands; unfortunately some of us are grateful to have just one that actually works. This anatomical limitation means that the best assistant surgeons have the opportunity to function as actual extensions of the surgeon's own hands under the microscope. However, to offer this type of assistance, the young surgeon must rapidly learn the techniques and timing essential to safely advance the operation. Sometimes these things are readily apparent; in other situations the assistant must wait for instructions, often while trying to decipher the impatient grunts that are muffled by mouthpiece and masks. Not infrequently, the assistant needs to do what the surgeon actually wants, not what the surgeon says at that moment. These tasks can only be accomplished if the assistant is completely immersed in the "rhythm" of the operative procedure; the skill to accomplish them requires time, patience, desire, and much perspiration. It's what marks a great surgeon-in-the-making.

The operative microscope provides the operator with an in-depth view of a very limited surgical field; simultaneously it eliminates the surgeon's awareness of structures and threats outside this area; these are the responsibility of the alert assistant surgeon. With multiple cables for bipolar and monopolar cautery, several suction tubes, as well as multiple arms and blades from the retractor system all in and around the operative field, the assistant must also be aware of the surgeon's continually moving hands and arms. A bipolar cord wrapped around a carefully placed brain retractor is a disaster in the making, and one that only the assistant surgeon can identify and prevent.

While the surgeon and the assistant have a limited view in the eyepieces, the microscope lamp tends to heat everything in the field, often drying out the dura, brain parenchyma, and vessels. The surgical assistant must be mindful to always keep these areas wet. Without proper irrigation, the dura becomes dry and tense, the brain will become friable, and the surgical instruments will adhere to everything; frankly, this will drive the surgeon to distraction. Proper irrigation not only obviates these problems, it also makes for a more visually pleasant environment, clearing blood and brain from the area where the surgeon is working. On the other hand, certainly all of us have encountered the overzealous irrigator who floods the operative field every time the surgeon starts to make a move; so knowledge of the appropriate amount and rate of irrigation is important. For his part, the surgeon should be willing to explain, and even demonstrate, his own preferences to the assistant early in their combined experience. Here, as in other aspects of surgical mentoring, rebuke is a poor substitute for instruction.

At some point in many aneurysm procedures, it will prove advantageous to retract certain areas of the brain, whether with a retraction system or with a brain ribbon. The assistant surgeon must make sure that the retraction system is not only in working order—always done before going under the microscope—but also that a previously placed retractor does not move when a second blade is being placed in the operative field. Further, if the assistant is asked to retract parenchyma directly with a hand-held brain ribbon, there must be an understanding of the amount of tension and the direction of retraction required. If the assistant doesn't appreciate the compliance—or lack thereof—of the region of brain retracted, serious and permanent consequences can ensue.

Lastly, adroit use of the assistant's suction tube can significantly promote the surgeon's ability to perform complex two-handed maneuvers, instead of attempting an unsafe exercise without adequate exposure. The assistant must know how much, how often, and with what force to apply suctioning, which is an art in and of itself. The last thing the surgeon wants is for the assistant to suck up the recurrent artery of Huebner to the point of avulsion or plant a strategic O-ring shape on the optic nerve.

Some situations require the assistant to be involved much more intensely than others; in other words, here the procedure cannot be successfully completed without expert assistance. Most obviously, intraoperative aneurysmal rupture—especially when it occurs prior to the establishment of proximal and distal control—uniformly necessitates the active and cooperative involvement of both surgeon and assistant. The assistant's job is easy to articulate but often hard to do—he must clear the surgical field of blood (and keep it clear) while the surgeon identifies the source of bleeding and either deals with it definitively or isolates it with temporary clips. Unfortunately, often this effective control cannot be established immediately; the assistant may be forced to change the position of his hands or his suction tube multiple times to accommodate the surgeon's access, allow the microscope to be redirected, or simply to provide needed brain retraction. Success here depends on staying focused, alert, and attentive. Regardless of the level of tension or degree of personal discomfort, the assistant must stay the course, buying the surgeon space and time to gain control of the situation.

Large and complex aneurysms also present a myriad of important tasks ideally suited for the assistant surgeon. Large or giant ophthalmic artery aneurysms may require a high-flow bypass or cervical carotid exposure for proximal control or suction decompression. As such, the assistant must be able not only to expose the proximal site of anastomosis/access but also to harvest the graft, whether a saphenous vein or radial artery, itself. After exposing the cervical carotid, the assistant must know when, how, and in what sequence to clamp the carotid vessels. Once the internal carotid is cannulated, the assistant will then have to know when to use suction to decompress the aneurysm. Here, the operating surgeon is completely dependent on the assistant surgeon, not only for his second set of hands but also for the synchronization of actions, which can make these complex procedures both smooth and successful.

Superficial temporal artery bypasses also require assistant surgeons to anticipate the surgeon's needs and moves. When sewing the arterial anastomosis, it is often the case that, despite the meticulous degree of hemostasis obtained prior to the arteriotomy, bleeding from every regional capillary bed appears to obscure the anastomotic site. Careful and strategic suctioning by the assistant can turn a frustrating mess into a pleasant technical exercise. Take an inattentive assistant, add careless suction and clumsy irrigation, and you have the bypass surgeon's nightmare.

The assistant surgeon has an important dual role throughout any aneurysm procedure. First and always foremost, his job is to enhance the patient's quality of operative care and in so doing reduce the potential surgical morbidity. Of almost equal importance, these operative procedures offer the attentive, aggressive assistant surgeon an unparalleled opportunity to learn in real time the critical aspects of this complex and high-risk surgical discipline. Aneurysm surgery is a contact sport—it can't be assimilated or mastered by a passive, disengaged student. If you want to learn to operate on intracranial aneurysms, you must first learn to assist—and to bring your A game everyday.

Once the young surgeon has become a capable assistant, it's time to begin the transition from the observer eyepieces to the operator's chair. As anyone who has made this trip will testify, this is not an all-or-nothing transition, nor is it a signal that all further learning ceases as the primary surgeon. The young surgeon must continue to assimilate information during his shifts at the observer's scope, where being a good assistant will not only enhance the attending surgeon's work but will also increase his willingness to share the operative experience.

Interestingly, once the assistant surgeon begins this rite of passage, the primary surgeon assumes a dual role; his first responsibility remains the assurance of the patient's health and safety, but also he now adopts responsibility for the surgical maturation of the assistant. This duality is—at best—admittedly uncomfortable, especially for the highly competitive, take-charge mentality of the typical vascular neurosurgeon. Nonetheless, neurosurgeons must be teachers, whose duty is to ensure that their pupils' education is based on the first principles of safe and effective aneurysm surgical techniques. That's next.

3

Aneurysms of the Internal Carotid Artery at the Origins of the Posterior Communicating and Anterior Choroidal Arteries

General

Following anterior communicating artery aneurysms, internal carotid artery–posterior communicating artery (ICA-PCOMM) aneurysms are the most common causes of aneurysmal subarachnoid hemorrhage, and these two sites taken together account for fully a third of all intradural, intracranial aneurysms. Although aneurysms in these locations are generally felt to be among the easier vascular surgical challenges, there are unique features of each of these aneurysms that can significantly impact both the technical difficulty of their management and the outcome of their surgical treatment.

Because of the relative frequency of these lesions, we'll use their discussion to briefly describe our standard version of the frontotemporal or "pterional" craniotomy, used throughout this book for the treatment of aneurysms of the carotid and distal basilar circulations.

Anatomy

The PCOMM varies in size from trivial to being as large as the posterior cerebral artery in 15 to 20% of individuals. It originates from the posterior aspect of the ICA 2–4 mm distal to the anterior clinoid process (**Fig. 3.1**), is directed medially in its posterior course to penetrate the membrane of Liliequist, and terminates in the posterior cerebral vessel some 3 to 4 mm lateral to the basilar apex. Its only branches are four to eight anterior thalamoperforating arteries, which emerge from its superior aspect and pass through the roof of the interpeduncular fossa en route to the anterior thalamus and lateral basal ganglia.

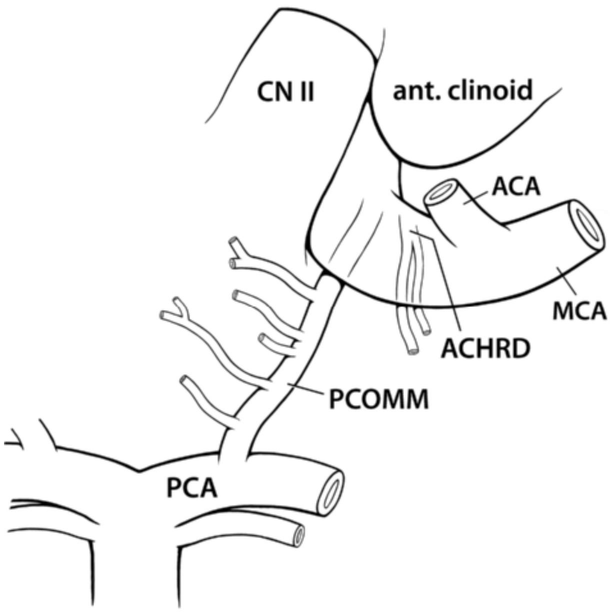


Fig. 3.1 Anatomy of the posterior communicating artery.

The anterior choroidal artery (ACHRD) is uniformly a much smaller artery, rarely greater than 1 mm in diameter. It arises millimeters distal, and slightly lateral, to the posterior communicating vessel from the posterior-lateral aspect of the ICA proximal to the bifurcation. Often double or more frequently bifurcating immediately after its origin, the ACHRD uniformly provides an early branch to the mesial temporal lobe (the uncal artery) then passes superiorly and medially around the mesial temporal lobe to enter the choroidal fissure and then the temporal horn of the lateral ventricle. Its terminal branches supply varying areas of the internal capsule, limbic system, and basal ganglia. The ACHRD's small size, intimate approximation to the deep aspect of the carotid, and important parenchymal distribution make it a frequent source of morbidity in surgical procedures involving the carotid cistern and anterior temporal lobe.

Projection

Aneurysms of the posterior aspect of the carotid wall project either laterally (**Fig. 3.2**) into the temporal lobe (both PCOMM and ACHRD), posteriorly (both PCOMM and ACHRD), or posterior-inferiorly (uniquely PCOMM). The direction

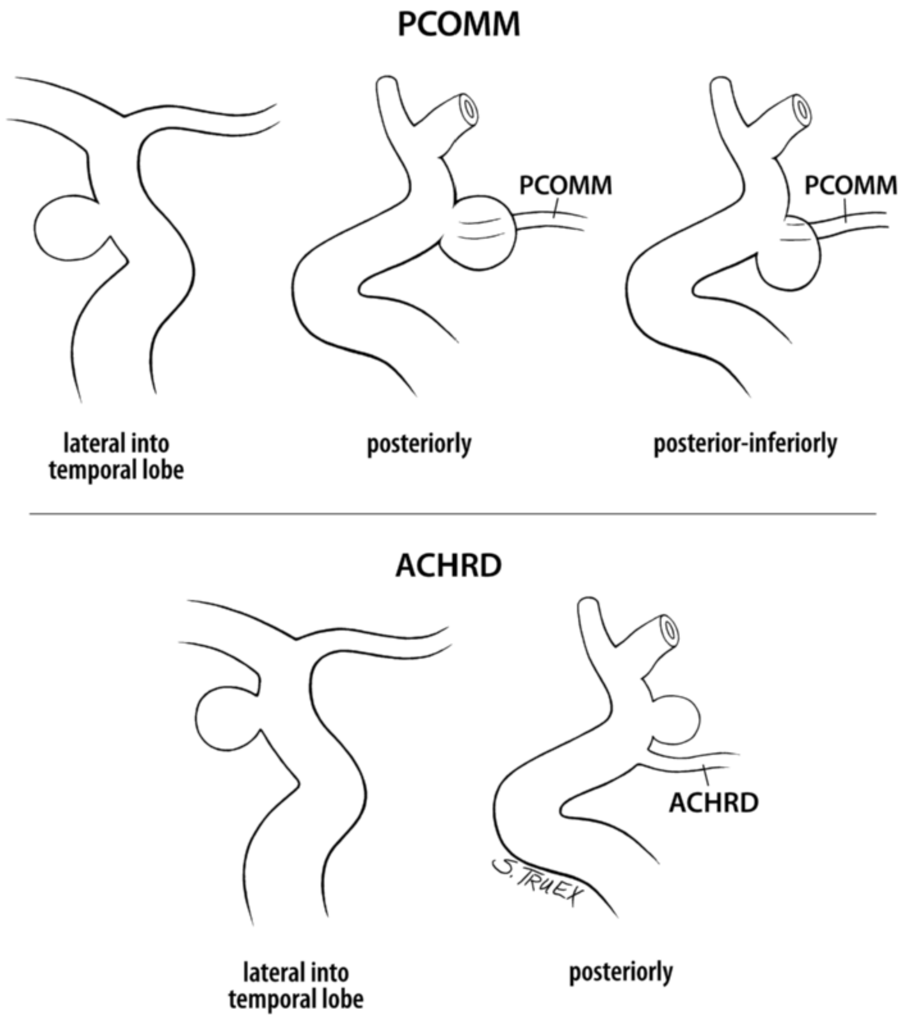


Fig. 3.2 Aneurysms of the posterior carotid wall.

of projection is not only important in terms of the classic hemorrhage pattern, but also influences the operative approach to each lesion. The aneurysms that project laterally or posteriorly are usually unassociated with the third cranial nerve: however, those that project inferiorly or inferolaterally routinely are in direct contact with the nerve itself along its medial border. Especially long “windsock” aneurysms may actually extend beneath the oculomotor nerve, elevating it and deviating it laterally.

Procedure

Positioning

Optimal position of the patient's head encourages the brain to drop away from the inner table of the skull and decreases the amount of brain retraction necessary to visualize the area of interest. In operations directed at the posterior carotid wall, the major impediments to exposure are the orbital cortex of the frontal lobe and the temporal tip. Hyperextension of the neck maximizes the degree of frontal lobe displacement by gravity, but the head should only be rotated away from the operative side the minimal amount necessary to permit exposure of the posterior carotid wall without requiring mandatory retraction of the temporal lobe. In general, this is ~30 degrees. However, if there are mitigating factors which suggest that more exposure of the posterior aspect of the carotid cistern would be advantageous (very large aneurysm, extensive neck, temporal lobe clot, multiple aneurysms, etc.) we suggest rotating the head fully 45 degrees away from the operative side and mobilizing the temporal tip posteriorly with a second retractor blade, as demonstrated in the management of distal basilar artery aneurysms.

Craniotomy

These aneurysms are routinely operated via one of many variations of a lateral subfrontal, frontotemporal, or transsylvian exposure. A small (4 × 5 cm) frontotemporal craniotomy, centered on or about the pterion, is combined with a generous subtemporal craniectomy of the squamosal temporal bone and a subsequent aggressive extradural removal of the bony sphenoid wing (**Figs. 3.3** and **3.4**).

The inner table of the intact frontal calvarium is removed to facilitate exposure of the anterior aspect of the sylvian fissure, and then the dura is opened low along the entire length of bony defect and tacked back against the inner table.

Initial Approach

It's possible to expose both ICA-PCOMM and ICA-ACHRD aneurysms via an exclusive subfrontal approach by simply elevating the posterior aspect of the orbital cortex, opening the carotid cistern and then dissecting along the posterior carotid wall until the aneurysm or parent vessel is encountered. The limited visualization provided by this "sneak and peek" exposure (**Fig. 3.5**) is generally adequate for clip ligation of small posteriorly and laterally projecting aneurysms of both posterior communicating and anterior choroidal origins, providing intraoperative hemorrhage doesn't occur and assuming preservation of the parent arteries is not a high surgical priority.

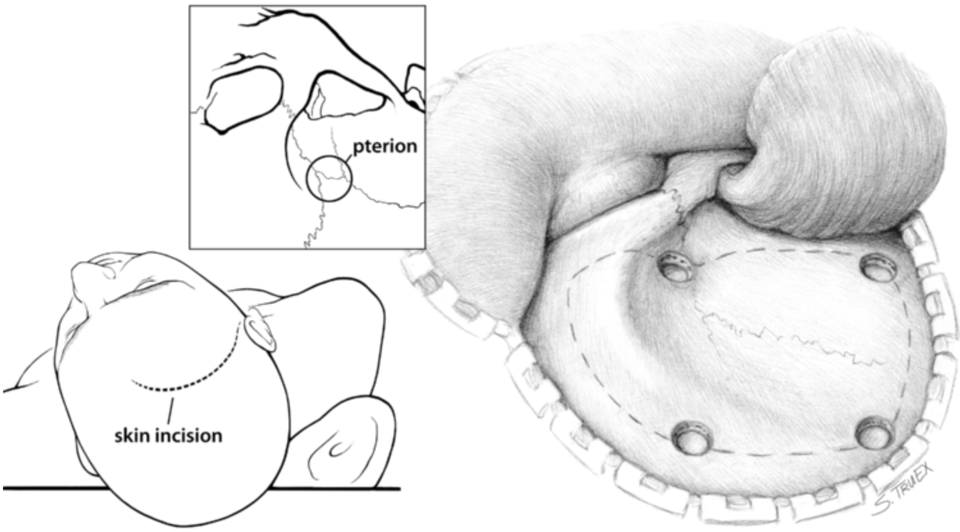


Fig. 3.3 Skin incision and frontotemporal craniotomy.

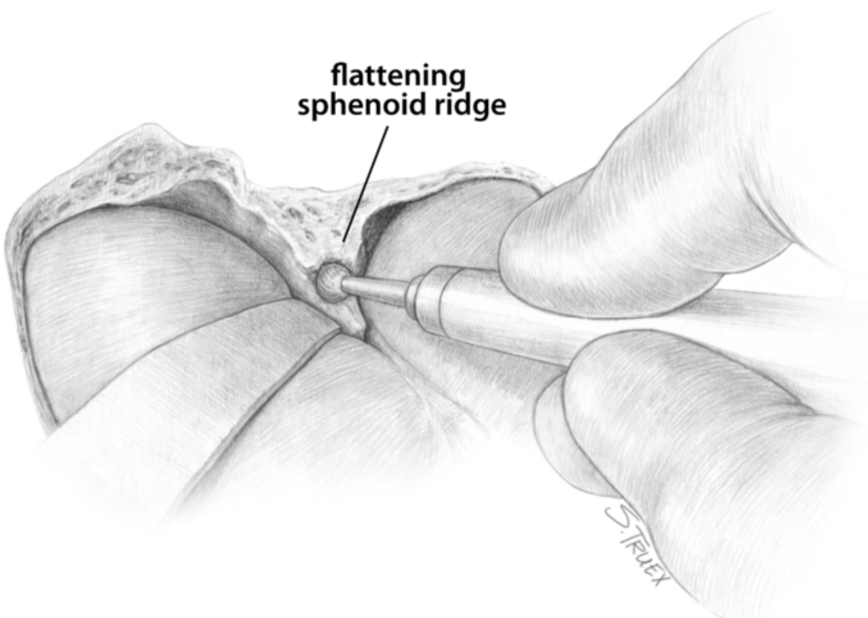


Fig. 3.4 Extradural flattening of sphenoid ridge.

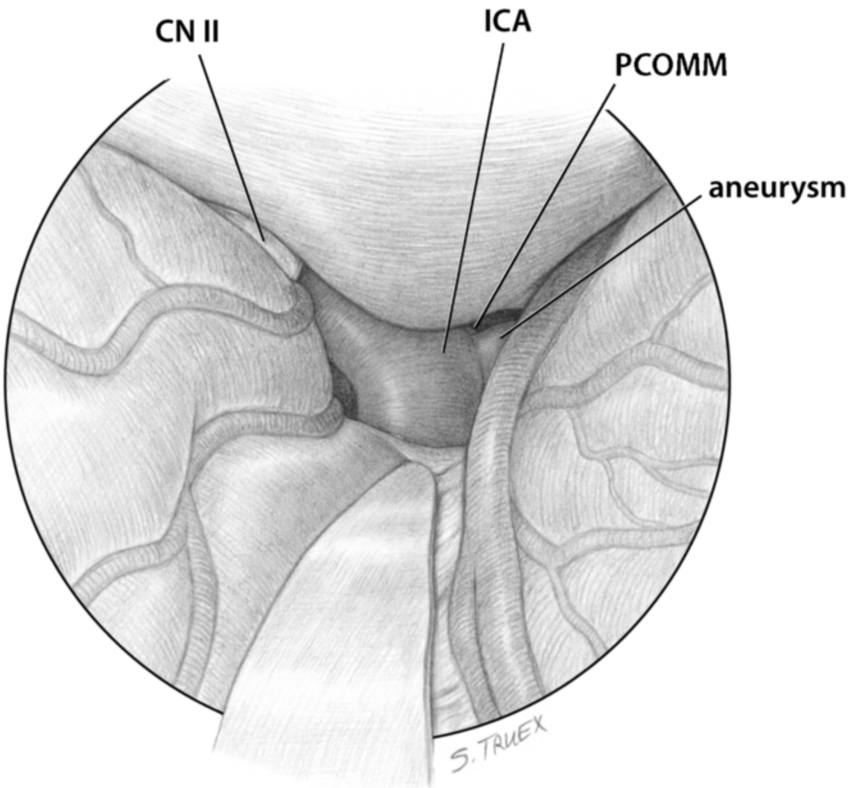


Fig. 3.5 Initial surgical view of internal carotid artery.

The initial step in a somewhat more conservative approach involves a variable opening of the horizontal segment of the sylvian fissure. When dealing with a tense, edematous, postsubarachnoid hemorrhage brain, especially with a laterally projecting aneurysm, a wide opening of the fissure from the middle cerebral bifurcation to the carotid cistern is advisable. This provides the maximum transsylvian and subfrontal exposure while simultaneously decreasing traction on the temporal lobe and attached aneurysm. After the institution of ventricular drainage and completion of a wide opening of the fissure, very frequently no temporal lobe retraction is necessary once the frontal lobe retractor has been placed on the orbital cortex at the level of the carotid bifurcation.

If the brain isn't "hot" or there is significant cerebral atrophy, opening only the medial several millimeters of arachnoid covering of the fissure may be adequate to provide ample visualization of the entire length of the carotid artery, again without significant posterior retraction of the temporal tip. This can be accomplished by first gently elevating the orbital cortex while inspecting the arachnoid reflection over the horizontal segment of the fissure. Approximately half the distance from the lateral cortex to the basal cisterns, the arachnoid is opened superficially, and then the exposure is deepened gradually with sharp dissection as the retractor blade is advanced medially across the posterior aspect of the orbital cortex (**Fig. 3.6**).

Generally, as the retractor is placed over the posterior aspect of the gyrus rectus, the final arachnoid band covering the origin of the middle cerebral artery (MCA) will be exposed, often overlaid by the bridging vein that commonly marks the medial extent of the sylvian fissure. When the vein and arachnoid have been sectioned, a slight touch on the retractor will demonstrate the entire lateral wall of the carotid cistern.

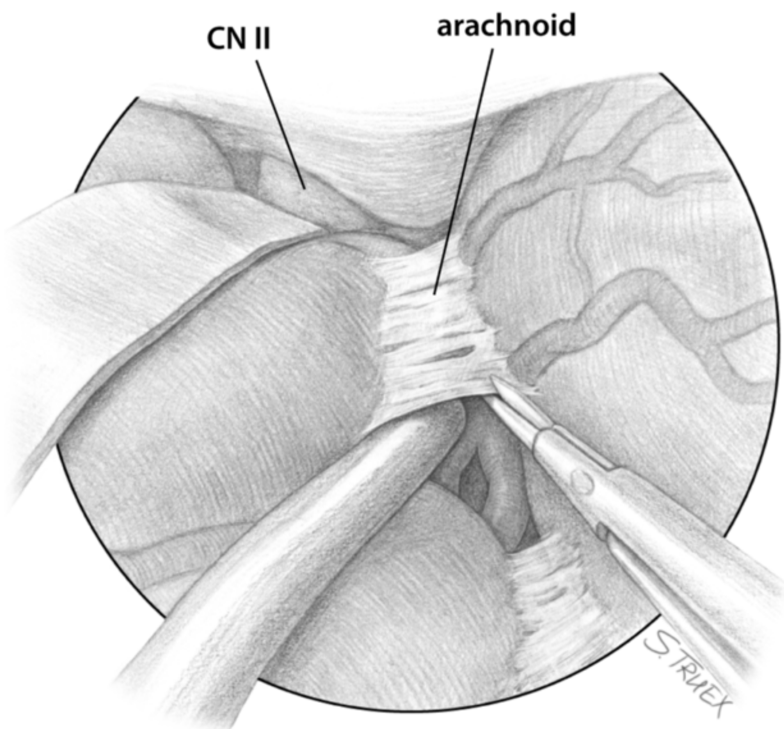


Fig. 3.6 Sharp dissection of arachnoid bands.

Proximal Control

The origin of the PCOMM is quite proximal and, in addition, many carotid arteries are very posteriorly directed, meaning that the aneurysm and the healthy proximal carotid vessel have two valid reasons to be located in much greater proximity to the skull base than the surgeon might imagine. Operationally, this translates into a very basal search to establish proximal control of the ICA, optimally done very early in the subarachnoid exposure.

If the surgeon goes directly to the lateral aspect of the optic nerve at the level of the optic canal (**Fig. 3.7**) and opens the arachnoid binding the nerve to the underlying carotid artery, the nerve can be gently reflected medially and the carotid circumferentially dissected for temporary clip placement if necessary. It is almost never necessary to remove the anterior clinoid process to expose the ICA proximal to the PCOMM origin; by pushing the dissection at the junction of the optic nerve and carotid, a sufficient length of artery can routinely be demonstrated not only to allow temporary clip placement but also to permit the surgeon to work effectively distal to the clip once it has been applied. Thus, removal of the anterior clinoid process during the management of these aneurysms is another chapter in the swagger stick story. If you need it, use it—but most folks can do without.

Dissection

When proximal control has been established, the surgeon proceeds distally along the posterior margin of the ICA and will first encounter the origin of the PCOMM (**Fig. 3.8**); the initial course of this vessel is directed exactly away from

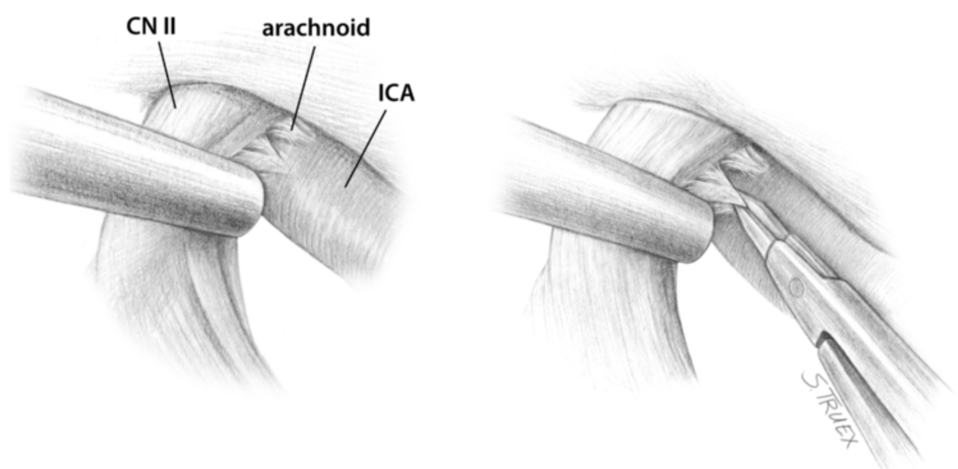


Fig. 3.7 Dissection of lateral optic nerve.

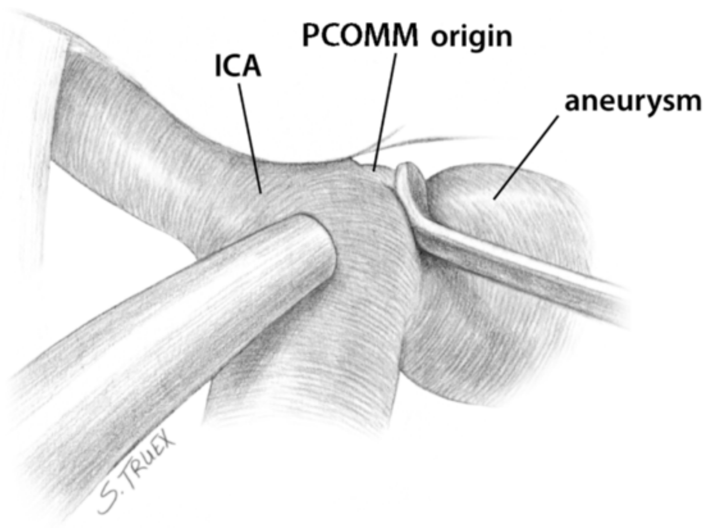


Fig. 3.8 Origin of the PCOMM.

the surgeon, making its origin often difficult to identify, especially if the surgeon's eyes are drawn to the much more apparent and threatening-appearing aneurysm, which lies immediately adjacent. This initial medial direction of the PCOMM quickly interposes the carotid between the surgeon and the communicator; invariably, the more distal portion of the PCOMM is easiest to identify by dissecting medial to the parent artery and then reflecting the carotid laterally. However, at this point in the procedure, all the surgeon needs is the smallest glimpse of the PCOMM origin to aid in identification of the inferior aneurysm neck—the rest can wait. If the small swelling of the posterior carotid wall, which represents the lateral aspect of the communicator origin, can be carefully dissected free from the laterally projecting aneurysm neck, no further definition is necessary at this time.

Exposure is then carried distally along the posterior-lateral aspect of the carotid across the aneurysm neck until healthy artery is encountered (**Fig. 3.9**). The distal neck of a PCOMM, the aneurysm, and the origin of the ACHRD are almost always in intimate association; sometimes there is only an imperceptible seam dividing the two, whereas in other patients there is a small but distinct separation. Very infrequently can the surgeon actually see normal arterial wall in the interval, but the choroidal artery never takes origin from the aneurysm itself. With patience, good technique, and occasionally the use of temporary occlusion, the aneurysm can always be reflected inferiorly away from the ACHRD; in doing so the surgeon defines the distal neck for clip placement.

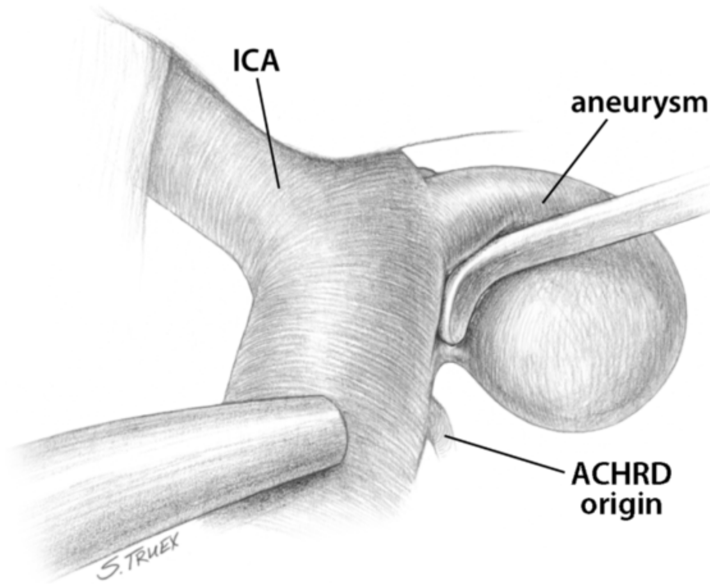


Fig. 3.9 Dissection of the posterior lateral aspect of ICA.

Once this plane has been established, the choroidal artery ceases to be a concern when dealing with nongiant PCOMM aneurysms, because the vessel's superiorly directed course takes it quickly out of any reasonable clip trajectory.

When operating on an anterior choroidal aneurysm, the sequence is slightly different. Proximal control is obtained at the same very proximal location—inferior to the PCOMM—because it is very difficult to place a temporary clip between the origin of the PCOMM and the anterior choroidal aneurysm and still leave room for dissection and definitive clip application. The PCOMM itself must be exposed, usually medial to the carotid, and then distal control of the carotid obtained. Actually, in most situations, it is safer and easier to isolate the aneurysm by exposing the initial millimeters of both the M1 and A1 segments for temporary clip placement if necessary, as opposed to working in the very narrow gap between the ACHRD's origin and the bifurcation itself. Thus, faced with relatively early intraoperative rupture of an anterior choroidal aneurysm, the surgeon's best bet is to isolate the lesion between a proximal clip located proximal to the PCOMM origin, a clip on the PCOMM itself, and two distal temporary clips, one on the MCA and one on the anterior cerebral artery (ACA). This configuration will eliminate the hemorrhage while leaving ample room for final dissection of the neck and an accurate clip application sparing the ACHRD.

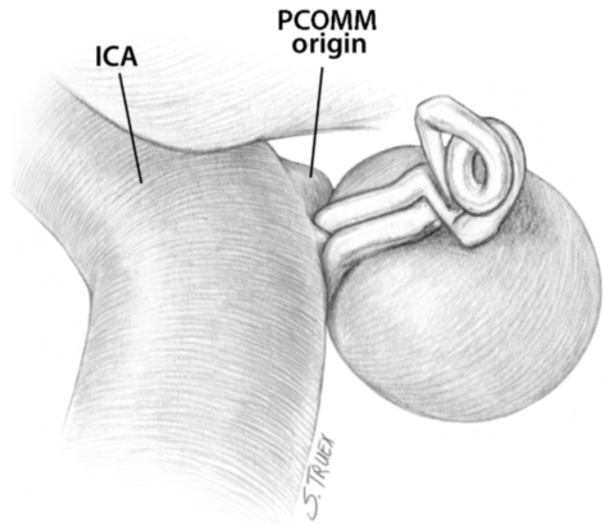


Fig. 3.10 Clip application for PCOMM aneurysm.

Clip Placement

The overwhelming majority of PCOMM aneurysms are treated by clips applied along the lateral aspect of the carotid artery (**Fig. 3.10**). This makes potential stenosis of the carotid unlikely and allows the surgeon to focus attention on complete occlusion of the aneurysm neck while ensuring continued patency of both the posterior communicating and the ACHRDs. Preliminary exposure of the distal PCOMM medial to the ICA prior to clip placement will permit initial baseline Doppler insonation of the vessel that can be compared with postclipping signals to prevent inadvertent arterial compromise.

Large aneurysms frequently have expansive necks, which can involve relatively long segments of the parent PCOMM vessel, or less commonly incorporate extensive aspects of the carotid itself. Let's consider the aneurysms that stretch out along the PCOMM first.

To further complicate matters, in this situation the PCOMM frequently represents the major or sole supply of the posterior cerebral artery. Because of the length of the aneurysm neck, the surgeon needs to use plenty of clip, but because of the importance of the PCOMM, this long clip needs to be applied in a trajectory almost parallel to the initial several millimeters of the PCOMM itself (**Fig. 3.11**).

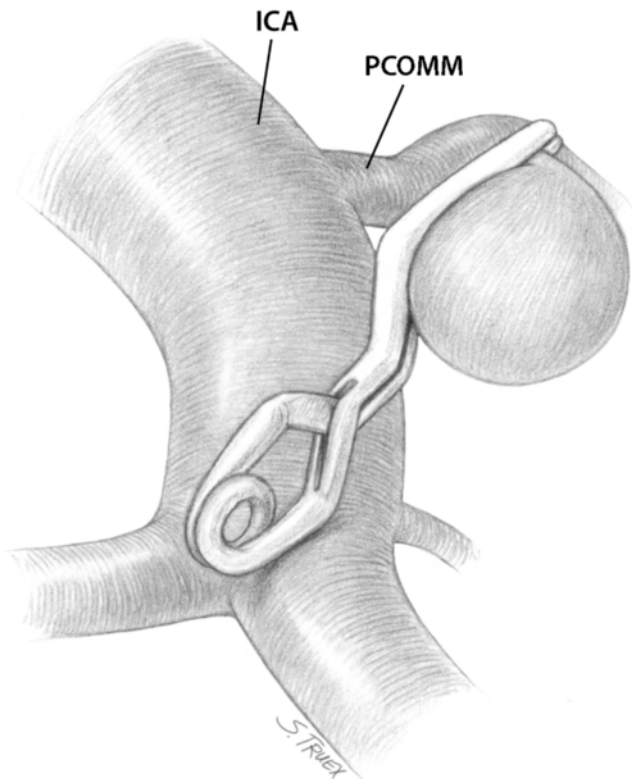


Fig. 3.11 Trajectory of PCOMM aneurysm clip.

Bayonet clips work especially well here (as they do almost everywhere) offering optimal visualization, a ready gauge of clip depth, and a nice straight blade. Curved clips, whose blades will lie tight to the carotid's posterior wall, should be generally avoided because this is the trajectory most likely to encounter the parent PCOMM as well as its anterior thalamoperforating branches.

If the surgeon has elected to use a long, straight-bladed or bayonet clip, almost the only object of concern in the potential clip path is the third cranial nerve. Dissection along the initial millimeters of the PCOMM should demonstrate the nerve sufficiently to permit avoiding it with the clip; if not (usually when the aneurysm is projecting down toward or even into the nerve) the use of temporary occlusion is recommended to complete this dissection. The third nerve is very resilient, but it won't recover from being crunched by an aneurysm clip, so don't put the clip down if the third can't be seen.

As a rule, after dissection, one aspect of the aneurysm neck will be relatively easily visualized and one will be difficult to see without retraction. When dealing with PCOMM aneurysms, most frequently the distal neck adjacent to the

ACHRD cannot be adequately demonstrated without retracting the aneurysm inferiorly; this exposure is provided by gentle retraction with the suction tip as the clip is passed along the previously determined trajectory. Because it's generally impossible to visualize both blades of the clip throughout its application, the surgeon must be content (leap of faith) with the course of one blade while continually watching the passage of the other. If the surgeon wishes to check the placement of the inferior clip blade prior to clip closure, once the desired blade depth has been reached, the pressure of the suction tip can be released and switched to the contralateral aspect of the neck if necessary.

When aneurysms of the PCOMM origin involve a significant portion of the ICA's circumference, they become more difficult to treat successfully. The aneurysm itself is harder to exclude from the arterial circulation, and preservation of the patency of the PCOMM and ACHRDs becomes more problematic (**Fig. 3.12**).

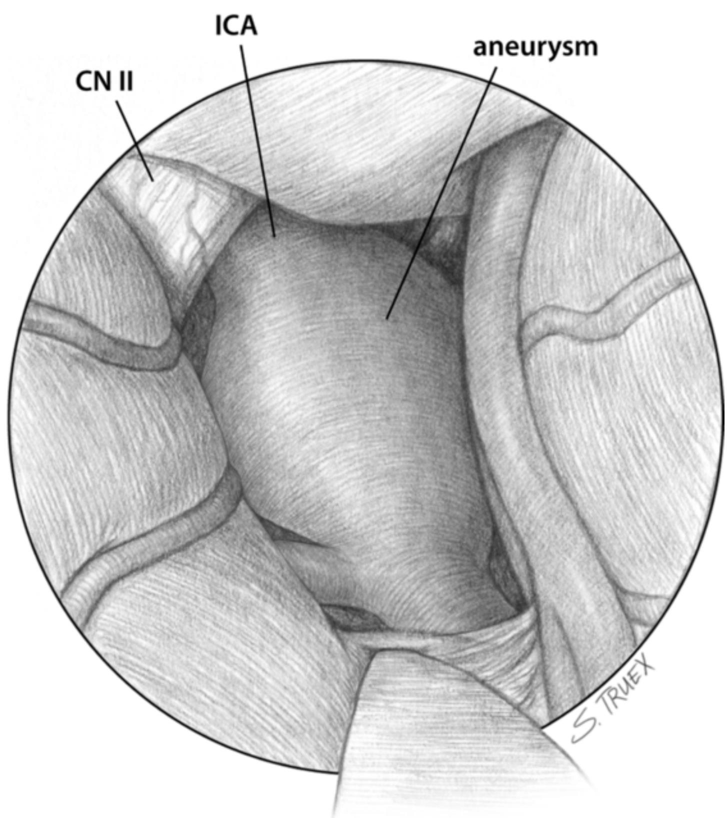


Fig. 3.12 Wide-necked PCOMM aneurysm.

The keys to management of these lesions (insofar as there are any keys) are three in number:

1. Extensive dissection of the aneurysm neck, PCOMM, and ACHRDs
2. Liberal use of temporary proximal occlusion, complete trapping, and aneurysm evacuation
3. Heavy reliance on fenestrated aneurysm clips

None of these aneurysms can be occluded by a clip applied in the routine trajectory parallel to the PCOMM; large, curved clips applied lateral to the carotid in hopes of squeezing the expansive neck routinely neither close the neck nor spare the origin of the PCOMM, and may kink the ICA itself. A different strategy is necessary, one that begins with complete exposure of the ICA from the clinoid to the bifurcation. This provides adequate access for temporary clip application, evacuation and mobilization of the aneurysm sac if necessary, and final application of a multiclip construct.

The PCOMM should be dissected from its origin to the P1–P2 junction if possible and should be visualized on both the medial and lateral aspects of the ICA; distal control of the PCOMM is essential if the aneurysm is to be trapped and evacuated (**Fig. 3.13**). When exposing the PCOMM medial to the carotid artery, the anterior thalamoperforating arteries can usually be swept laterally behind the carotid itself; when this is not possible, the surgeon can dissect them one by one along their long axis and then part them like a “bead curtain” to follow the PCOMM to the basilar apex.

Especially in very large aneurysms, the ACHRD will be found adherent to the aneurysm’s superior aspects for a surprising length of its course. If it is not freed completely prior to permanent clip placement, it will be irrevocably and catastrophically occluded. Often this dissection can’t be done without softening the aneurysm, and sometimes complete trapping is necessary; however, most frequently, proximal occlusion of the ICA is all that is required to allow careful sharp dissection, which will free the artery from its attachments to the generally thick aneurysmal wall.

Once the dissections of the ICA, PCOMM, and ACHRD are complete, the patient should be placed in burst suppression and temporary clips placed on the carotid artery at the level of the clinoid process and immediately proximal to the bifurcation. There is never sufficient room between the ACHRD origin and aneurysm for a temporary clip that will permit the surgeon to work on the aneurysm itself. A third temporary clip is applied to the distal PCOMM medial to the ICA, and then the aneurysm sac is aspirated (**Fig. 3.14**).

In the happy event that the sac collapses and remains flat, the surgeon can proceed to dissect the sac free of its attachments to the deep structures (third nerve, posterior clinoid process, medial temporal lobe, optic tract) that will prevent its complete closure by permanent clips. When the sac is free, the surgeon should be able to see the entire course of the PCOMM, from its emergence from the aneurysm neck to its connection with the posterior cerebral artery. This is

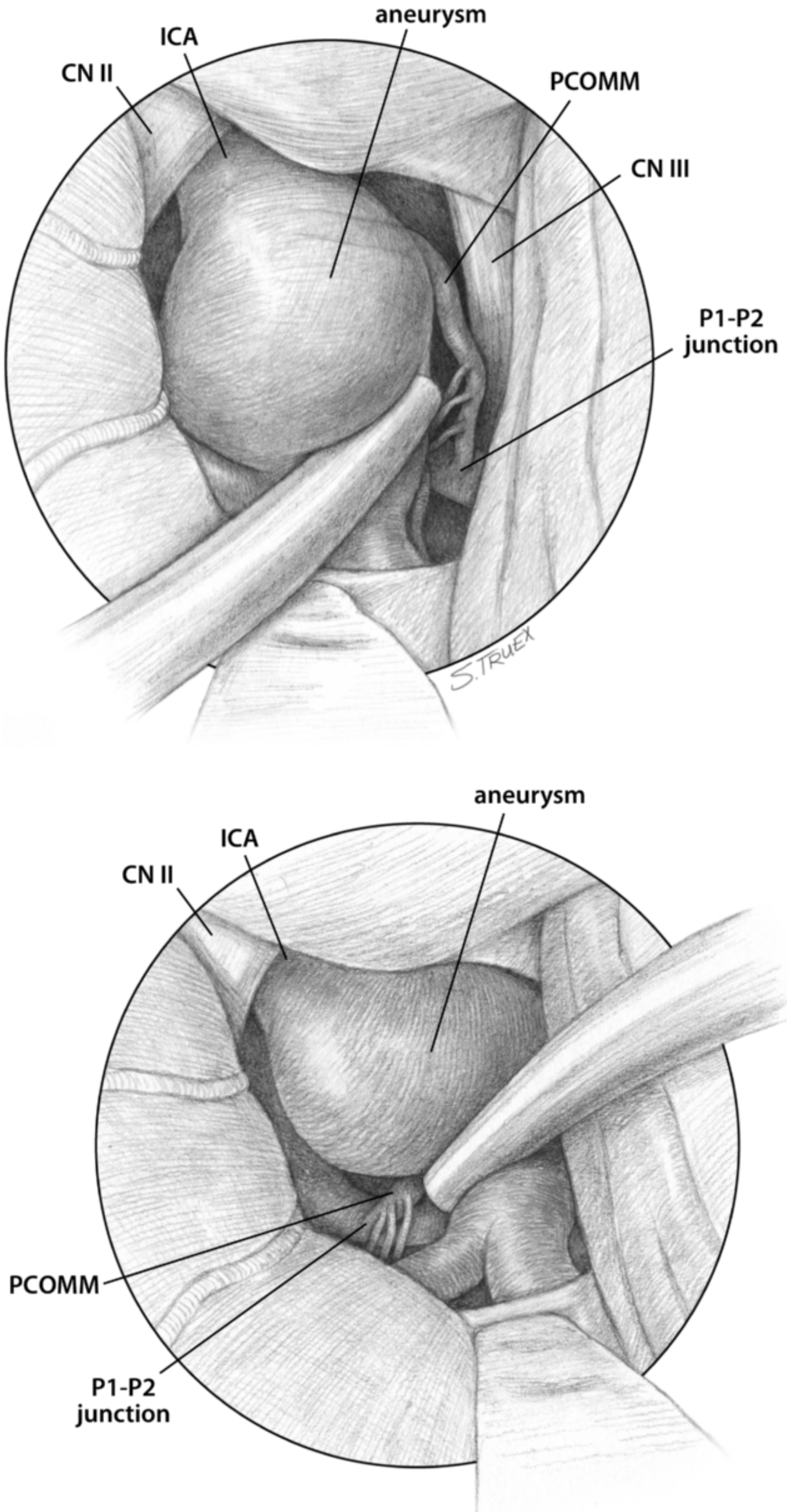


Fig. 3.13 Exposing distal aspect of PCOMM.

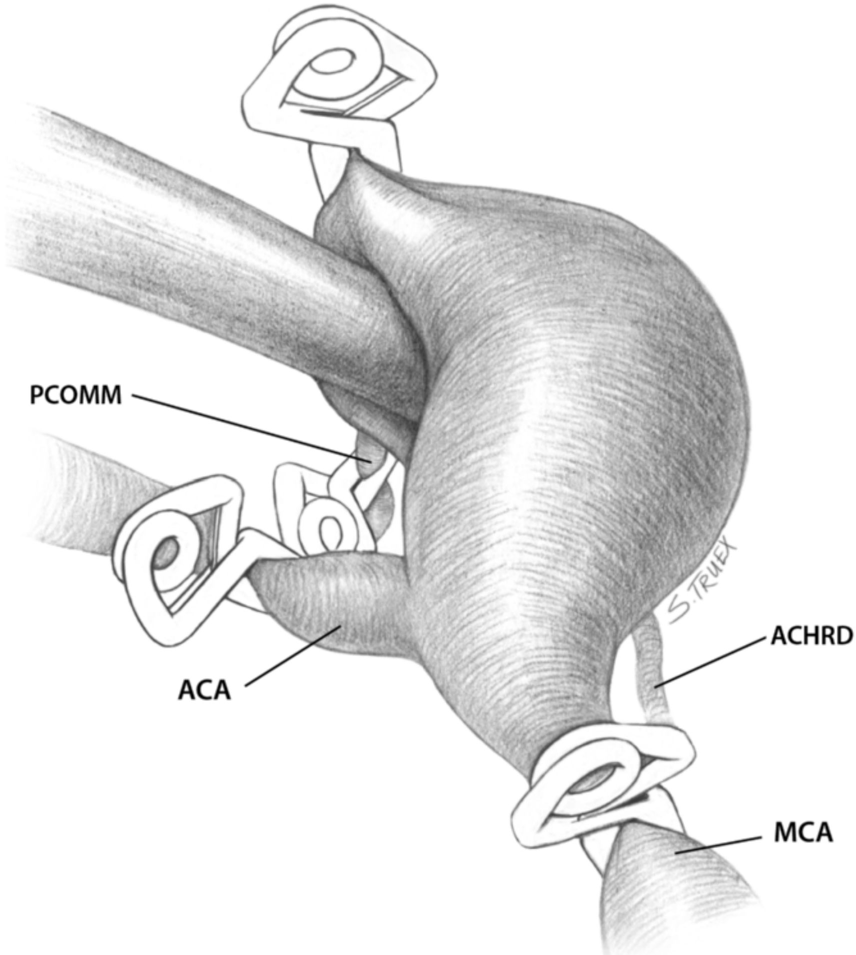


Fig. 3.14 Application of temporary clips.

of real importance in maintaining the patency of the PCOMM during permanent clip application. It's always attractive to conceptualize reconstruction of this type of aneurysm with one, or at most two, carefully placed right-angled fenestrated clips. Unfortunately, the irregular extent of these large aneurysm necks seldom conforms to the strict angles of these clips. A better alternative is to begin by placing a very short bladed, straight, small-hole fenestrated clip over the ICA and down onto the most proximal portion of the aneurysm neck adjacent to and in parallel with the origin of the PCOMM. If the neck extends well out onto the PCOMM, use a slightly longer clip, but most commonly the shortest blade will suffice (**Fig. 3.15**). The second clip should be an identical,

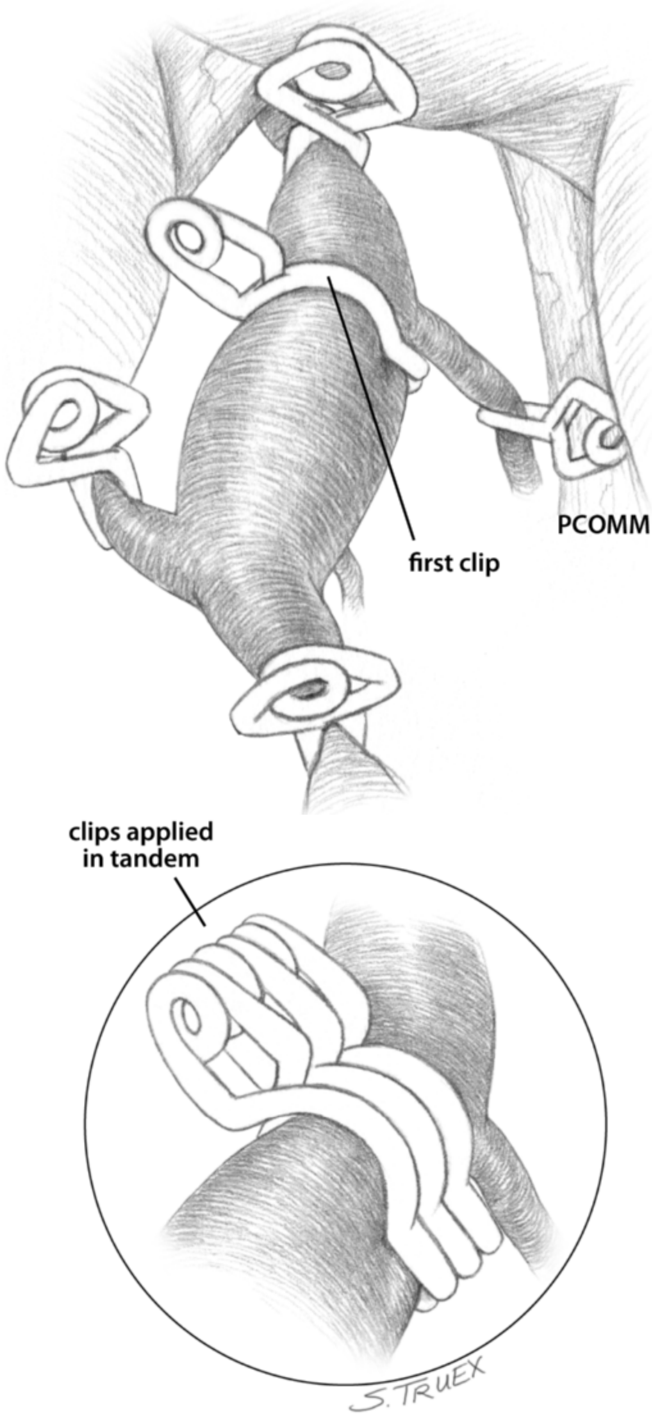


Fig. 3.15 Complex clip application of PCOMM aneurysm.

short, straight, fenestrated clip placed in exact tandem with the first, and if there is remaining visible neck, use a third tandem clip again of the same shape and size. The beauty of these clips is that they can be placed with exactitude by the surgeon, who can see the entire span of the clip blades and who knows, because they are placed tightly adjacent one to the other, there is no intervening patent portion of the neck.

Three tandem fenestrated clips will effectively deal with most large aneurysm necks and will span the distance from the PCOMM origin to the ACHRD in almost all patients. In those with residual necks, the aneurysm mass can be mobilized laterally out from under the carotid and the fundus obliterated with one or more long, straight-bladed clips. If the residual neck/fundus has thick irregular walls, longer-bladed fenestrated clips are excellent options to finish off the occlusion.

When the neck appears to be completely closed, begin by carefully "cracking open" the distal carotid temporary clip. If the aneurysm refills, look carefully at the most proximal clip for evidence that it might not be occluding the entire proximal neck, or that the clip is too short to reach out along the PCOMM. If this placement seems adequate, ensure that the tandem clips are tight to one another, and finally that the distal aspect of the neck is secured. Don't get discouraged—having to realign the clips once or twice is the rule, not the exception.

Important: Replace the distal temporary clip before revising the clip construct—if it's hard to do right when there's no blood in the field and the aneurysm is soft, imagine how difficult things will be when you've got "two-sucker" bleeding from a tense aneurysm sac.

Final Thoughts

1. Don't underestimate how proximal "proximal control" is in these aneurysms; expose the carotid artery just at the lateral aspect of the optic nerve as it emerges from the falciform dural ligament before exploring.

2. Failure to establish a clear dissection plane between ICA-PCOMM aneurysms and the adjacent ACHRD origin is the major source of surgical morbidity in treating these common lesions.

3. Large posterior carotid wall aneurysms with expansive necks are most safely and effectively clipped using, at a minimum, temporary proximal occlusion and, in many cases, temporary trapping of the entire aneurysm-bearing arterial segment followed by deflation of the aneurysm sac.

4. In patients presenting with third nerve palsies, there is no need to dissect the aneurysm sac from the nerve after clipping. Simple evacuation of the fundus is all that's required for recovery of neural function.

4

Aneurysms of the Proximal Internal Carotid Artery

General/Anatomy

The nomenclature of these aneurysms, which emerge from the parent artery at or near its entry into the subdural space, is varied; however, surgeons agree that there are three separate and distinct common sites of origin. In order of frequency, these are the origin of the ophthalmic artery (OPHT), the origin of the superior hypophyseal artery, and the posterior carotid wall proximal to the origin of the posterior communicating artery (PCOMM). For the sake of discussion, we will label these aneurysms internal carotid artery (ICA)-OPHT, ICA-superior hypophyseal, and ICA-paraclinoidal (**Fig. 4.1**). The problems common to the treatment of these three varieties are discussed initially, followed by a brief consideration of the features unique to each distinct aneurysm site.

The two common issues that complicate the treatment of this group of aneurysms are very straightforward: (1) proximal control and (2) complete aneurysm exposure. Both of these issues are directly related to the lesion's location, which is buried in the structures of the skull base.

Proximal Control

Over the past decade and a half, the development of innovative "skull base" approaches has proven that with the expenditure of sufficient time and effort, any reasonably competent surgeon can expose the intracranial carotid artery proximal to the takeoff of the ophthalmic artery. While this exposure is invaluable for managing neoplastic diseases of the area, it is not as critical for obtaining proximal control of the aneurysms in question. The reason underlying this seeming paradox is simple: once the ICA proximal to the ophthalmic origin is exposed

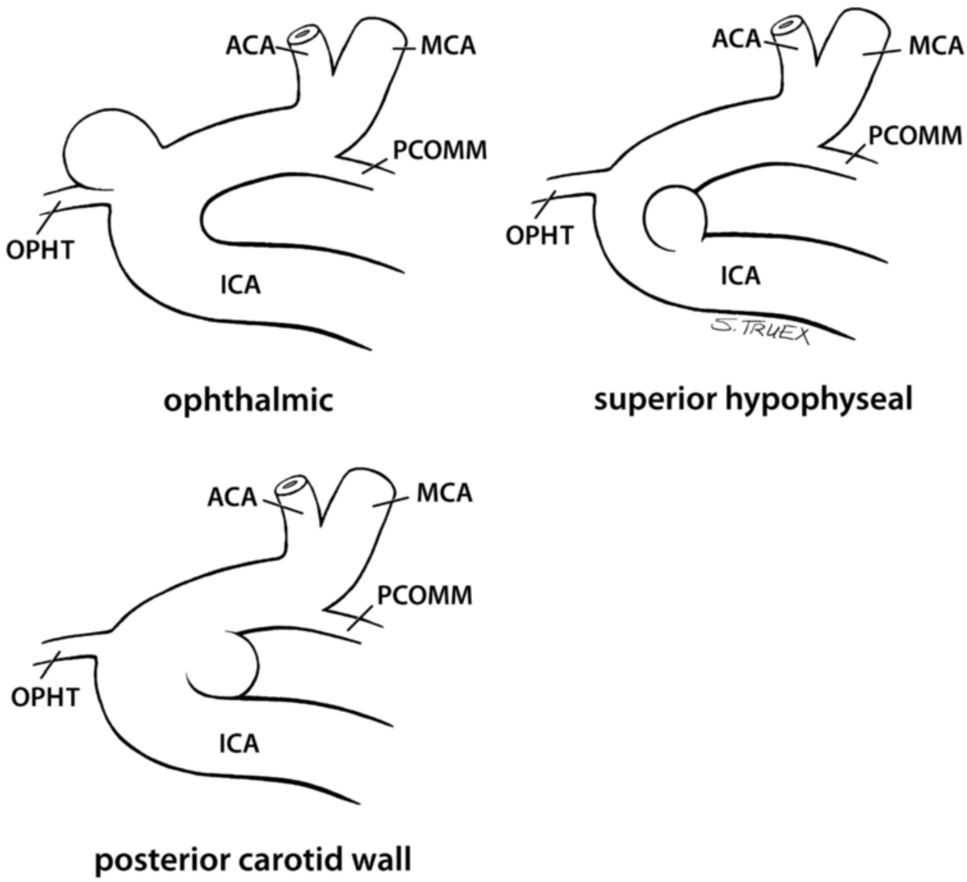


Fig. 4.1 Aneurysms of the proximal carotid artery.

and occluded with a temporary clip, a surgeon does *not* have sufficient working room to either expose and manipulate the adjacent aneurysm or to apply permanent clips in a fashion certain to span the aneurysm neck, as demonstrated in **Fig. 4.2**. Fortunately, cervical exposure of the ICA is beneficial/advantageous in several ways. It provides excellent (and early) proximal control, does not hinder aneurysm dissection or clipping, permits retrograde suction-decompression of the aneurysm, and also facilitates intraoperative angiography. This initial exposure, obtained prior to performing the craniotomy, is recommended in all ruptured and giant lesions; in contrast, when dealing with smaller aneurysms, the neck is always prepped and draped, but the craniotomy is performed first. The aneurysm should be exposed intradurally before a decision regarding the advisability of cervical carotid exposure is made.

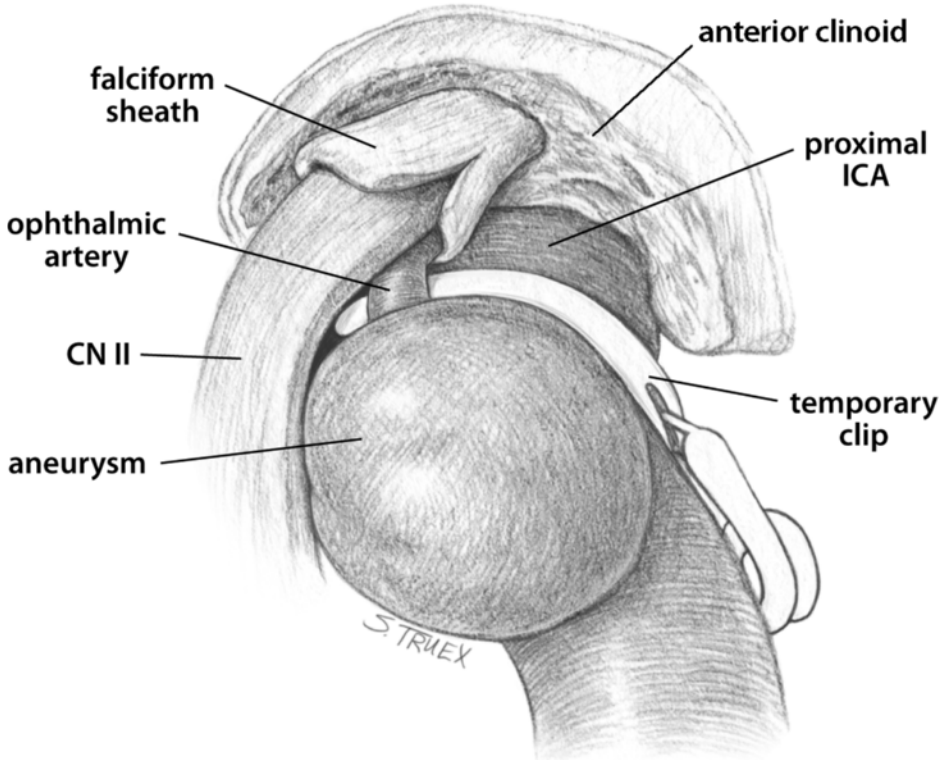


Fig. 4.2 Demonstration of limited room for proximal temporary clip application.

Procedure: Craniotomy and Initial Approach

Aneurysms of the proximal intracranial ICA are easily exposed via a routine pterional craniotomy, which extends anteriorly to the midpupillary line and posteriorly exposes the sylvian fissure. Unless the surgeon elects to remove the anterior clinoid process extradurally, a normal resection of the sphenoid wing will suffice.

Most aneurysms of regular or large size can be operated on without opening the sylvian fissure or mobilizing the temporal lobe; in fact, wide opening of the sylvian fissure makes the main trunk and branches of the middle cerebral artery (MCA) vulnerable to subsequent inadvertent injury by the shaft of the microdrill. This action/risk should be avoided when possible. For the same reason, it is often wise to place a self-retaining retractor blade gently over the tip of the temporal lobe and its associated draining veins, especially in the case of a right-handed surgeon operating through a right-sided exposure (**Fig. 4.3**).

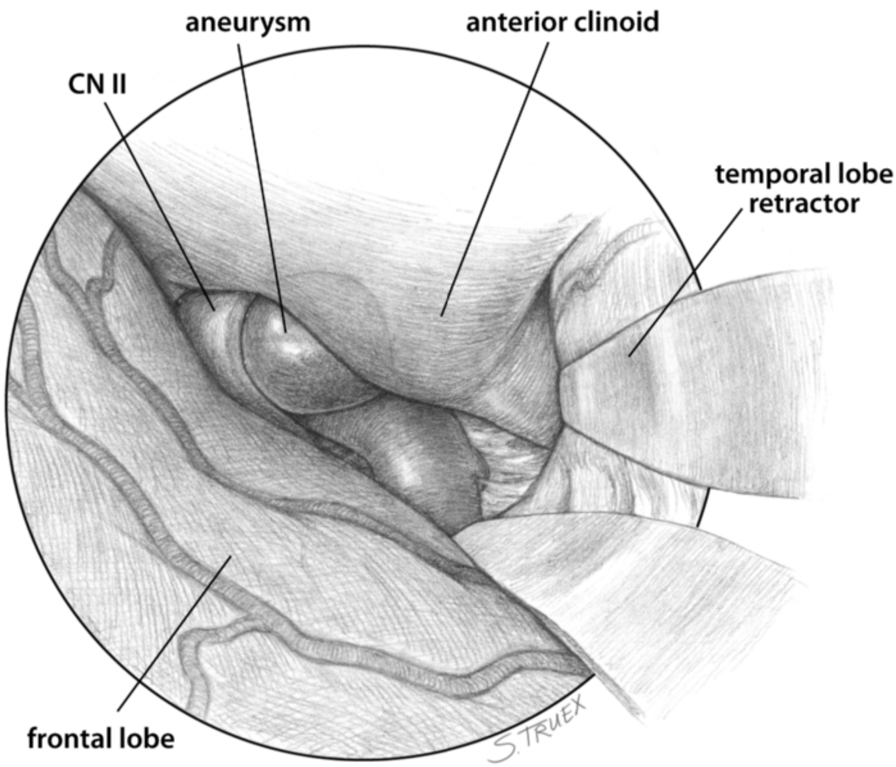


Fig. 4.3 Application of temporal lobe retractor.

The initial opening of the basal cisterns should begin with the carotid cistern, rather than the prechiasmatic cistern, for obvious reasons. The surgeon should also recall that large proximal ICA aneurysms tend to displace the supraclinoid carotid posteriorly, sometimes by a surprising amount. A single self-retractor blade placed on the posterior aspect of the orbital cortex adjacent to the sylvian fissure will provide excellent exposure of the carotid cistern. Once that cistern has been opened and cerebrospinal fluid removed, almost all ICA-ophthalmic and posterior carotid wall aneurysms will be visible to some degree (**Fig. 4.4**).

The temptation to proceed directly to aneurysmal dissection is difficult to resist; nonetheless, a wiser course is to complete the dissection of the ICA distal to the lesion, then to prepare the artery for temporary occlusion, if necessary, proximal to the origin of the PCOMM. This exposure will also delineate the distal aspect of the necks of ophthalmic and posterior carotid wall lesions.

The surgeon's attention now turns to exposure of the proximal portion of the aneurysm, which almost invariably means removal of a portion of the skull base adjacent to the ICA and optic nerve.

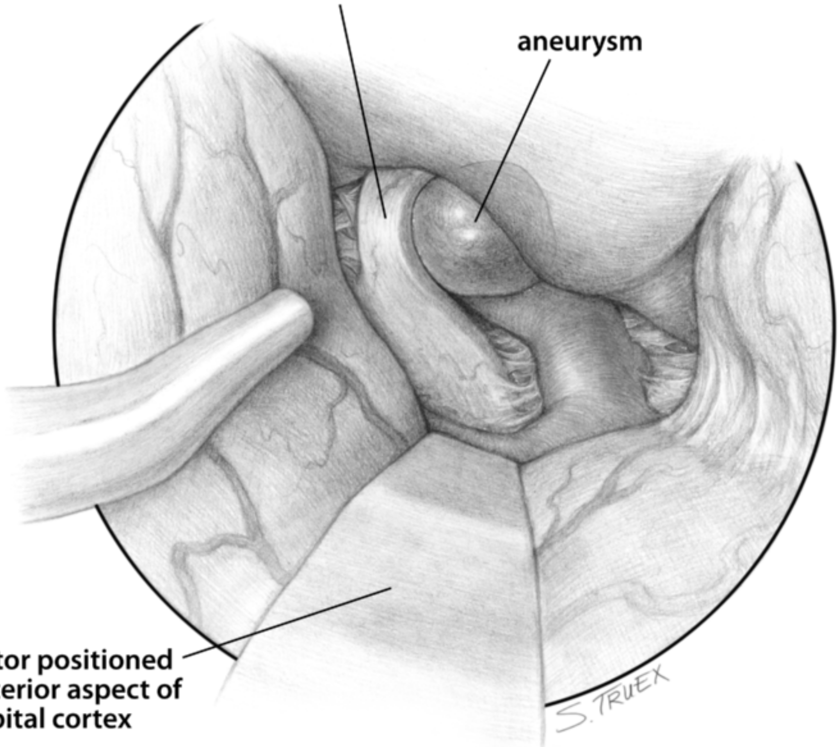


Fig. 4.4 Visualization of proximal carotid wall aneurysms.

Aneurysm Exposure

The focus of skull base resection in these cases should be exposure of the aneurysm itself to facilitate dissection of the neck and permanent clip application. For ophthalmic origin aneurysms, this generally means unroofing of the optic canal, aggressive resection of the optic strut, and minimal removal of the anterior clinoid process (**Figs. 4.5** and **4.6**). More of the clinoid process must be resected for superior hypophyseal aneurysms, but often unroofing of the optic canal is not necessary (**Fig. 4.7**). ICA-paraclinoidal lesions almost always require an aggressive removal of the anterior clinoid process, but the optic strut and orbital roof can remain intact (**Fig. 4.8**).

The question of exactly how much bone should be removed is frequently posed. There is no one absolute answer. However, the surgeon can begin by turning a semilunar dural flap hinged medially. This exposes the roof of the canal, the underlying strut, and the anterior two thirds of the clinoid process, which will provide sufficient exposure for the surgeon to cope with virtually any eventuality (**Fig. 4.9**).

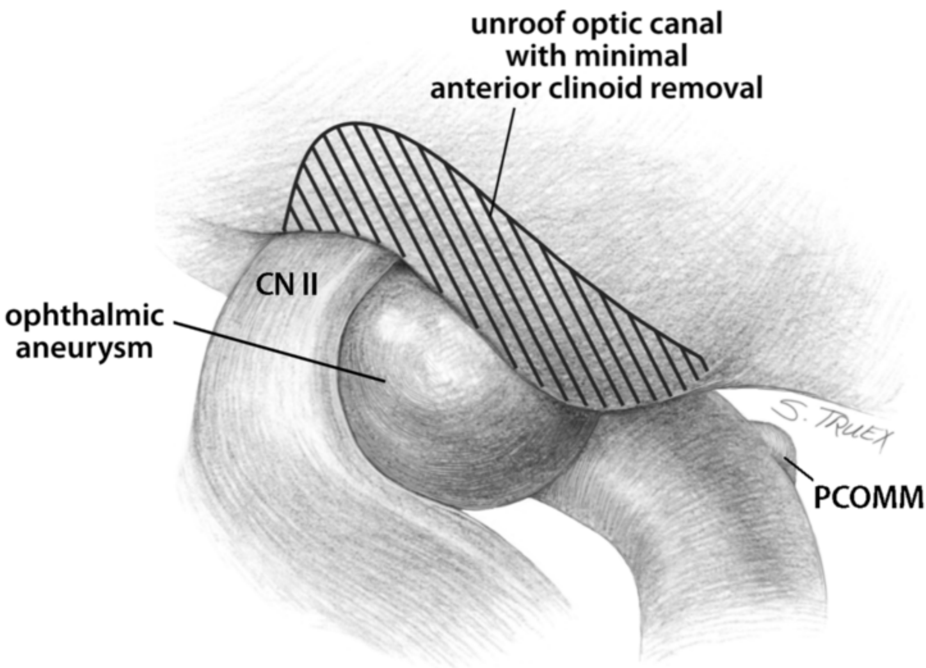


Fig. 4.5 Unroofing of optic canal.

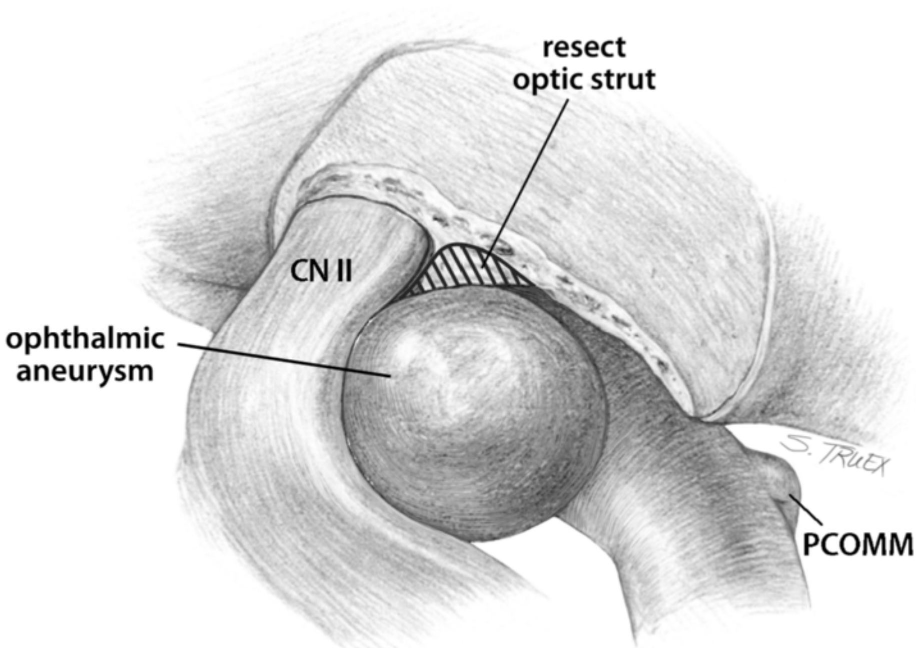


Fig. 4.6 Removal of optic strut.

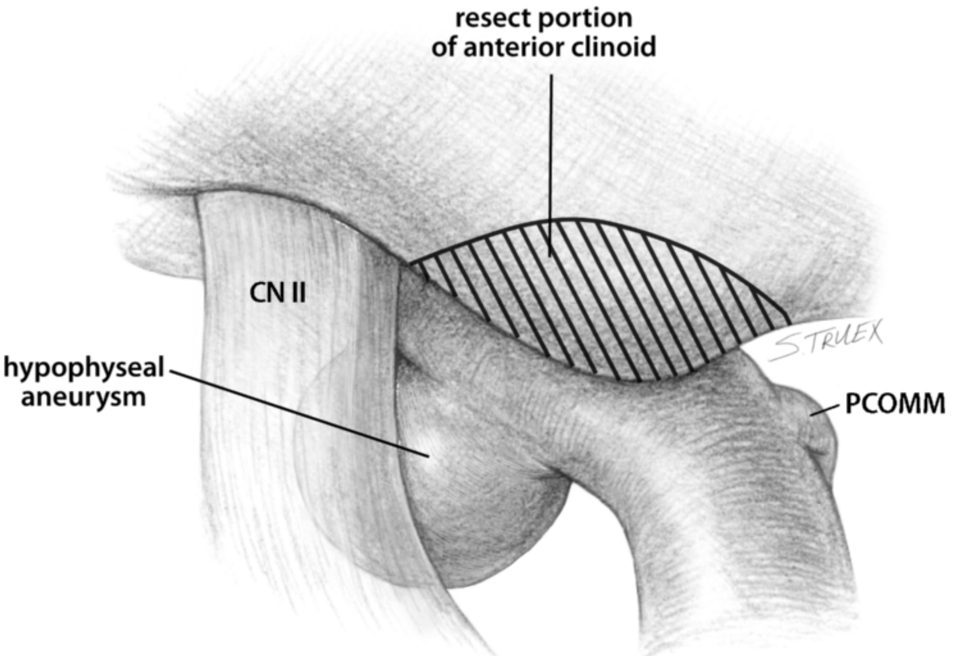


Fig. 4.7 Removal of anterior clinoid process.

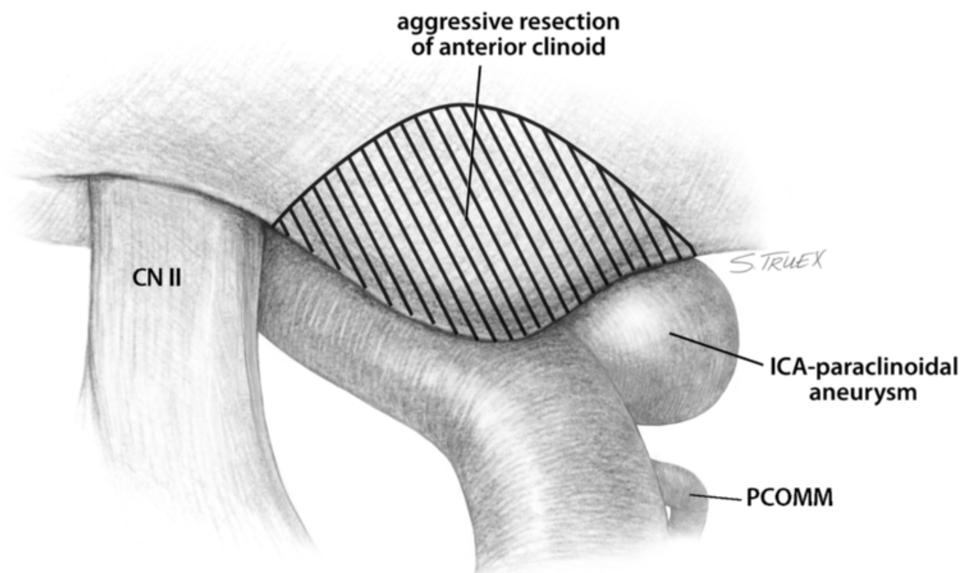
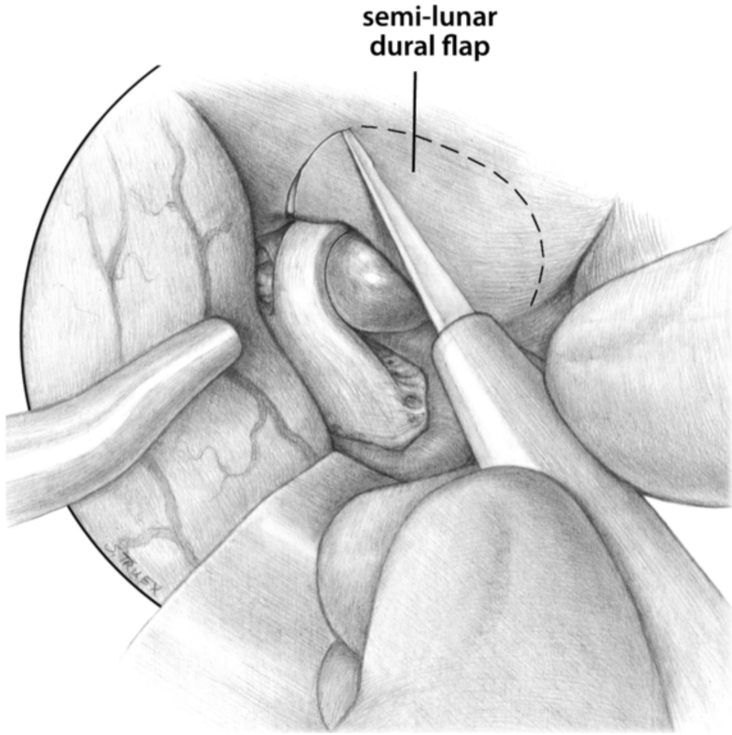


Fig. 4.8 Aggressive removal of anterior clinoid process.



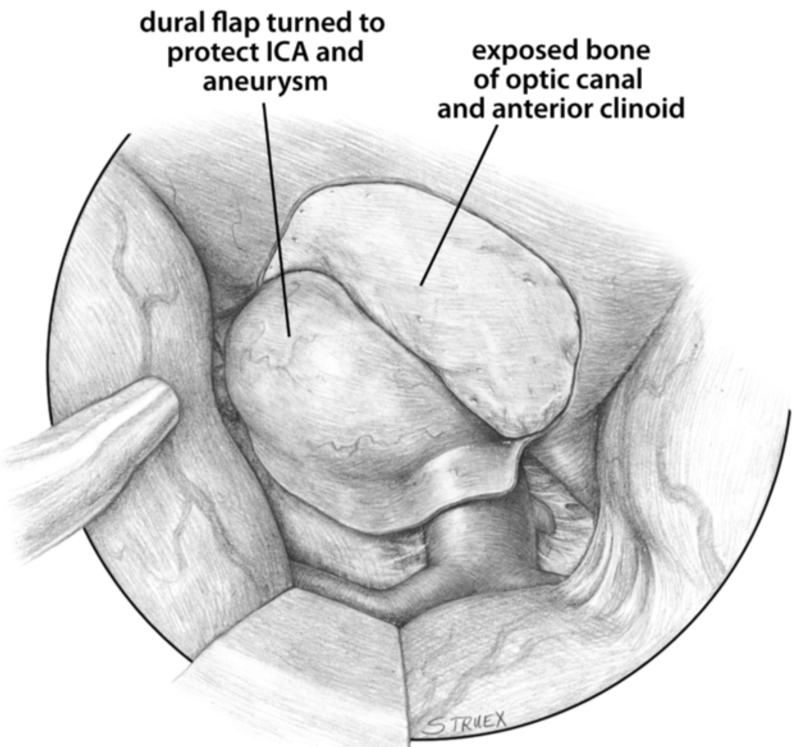


Fig. 4.9 Exposure of optic canal and anterior clinoid process.

Although it is certainly possible to do the subsequent bone removal prior to opening the dura, this extradural approach involves removing more bone than is required in most situations and does not provide for distal carotid exposure in case of an early aneurysmal rupture.

The optic strut is a bony structure that obstructs the view of both the ophthalmic and the superior hypophyseal arteries' origins (**Fig. 4.10**). To gain access to this structure the surgeon must first remove a portion of both the laterally positioned anterior clinoid process and the medially lying optic canal. This resection will expose the bladelike strut, which represents the lateral and inferior-lateral wall of the optic canal.

It is virtually impossible for the surgeon to remove too much of the strut with ICA-OPHT aneurysms; every millimeter resected facilitates exposure of the proximal ICA and OPHT origin.

The optic canal and strut are not important with paraclinoidal aneurysms because the lateral and posterior aspects of the carotid artery are shrouded from view by the anterior clinoid process alone. A generous removal of the clinoid that extends anteriorly to the level of, but does not include, the optic strut will suffice for exposure of these aneurysms (**Fig. 4.11**).

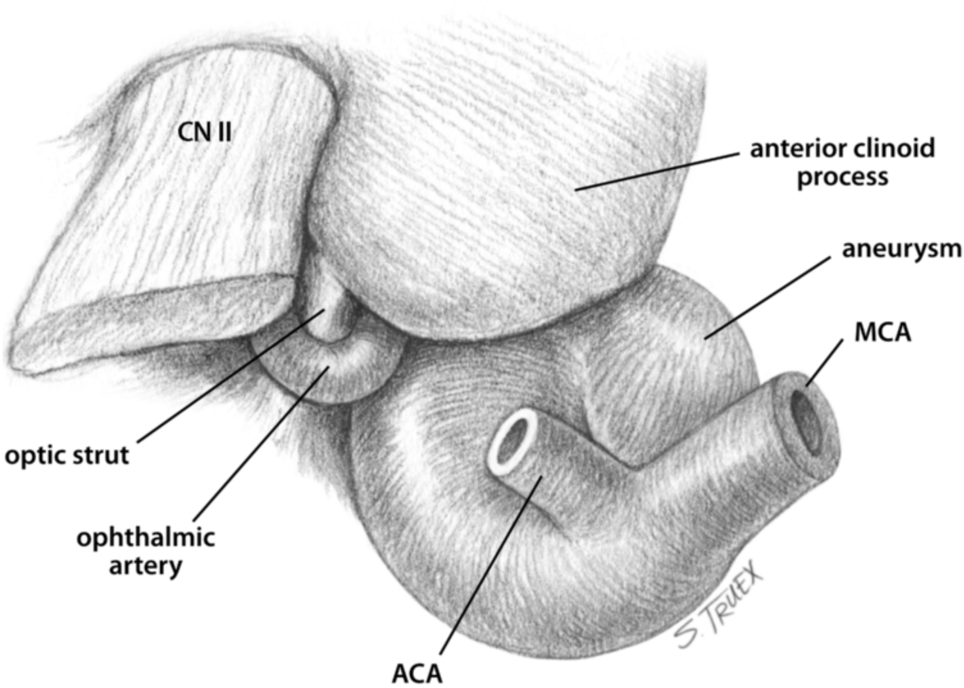


Fig. 4.10 Anatomy of optic strut and anterior clinoid process.

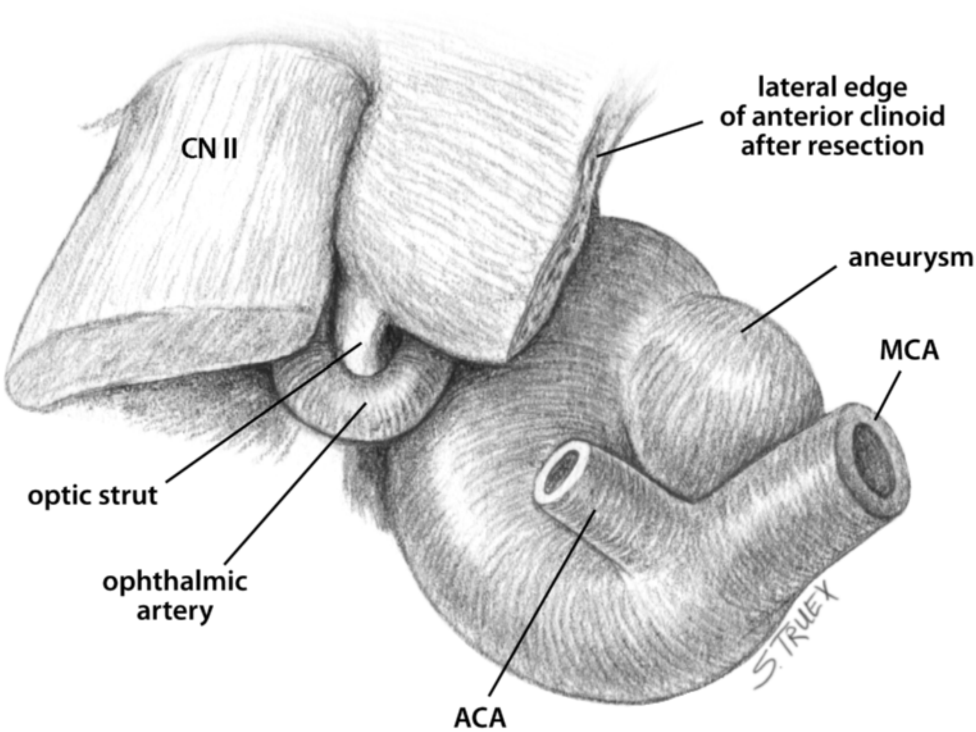


Fig. 4.11 Exposure after anterior clinoid process removal.

When dealing with nongiant ophthalmic origin lesions, unroofing of the last 5 to 7 mm of the optic canal will sufficiently expose the optic strut to allow the surgeon to drill away the portion that obscures the medial aneurysm neck, proximal carotid wall, and OPHT origin (**Fig. 4.12**). These structures are completely displayed once the strut has been erased with a drill, the falciform sheath of the nerve is opened sharply, and the nerve itself is mobilized medially (**Fig. 4.13**).

By working exactly superior to the first 1 to 2 mm of the OPHT, the surgeon will be able to define the medial aspect of the aneurysm's proximal neck by separating it from the nerve. This is the most critical aspect of the dissection; the neck must be clearly defined not only superficially but also deep to the nerve.

During clip application, the deeper of the two clip blades must pass behind the medial aspect of the aneurysm neck and then optimally be brought back up against the neck to parallel the course of the ICA (**Fig. 4.14**); unless the proximal aspect of the neck is clearly separated from the optic nerve, this necessarily blind maneuver can be disastrous. When dealing with large and giant aneurysms, the final stages of this dissection and subsequent clip application are best done with the aneurysm sac softened by temporary proximal occlusion of the ICA.

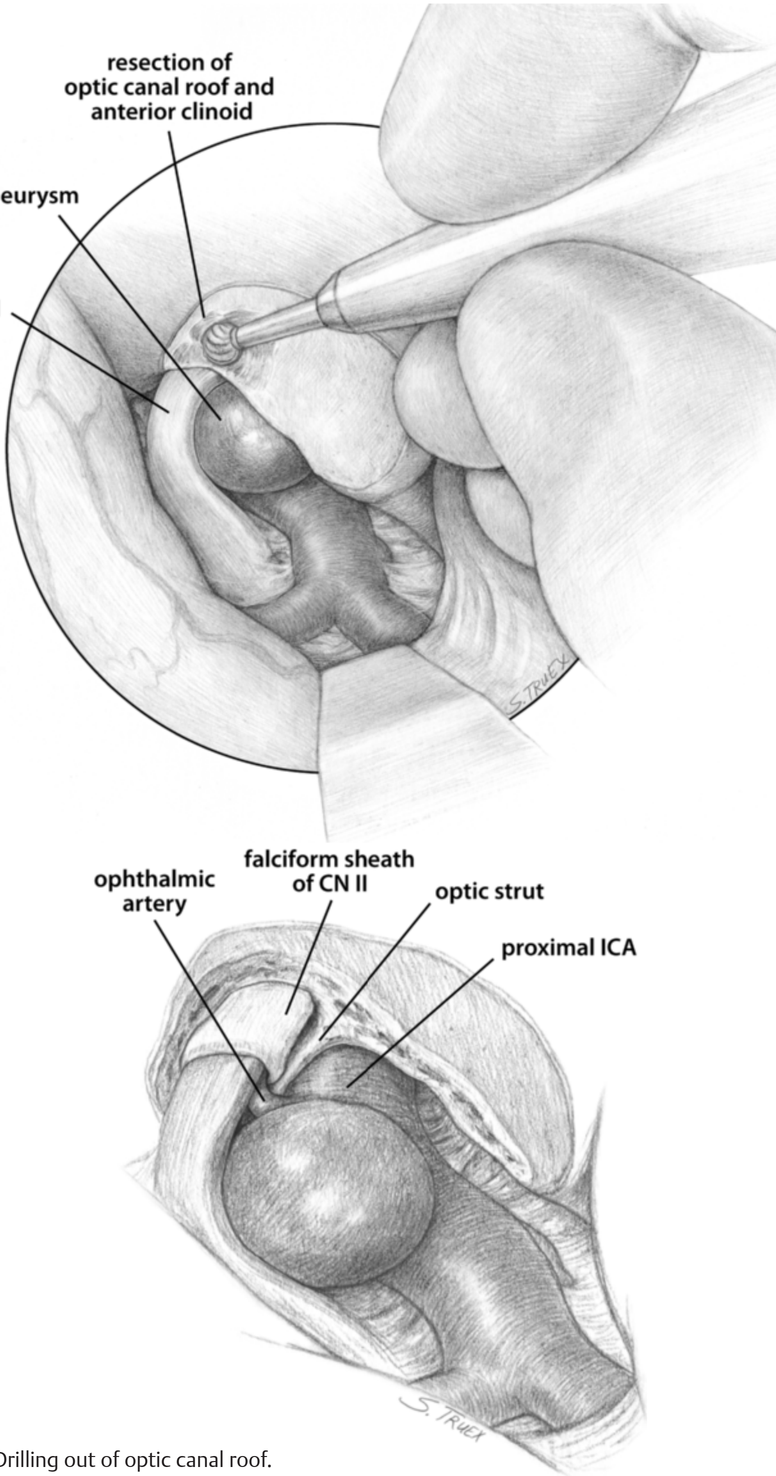


Fig. 4.12 Drilling out of optic canal roof.

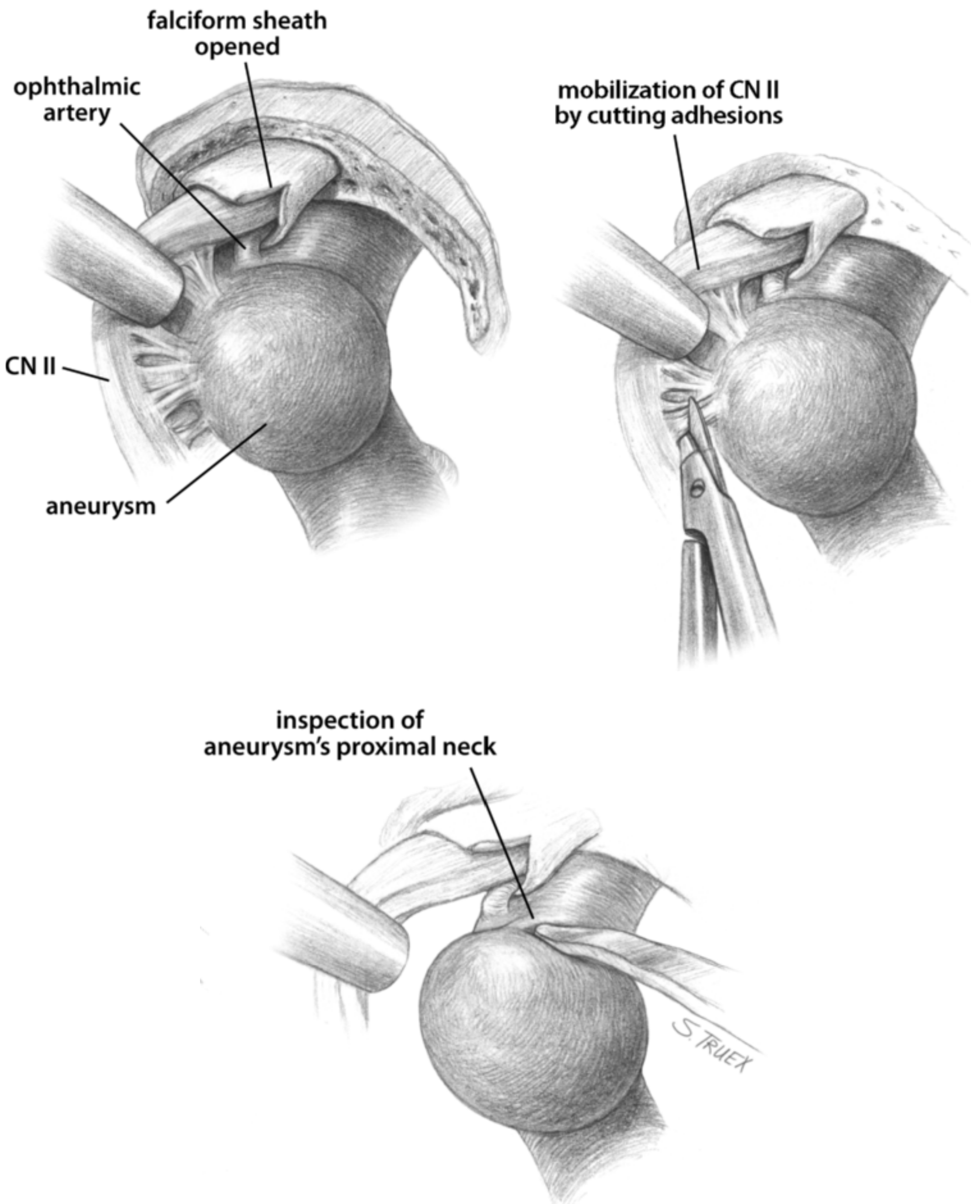


Fig. 4.13 Medial mobilization of aneurysmal dome.

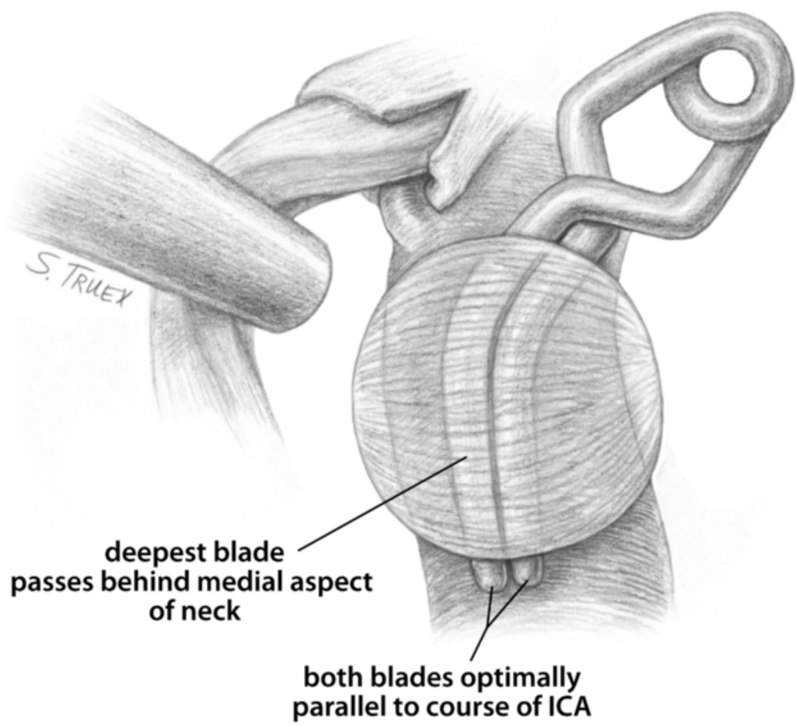


Fig. 4.14 Aneurysm clip application.

Institution of Temporary Occlusion and Retrograde Suction Decompression

Intracranial proximal control of these aneurysms is, as a rule, impractical. Consequently, small and medium-size unruptured lesions are usually clipped directly without temporary proximal occlusion. Ruptured aneurysms and larger lesions occurring relatively distally on the carotid can be clipped after being softened by temporary occlusion of the cervical internal carotid artery under the protection of pentothal-induced burst suppression. For larger and more threatening aneurysms, the best results are obtained by maximally decompressing the aneurysm sac prior to attempting clip placement.

After the initiation of burst-suppressive anesthesia, temporary occlusion of the cervical ICA and the intracranial ICA proximal to the PCOMM origin is performed. The OPHT should be occluded with a small temporary aneurysm clip. If this clip hinders neck dissection and final clip placement, the OPHT may be briefly cauterized by the bipolar forceps. This cauterization will serve to transiently occlude the artery and prevent retrograde flow into the aneurysm during suction decompression.

An 18-gauge angiocath is carefully introduced into the cervical ICA distal to the occluding clip, and the needle is withdrawn. When pulsatile flow is seen, suction is gradually applied to a short length of venous extension tubing attached to the angiocath. The angiocath can be introduced over a guide wire if necessary, but generally, if a nonatherosclerotic portion of the vessel is punctured, the catheter may be easily advanced with a low risk of dissection.

When suction is applied to the angiocath, the surgeon should notice the aneurysm immediately becoming softer and more pliable. In some situations the sac will collapse, but even if it does not, there will be sufficient decompression to permit atraumatic application of permanent clips (**Fig. 4.15**).

When the aneurysm is occluded, suction is discontinued, but the angiocath is left in place until the final clip reconstruction is achieved. If an immediate intraoperative angiogram is to be done, this arterial access can be used. If there is to be any significant time delay, the angiocath should be removed, and a fresh puncture of the artery should be made with a small-gauge needle. The site of the angiocath's insertion should always be inspected radiographically at the time of intraoperative angiography for evidence of dissection.

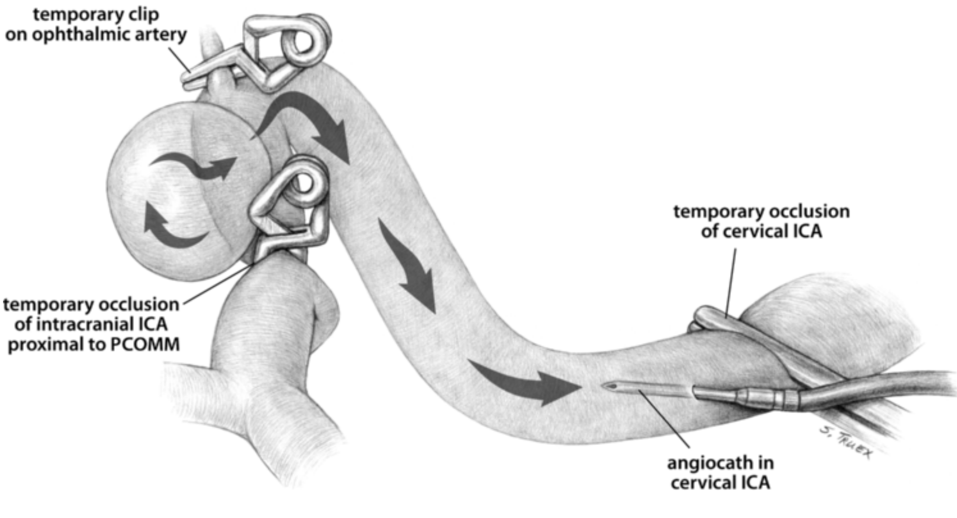


Fig. 4.15 Aneurysm suction decompression.

Clip Application

After appropriate exposure and delineation of the aneurysm's neck, the surgeon must choose the plane for the occlusion of the aneurysm. For lesions with very small necks this is *generally* of little importance because any clip application that spans the neck may be adequate. Unfortunately, this is not the case for most aneurysms in this location. These aneurysms generally have relatively extensive necks, which extend along the long axis of the arterial wall and sometimes involve over 50% of the circumference of the parent artery.

As a *general* rule, these ICA-ophthalmic aneurysms are best clipped in parallel with the vessel's long axis—the direction of application being from proximal to distal.

This approach has the greatest chance of producing a complete atraumatic apposition of the walls of the neck while preventing inadvertent occlusion of the parent artery. Because the initial intradural course of the carotid artery from the distal dural ring to the origin of the PCOMM is slightly medially directed, it favors a proximal-to-distal clip trajectory; accordingly, the clip shape with a relatively sharp horizontal bend in the midshaft portion of the blades is most generally used. These clips—all patterned on the initial Yasargil Aesculap design #FT746T (Aesculap, Inc., Center Valley, PA)—are applied in the trajectory shown and then "walked around" the neck to bring the distal blades almost parallel with the carotid's long axis (**Fig. 4.16**). When the neck is atherosclerotic or contains a calcific plaque, two or even three of these clips applied in tandem may be necessary to ultimately produce definitive occlusion.

If the aneurysm neck involves a large circumferential portion of the parent artery, a different approach is indicated/implemented. Once the aneurysm has been decompressed by trapping and retrograde suction, it should be clipped by the application of a series of very short, straight fenestrated clips applied in sequence from proximal to distal across the carotid artery. The blades of the first clip should extend proximally below the proximal neck of the aneurysm, and each of the remaining clips is applied immediately adjacent to the previous one. If the distal neck is easily visible, it can sometimes be dealt with using a fenestrated 45- or 90-degree angled clip. However, the entire neck can always be closed by a series of short-bladed straight fenestrated clips. The proximal neck cannot be effectively dealt with in any other fashion (**Fig. 4.17**).

Once the aneurysm has been occluded, the distal carotid clip should be removed; if the neck remains patent the aneurysm will refill slowly, allowing the temporary clip to be replaced and the clip reconstruction to be thoughtfully reevaluated. Unless there are obvious deficiencies, the wisest course is usually to remove all permanent clips and begin the reconstruction anew. The default option is always to establish a sequence of very short, straight-bladed, fenestrated clips applied in tight tandem.

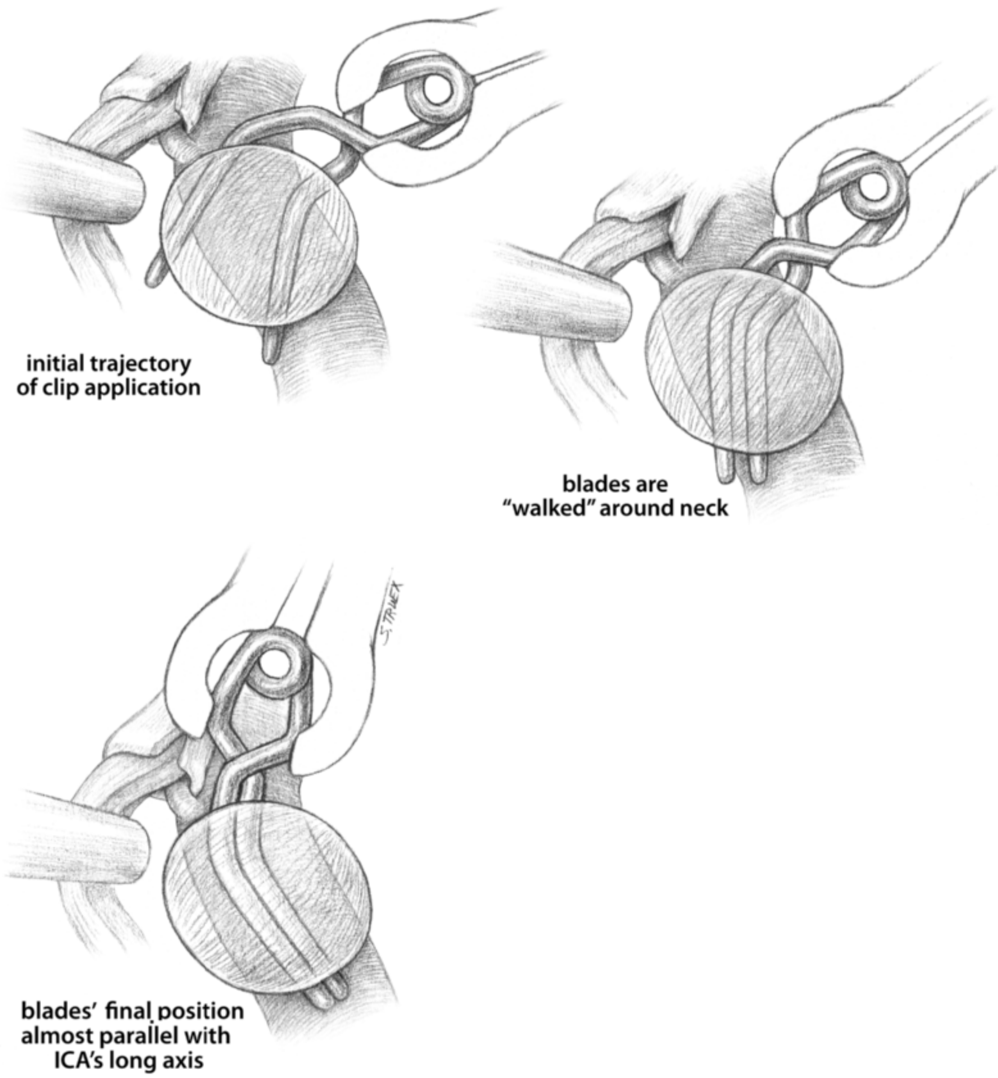


Fig. 4.16 Aneurysm clip application.

When the surgeon is satisfied with the clip reconstruction, the sequence of temporary clip removal is first, the distal ICA clip intracranially; second, the proximal cervical ICA clip; third, the OPHT clip. *Don't forget number 3*. Intraoperative angiography is almost always indicated in the management of these aneurysms.

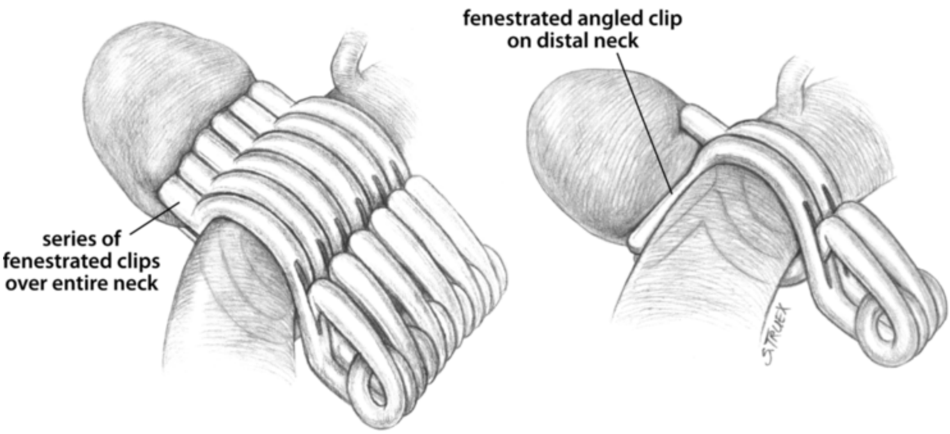


Fig. 4.17 Application of short fenestrated aneurysm clips.

Specific Issues Related to ICA-Superior Hypophyseal Aneurysms

These aneurysms are generally located on the medial wall of the ICA at or slightly distal to the OPHT origin. They project both medially and inferiorly toward the sella and often occupy the bony depression on the sella's lateral margin known as the carotid cave. They may be in part, extradural, but invariably their origin and a significant portion of the aneurysm itself lie within the subarachnoid space. These aneurysms are essentially never within the cavernous sinus; they can and do produce subarachnoid hemorrhage (SAH).

Exposure of ICA-SAH aneurysms involves steps common to the exposure of ICA-OPHT aneurysms as regards proximal control and bony removal. Although the roof of the optic canal does not impede the view of the mesial carotid wall at this level, the underlying optic strut is definitely a visual obstruction. In general, the strut must be effaced and the carotid reflected laterally to expose the aneurysm's neck. Large aneurysms in this location conventionally have a well-defined neck, which facilitates direct clipping; smaller lesions resist simple clip closure; the clip blades migrate immediately to the distal fundus and then pop off the aneurysm completely, an action synchronous with the abrupt onset of tetany in all surgical sphincters. Direct clipping may be worth one try in these situations. However, if the initial attempt is unsuccessful, use of a fenestrated clip with an angled or offset angled blade such as the Aesculap no. 602 (Aesculap, Inc., Center Valley, PA) or the Sugita no. 17–001–11 (Mizuho America, Inc., Union City, CA) is better tolerated by both aneurysm and surgeon.

Specific Issue Related to Paraclinoidal Aneurysms

These very proximally located posterior carotid wall aneurysms are frequently misconstrued at first glance to be located at the PCOMM origin. Even in the absence of an identifiable PCOMM artery, the lateral angiographic view of the ICA injection reveals their true location. The aneurysm arises at the level of the OPHT's origin on the abluminal side of the vessel. These aneurysms always project posteriorly and inferiorly from this straight segment of the ICA. The proximal fundus is almost invariably covered by the dural roof of the cavernous sinus, and periodically the proximal aneurysm neck is covered as well, yet it is rarely necessary to open the sinus to obtain adequate exposure. In fact, the only real difficulty in dealing with these lesions is finding them in the first place.

As a rule, once the carotid cistern has been opened, the distal aspect of the aneurysm's fundus will be seen peeking out from under the clinoid process (**Fig. 4.18**).

In the presence of a large clinoid process, the lesion may be completely hidden because the posterior portion of the clinoid is wrapped around the un-

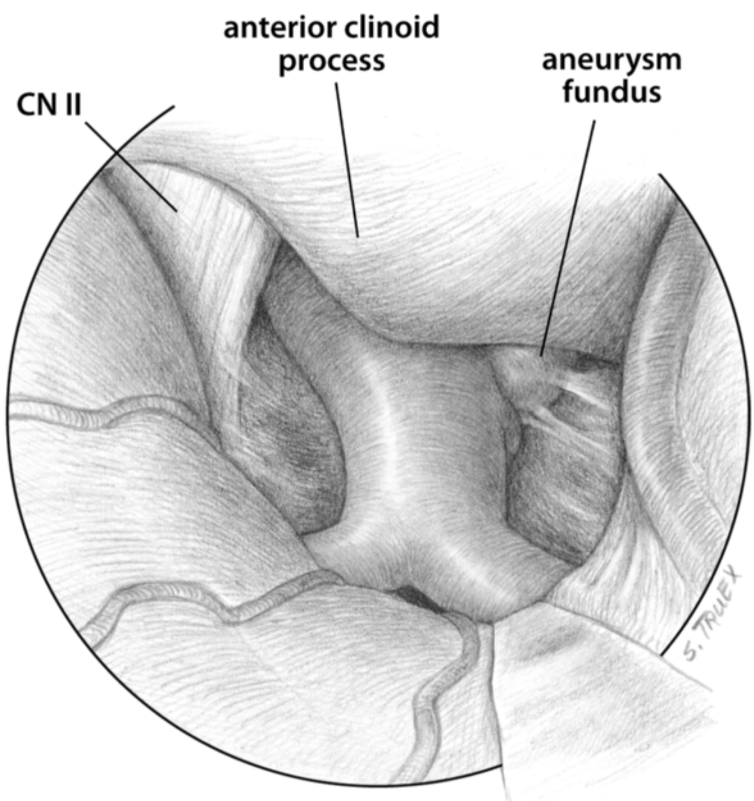


Fig. 4.18 Opening of carotid cistern exposing aneurysm fundus.

derlying artery. A very aggressive removal of the clinoid must be conducted. Special attention should be directed to the medially directed tip of the process, which, if left in place, will impede both the view of the aneurysm neck and any attempts at clip placement.

Once the clinoid has been completely removed and the overlying dura resected, the fundus and distal neck should be visually accessible, whereas the proximal neck sections of these lesions are often obscured by the superficial dural ring (**Fig. 4.19**). The fundus itself is often densely adhered to the dural reflection as well. The surgeon can either elect to sharply open the ring and peel the dura away from the carotid circumferentially, or simply dissect the dura away from the neck, tolerate the vigorous venous bleeding from the underlying plexus, and apply a clip from distal to proximal down the posterior wall of the carotid (**Fig. 4.20**). The tips of a clip applied in this fashion will lie deep to the dural reflection but will uniformly span the neck. The attendant venous bleeding can be managed with simple packing.

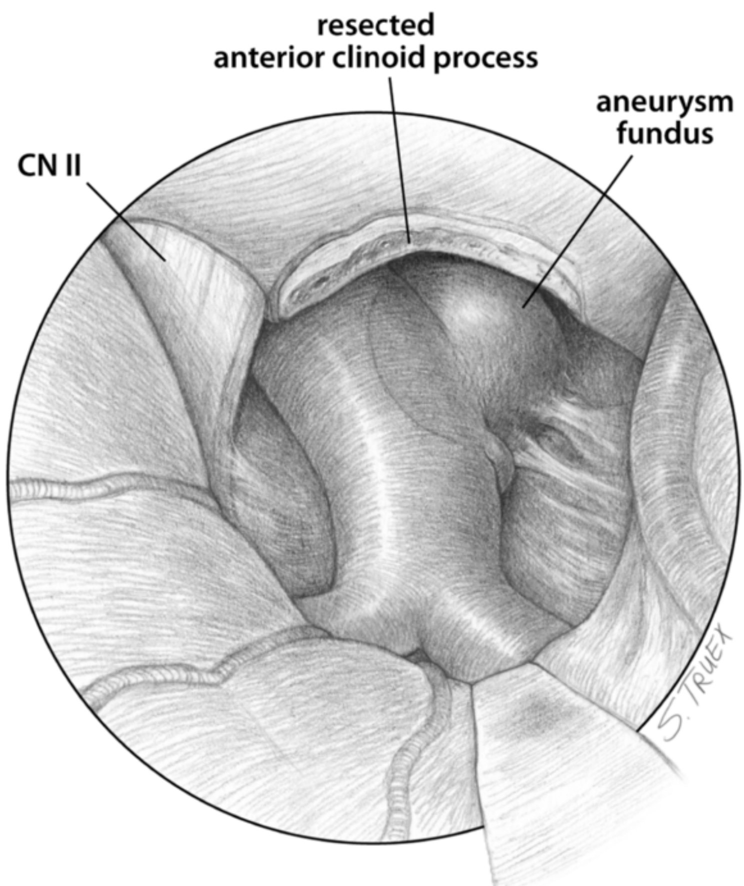


Fig. 4.19 Exposure of aneurysm proximal neck.

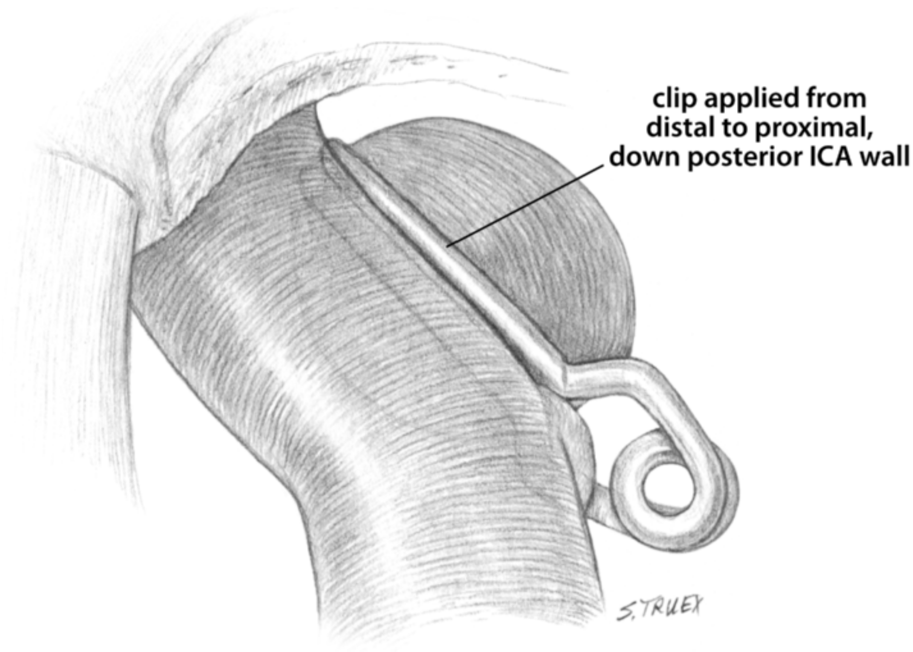


Fig. 4.20 Distal to proximal aneurysm clip application.

Final Thoughts

1. Understanding the relevant anatomy of the skull base will allow surgeons to focus their bony removal on the structures essential for exposure of the specific lesion under treatment, making the procedure both swifter and safer. Think before you drill.
2. Giant aneurysms of this region, especially those of the ICA-ophthalmic artery location, are extremely difficult lesions. They have expansive necks (longitudinally and circumferentially) and generally have intramural calcification as well as intraluminal thrombosis. In addition, they routinely present with significant and irreversible visual loss secondary to optic nerve compression.

5

Aneurysms of the Internal Carotid Artery Bifurcation

General

These are relatively uncommon aneurysms with a special predilection for occurring in children and adolescents. Both technically and conceptually they have much in common with basilar bifurcation aneurysms, being situated at the terminal apex of the artery at the origin of major large branch arteries and intimately involved with small important perforating vessels on their deep aspect.

Anatomy

The carotid bifurcation itself generally occupies the rostral extent of the carotid cistern immediately medial to the origin of the sylvian fissure; elongated, ectatic carotid arteries may extend laterally into the fissure itself, while abnormally short supraclinoid carotid segments may terminate in the posterior portion of the cistern.

Internal carotid artery (ICA) bifurcation aneurysms may take origin from the apex alone (small aneurysms with small necks) or from the apex with some involvement of either the proximal A1 or M1 segment (larger aneurysms with broad necks), or they may actually be located exclusively on the very proximal aspect of either main branch (usually small aneurysms). Not infrequently, very small lesions at the A1 origin may only be visible on routine angiographic projections as a double density superimposed on the proximal A1 segment; special views (such as rotational or transorbital oblique projections) may be required to conclusively identify the lesion (**Fig. 5.1**).

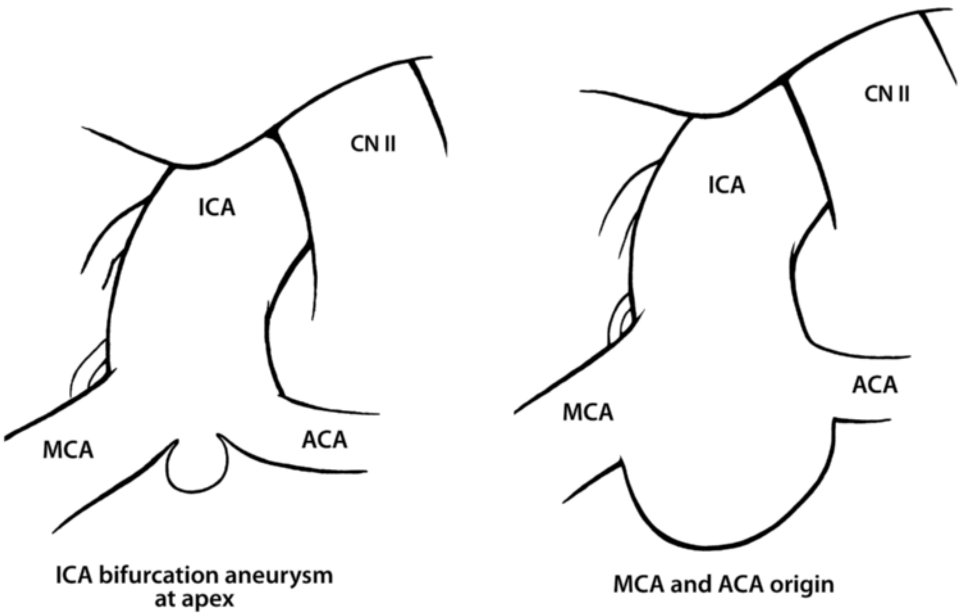


Fig. 5.1 Aneurysms of the ICA bifurcation.

In addition to the obvious A1 and M1 branch origins, perforating arteries from the carotid bifurcation and the medial aspect of the middle cerebral artery (MCA) may be involved with the aneurysm neck; deep to the aneurysm and hidden by it from the surgeon lies the anterior choroidal artery, a very real potential source of morbidity in the treatment of these aneurysms.

Projection

While the principal axis of projection for these aneurysms, like those of the basilar bifurcation, is superior, there is a surprising amount of variability in the degree of anterior-posterior tilt (**Fig. 5.2**). Lesions involving the A1 origin generally project somewhat anteriorly into the overlying orbital cortex, while those of the apex itself or proximal M1 segment may be directed sharply dorsally into the posterior aspect of the carotid cistern. This may result in the aneurysm projecting behind and somewhat medial to the distal ICA when viewed through the microscope. Aneurysms with this posterior projection are frequently intimately involved with the anterior choroidal artery.

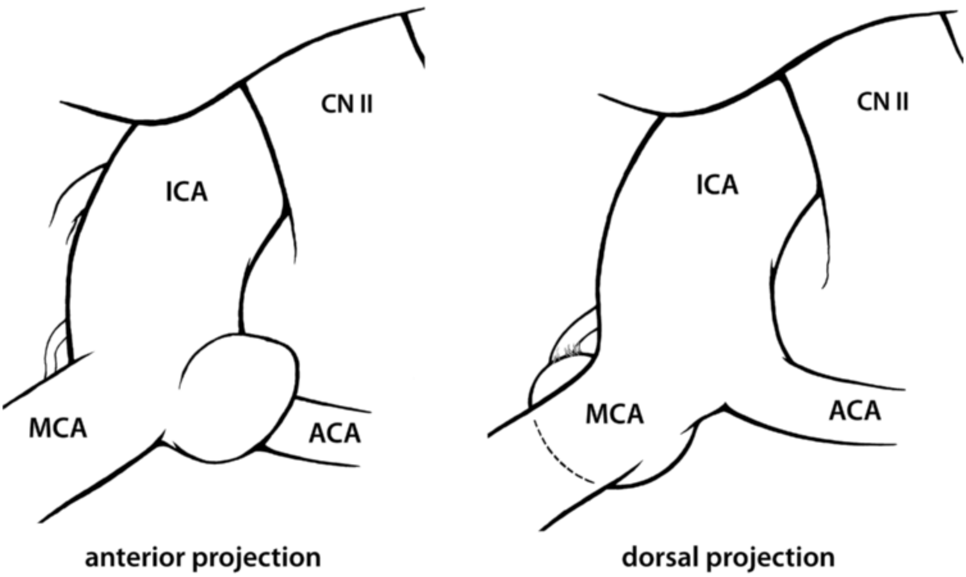


Fig. 5.2 Projection of ICA bifurcation aneurysms.

Procedure

Approach

Prior to selecting a final operative approach the surgeon should carefully evaluate the exact location and projection of the aneurysm and be aware of the size of the contralateral A1 segment, the patency of the anterior communicating artery, the course of the ipsilateral anterior choroidal artery, and the proximity of the lenticulostriate arteries to the M1 origin.

Here are some specific questions better asked and answered early than late:

1. Where are the best locations for temporary clip placements? Can I get a clip on the MCA proximal to the lenticulostriate origins? Will a clip on the ICA—distal to the anterior choroidal origin—give me room to work?
2. Can the contralateral A1 segment supply the ipsilateral A2 distribution (meaning, can the ipsilateral A1 be permanently trapped if necessary)?
3. Does the anterior choroidal artery come in contact with, or is it in proximity to, the deep aspect of the aneurysm?

The location of the ICA bifurcation mandates that the final common pathway to these aneurysms lie through the medial aspect of the sylvian fissure. Some surgeons prefer to approach the carotid cistern subfrontally, expose the proximal carotid artery at or near the level of the anterior clinoid process, and then work their way distally along the parent vessel, ultimately opening the arachnoid seam over the mesial sylvian fissure to expose the A1, bifurcation, M1, and dorsally located aneurysm. The principal advantage of this approach is the early establishment of proximal control of the carotid artery; the disadvantage is a somewhat restricted exposure of the bifurcation itself, the M1 and A1 origins, and, most importantly, the small perforating branches deep to the aneurysm complex. It also may require more brain retraction than absolutely necessary for exposure of the distal M1 and A1 segments, which can be important, especially in case of unexpected intraoperative problems.

In our opinion, a preferable alternative is to approach these aneurysms completely through the sylvian fissure, beginning with a superficial exposure of the MCA bifurcation (**Fig. 5.3**). The horizontal segment of the fissure is then carefully opened from lateral to medial, following the inferior aspect of the M1

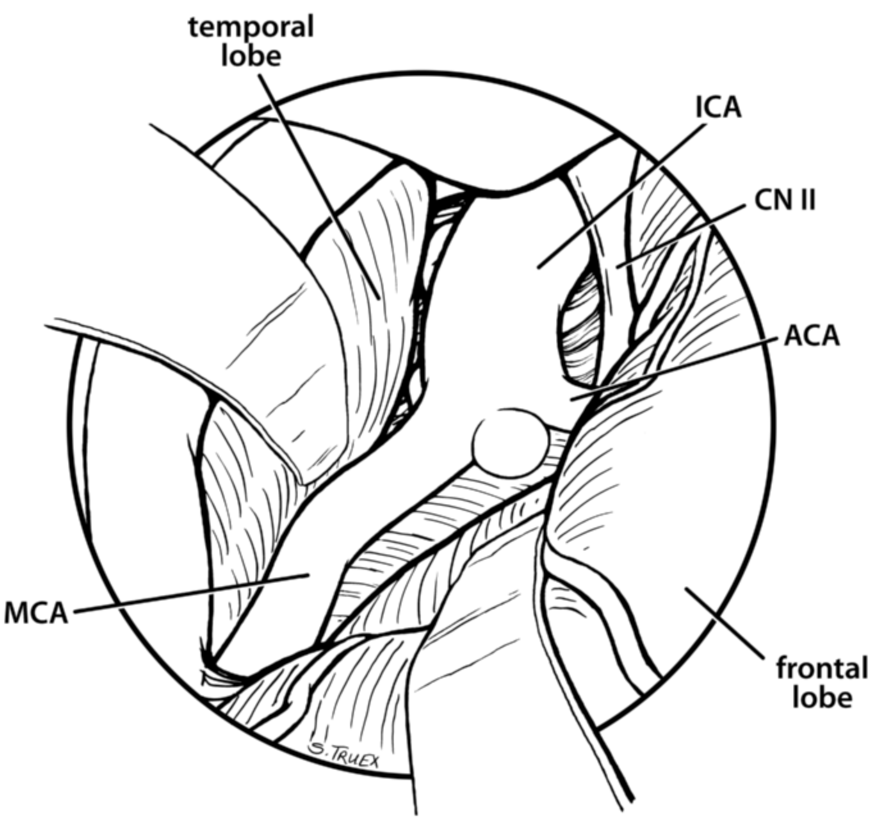


Fig. 5.3 Exposure of ICA through sylvian fissure.

trunk retrograde to its origin from the carotid artery. The A1 segment is then dissected, again on its inferior margin, almost to the interhemispheric fissure. The ICA itself is skeletonized and prepared for temporary clip placement distal to the anterior choroidal origin if possible.

With one retractor blade on the orbital surface of the frontal lobe immediately anterior to the sylvian fissure and a second retractor, if necessary, on the temporal tip, the surgeon can then begin to dissect the superior aspects of both A1 and M1 segments, exposing the aneurysm neck. These lesions are often quite friable, and in some situations the dissection will proceed more smoothly if it is begun several millimeters distal to the aneurysm neck and gently brought proximally along the healthy arteries to ultimately delineate the neck at both A1 and M1 origins. When dealing with ruptured aneurysms, the latter part of this dissection can be done most safely with the aneurysm softened by temporary ICA occlusion, and uniformly, when it's necessary to reflect the lesion anteriorly or medially to inspect the dorsal wall, temporary proximal occlusion is beneficial. For larger, more complex lesions (which are uncommon in this location) complete isolation of the local arterial circulation may occasionally be indicated. Although it would be ideal to temporarily trap the bifurcation distal to the origin of the anterior choroidal artery, the anatomical constraints posed by a temporary clip placed at this location generally make this maneuver not feasible. On the other hand, it is a trade-off of sorts. While the line of sight to the neck of the aneurysm could be obstructed, the placement of the temporary clip proximal to the origin places the anterior choroidal distribution at risk of ischemic injury.

To dissect or inspect the dorsal wall of a posteriorly projecting ICA bifurcation aneurysm can be quite difficult, but an excellent option is to begin that exposure inferior to the M1 origin (**Fig. 5.4**). By gently elevating the proximal MCA, the surgeon can frequently separate the anterior choroidal artery from the underside of the aneurysm and remove any small perforating branches that are adherent to its neck, clearing the path for a clip to be placed across the neck from above the MCA.

Clip Application

Most small-necked aneurysms, regardless of origin, can be safely clipped by a short straight or bayonet-shaped clip applied along the MCA axis (generally speaking in the coronal plane). Larger lesions with necks extending out on either A1 or M1 origins or posteriorly projecting aneurysms may require a more creative approach to avoid stenosing one or more parent arteries. Here the Yasargil ophthalmic clip shapes can be very helpful, providing the back wall of the neck has been definitively dissected; to bring the blades of this clip in parallel with the emerging artery, the "deep" blade must be passed behind the aneurysm neck, meaning the surgeon must know that this aspect of the neck is free from any adherent perforators or the anterior choroidal artery (**Fig. 5.5**). After

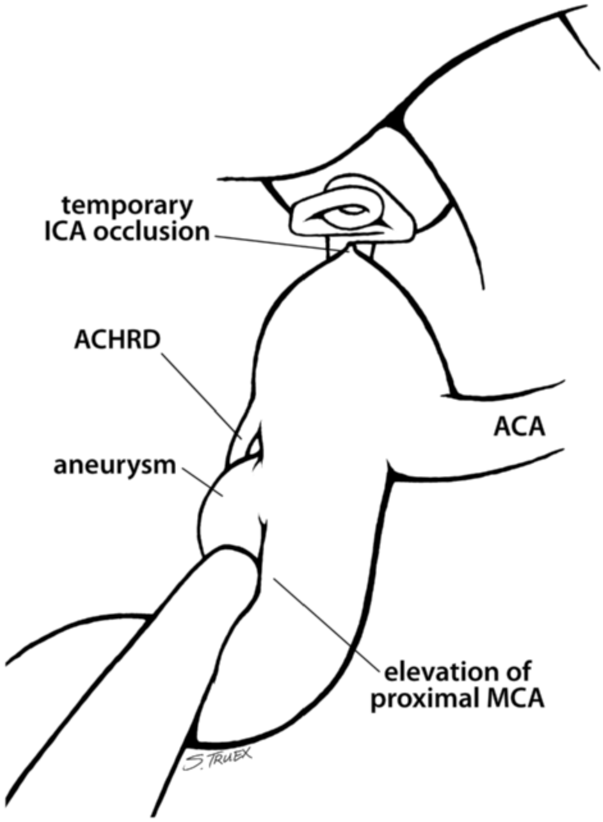


Fig. 5.4 Exposure of posterior projecting ICA bifurcation aneurysm.

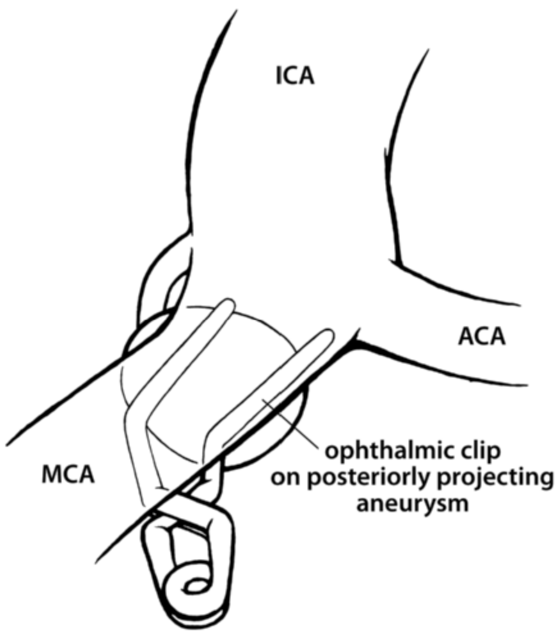


Fig. 5.5 Aneurysm clip application.

clip application the choroidal artery should be identified again. If you can't find it, it's probably in your clip blades.

For large lesions with calcified necks or in case of a "shear" of the aneurysm neck during dissection or clip application, an effective salvage maneuver can be a curved clip applied from distal to proximal down the superior margin of M1, crossing both aneurysm neck and A1 origin. A second clip, applied distally along A1, will trap the aneurysm–A1 complex, leaving the MCA in continuity with the parent ICA (**Fig. 5.6**). Foreknowledge of the competency of the contralateral A1 and anterior communicating artery is obviously a prerequisite for the successful use of this option.

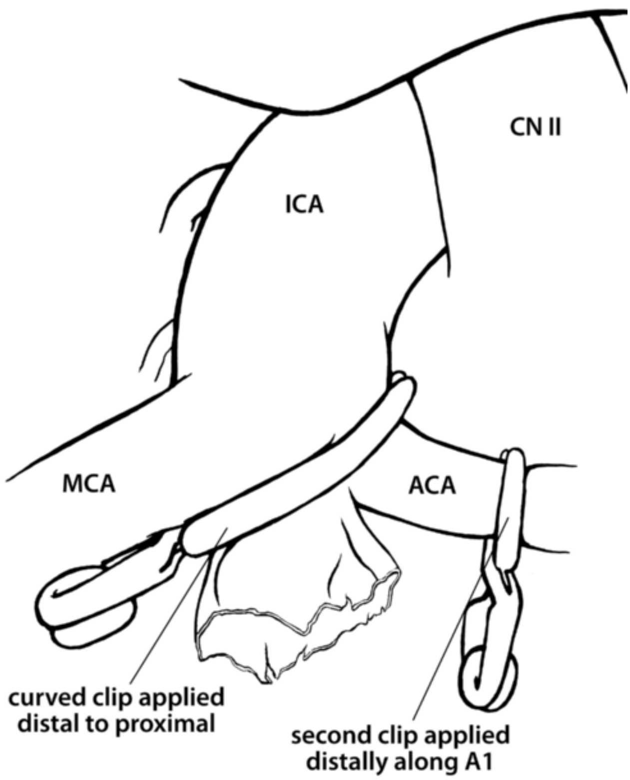


Fig. 5.6 Sacrifice of A1 segment for large aneurysms.

Final Thoughts

1. Small ICA bifurcation and A1 origin aneurysms can be easily missed on routine angiographic views.
2. A true transsylvian approach will allow the surgeon to completely expose any aneurysm variant in this location.
3. Most of the potential morbidity associated with these lesions lies along the posterior aspect of the aneurysm in the form of small perforating arteries and the anterior choroidal artery.

6

Aneurysms of the Middle Cerebral Artery

General

Aneurysms of the middle cerebral artery (MCA) represent some 15 to 25% of all intracranial aneurysms in large clinical series, being less frequent in series of ruptured aneurysms and somewhat overrepresented in series combining both ruptured and unruptured lesions. They classically occur at the main bifurcation of the MCA's main trunk or M1 segment but not infrequently are found in association with more proximal branches (lenticulostriate and anterior temporal arteries); they may also arise distal to the MCA bifurcation, where mycotic and dissecting lesions are most common. Large and giant aneurysms occur with a disproportionate frequency along the MCA and may be of saccular, fusiform, mycotic, marantic, or dissecting origin.

Subarachnoid bleeding from MCA aneurysms typically fills both the sphenoidal and insular portions of the ipsilateral sylvian fissure, with variable extension into the basal cisterns. Intraparenchymal hemorrhage occurs with greater frequency than is found in any other aneurysmal location; bleeding is typically into the overlying temporal lobe, although superiorly directed aneurysms may on occasion rupture into the frontal operculum.

Anatomy

For purposes of discussion, these aneurysms can be divided into three separate and distinct anatomical groups:

1. Proximal MCA lesions, which arise along the M1 segment between the internal carotid artery (ICA) bifurcation and the main MCA bifurcation

2. MCA bifurcation aneurysms
3. Distal MCA aneurysms, arising in the cortical or hemispheric portion of the sylvian fissure beyond the M2 origins

Proximal Middle Cerebral Artery Aneurysms

Proximal MCA aneurysms are found in the horizontal or sphenoidal segment of the sylvian fissure, arising along the M1 segment from either the dorsal aspect in association with the lenticulostriate arteries or the ventral aspect, usually at the site of the anterior temporal artery's origin or at an early MCA bifurcation (**Fig. 6.1**). The dorsal lesions tend to be quite small and to project superiorly into the brain, and they often have a lenticulostriate branch emanating from either their medial or lateral margin. These dorsal aneurysms are not infrequently the cause of subarachnoid hemorrhage (SAH) and may easily be overlooked on a cursory examination of a poorly performed angiogram.

Ventral aneurysms are more consistent in their size, projection, and general appearance. As a rule they have small, well-defined necks, with the entire aneurysm complex lesion lying in the subarachnoid space. Although they can produce subarachnoid hemorrhage, more frequently they are unruptured, asymptomatic aneurysms found incidentally on magnetic resonance imaging (MRI) or identified in the evaluation of SAH produced by a separate aneurysm, often another MCA lesion.

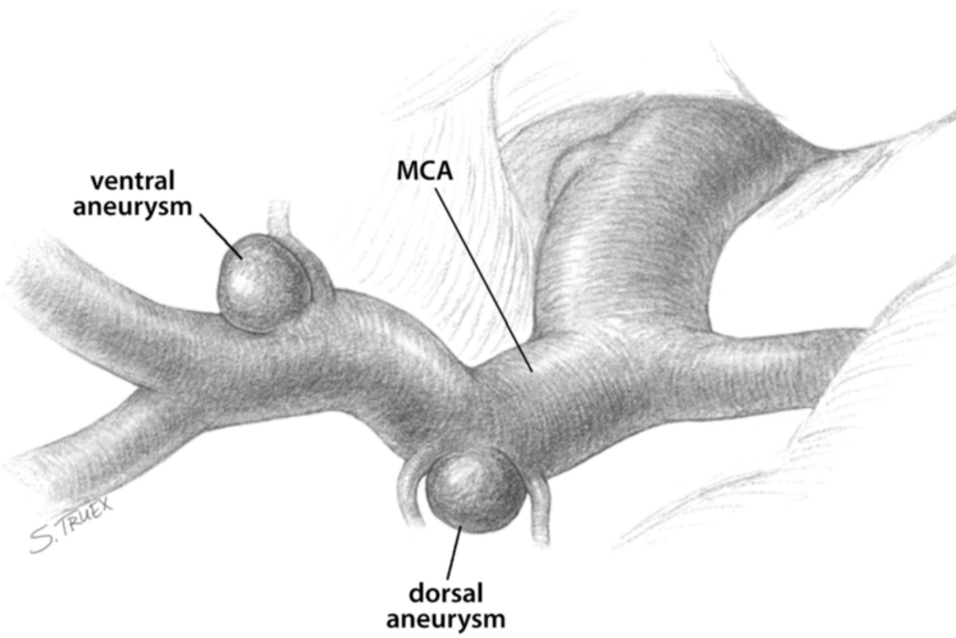


Fig. 6.1 MCA aneurysms.

Middle Cerebral Artery Bifurcation Aneurysms

By far the most common location for aneurysm formation on the MCA is the MCA bifurcation (**Fig. 6.2**), which is routinely situated in the lateral aspect of the horizontal segment of the sylvian fissure, immediately medial to the limen insulae (**Fig. 6.3**, arrow indicating MCA bifurcation). The bifurcation is almost always more proximal than the surgeon conceives it to be, meaning an exposure that opens only the cortical or hemispheric portion of the fissure is inadequate for aneurysm exposure, much less for obtaining proximal control.

The M1 trunk ends in a true bifurcation in over 90% of cases; references to this division as a trifurcation are both inaccurate and misleading. Not uncommonly, the more anterior of the two M2 branches (frontal ascending trunk) divides quickly, the two M3s joining the posterior M2 (insular trunk) to make three large branches surrounding the aneurysm fundus, all of which must be accounted for at the time of clip placement.

Almost invariably, the M1 segment terminates in a T-shaped bifurcation, with the M1 itself representing the long stem of the T (**Fig. 6.4**). The two M2 segments routinely exit the bifurcation at roughly 90-degree angles from the M1 and at 180 degrees from each other. The larger the aneurysm, the more the branches correspond to this general configuration. Even in giant lesions, when the initial millimeters of each M2 segment may actually be intramural, the branches are located on exact contralateral sides of the M1 termination, exiting the parent vessel at an angle of no more than 90 degrees and running diametrically opposite courses. Awareness of this phenomenon can be of great assistance to the surgeon, both in seeking to initially identify the exiting branches and in planning clip application.

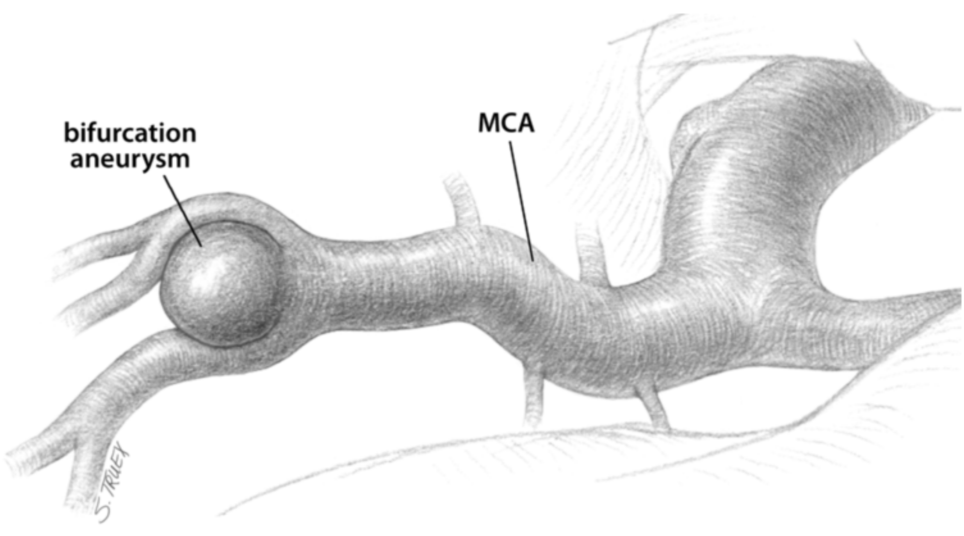


Fig. 6.2 Most common location for MCA aneurysm.

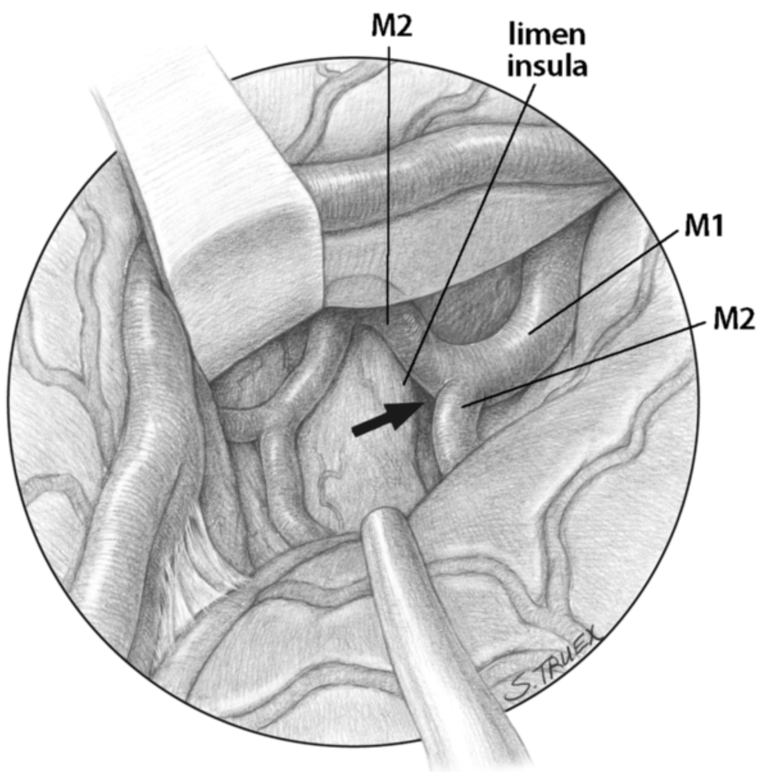


Fig. 6.3 Anatomic position of MCA bifurcation.

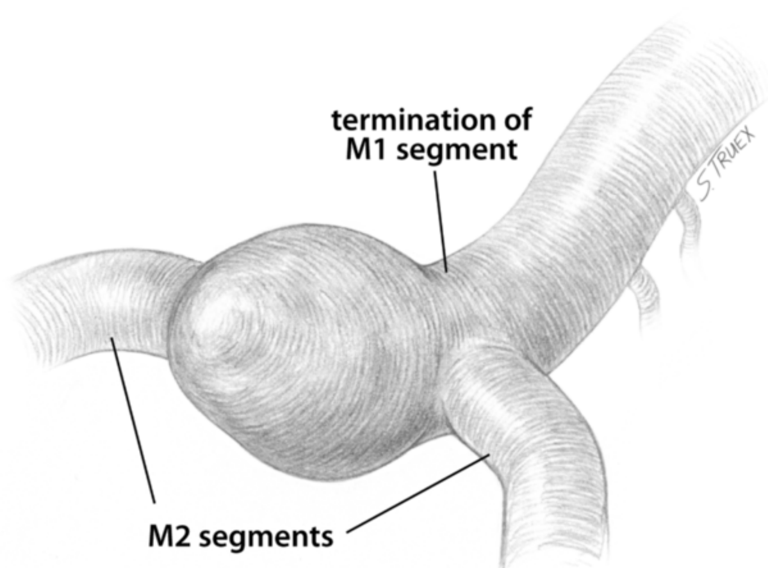


Fig. 6.4 Configuration of an MCA aneurysm.

Distal Middle Cerebral Artery Aneurysms

These aneurysms arise in the cortical or hemispheric segment of the sylvian fissure, distal to the main M1 bifurcation (**Figs. 6.5** and **6.6**, arrow indicating distal MCA). They lie on the insular cortex and, depending on their size, may invaginate into either or both frontal and temporal operculae. Frequently these aneurysms are more distal than expected and therefore can be difficult to expose. Smaller aneurysms in this location may be routine saccular lesions, but more frequently these aneurysms are fusiform in contour and dissecting or mycotic in etiology. As such, they may involve not solely a bifurcation or branch point but often incorporate large segments of both afferent and efferent arteries. Early recognition of the nature and anatomical extent of these lesions is critical to their successful management.

Projection

Coupled with the aneurysm's location, the projection of these lesions determines the optimal route of approach. For proximal aneurysms, it is always necessary to open the sphenoidal portion of the fissure for proximal control and aneurysm exposure. When dealing with the dorsally projecting aneurysms associated with the lenticulostriate arteries, proximal control is simple to achieve with distal to proximal opening of the sylvian fissure beginning at the MCA bifurcation; the reverse is true with ventrally projecting aneurysms in which proximal control is best obtained by careful dissection of the ICA in the carotid cistern followed by exposure of the MCA at the carotid bifurcation, prior to opening the distal aspect of the fissure.

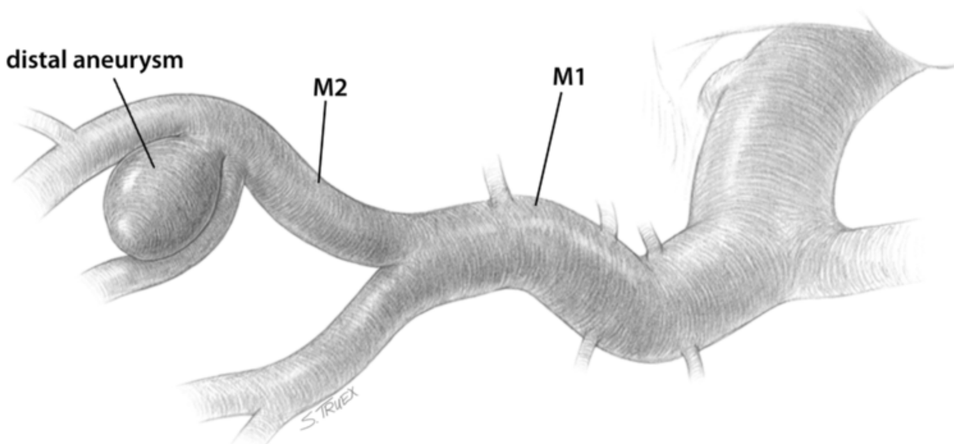


Fig. 6.5 Distal MCA aneurysm.

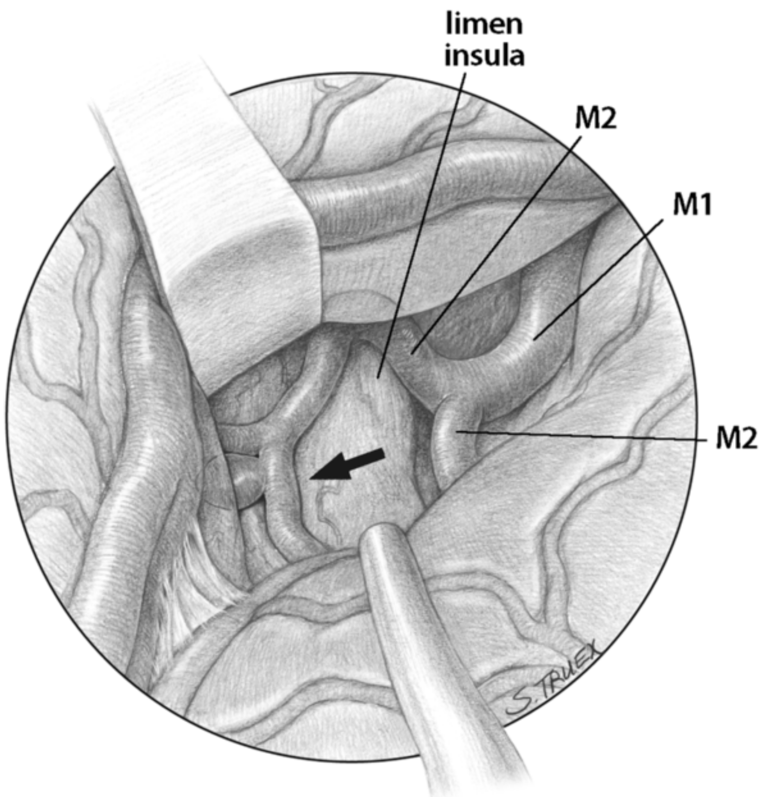


Fig. 6.6 Anatomic position of distal MCA aneurysm.

For the common aneurysms at and near the M1 bifurcation, the critical aspect of their projection relates to the axis of the parent MCA. If the aneurysm's projection is inferior to the M1 (**Fig. 6.7**) the surgeon can first open the hemispheric portion of the fissure, identifying the M2 branches and following them retrograde to the bifurcation. Then, by hugging the cortical surface of the limen insula on the anterior aspect of the aneurysm's neck and dissecting medially into the fissure, the M1 segment can be safely identified. When dealing with these inferiorly projecting lesions there is no necessity to open the sylvian fissure proximally to obtain proximal control.

On the other hand, if the aneurysm in question projects superiorly rostral to the axis of the M1 segment (**Fig. 6.8**), the sphenoidal portion of the sylvian fissure should be opened initially to secure the M1 segment, prior to exposure of the more laterally located aneurysm. A safe way to accomplish this is to begin the fissure dissection laterally at the junction of the sphenoidal and hemispheric portions, deepen the exposure until the base of the aneurysm is seen,

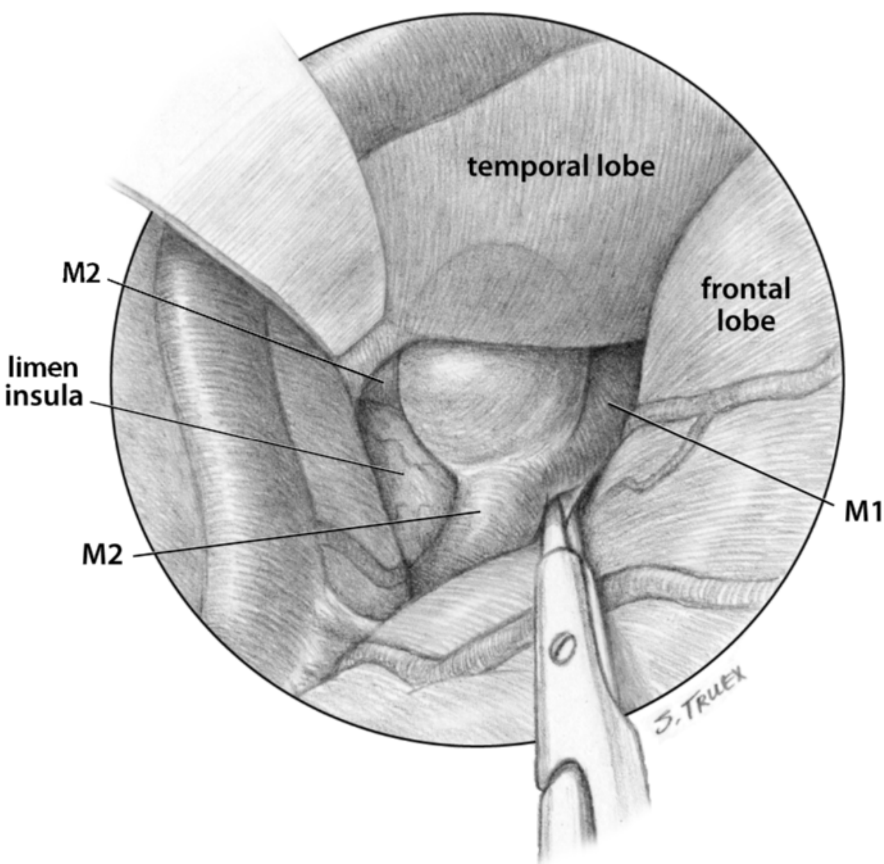


Fig. 6.7 Inferior projection of MCA aneurysm.

and then carry the dissection medially, opening the horizontal segment fissure from lateral to medial for ~2 cm. The frontal and temporal operculae should be completely separated superficially along the sphenoid ridge and then gently retracted to expose the M1 lateral to the lenticulostriate origins and medial to the bifurcation, an optimal site for temporary arterial occlusion if necessary.

The relatively rare and unusual distal MCA aneurysms are, by definition, located completely within the hemispheric segment of the sylvian fissure. If the MCA bifurcation is not involved, proximal control of the M2 trunks can be obtained by initially opening the fissure at the junction of the sphenoidal and hemispheric portions, and then the aneurysm is exposed by carrying the dissection as distally as the size and anatomy of the lesion dictate. Because of the complexity of these aneurysms and the consequent difficulties with their effective treatment (complex clip reconstruction, distal bypass, branch reimplantation, etc.), it's almost impossible to expose too much of the distal M2 and M3 branches.

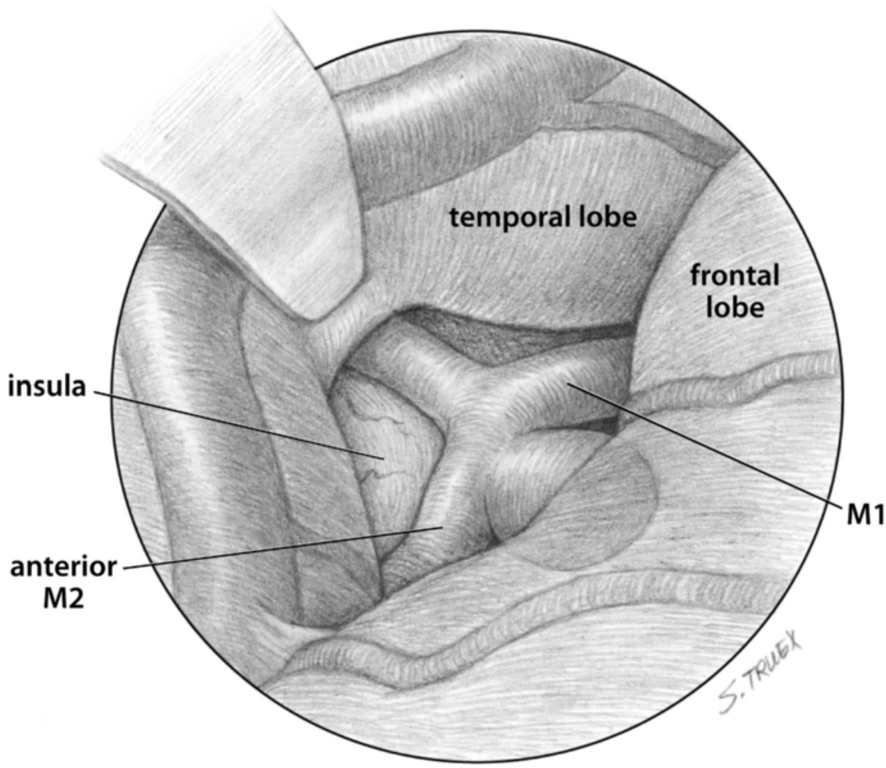


Fig. 6.8 Superior projection of MCA aneurysm.

Procedure

General

All MCA aneurysms can be exposed using some variation of the standard frontotemporal (“pterional”) approach, with the specific variation being chosen with the location, projection, size, and anticipated complexity of reconstruction in mind. The potential need for revascularization should be evaluated in planning the exposure; at a minimum, the parietal branch of the superficial temporal artery (STA) should be identified and preserved as the scalp flap is reflected.

Craniotomy

Currently there are two craniotomy variations in use at University of Texas Southwestern, one for small, routine (usually unruptured) aneurysms, and a second, larger standard exposure for more complicated lesions, ruptured aneurysms, and all giant aneurysms. Let's discuss the latter first.

A generous frontotemporal exposure will suffice for any variation of MCA aneurysms; it preserves all of the surgeon's options in terms of approach and exposure and is obviously ideal when one is dealing with multiple lesions. To improve temporal lobe exposure, the horizontal limb of the incision is tilted posteriorly slightly, and the horizontal limb extends to the midline at the brow (**Fig. 6.9**).

The scalp flap can be raised in the interfascial plane as will be described, or it can be turned as a musculocutaneous flap over the orbital roof to be held there with fishhook retractors. When using the interfascial exposure, the attachments of the temporalis muscle to the outer table are cut in a horseshoe-shaped fashion and hinged inferiorly, and that incision is extended from anterior to posterior ~2 cm along the frontozygomatic process. The temporalis muscle flap so formed is aggressively reflected inferiorly across the intact zygoma and again held with one or two fishhook retractors. The combined flap is considerably faster, but the interfascial approach provides an easier visualization of the skull base at the level of the zygoma.

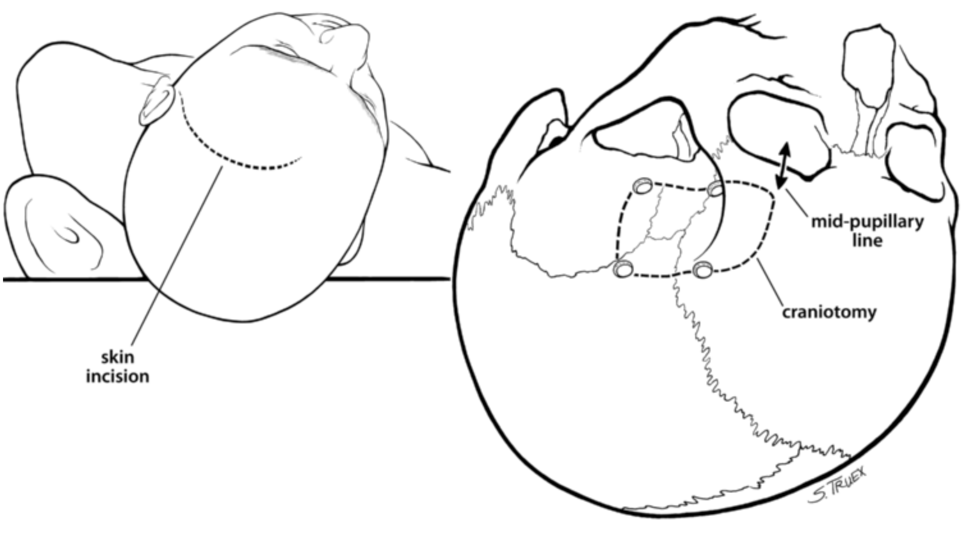


Fig. 6.9 Skin incision and craniotomy for MCA aneurysm.

The craniotomy flap is rectangular in shape, and generally some 8 cm in length (**Fig. 6.10**). It extends anteriorly from the temporal squama to the mid-pupillary line, superiorly some 4 cm, then posteriorly to cross the superior temporal line at approximately the level of the coronal suture before turning inferiorly to end at the temporal burr hole. It is routinely turned as a free flap with burr holes placed in the anatomical key, over the temporal squama and below the superior temporal line anterior to the squamosal suture. The inferior limb of the flap—where the bony incision crosses the sylvian fissure—is usually not connected with the craniotome but rather is completed with a high-speed burr to avoid injury to the underlying dura and to ensure the cut is complete across the lateral aspect of the sphenoid ridge before the flap is elevated.

A routine resection of the lateral aspect of the sphenoid ridge is done (**Fig. 6.11**) after a generous subtemporal removal of the squamosal temporal bone with rongeurs. Once bony hemostasis is obtained, the dura is opened in a stellate fashion, with the cuts being carried into each corner of the exposure. The four dural flaps are then tacked back tightly against the inner table of the skull (**Fig. 6.12**).

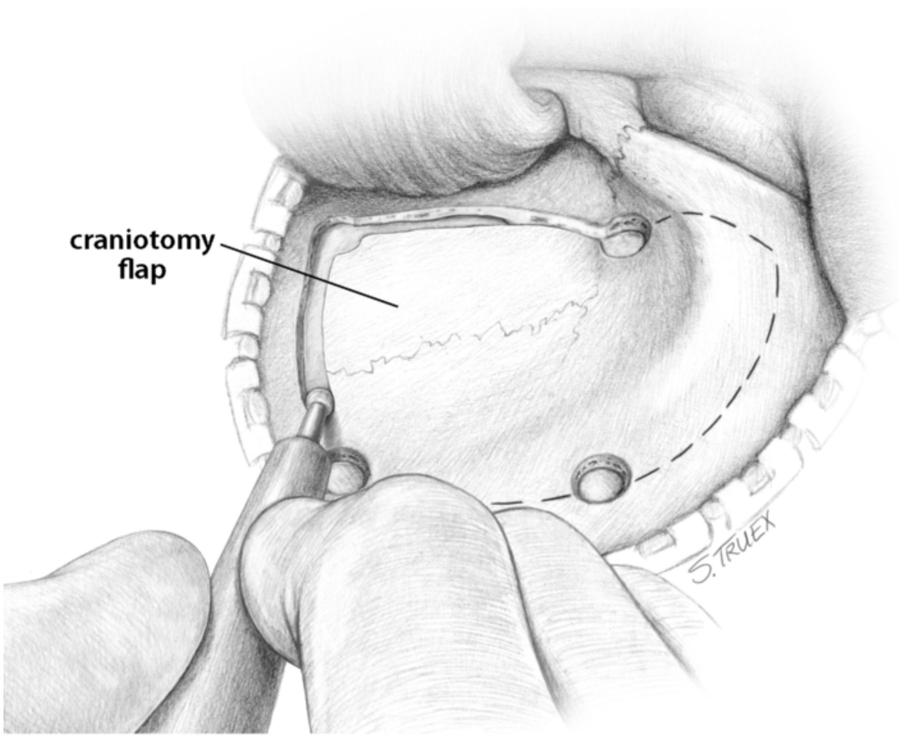


Fig. 6.10 Craniotomy flap for MCA aneurysm.

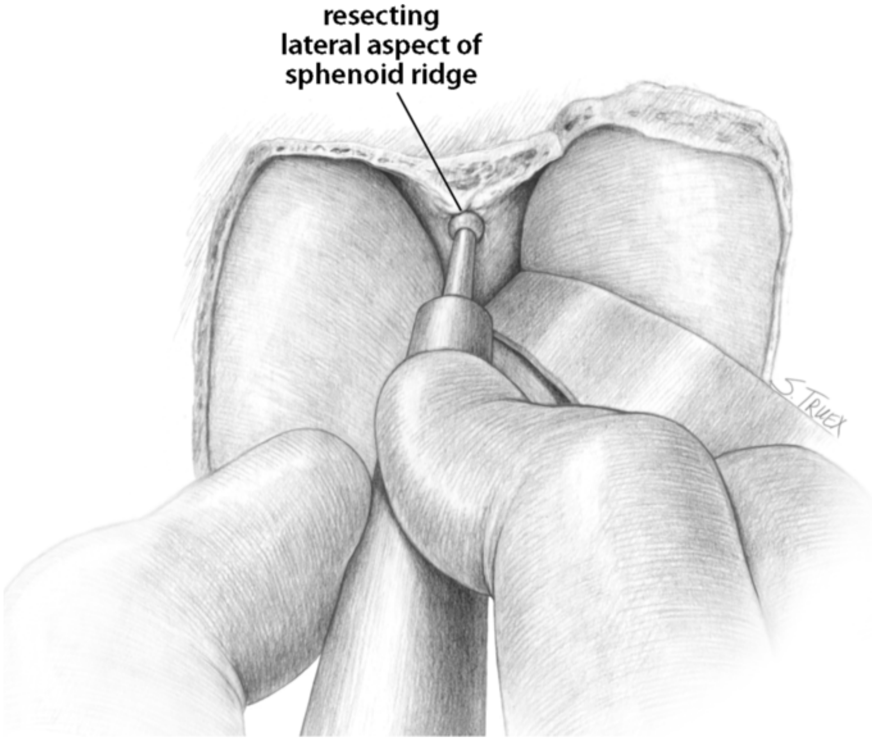


Fig. 6.11 Extradural drill resection of sphenoid ridge.

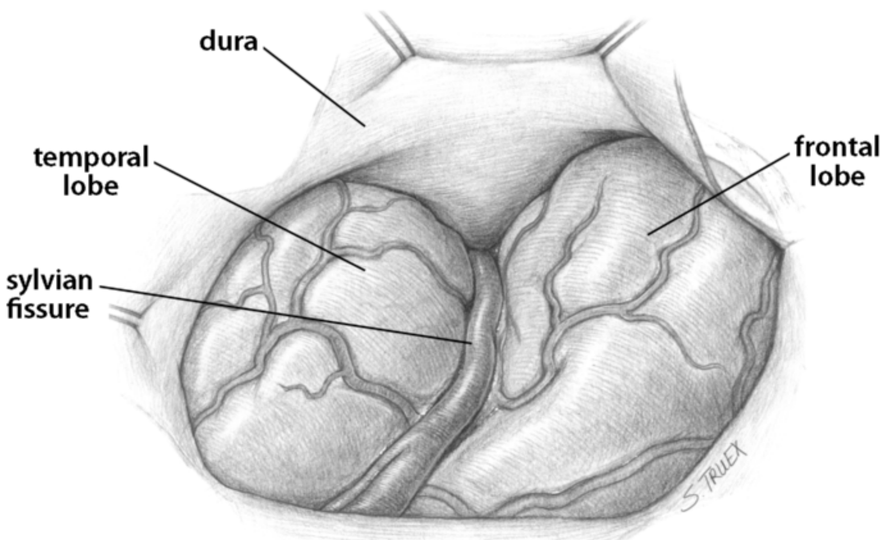


Fig. 6.12 Opening of dural flaps over sylvian fissure.

The cortical exposure now includes the orbital and hemispheric surfaces of the frontal lobe, the superior and middle temporal gyri, and some 5 cm of the hemispheric portion of the sylvian fissure; in addition to permitting placement of a ventriculostomy at the Payne point, this exposure will allow the surgeon to approach the MCA from a subfrontal route, a transsylvian route, a transtemporal or transcortical route or an anterior temporal exposure, or any necessary combination of the above.

Initial Exposure

The microsurgical portion of all MCA aneurysm operations, except the transcortical approach to the MCA bifurcation, begins with opening of some portion of the sylvian fissure. For lesions located along the M1 segment in the proximal aspect of the sphenoidal segment of the fissure, the initial approach is usually subfrontal to the M1 origin and can be facilitated by opening the arachnoid of the carotid cistern prior to entering the mesial portion of the fissure to demonstrate the carotid bifurcation.

For aneurysms distal to the MCA bifurcation (**Fig. 6.13**), the entire cortical segment of the fissure must be opened; this can be accomplished by

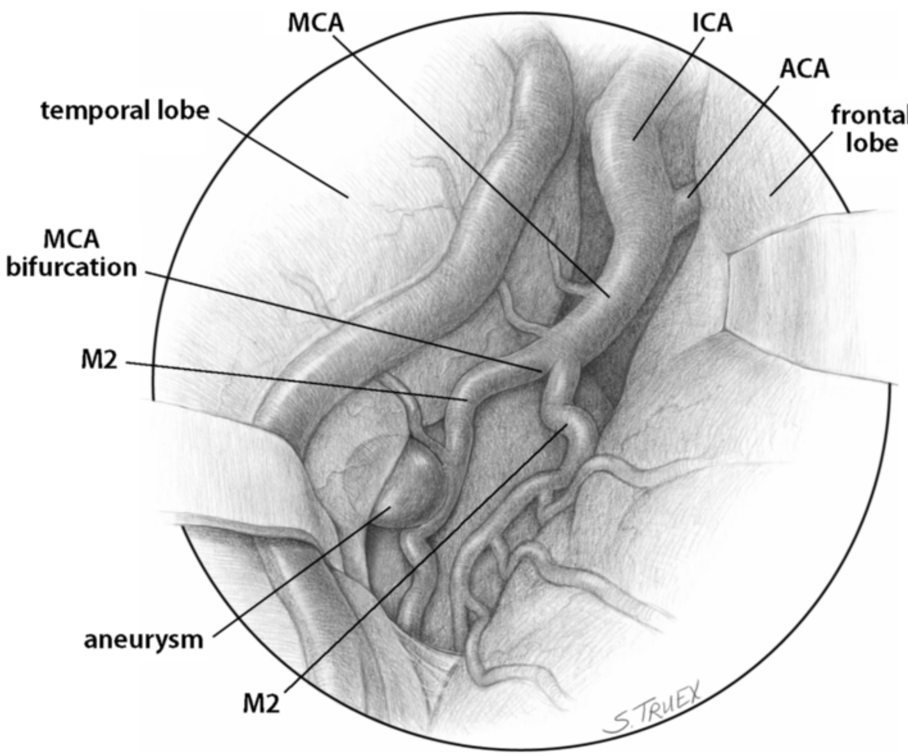


Fig. 6.13 Exposure of entire cortical segment of sylvian fissure.

beginning the dissection 2 to 3 cm lateral to the site of the MCA bifurcation and opening the arachnoid both proximally and distally. As the dissection is deepened and the frontal and temporal operculae retracted, the insula, aneurysm, and M2 segments will gradually be exposed. When exposing a distal ruptured lesion, after opening the proximal aspect of the fissure, the surgeon may elect to defer exposure of the lesion itself until the distal M2 and M3 branches are controlled. In this circumstance, the angiographic sylvian point can be identified (or estimated) and the cortical aspect of the fissure opened retrograde from that point.

The length of fissure opening will obviously be dictated by the aneurysm's size and site of origin, but a very generous insular exposure is usually quite helpful in light of the complexity of many of these lesions.

Most nongiant MCA bifurcation aneurysms, be they ruptured or intact, can be adequately exposed via a relatively limited opening of the sylvian fissure centered on the junction of the sphenoidal and hemispheric segments. The MCA bifurcation itself is located in the most lateral aspect of the sphenoidal portion of the fissure, a point that projects on the lateral aspect of the temporal lobe beneath the superior temporal sulcus some 2 cm posterior to the anterior extent of the superior temporal gyrus (**Fig. 6.14**). This relatively constant loca-

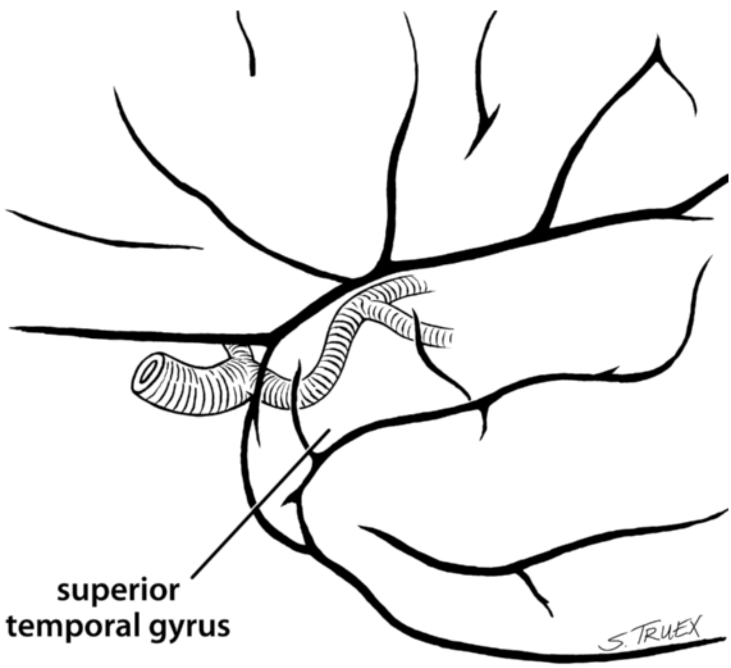


Fig. 6.14 Cortical localization of MCA bifurcation.

tion implies that, to expose the bifurcation, both the lateral and mesial aspects of the fissure must be opened and more retraction of the temporal lobe than of the frontal lobe will be required.

In general the surgeon can easily identify the cortical representation of the fissure, which is commonly marked by the overlying middle cerebral veins, vessels that typically but not invariably “belong” to the temporal lobe. If the surgeon begins dissection adjacent to the anterior aspect of these veins, in close proximity to an emerging cortical branch of the MCA and some 3 cm posterior to the remnants of the sphenoid ridge, the fissure can be opened relatively atraumatically down to the level of the insula (**Fig. 6.15**). It’s important for the inexperienced surgeon to have a firm concept of what “relatively atraumatically” actually means.

Certainly, a pristine opening of this critical cerebrospinal fluid space is ideal; its accomplishment represents a technical feat of which any surgeon can be justly proud. This fortuitous result is most likely to occur when dealing with unruptured lesions in older patients having capacious fissures amenable to

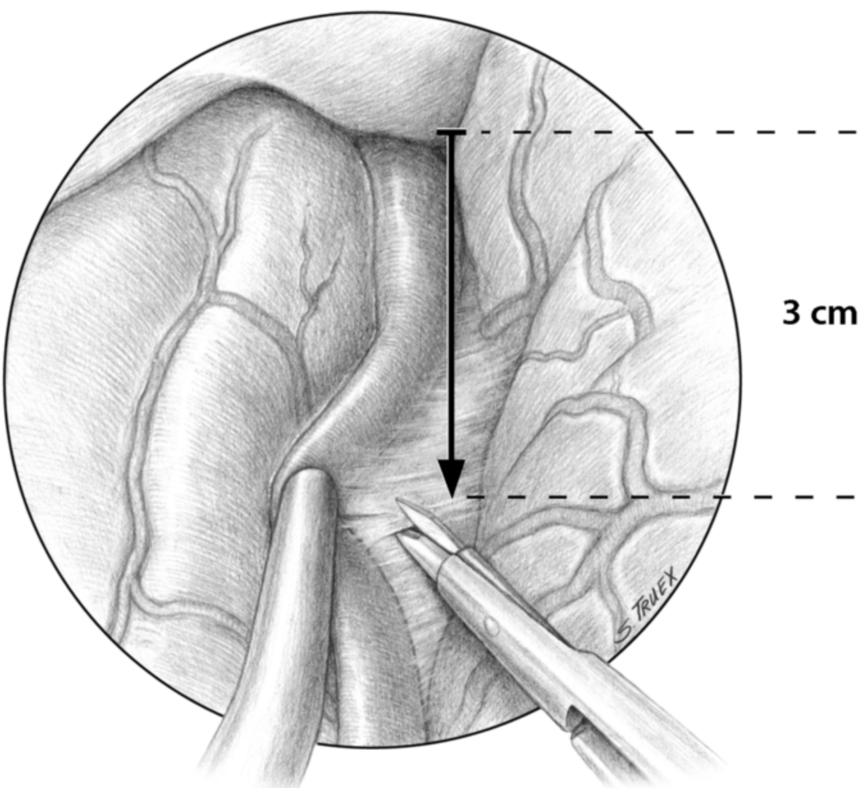


Fig. 6.15 Initial opening of sylvian fissure.

sharp dissection. When operating on ruptured aneurysms in younger individuals with “hot brains” and sylvian fissures packed with fresh clot, we believe the fissure should be opened quickly and definitively without untoward concern for the patency of small bridging veins that cross the sylvian fissure from the frontal lobe to join the superficial middle cerebral vein coursing along the temporal lobe (**Fig. 6.16**). Therefore, in such cases, we identify the fissure 3 to 4 cm posterior to the anterior aspect of the superior temporal gyrus, open the arachnoid there sharply, and then alternate use of the bipolar forceps and microscissors to first cauterize and then cut the arachnoid “seam,” along with any small veins bridging from the frontal lobe (**Figs. 6.17** and **6.18**). This approach will not embarrass the venous drainage of either frontal or temporal lobe, and it is never necessary to sacrifice even a small artery because the arteries do not cross the fissure and can be mobilized toward the frontal or temporal lobe side.

The superficial opening is carried medially along the ridge for ~2 cm. The surgeon will now be proximal to the bifurcation (**Fig. 6.19**) and, if the aneurysm

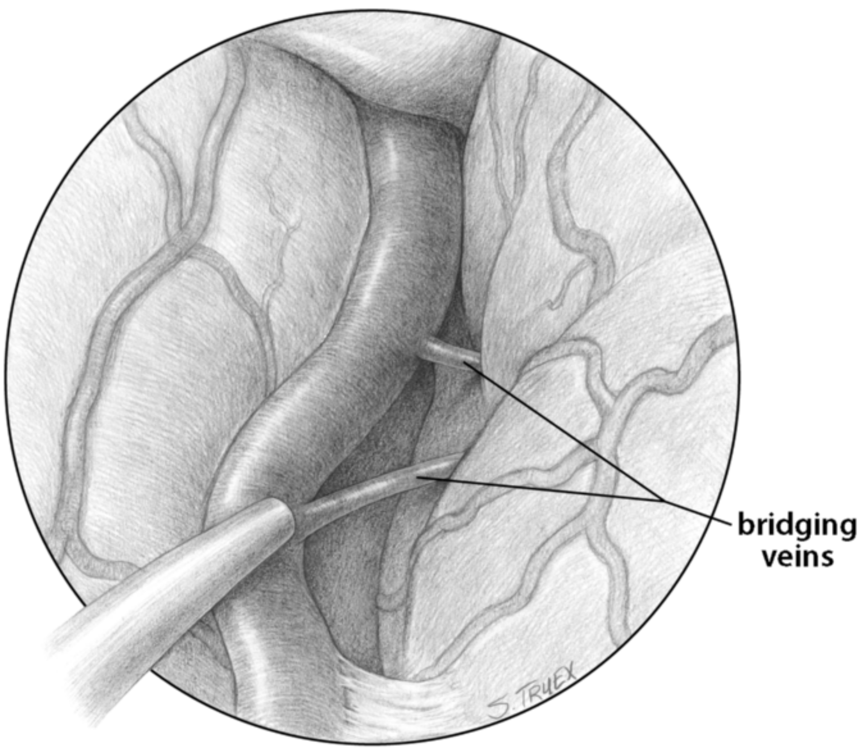


Fig. 6.16 Bridging veins of the sylvian fissure.

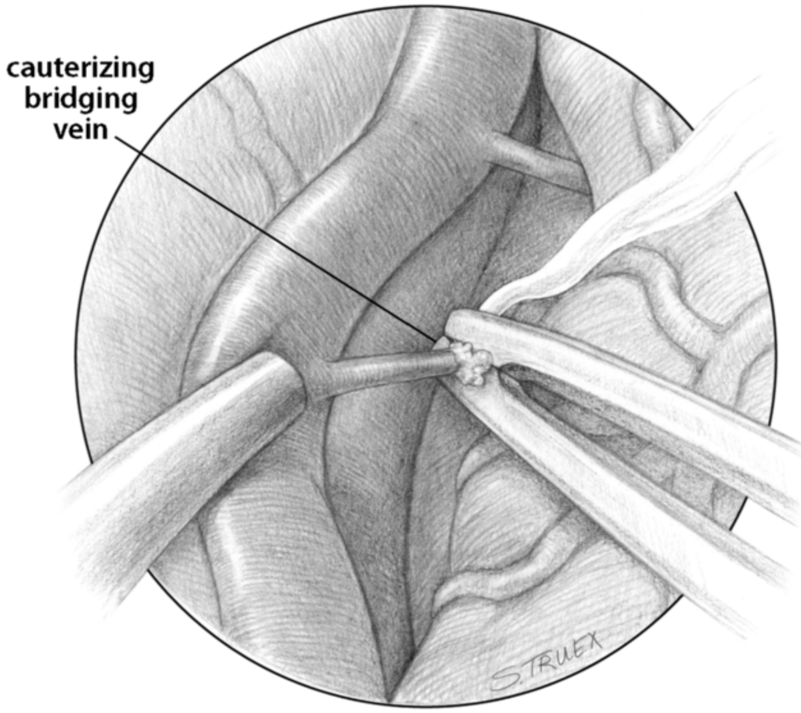


Fig. 6.17 Cauterizing bridging sylvian veins.

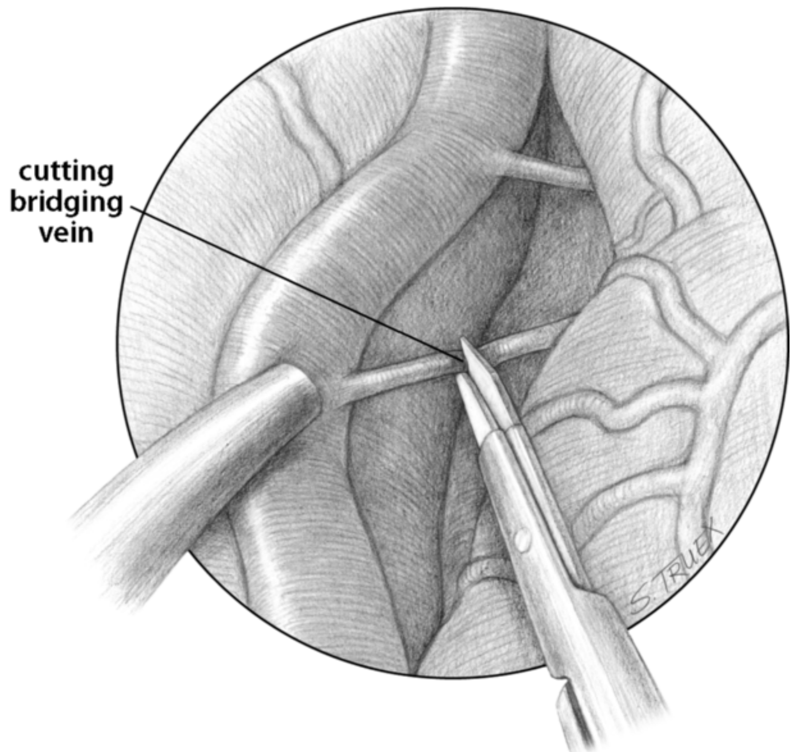


Fig. 6.18 Cutting bridging sylvian veins.

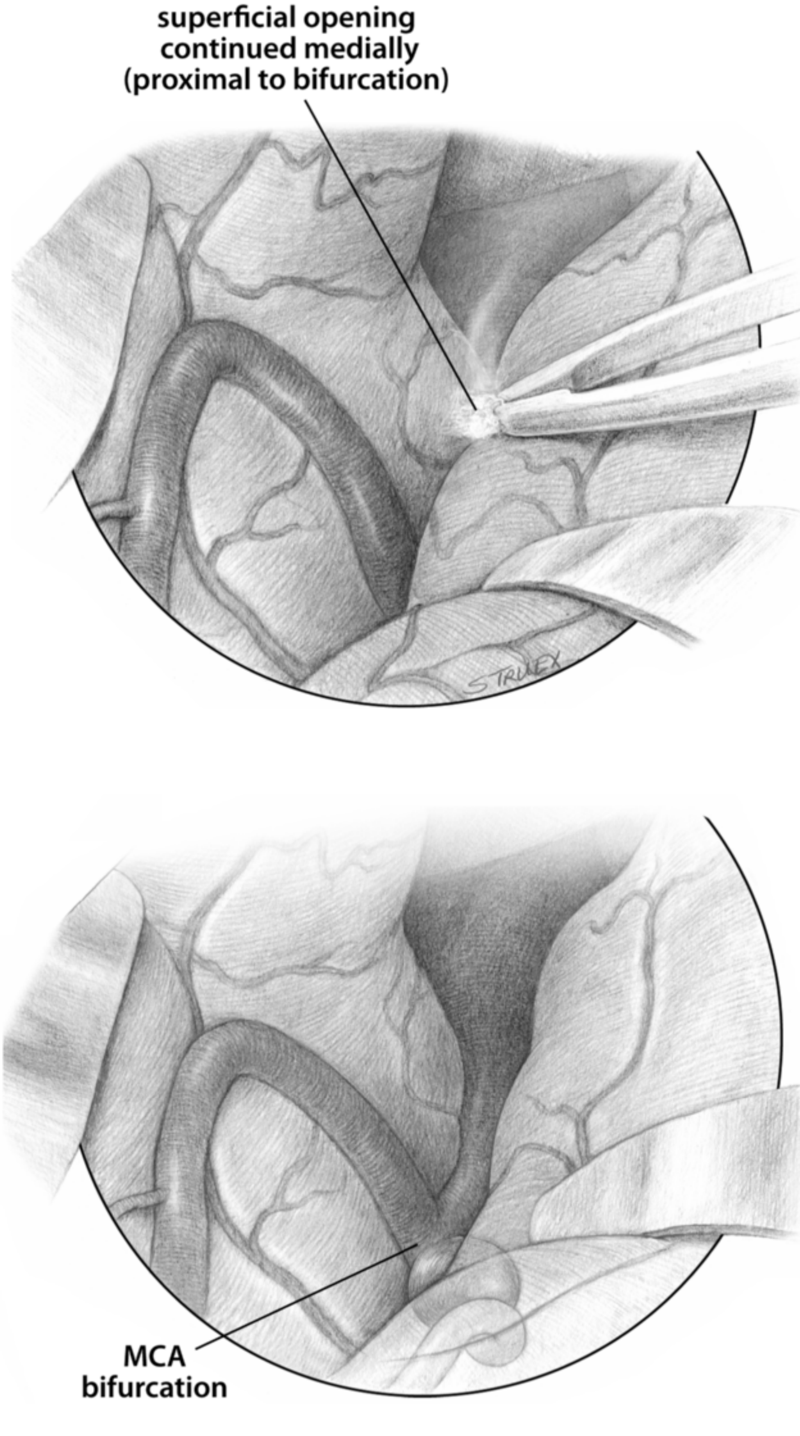


Fig. 6.19 Localization of M1 segment.

projects superiorly, may deepen the exposure into the fissure to obtain proximal exposure and control of the MCA's M1 segment without first encountering the aneurysm's fundus and dome.

For other aneurysm projections, once the superficial arachnoid has been opened medially along the sphenoid ridge, the surgeon should return to the initial arachnoid opening over the lateral aspect of the fissure to begin exposure of the insula by separating the frontal and temporal operculae. This is the preferred approach for inferiorly projecting aneurysms, with the M2 segments being exposed and then followed retrograde to the level of the bifurcation (**Fig. 6.20**). Here the aneurysm will be seen to project "up"—at 12 o'clock in the surgeon's view—into the temporal lobe. Now, by remaining on the anterior aspect of the anterior M2 branch, hugging the limen insula and dissecting proximally, the surgeon will relatively painlessly expose the distal M1.

Clip Application

Proximal MCA Aneurysms

The small size and routine projections of proximal MCA aneurysms generally make their clipping relatively straightforward. The primary issue of concern, both with aneurysms at the origin of the anterior temporal artery and with those in association with the lenticulostriate arteries, is the necessity to ensure that the small branches emanating from the base of the aneurysm are not stenosed by the closing clip blades.

This concern is most marked along the dorsal surface of the M1, where the unusual configuration of the lenticulostriate arteries almost always mandates the use of a small straight clip applied exactly parallel to the M1 axis (**Fig. 6.21**). If, after clip closure, there is any question regarding the patency of the lenticulostriate vessel, the clip should be promptly removed.

Some "last ditch" options for ruptured small aneurysms here that must be secured include the use of fenestrated clips with the M1 trunk placed in the fenestration (**Fig. 6.22**), preliminary temporary occlusion of the M1 prior to definitive clip placement (**Fig. 6.23**), and the placement of a small right-angled clip whose blades parallel the emerging lenticulostriate artery and whose tips encompass the entire aneurysm dome and of necessity must, because of the small size and exquisitely thin walls of the aneurysm, encroach slightly on the M1 lumen (**Fig. 6.24**).

Distal MCA Aneurysms

Most larger and fusiform aneurysms, whether in the sylvian fissure or elsewhere, will require preliminary trapping and evacuation prior to definitive clip placement. The thick irregular walls and complex anatomy of these le-

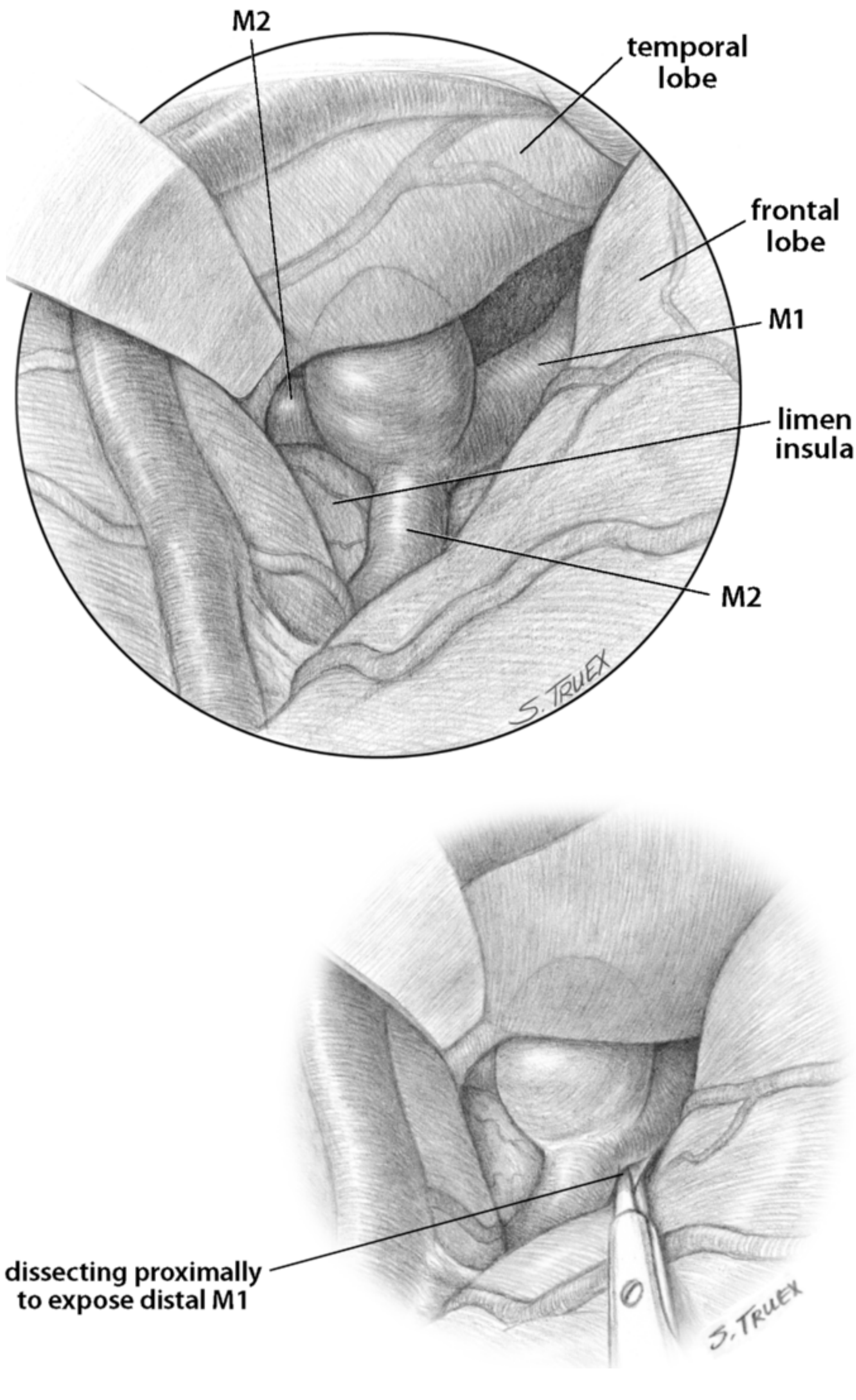


Fig. 6.20 Localization of M2 segments.

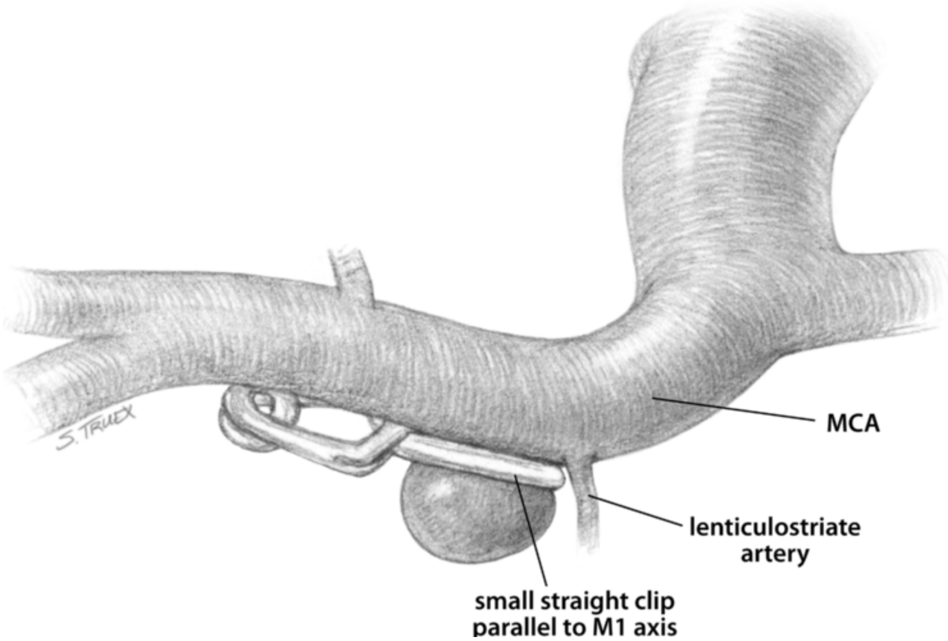


Fig. 6.21 Clip application with regard to lenticulostriate arteries.

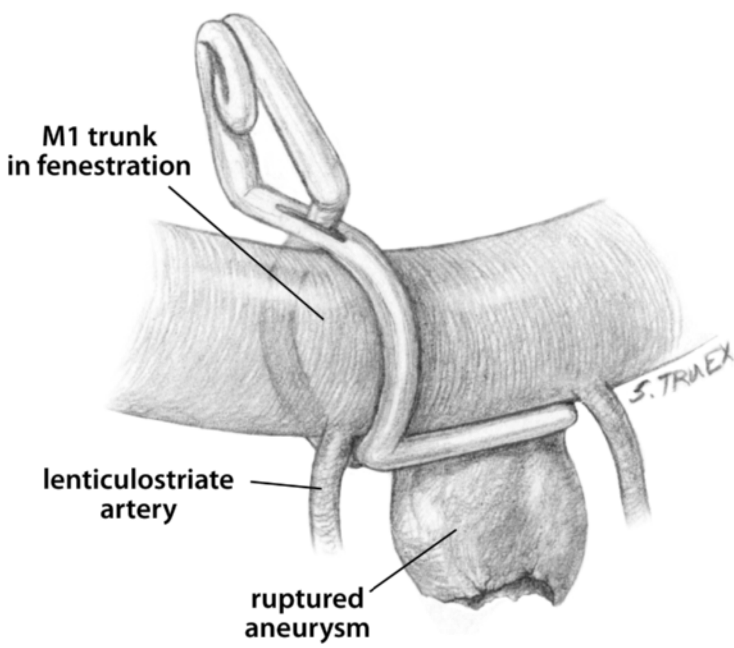


Fig. 6.22 Fenestrated clip application to M1 aneurysm.

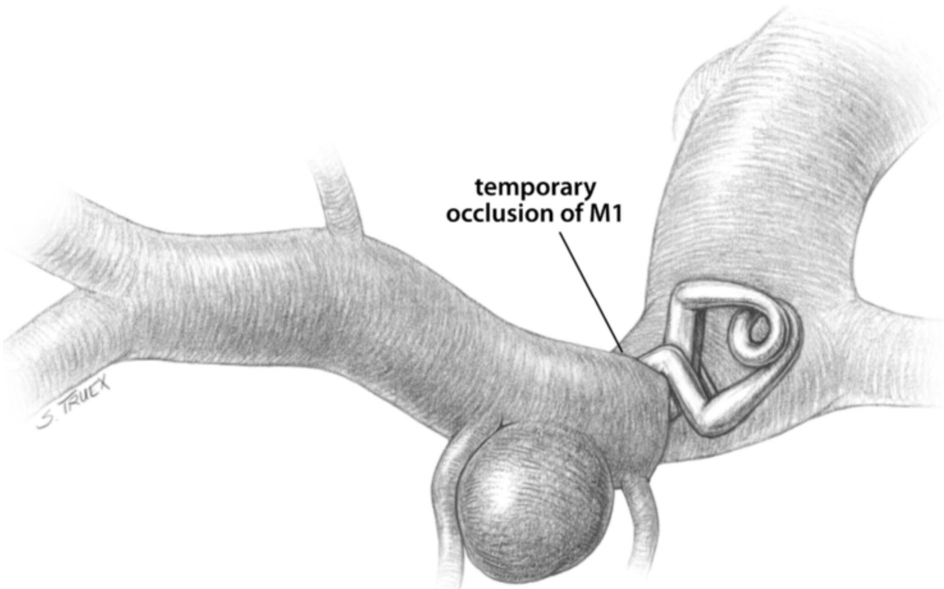


Fig. 6.23 Temporary occlusion of M1 segment.

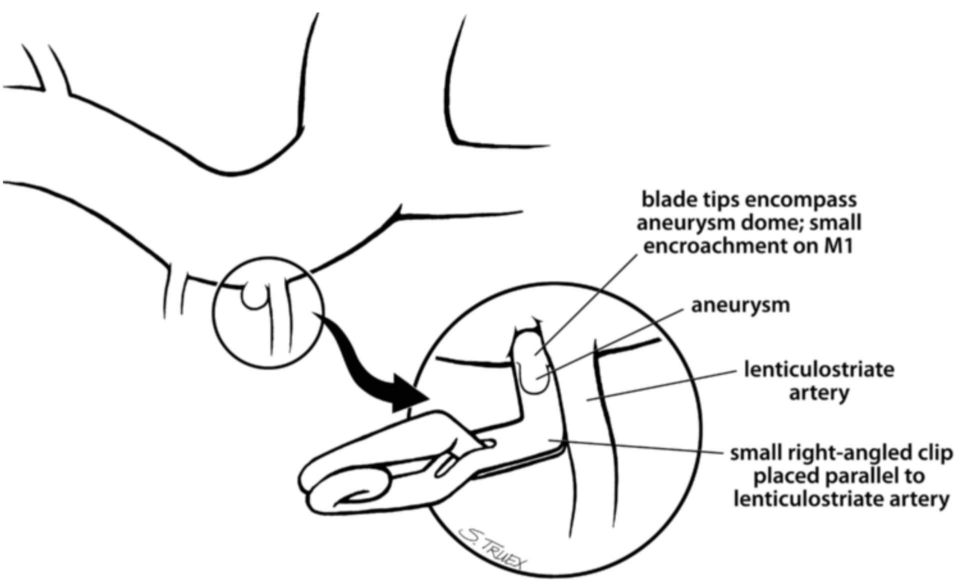


Fig. 6.24 Lenticulostriate aneurysm clip application.

sions mandate that they be flaccid to permit apposition of their necks and preservation of the origins of the branch vessels. When it's necessary to open and empty such an aneurysm, care must be taken to respect the intima at the confluence of the parent and branch arteries, because even a small disruption here will result in luminal occlusion once antegrade flow is restored. Sufficient thrombus must be removed from the proximal aneurysm neck to permit clip reconstruction without encroaching on the "confluence" of parent and branch arteries. An optimal end result leaves a large, almost bulbous atrium proximal to the clips; do not attempt an anatomical reconstruction, which may look perfect from the outside but almost certainly represents stenosis, if not occlusion, of the branch origins.

It's critical that the surgeon be convinced of patency of each branch after clip reconstruction: microvascular Doppler insonation and intraoperative angiography are both of great value in this situation. When one or more of the emerging arterial branches do not demonstrate adequate flow, immediate revision of the clip construct may be helpful, but other alternatives, such as arterial transposition and revascularization, should also be considered.

Important: Don't abandon an M2 or M3 branch with absent or markedly diminished flow in hopes something magical will happen to improve the situation. It won't.

MCA Bifurcation Aneurysms

The unique vascular anatomy of the MCA bifurcation renders almost all of the clipping situations at this site variations on a theme. The M1 trunk and emerging M2 branches invariably form a T—the M1 segment representing the long stem of the T. The M2 branches exit the bifurcation on contralateral aspects of the M1 at an angle of no more than 100 degrees with the main trunk. As a general rule, the larger the aneurysm neck, the smaller this angle becomes. Foreknowledge of this anatomical consistency helps the surgeon in the initial identification of the M2 segments and dictates the optimal axis of aneurysm neck closure, which should be parallel to the plane of the M2s and perpendicular to the axis of the M1 (**Fig. 6.25**). Very often, even when dealing with an aneurysm of relatively modest size, the ideal clip closure cannot be achieved with a single clip, no matter how innovative its configuration. In such situations, the surgeon should conceptually divide the aneurysm neck into segments and design the reconstruction to occlude each section in sequence with a clip of appropriate shape for that purpose.

Complex clip reconstructions are most accurately performed with the aneurysm sac softened by proximal M1 occlusion; for larger aneurysms with expansive necks, the surgeon should strongly consider proceeding directly to

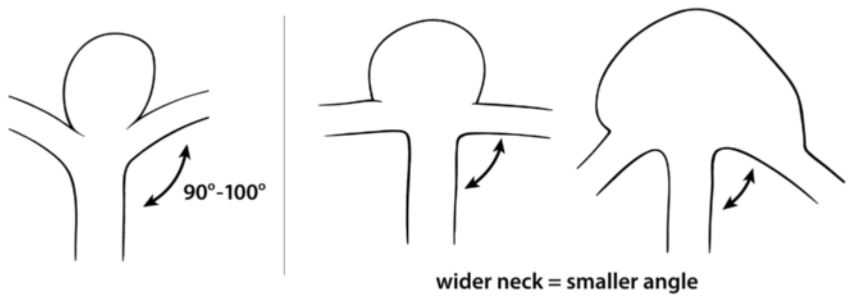


Fig. 6.25 Anatomic configuration of MCA bifurcation aneurysms.

completely trapping the lesion and evacuating its contents prior to any attempt at permanent clip application.

Craniotomy Number 2

MCA bifurcation aneurysms, when small and unruptured, can be quickly, safely, and easily exposed via a small version of the traditional pterional craniotomy, placing the entire bony opening beneath the temporalis muscle (**Fig. 6.26**). The initial steps (skin flap and muscle reflection) are identical to those in the more traditional exposure.

The bone flap is a small triangular-shaped exposure centered on the underlying sylvian fissure (**Fig. 6.27**). A routine removal of the lateral aspect of the sphenoid ridge is followed by an almost linear opening of the dura above the sylvian fissure (**Fig. 6.28**). The linear incision is then tacked open with stay sutures to expose the underlying fissure (**Fig. 6.29**). The subsequent microsurgical exposure is entirely through the sylvian fissure, beginning some 2 cm distal along the course of the cortical segment of the fissure (**Fig. 6.30**). Exposure proceeds from lateral to medial and must extend sufficiently proximally to ensure that the lateral portion of the sphenoidal segment of the fissure is opened. Small retractors are generally used to separate the temporal and frontal operculae, although when dealing with very laterally located lesions only a single retractor, usually on the side of the surgeon's dominant hand, may be necessary (**Fig. 6.31**).

The downsides of this "minimalist" approach are the lack of alternative exposures of the MCA, the inability to deal with a tight, swollen brain, and the lack of access to the Payne point for placement of an intraoperative ventriculostomy.

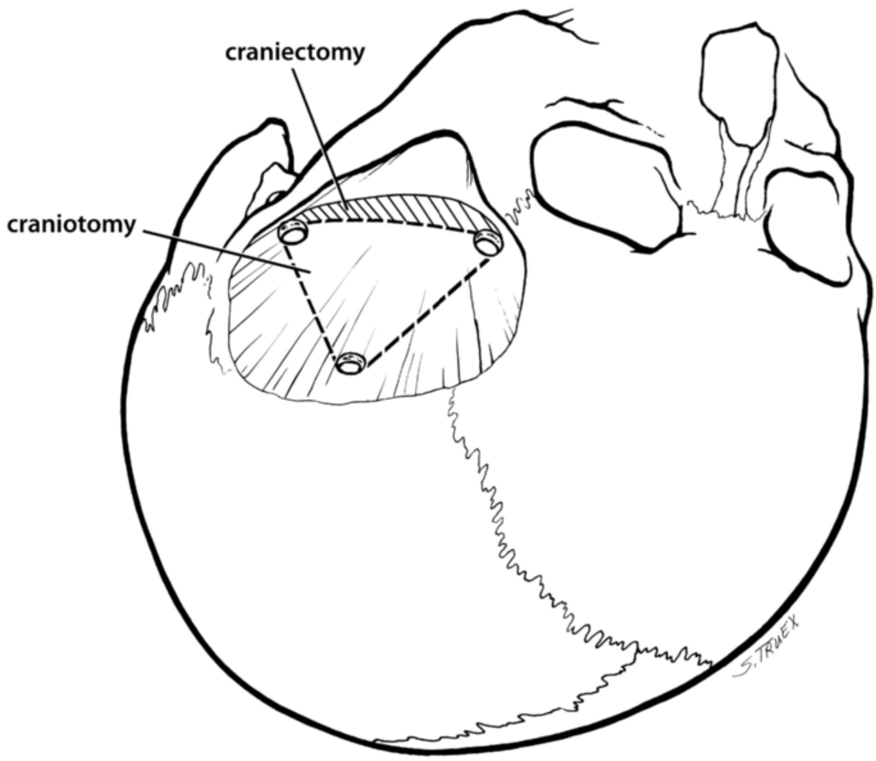


Fig. 6.26 Alternative craniotomy for MCA aneurysms.

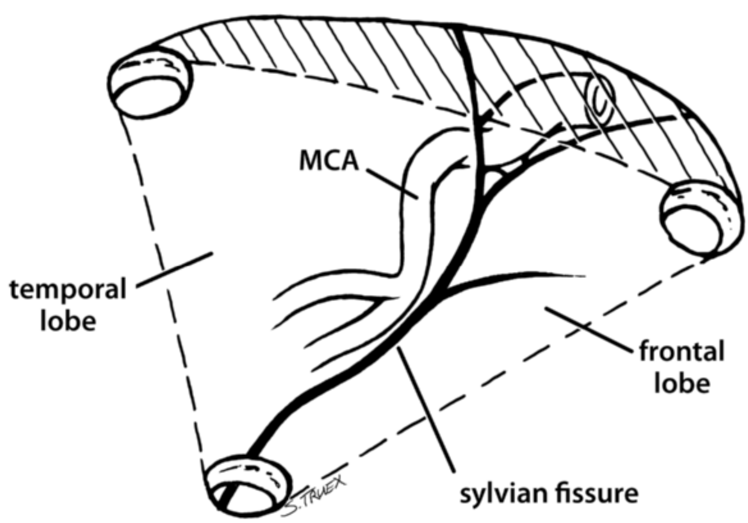


Fig. 6.27 Relation of craniotomy to MCA anatomy.

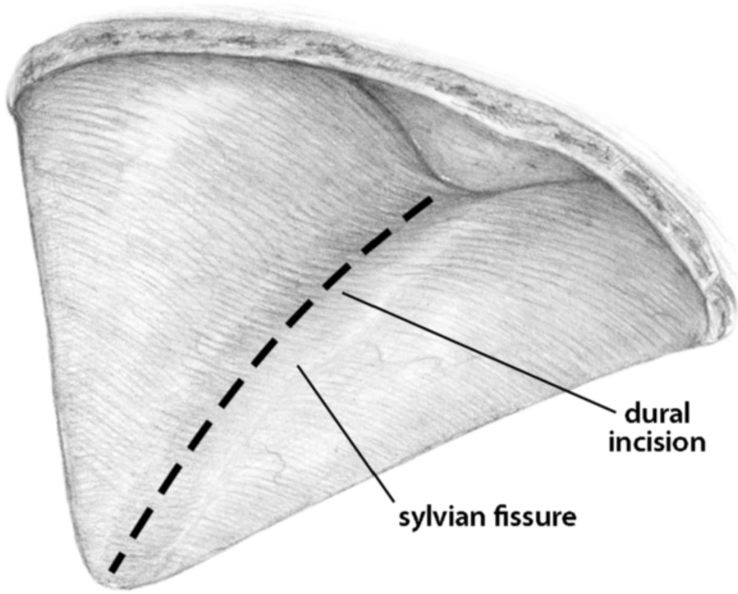


Fig. 6.28 Dural incision for alternative craniotomy.

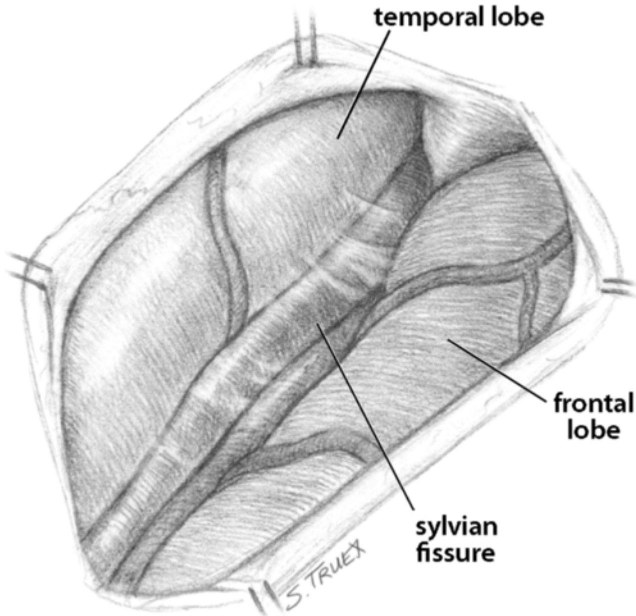


Fig. 6.29 Sylvian fissure exposure of alternative craniotomy.

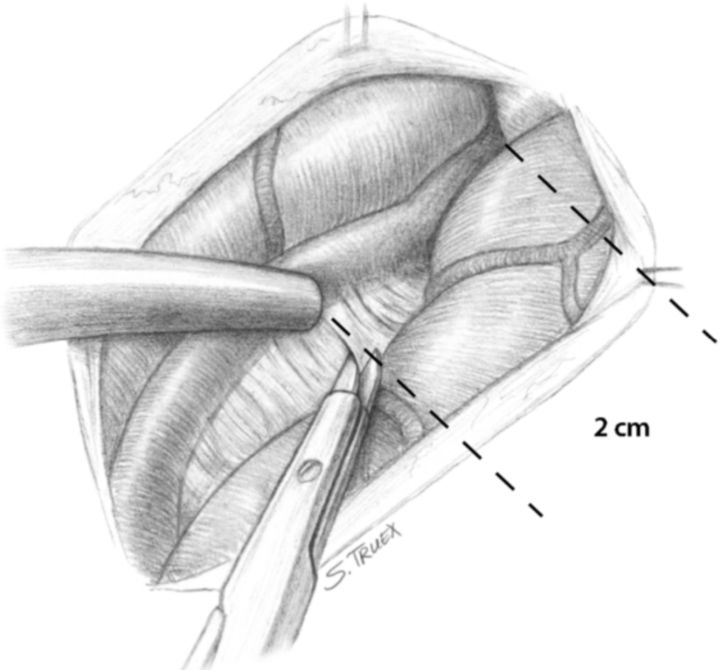


Fig. 6.30 Subarachnoid dissection of sylvian fissure.

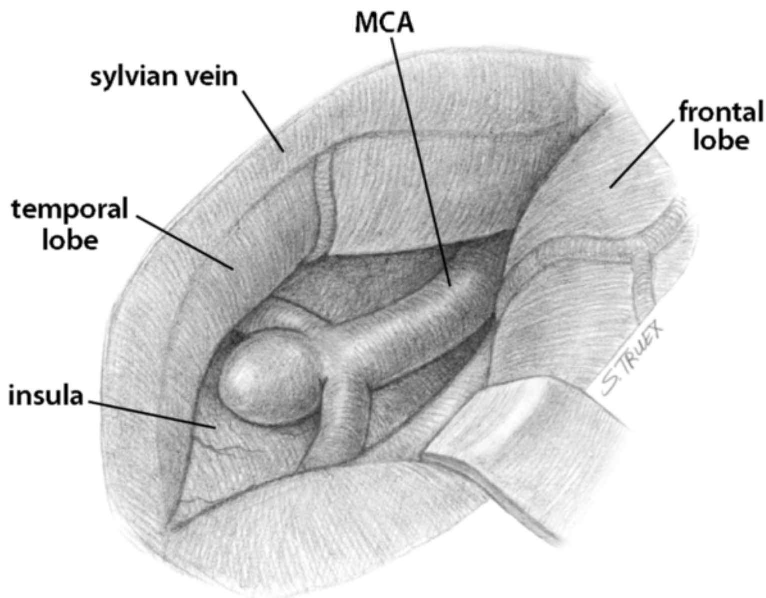


Fig. 6.31 MCA bifurcation through sylvian fissure.

Final Thoughts

1. Understanding the anatomy of the sylvian fissure and its relationship to the segments of the MCA is critical to successful treatment of these common aneurysms.
2. The proper approach to a specific MCA aneurysm depends on a preoperative understanding of the aneurysm's location and projection.
3. Giant MCA aneurysms frequently have calcific walls, contain copious amount of thrombus, and actually give rise to MCA branch origins.
4. The iatrogenic occlusion of M2 branches is an all-too-common source of neurological morbidity in the surgical treatment of MCA aneurysms.
5. Avoid using a "minimalist" craniotomy until you've had ample experience (and success) with a standard approach.

7

Aneurysms of the Anterior Communicating Artery

General

While often regarded as relatively simple anterior circulation lesions, these aneurysms can be deceptively difficult. Their interhemispheric location and close relationship to critical areas of brain function account for the significant morbidity and mortality associated with their rupture. Successful surgical treatment requires an understanding of the complex anatomy of the anterior communicating artery (ACOMM) complex and the multiple parent and branch arteries that must be identified and controlled prior to clip application.

ACOMM aneurysms are the most common aneurysms associated with intracerebral bleeding. The hemorrhage pattern seen on computed tomographic (CT) scan is often characteristic, with varying amounts of hemorrhage in the subarachnoid space (prechiasmatic cistern and interhemispheric fissure), the brain parenchyma (gyrus rectus), and the ventricular system (lamina terminalis and third ventricle).

Anatomy

As a general rule, ACOMM aneurysms arise at the junction of the larger A1 segment, the ACOMM, and the ipsilateral A2 segment origin. Exceptions to this rule are common (**Fig. 7.1**); these lesions may occupy the entire ACOMM, may arise on any one of several ACOMMs, and on occasion will arise from the lateral aspect of the A1–A2 junction abluminal from the anterior communicating origin. With the widespread use of both rotational angiography and CT angiography there are fewer intraoperative surprises awaiting the surgeon in terms of origin now than formerly, but we recommend a healthy dose of

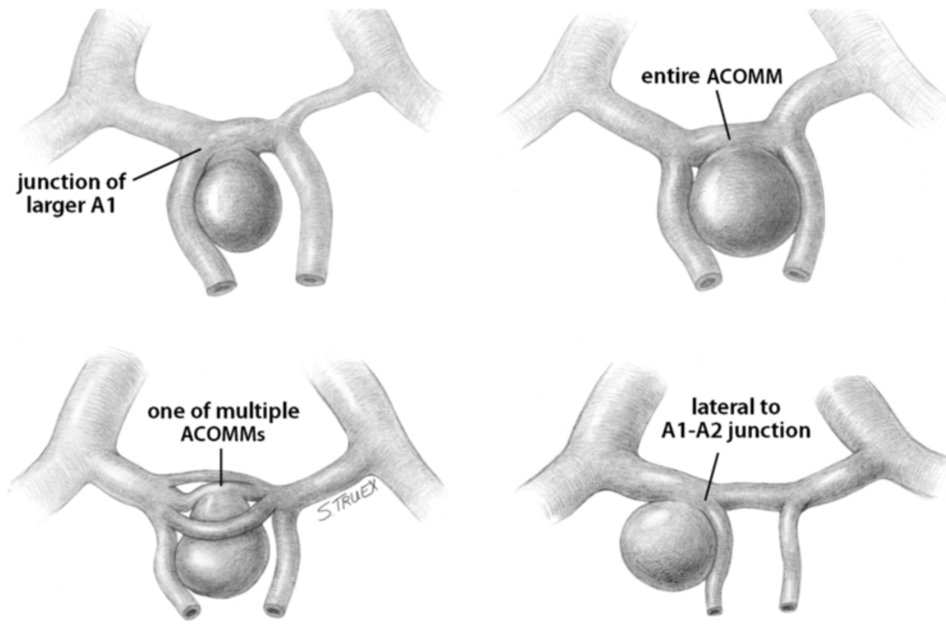


Fig. 7.1 Alternative anatomic configurations of ACOMM aneurysms.

skepticism regarding the exact anatomy of the origin until it's been conclusively demonstrated at surgery. Stubbornly trying to make the vasculature correspond to your (or someone else's) interpretation of the imaging studies is a sure recipe for disaster when dealing with these complex anatomical situations.

Projections

We normally think of the ACOMM as lying in the coronal plane, but actually, its orientation varies from coronal to truly sagittal, and preoperative awareness of this variability is important. A sagittal orientation of the communicating artery seems to be especially common when there is a large disparity in size between the two A1 segments and is most frequent when only a single A1 supplies both A2 segments. In this latter situation, the A2 origin ipsilateral to the large A1 has its origin in the interhemispheric fissure close to the optic chiasm, whereas the contralateral A2 exists as the distal continuation of the sagittally directed communicating artery. More on these specific aneurysms later.

In addition to the orientation of the communicating artery, it's important to consider the projection of anterior communicating aneurysms in both the sagittal and the coronal planes (**Fig. 7.2**). The most common sagittal (**Fig. 7.2**) projections are inferiorly into the prechiasmatic cistern or anteriorly into the subarachnoid space of the interhemispheric fissure. Less commonly, the aneurysm will project superiorly, and most uncommon of all is the rare superior-posterior projection.

In the coronal plane, anterior communicating aneurysms may remain in the midline or jut laterally into one or the other gyrus rectus and mesial frontal lobe.

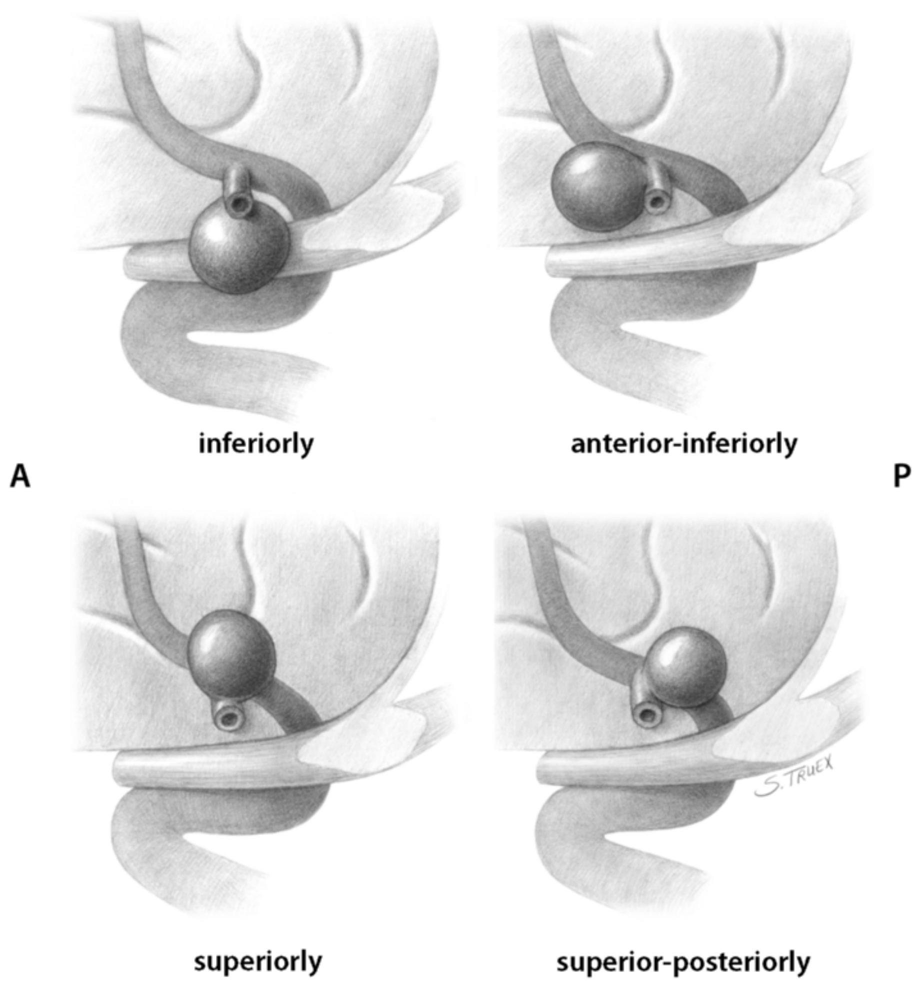


Fig. 7.2 Projections of ACOMM aneurysms.

Procedure

Approach

The preceding information—orientation of the parent-communicating artery, probable site of origin of the aneurysm, and plane of projection of the aneurysm's dome—is helpful in defining the laterality of operative approach and the sequence of events in dissection of the afferent and efferent vasculature.

In general, assuming that both patient and surgeon are left-hemisphere dominant, we think the majority of anterior communicating aneurysms are best treated from a right-sided approach. Dissection and clip application are somewhat easier for a right-handed surgeon approaching the anterior aspect of the circle of Willis from the right; similarly, the risk of serious neurological injury is somewhat reduced if the necessary brain retraction involves the patient's nondominant frontal cortex. Regardless of approach, both A1 segments must be isolated for adequate proximal control; thus the laterality of the dominant A1 is generally irrelevant in determining the optimal side of operative exposure.

Exceptions to these general rules are few but important; in the small number of patients in whom the aneurysm appears to arise from the lateral aspect of the A1–A2 junction and in those more common cases that harbor a large gyrus rectus hematoma, the procedure will proceed more smoothly if the surgeon has direct access to the aneurysm origin in the first situation and to the clot itself in the second. Finally, when the anterior communicating aneurysm is only one of multiple aneurysms undergoing treatment, obviously the laterality of approach should be selected to facilitate obliteration of the ruptured lesion, if one can be identified, and second to maximize the number of aneurysms that can be treated safely via a single exposure.

Positioning

Regardless of the operative side, the patient is placed supine with the neck extended and the head rotated away from the surgical site, then tilted to bring the floor of the frontal fossa roughly perpendicular to the long axis of the patient's body (**Fig. 7.3**). Normally, for a right-sided approach the head is rotated ~45 to 60 degrees; when operating from the left we prefer a full 60 degrees of rotation.

Craniotomy

These aneurysms can be successfully approached via an interhemispheric exposure, a lateral subfrontal route, or a "modified" transsylvian approach that morphs into a subfrontal exposure once the carotid bifurcation has been reached.

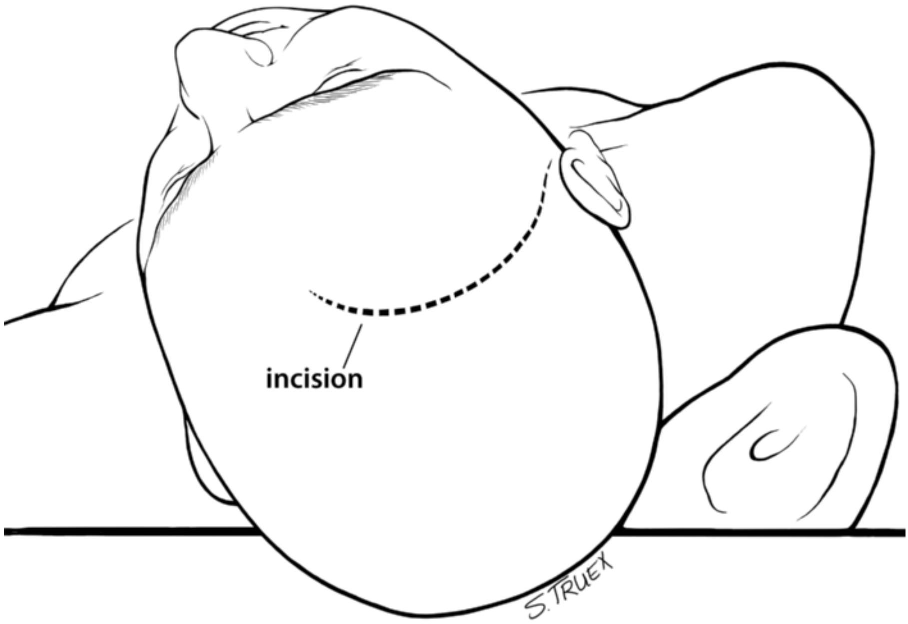


Fig. 7.3 Skin incision for ACOMM aneurysm.

This latter approach has been used at University of Texas Southwestern (UTSW) for most anterior communicating aneurysms over the past 30 years; it works equally well in small and giant lesions, in the slack brains of patients with unruptured aneurysms, and in the hot, swollen brains of extremely sick subarachnoid hemorrhage victims. This exposure offers immediate access to the ventricular system via the Payne point, and with very little modification can be used to expose lesions in the sagittal plane from the basilar apex to the ACOMM. It's the best approach for young surgeons to safely learn the vascular anatomy of the anterior circle of Willis and is obviously the exposure of choice if more than one aneurysm is to be treated at a single sitting. Currently about two thirds of our anterior communicating aneurysms are approached in this fashion.

When compared with the bony exposure used routinely for aneurysms of the middle cerebral, internal carotid, and basilar arteries, this craniotomy is centered slightly more anteriorly (extending to the midpupillary line) and exposes less of the temporal lobe, as the posterior burr hole is placed only slightly posterior to the pterion (**Fig. 7.4**). No subtemporal craniotomy is done, and the sphenoid ridge is only flattened, rather than being radically resected with the burr (**Fig. 7.5**). The inferior aspect of the craniotomy is carried as low as humanly possible without opening the bony orbit, and then the inner table of the skull along the inferior margin of the craniotomy defect is aggressively drilled

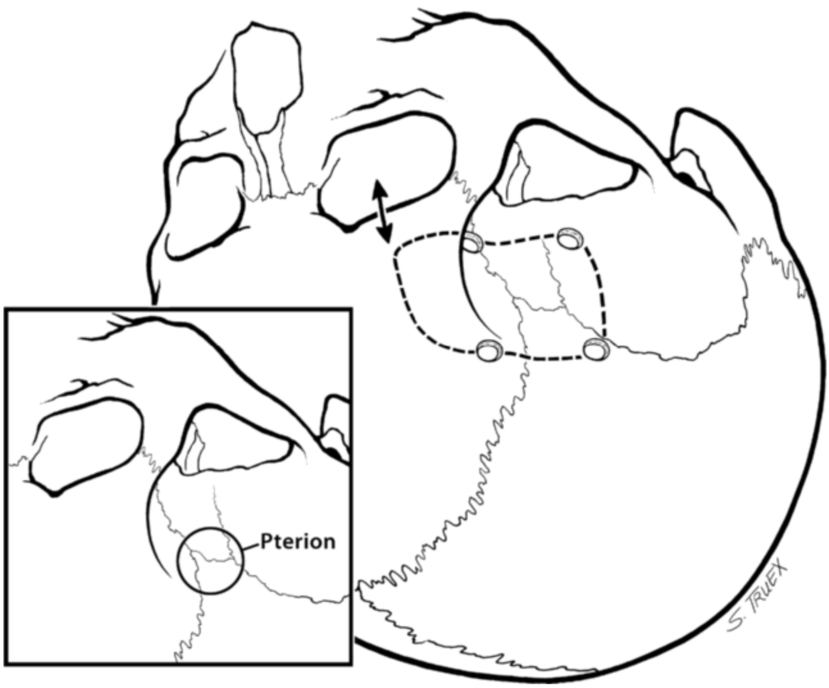


Fig. 7.4 Craniotomy for ACOMM aneurysm.

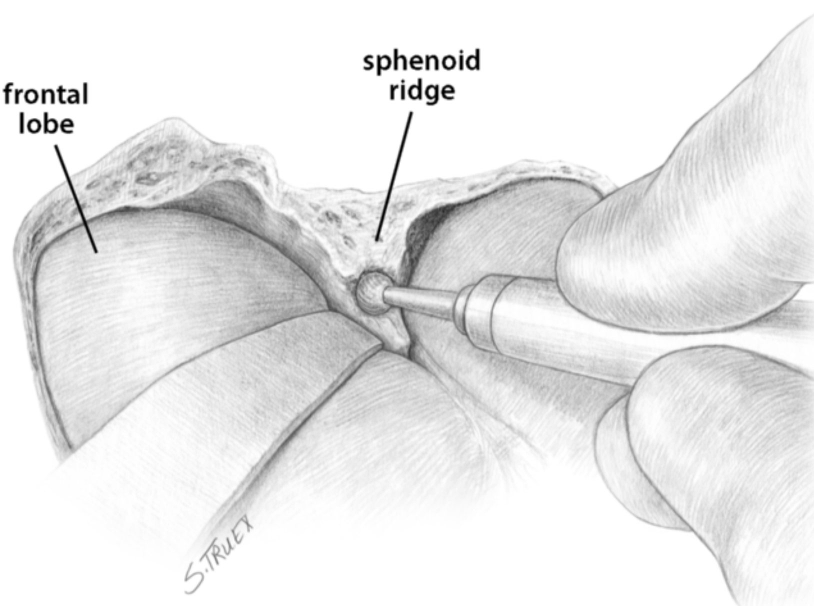


Fig. 7.5 Extradural drill resection of sphenoid ridge.

away to effectively lower the inferior limit of exposure to the level of the orbital roof. After a small amount of experimentation with orbitotomy, we felt it honestly provided little or no improvement in the ultimate exposure and have not subsequently relied on this additional bone removal. It's a little bit like a swagger stick; if you need one, by all means use it, but most folks can learn to do without.

The dural opening should extend from the most anterior-inferior corner of the bony exposure to the corresponding point posteriorly. The dura can be opened in a linear, curvilinear, semilunar, triangular, or stellate fashion—all that really matters is that the dural exposure takes advantage of the entire extent of the bony opening at the level of the orbital roof. Generally, we tack the inferior flap of dura back against the intact calvaria to maximize exposure of the orbital cortex.

Initial Approach

The arachnoid overlying the most inferior aspect of the cortical portion of the sylvian fissure is identified and opened sharply to expose the insula and M2 segments of the middle cerebral artery. Dissection then proceeds from laterally to medially, opening the sphenoidal portion of the fissure to expose the middle cerebral bifurcation and then the M1 segment. Retractors are not placed on the frontal and temporal opercula unless the brain is swollen; generally, the entire fissure can be opened to the carotid cistern, using the microscissors and suction tube to gently separate the two lobes as the arachnoid binding them is cut sharply. However, if necessary, the retractor can be placed on the parenchyma overlying the carotid-ophthalmic cistern (**Fig. 7.6**).

When the origin of the A1 segment is identified (**Fig. 7.7**), a thin, self-retaining retractor blade can be situated on the posterior orbital cortex immediately anterior to and parallel with the sylvian fissure. The tip of the blade should extend to the carotid bifurcation and expose the initial millimeters of the anterior cerebral artery. The A1 segment is circumferentially dissected at this point for temporary clip application if necessary. Then, by cutting the arachnoid fibers holding the gyrus rectus to the optic nerve, the cistern of the A1 can be opened and the artery followed anteriorly and medially across the nerve toward the prechiasmatic cistern.

When the A1 segment is seen to separate from the optic nerve, the retractor blade is anteriorly relocated to the point at which the A1 segment disappears beneath the gyrus rectus (**Fig. 7.8**). The surgeon now focuses on identification of the contralateral A1 segment. This step, one of the critical aspects of the procedure, represents the keystone on which the remaining steps of exposure and dissection rest.

The surgeon must gently elevate the ipsilateral A1 artery at the point at which it departs from the optic nerve, while deepening the exposure across the chiasm and lamina terminalis (**Fig. 7.9**). Immediately superior to the contralateral optic nerve the second A1 segment will be identified, relatively high in the

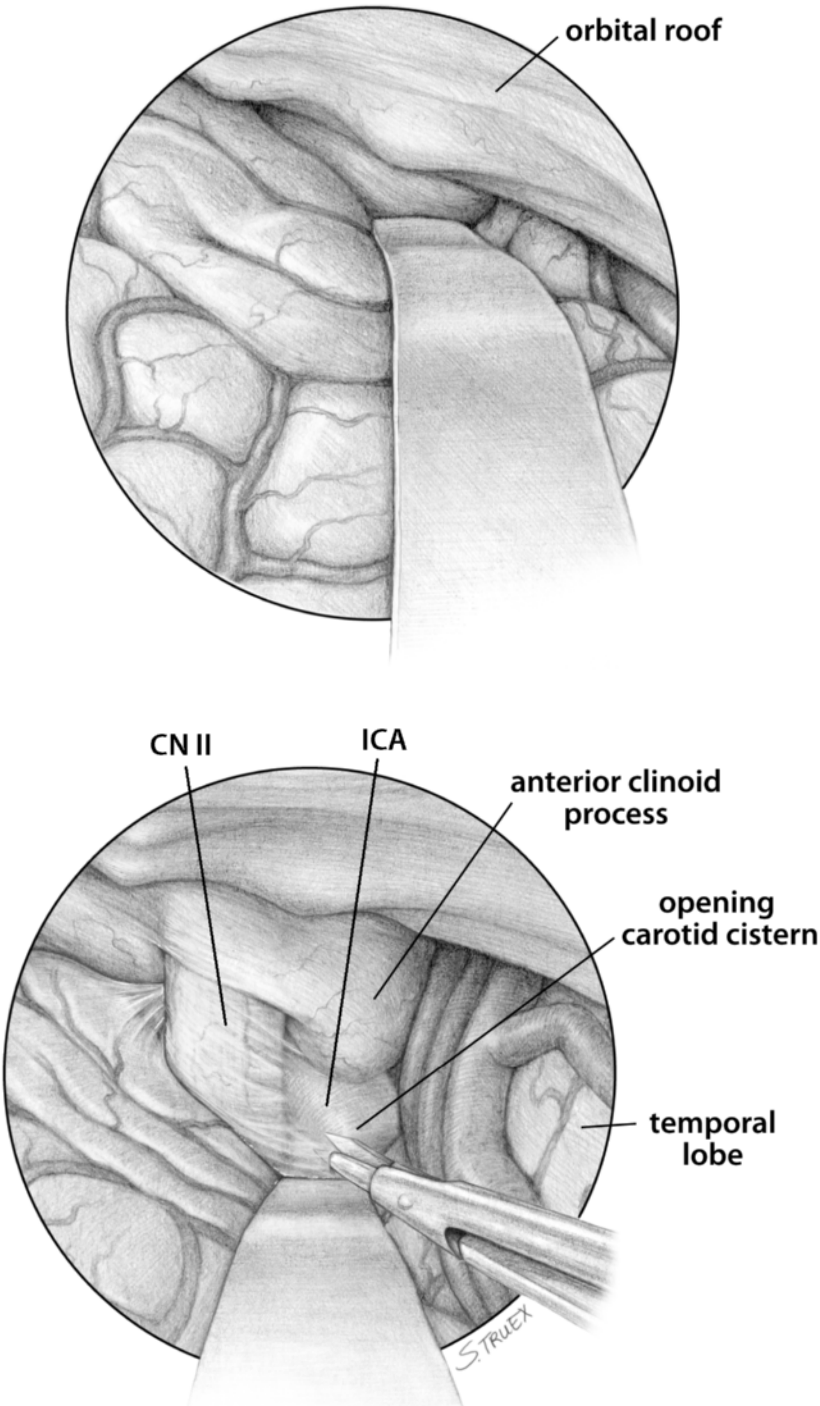


Fig. 7.6 Placement of retractor over carotid-opthalmic cistern.

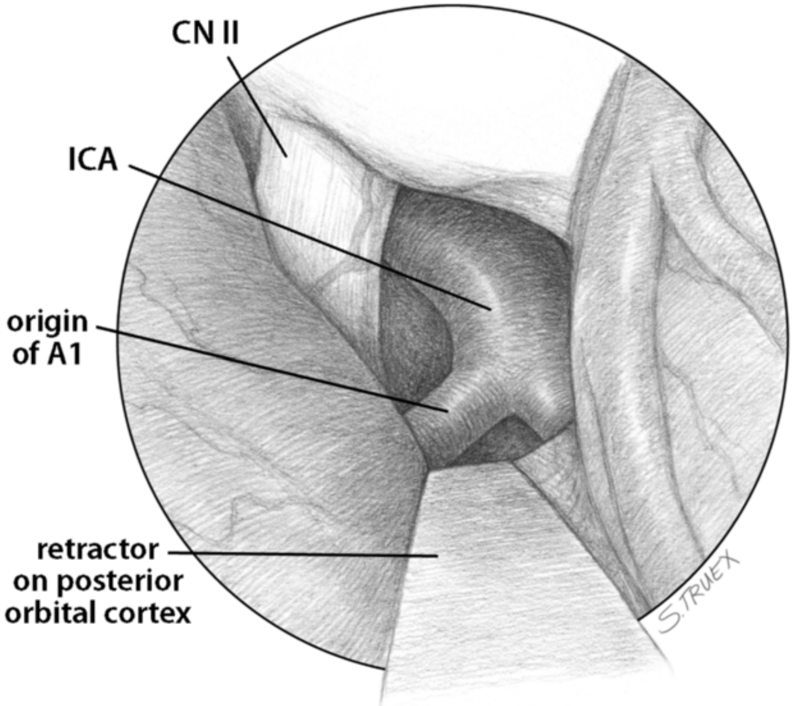


Fig. 7.7 Identification of the A1 segment.

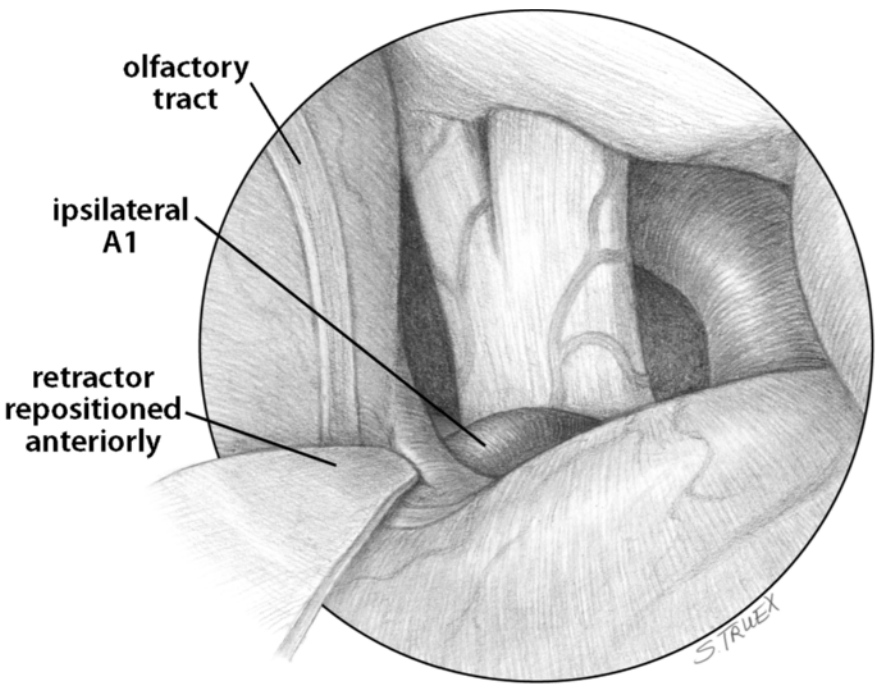


Fig. 7.8 Placement of the retractor on the gyrus rectus.

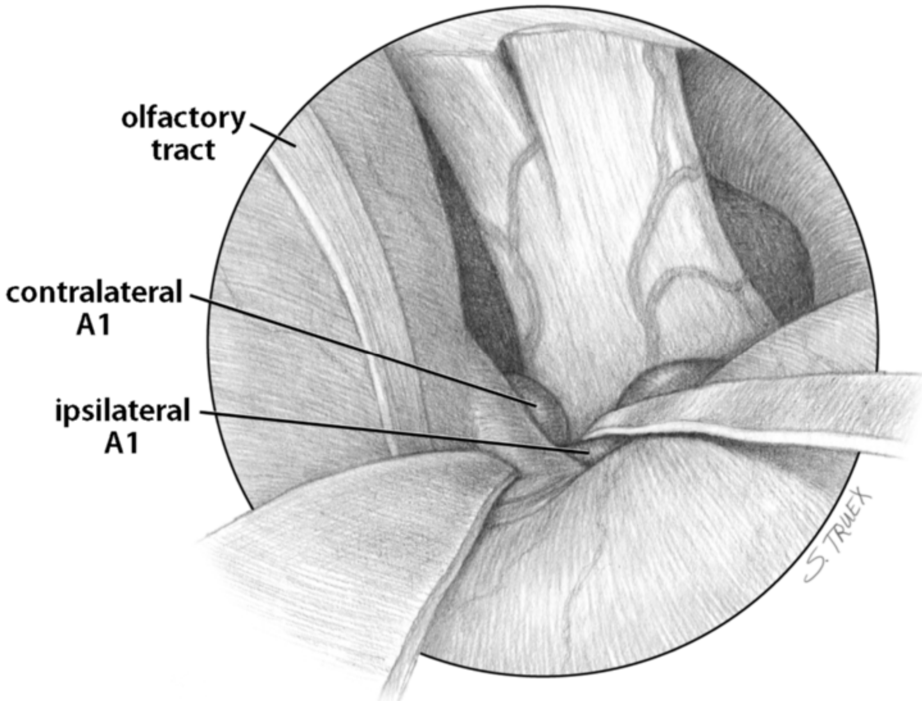


Fig. 7.9 Dissection of the contralateral A1 segment and optic chiasm.

prechiasmatic cistern. The vessel should be dissected sufficiently for temporary clip application, and then covered with a small cotton ball. In the event of an unexpected aneurysmal rupture, the cistern will immediately fill with blood, making reidentification of the contralateral A1 difficult; however, the cotton ball can easily be identified and quickly removed to permit clip occlusion of the underlying artery.

In the absence of a prior subarachnoid hemorrhage, the contralateral A1 segment is easily seen simply by opening the prechiasmatic cistern; the story is different in patients whose cisterns are packed with fresh clot. In the latter situation, the surgeon must actually find the artery; failure to do so invariably means the surgeon is looking in the wrong place. Generally, the search has been performed too far anteriorly along the nerve and too close to the optic canal. Look at the ipsilateral A1 segment that has already been dissected free—it's tight to the lateral margin of the nerve and just rostral to the nerve's junction with the chiasm.

A frequent complaint of inexperienced surgeons using this technique is their belief that inferiorly projecting aneurysms will block this route of access to the contralateral A1 segment, or will rupture during the exposure. Both worries are theoretically possible but extremely improbable. Because the ACOMM complex lies anterior to the chiasm, only an aneurysm that projects both inferiorly and posteriorly can prevent visualization of the contralateral A1 if the route of exposure is immediately adjacent to the chiasm. Furthermore, this exposure does not involve any retraction on the communicator complex or the gyrus rectus anteriorly.

In more than a thousand nongiant aneurysms of the ACOMM, we've never encountered this anatomical variant nor have we ever produced an intraoperative rupture by carrying out this exposure. So, when you're faced with a Fisher grade 3 subarachnoid hemorrhage patient with bilateral large A1 arteries and an ACOMM aneurysm projecting inferiorly and adherent to the tuberculum sella—suck it up. Hug the chiasm up high, elevate your A1 into the gyrus rectus, and cleave the clot as you deepen your exposure to see the other A1. In this business, you gotta have faith in something.

Exposure of the Anterior Communicating Artery Complex

With secure proximal control of both A1s, it's time to expose the remainder of the ACOMM complex prior to final dissection of the aneurysm itself. Regardless of the aneurysm's size, origin, or projection, the surgeon must now concentrate on complete demonstration of the ipsilateral A2 segment; failure to do this in a systematic, methodical fashion may have unfortunate and even disastrous consequences.

The A2 origin is almost always located within the interhemispheric fissure; therefore, as a rule, the surgeon must open the arachnoid at the fissure's mouth, then retract the gyrus rectus superiorly or resect a portion of the gyrus rectus and then peel the arachnoid of the mesial cortex away. In the minority of cases (especially when dealing with unruptured aneurysms) it's possible to expose the initial millimeters of the A2 segment by simply teasing the arachnoid seam of the interhemispheric fissure open with scissors and then moving the retractor over the gyrus rectus. This is a neat trick when it works, although exposure high in the fissure is almost impossible to obtain, and, realistically, if the gyrus is retracted to any significant degree for any significant time period it's usually damaged beyond recognition.

Most commonly, the easiest and best exposure is obtained by a limited subpial resection of the gyrus rectus (**Fig. 7.10**). If the retractor is withdrawn to a position just lateral to the olfactory tract and placed under slight tension, the gyrus rectus will bulge anterior to the optic chiasm; if this hernia is resected beginning at the point the A1 segment disappears into the fissure and extending anteriorly ~10 mm, a thin veil of mesial arachnoid will be all that remains to obscure the surgeon's view of the entire ACOMM complex.

The retractor should then be repositioned into the resection cavity and the arachnoid over the hidden A1 divided (**Fig. 7.11**). It's very important that the entire artery, especially the dorsal surface, be exposed; the A1 often transitions almost seamlessly into the aneurysm, whereas the A2's origin lies at an acute angle directly superiorly. This means that, unless the surgeon is religiously following the dorsal surface of the A1 into the interhemispheric fissure, he or she may miss the A2's origin and drift out on the aneurysm itself in the mistaken

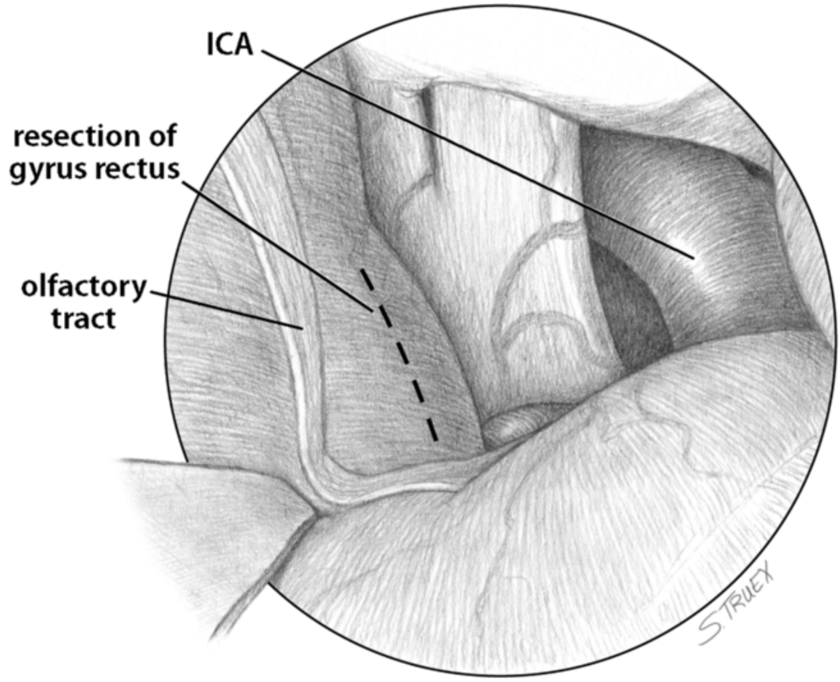


Fig. 7.10 Gyrus rectus resection.

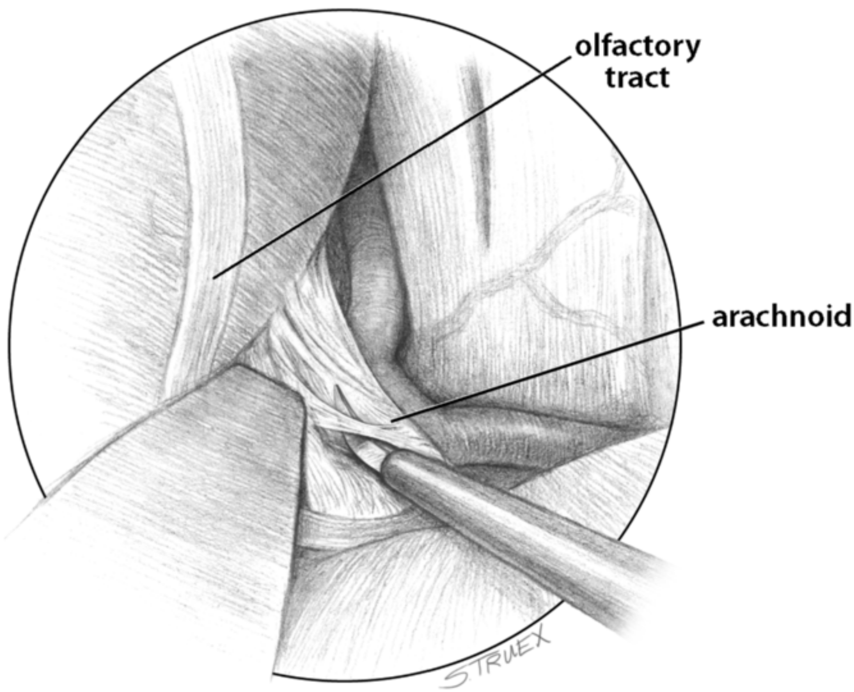


Fig. 7.11 Placement of retractor over resected gyrus rectus.

belief it is the A2 segment. Failure to identify the origin of the small recurrent artery of Heubner almost immediately after entering the interhemispheric fissure is an early warning that the vessel the surgeon assumes to be the A2 segment of the anterior cerebral artery may in fact be the aneurysm.

With the ipsilateral A2 identified and well exposed, the surgeon's attention is turned toward locating the contralateral A2 origin; here, for the first time, the aneurysm's origin and projection play a significant role in guiding the dissection. By following the communicating artery, one can almost always get a hint of the A2 origin, but actually exposing the initial 2 to 3 mm of the vessel sufficiently to permit safe clip application is usually a different story. As a general rule, this portion of the artery is hidden by the neck and fundus of the aneurysm and can't be safely demonstrated by simply pushing the dissection at the junction of the contralateral A1 segment and the communicating artery. A better option is to identify the anterior cerebral artery distal to the aneurysm itself because proximal dissection is often relatively easy from this point to the A2 origin.

To achieve this exposure, the use of a second small brain retractor is very helpful (**Fig. 7.12**). Placed just anteriorly and in parallel with the first retractor,

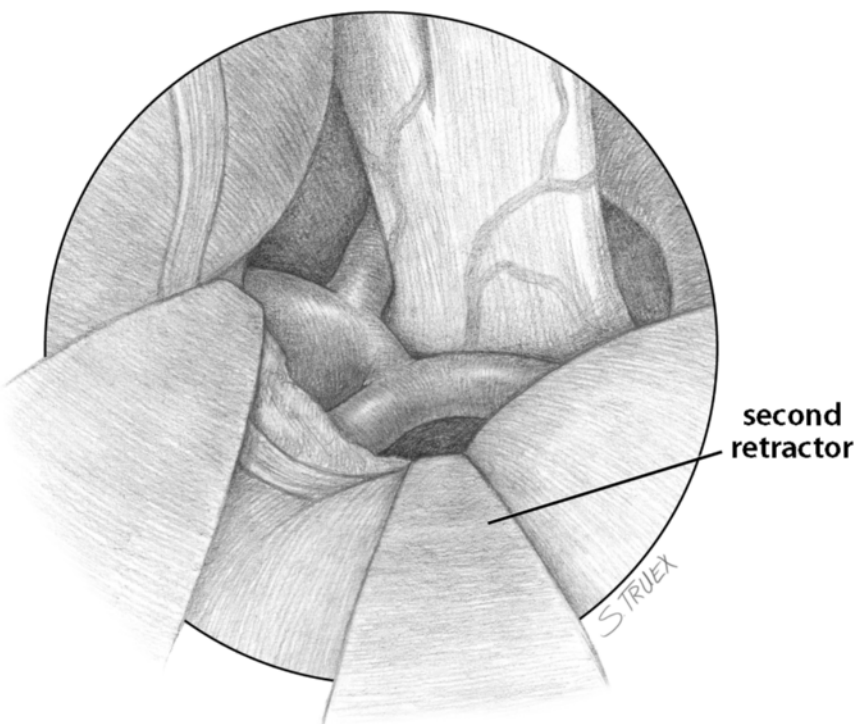


Fig. 7.12 Additional exposure of ACOMM using another retractor.

the tip of this blade should be located within the interhemispheric fissure at the most anterior extent of the gyrus rectus resection. Now the entire ACOMM complex is bracketed by the two blades, and covered only by arachnoid and some remaining gyrus rectus.

Important: From this point of the procedure onward, if the exposure is inadequate, the uniform answer is to remove more gyrus rectus.

Now the surgeon should extend the arachnoidal exposure of the ipsilateral A2 segment and simultaneously mobilize the initial millimeters of the artery. This is necessary to demonstrate the anterior neck of the aneurysm and the anterior aspect of the communicating artery, both of which are landmarks in the search for the contralateral A2 vessel.

In which direction should the A2 be mobilized? The anatomical variations of the early A2s are so numerous that no single recipe works in each case, but here are two very good options. If the two A2s lie close together, mobilizing the ipsilateral vessel a millimeter or two in either direction will identify the contralateral partner. If, however, the A2s have markedly disparate courses, then the ipsilateral A2 should be mobilized in whatever direction facilitates exposure of the anterior aspect of the communicating artery because the initial segment of the contralateral A2 will routinely be found in close approximation to the communicator. Once the A2 artery is identified, the exposure can be gently pushed proximally toward the aneurysm neck.

Despite our best efforts, not infrequently the girth of the aneurysm precludes safe visualization of the contralateral A1–A2 junction even if the distal aspect of that A2 can be exposed in the interhemispheric fissure. Faced with this situation, the surgeon can either estimate the early trajectory of A2 and apply a clip blindly, or use temporary proximal occlusion to facilitate further displacement of the aneurysm sac. Having tried both options, we strongly recommend the latter (**Fig. 7.13**).

Temporary clips properly applied to both A1 segments well away from the interhemispheric fissure will soften any nongiant, noncalcific anterior communicating aneurysm sufficiently to permit dissection of the anterior aspect of the artery and identification of the contralateral A2 origin.

Demonstration of the origins and initial 2 to 3 mm of both A2 segments usually provides ample exposure of the aneurysm neck to permit safe and effective clip placement (**Fig. 7.14**). The single situation in which this is not the case is when one is dealing with some superiorly projecting lesions when both A2 origins are anterior to the aneurysm itself (**Fig. 7.15**). In this unusual anatomical variant, the several hypothalamic perforating arteries, which arise primarily from the communicating artery's dorsal surface, will be densely adherent to the posterior neck and fundus of the aneurysm. They must be identified and carefully separated from the aneurysm prior to permanent clip placement; this tedious but necessary dissection can often be facilitated if the fundus is softened by the use of temporary proximal occlusion.

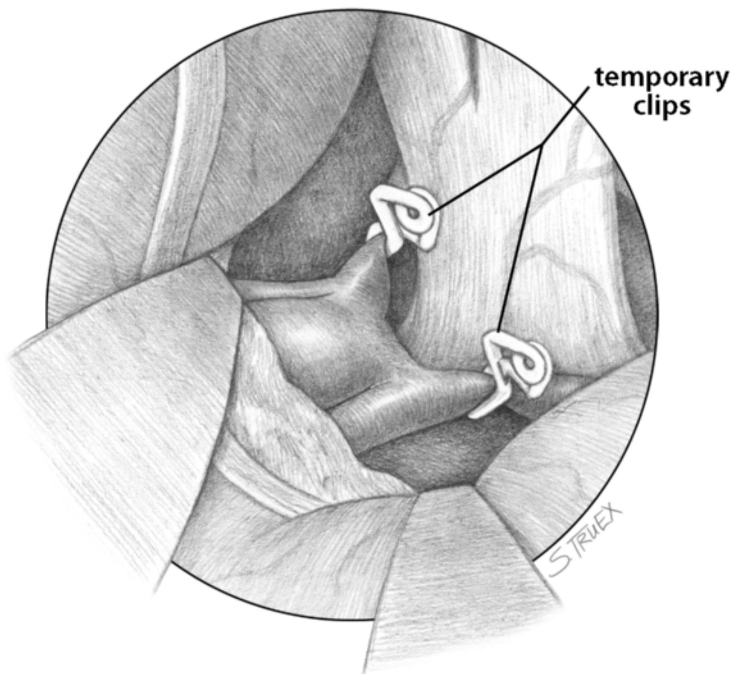


Fig. 7.13 Temporary occlusion of bilateral A1 segments.

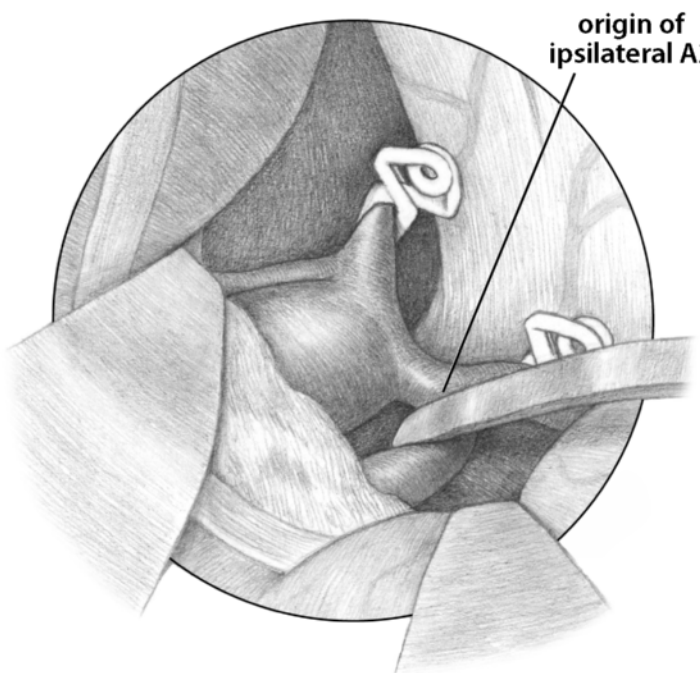


Fig. 7.14 Exposure of bilateral A2 origins.

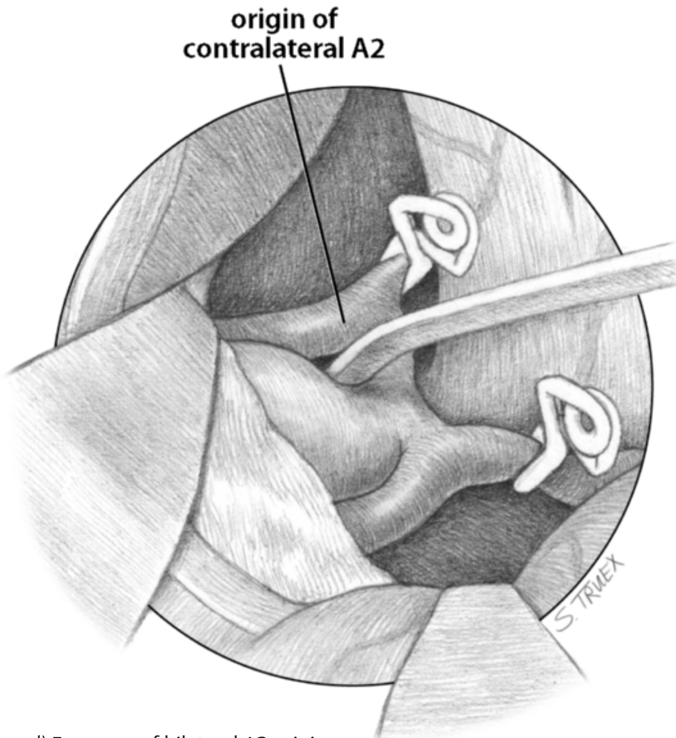


Fig. 7.14 *(Continued)* Exposure of bilateral A2 origins.

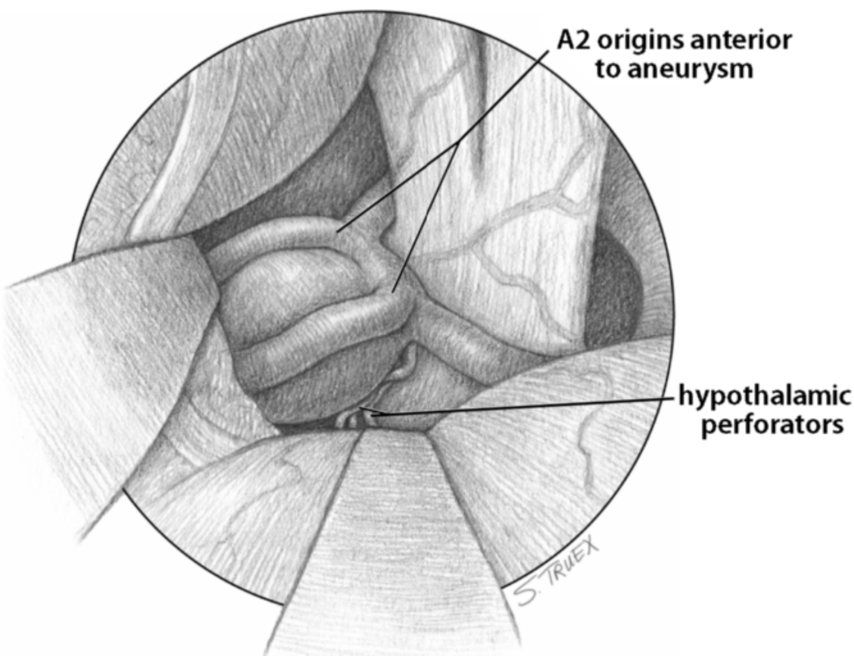


Fig. 7.15 A2 segments exposed in superiorly projecting ACOMM aneurysms.

Clip Application

Regardless of the experience or seniority of the surgeon, the liberal use of temporary proximal occlusion markedly facilitates clip ligation of all but the simplest ACOMM aneurysms. In testimony to this belief, over 75% of ACOMM aneurysms at UTSW currently have at least some part of their final dissection and permanent clip application performed after the institution of temporary occlusion of one or both A1 segments. The advantages of dealing with a slack aneurysm sac far outweigh the drawbacks of relatively brief periods of proximal A1 occlusion and are completely unrelated to the surgeon's intestinal fortitude.

Once the dissection outlined here has been done, most ACOMM aneurysms are relatively straightforward to clip. Although the occasional aneurysm may encompass most of the circumference of the communicating artery, these lesions very infrequently involve a portion of the distal vessel, as is seen frequently with posterior communicating aneurysms, posterior inferior cerebellar aneurysms, and lesions of the basilar artery at both the apex and the superior cerebellar origin. The most common problem in clip ligation of these aneurysms occurs when the aneurysm's axis of projection is identical to that of the ipsilateral A2 segment (**Fig. 7.16**). The lateral walls of the neck and fundus are generally tightly applied to the mesial aspect of the A2, making their separation difficult and potentially dangerous, and rendering ordinary clip application problematic with regard to patency of the A2 and preservation of the communicating artery. These concerns were essentially rendered moot by the development of the fenestrated aneurysm clip by Drake. When care is taken to avoid occlusion of the contralateral A2 by overly long clip blades, the short, "small-hole" fenestrated clip applied with the ipsilateral A2 segment in the fenestration offers an elegant solution to a tightly adherent underlying aneurysm.

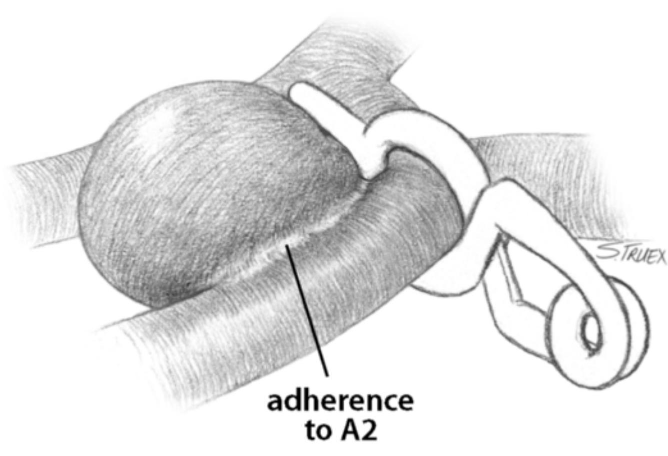


Fig. 7.16 Common axis of projection between ipsilateral A2 aneurysm.

On occasion, the unlucky surgeon will run up against a large ACOMM aneurysm emanating from a “blowout”-like circumferential dilatation of the communicating artery. These freaks are a little difficult to identify in advance, but the larger the aneurysm, the more likely the surgeon is to discover a markedly dilated communicator that balloons into a true aneurysm (**Fig. 7.17**). In our experience, these lesions are impossible to successfully clip reconstruct without being first completely trapped then evacuated and collapsed. Mobilization of the entire aneurysm necessitates a generous gyrus rectus resection; reconstruction usually requires at least two clips (often more) and generally involves a relatively protracted length of temporary arterial occlusion. Often, to exclude the bulk of the aneurysm sac from the circulation while ensuring that both A2 distributions continue to be perfused, the surgeon will be required to leave a portion of the enlarged communicating artery unsecured. In these situations, we wrap the segment with a single layer of fine mesh gauze and then repeat the postoperative angiogram in a year to 18 months. To date we’ve had no growth of this bulbous area of residual weakness in any of the patients who were willing to let us keep following them.

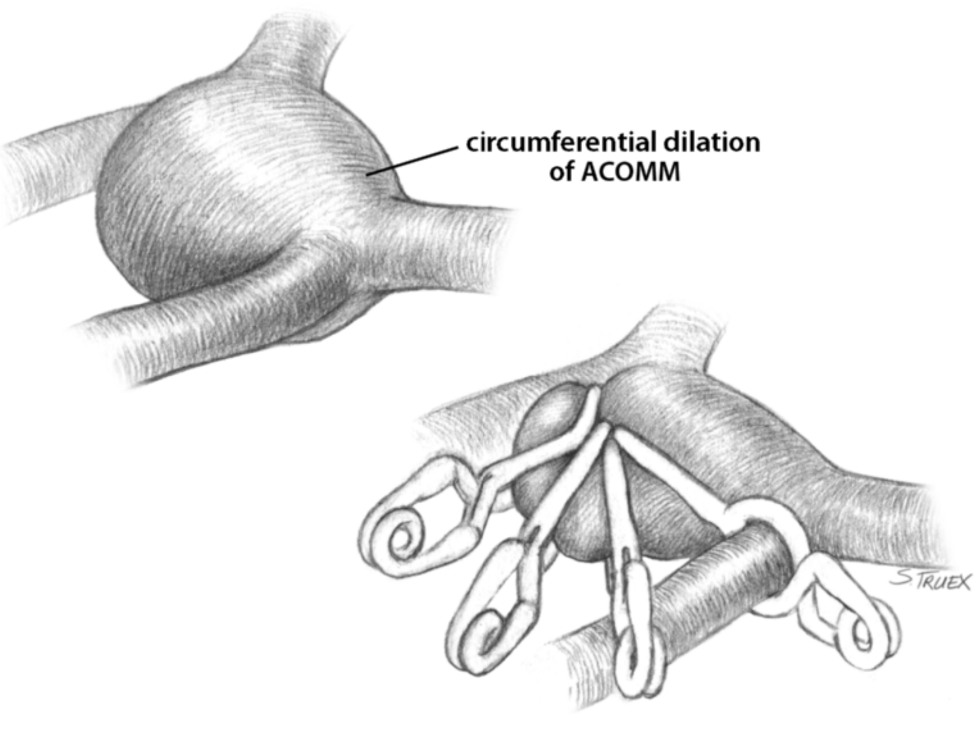


Fig. 7.17 Large aneurysm resulting in ACOMM “blowout.”

A last resort in dealing with these difficult aneurysms is permanent trapping of the entire ACOMM, a maneuver we think should be reserved for ruptured lesions that the surgeon is certain simply cannot be reconstructed without significant morbidity (**Fig. 7.18**). In these situations, obviously the surgeon must know that each A1 segment can adequately supply the ipsilateral A2 distribution, that there is no stenosis of either A2 origin produced by the trapping clips, and that no hypothalamic perforating arteries are sacrificed by or included in the clip construct.

In addition to the normal goals of aneurysm occlusion and preservation of normal vasculature, clip application of anterior communicating aneurysms should also be done with consideration of potential impact of the clip (or clips) on the optic apparatus. Many experienced aneurysm surgeons have had occasional patients develop visual loss in a delayed fashion following ACOMM aneurysm surgery related to brain reexpansion and subsequent clip compression of the optic chiasm. This complication can sometimes be reversed by early recognition and prompt clip repositioning, but like most complications is easier to prevent than to resolve. It occurs almost exclusively with inferiorly projecting aneurysms and is most common if a complex clip reconstruction has been done. Again, the use of temporary proximal occlusion during the final phases of dissection and clip application facilitates accurate blade positioning and will reduce the necessity for multiple clip constructs and eliminate the use of large, bulky clip patterns.

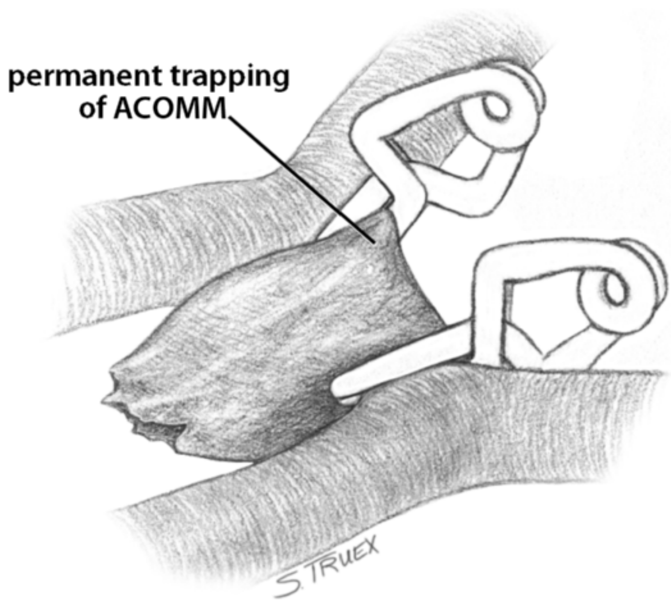


Fig. 7.18 Permanent trapping of ruptured ACOMM aneurysm.

Alternative

Over the last several years, we've experimented with a variety of smaller bony exposures, especially in the treatment of asymptomatic, unruptured ACOMM aneurysms. We don't like the supraorbital or "eyebrow" incisions because of their cosmetic consequences, we prefer to remain away from the frontal sinus, and we are not fond of the direct, midline, interhemispheric approach because of the difficulty with reliable proximal control. The combination approach we've found most satisfactory starts with a routine pterional skin flap turned in the interfascial plane down across the right orbit. The anterior attachments of the temporalis muscle are cut, and the resulting small triangular muscle flap retracted posteriorly with a stay stitch (**Fig. 7.19**).

A single burr hole is placed in the anatomical key, and a Kerrison rongeur is used to enlarge it somewhat posteriorly, which will ultimately simplify identification of the lateral sylvian fissure. Then a slightly lateral, low supraorbital flap of small size (3 × 2 cm) centered on the zygomatic-frontal process is created; the flap usually extends anteriorly to the midpupillary line (**Fig. 7.20**). The dura and underlying brain fill the small opening relatively quickly, but with gentle retraction the inner table across the entire inferior aspect of the craniotomy defect can be removed to provide a flat exposure of the orbital roof. We erase the several bony excrescences on the roof with the fine burr, and make a special attempt to identify and remove the large bump that is usually present just anterior to the sphenoid ridge ~2 cm medial to the inner table (**Fig. 7.21**). After plugging any holes in the orbital roof with Surgicel (Ethicon, Inc., Somerville, NJ), we open the dura in a linear fashion along the brow, tack it back, and bring the microscope in.

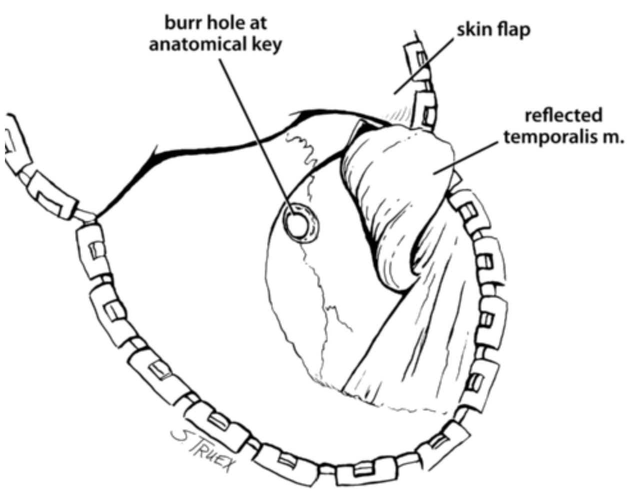


Fig. 7.19 Alternative craniotomy for ACOMM aneurysm.

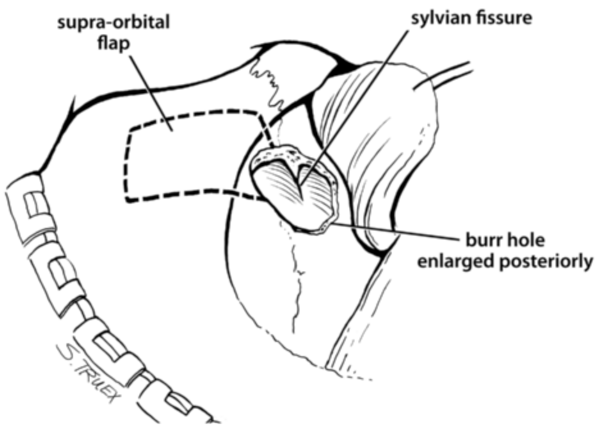


Fig. 7.20 Additional bone resection for alternative ACOMM craniotomy.

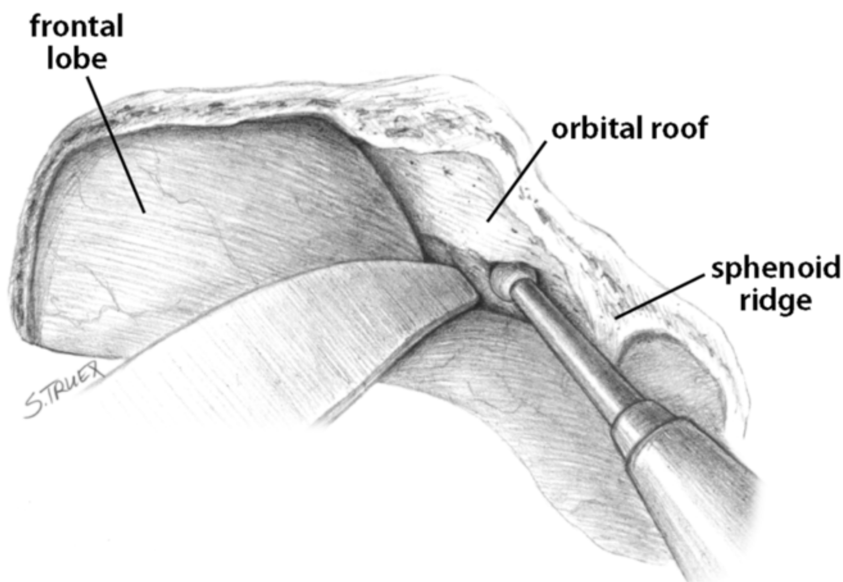


Fig. 7.21 Flattening out of orbital roof.

Generally, the first step under the scope is to identify the sylvian fissure very laterally and open it to release cerebrospinal fluid. This provides sufficient brain relaxation to permit exposure and opening of the carotid cistern, and from there on the procedure is much as already described. Small retractor blades are helpful, as are long “keyhole” microinstruments (especially bipolar cautery forceps) but routine scissors, dissectors, and clip appliers seem to work just fine.

The operative procedure done in this fashion is generally somewhat faster (~30 minutes), and to date the results (vascular, neurological, and cosmetic) have been uniformly good. As mentioned, we have limited the use of this approach to singular unruptured lesions and have not applied it to cases of multiple or large aneurysms we anticipate will prove difficult. It is also not an optimal exposure for teaching an inexperienced resident or fellow, since the constraints of the superficial exposure are relatively limiting and a preexisting appreciation of the vascular anatomy is almost mandatory. The other distinct drawback to this approach is lack of almost instantaneous access to the ventricular system via the Payne point.

Final Thoughts

1. Don’t underestimate the potential difficulty of these aneurysms.
2. Proximal control means adequate exposure—not just visualization—of both A1 segments at the level of the optic nerves and can be obtained with equal facility from either side.
3. Limited, focused, subpial resection of the gyrus rectus markedly facilitates exposure of the ACOMM complex.
4. The transition from ipsilateral A1 to aneurysm is very easily mistaken for the origin of the ipsilateral A2; therefore, the dorsal aspect of the A1 should be followed into the interhemispheric fissure to identify A2.
5. The final stages of exposure, neck dissection, and clip application are more safely and accurately done under the protection of temporary proximal occlusion.

8

Aneurysms of the Distal Anterior Cerebral Artery

General

These lesions—defined as aneurysms arising distal to the anterior communicating complex—are relatively uncommon and are frequently overlooked on initial diagnostic angiography (especially when occurring as unruptured companions to ruptured aneurysms). They are very common in the setting of multiple aneurysms and occur with disproportionate frequency in series of mycotic aneurysms. Their unique location makes them somewhat awkward to expose, in part because of the unfamiliarity of the approach, and in part because, as a rule, proximal control can only be achieved late in dissection. Unlike aneurysms at more common locations, the major morbidity of surgery for distal anterior cerebral artery (DACA) aneurysms relates neither to the risk of early aneurysmal rupture nor ischemia to the distributions of the afferent arteries, but rather to injury, either by direct retraction or by venous infarction, involving the cortex adjacent to the route of surgical exposure. For that reason, whenever feasible we prefer a nondominant, parasagittal exposure.

Anatomy

Vascular

The normal anatomy of the DACA involves a variable number of proximal branches to the mesial frontal cortex, the largest of which is referred to as the orbital-frontal artery (**Fig. 8.1**). These branches always arise inferior to the genu of the corpus callosum and may infrequently be the site of DACA aneurysms.

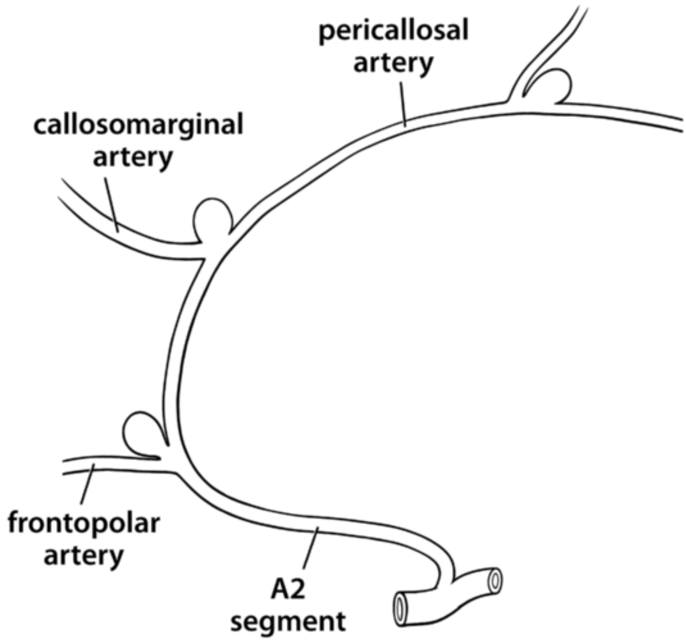


Fig. 8.1 Common locations for DACA aneurysms.

The most proximal large branch of the DACA is the frontopolar artery that routinely arises inferior to or at the level of the genu and projects anteriorly along the mesial frontal cortex in the general direction of the frontal pole. This origin is the second most common site of DACA aneurysms.

The largest branch of the DACA is usually the callosomarginal artery, which may arise inferior, anterior, or dorsal to the genu of the corpus callosum. This artery and its three terminal branches supply the majority of the mesial frontal cortex and anastomose with anterior and superior branches of the middle cerebral artery in the “watershed” area of the parasagittal cortex. As might be anticipated because of its size, the origin of the callosomarginal artery is the most frequent site of DACA aneurysms.

The anterior cerebral artery (ACA) continues after the takeoff of the callosomarginal artery as the pericallosal artery (A4 segment). This vessel runs in the cistern of the corpus callosum for a variable distance prior to terminating in several smaller cortical branches. In its distal segment it commonly anastomoses with the posterior pericallosal artery, a branch of the posterior cerebral artery. Aneurysms along the A4 segment are uncommon, but when they do occur, they are frequently mycotic in etiology.

Variations in the anatomy of the DACA are very common, with azygous A2 segments; proximal DACA bifurcations giving rise to long, parallel, callosomarginal and pericallosal arteries; and numerous small callosomarginal branches from a large parent DACA being perhaps the most frequent.

Cerebral

Obviously, one of the major determinants of exposure of DACA aneurysms is the relationship of the genu or rostrum of the corpus callosum to the aneurysm's site of origin. Because of the aforementioned variability in the branching points of the DACA, it's impossible to state categorically that any one approach is preferable for an aneurysm at any specific branch origin. Only when the exact vascular anatomy is coupled with a clear appreciation of the aneurysm's location with reference to the corpus callosum can the surgeon select an operative approach that will maximize vascular exposure while simultaneously minimizing the need for brain tissue retraction and/or resection. Sagittal magnetic resonance imaging (MRI) scans provide the most dramatic and accurate depiction of this relationship.

Procedure

Approach

Almost all DACA aneurysms will require some version of an interhemispheric approach, the few exceptions being those very proximal lesions located immediately distal to the ACOMM complex. Even when dealing with this small minority of cases, the theoretical disadvantages of a "distal-to-proximal" exposure of the aneurysm-bearing segment must be carefully weighed against the deep brain retraction and often very extensive gyrus rectus resection required for a lateral subfrontal exposure.

When dealing with aneurysms that arise inferior to the corpus callosum, a low anterior interhemispheric approach is recommended (**Fig. 8.2**). The patient is operated in the supine position with the neck slightly extended. After the scalp is reflected with a bicoronal incision, the craniotomy should expose the width of the sagittal sinus, although the intradural approach can generally be unilateral, preferably from the right. We prefer to place the craniotomy for these lesions immediately above the orbital roof, so usually the frontal sinuses are entered and must be appropriately managed prior to closure. Despite traditional propaganda to the contrary, it is never necessary to cut the anterior falx.

Aneurysms that are located anterior to or rostral to the genu are also operated via a bicoronal scalp flap and unilateral craniotomy, but in almost all such cases the bony exposure can be planned so as to avoid violation of the frontal sinuses (**Fig. 8.3**). The exact location of the craniotomy flap, in relationship to the coronal suture, obviously depends on the aneurysm's site of origin, but for almost all of these lesions we still prefer a flap that crosses the midline, exposing the sagittal sinus. This exposure allows the dural opening to expose the falx and interhemispheric fissure, minimizing brain tissue retraction. We also prefer to avoid sacrifice of any veins draining into the sinus if at all possible; most commonly, an operative window of 2 cm in length will suffice for the exposure and obliteration of all but the largest distal anterior cerebral artery aneurysms.

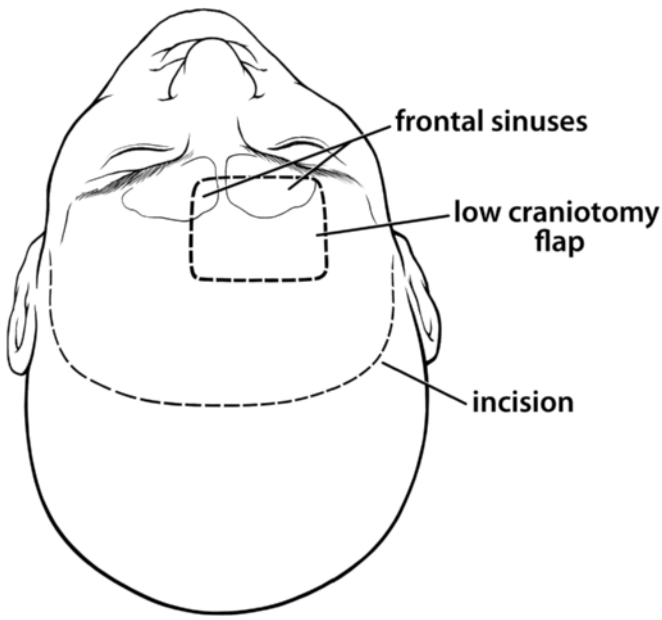


Fig. 8.2 Skin incision and craniotomy for DACA aneurysms inferior to the corpus callosum.

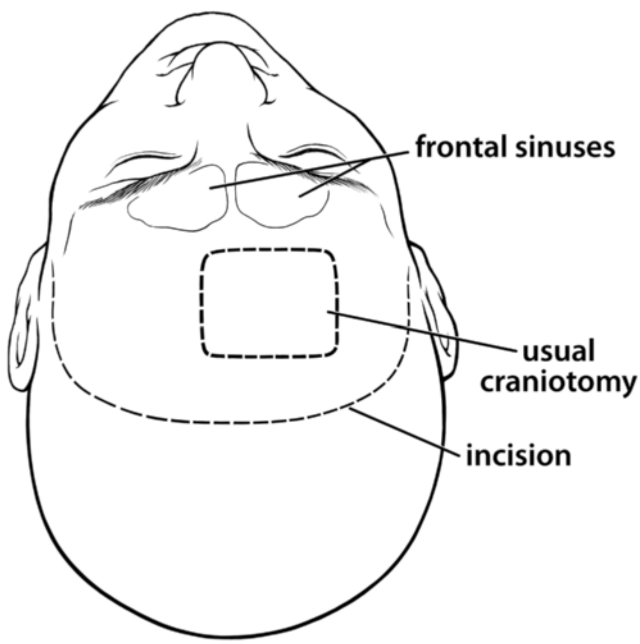


Fig. 8.3 Skin incision and craniotomy for DACA aneurysms anterior/rostral to the corpus callosum.

The interhemispheric approach is most expeditiously performed by gently separating the mesial frontal lobe from the falx and proceeding perpendicular to the sinus directly to the underlying corpus callosum (**Fig. 8.4**). In almost all situations, this exposure leads the surgeon to the A3 segments distal to the aneurysm-bearing segment, an apparent violation of the basic principle of proximal control. However, this approach provides the surgeon continuous appropriate orientation, certainty that the aneurysm will not be inadvertently exposed, and facile dissection of the interhemispheric fissure while avoiding retraction of swollen, inflamed brain. With identification of the corpus callosum, isolation of both A3 segments, and correlation of the arterial anatomy with the angiographic findings, the surgeon can then begin to move safely proximally retrograde along the A3 branch.

It is rarely necessary to enlarge the superficial interhemispheric corridor during this exposure; simply separating the two-cingulate gyri is sufficient to provide ample exposure of the proximal A3 and aneurysm-bearing segment. It is important that the surgeon confine the inevitable trauma associated with dissection to one cingulate gyrus.

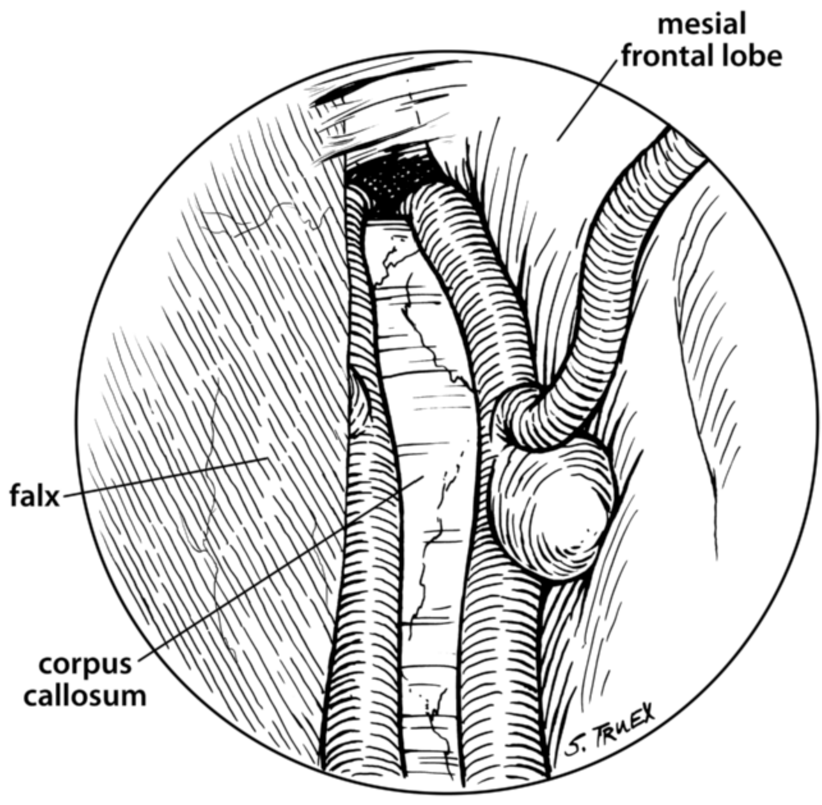


Fig. 8.4 Interhemispheric corridor for DACA aneurysms.

Aneurysms of this location typically project away from the corpus callosum and not infrequently into one or the other cingulate gyrus, meaning the safest route to proximal control of both the emerging arterial branch and the proximal A2 itself can be predetermined by close inspection of the angiographic anatomy. It is neither necessary nor wise to mobilize both cingulate gyri to obtain this exposure; the superior projection of these aneurysms will allow the surgeon to hug the corpus callosum and follow the parent vessel to proximal control (**Fig. 8.5**). For lesions located at and immediately distal to the genu, a very limited subpial resection of the superficial fibers of the corpus callosum will expose the proximal A2 segment.

Dissection/Clip Application

Once the surgeon has seen the proximal A2 segment, dissection and isolation of each of the emerging A3 segments are generally not difficult, but because the aneurysm will interpose itself between the surgeon and the deeper of these

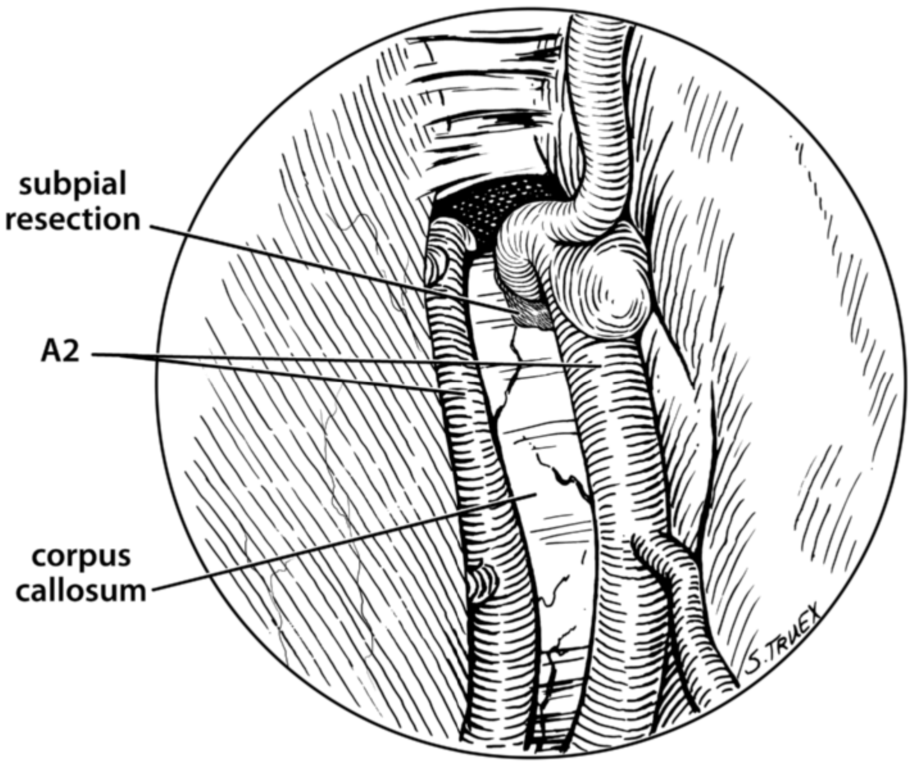


Fig. 8.5 Exposure of proximal A2 segment.

two arteries, it is very important that the neck actually be separated from both the emerging A3 segments rather than simply inspected. Unless this interface is well defined, at the time of clip placement there is a significant danger of occluding the deeper A3 with the tips of the clip. When dealing with a ruptured lesion, performing this last phase of dissection after temporary proximal occlusion of the parent anterior cerebral artery is an excellent strategy.

In the relatively infrequent anatomical situation when the aneurysm arises between the origins of the frontopolar and callosomarginal arteries, an attractive clipping alternative involves the use of a short, straight fenestrated clip with the callosomarginal artery placed in the fenestration. Here it is equally important to actually see and separate the neck from the frontopolar branch prior to clip application to avoid inadvertent occlusion of the proximal artery.

Final Thoughts

1. Almost all of these aneurysms should be approached via an interhemispheric exposure.
2. It is very easy to become lost in the interhemispheric fissure. The simplest way to maintain appropriate orientation is by ensuring that the angle of initial approach is perpendicular to the corpus callosum.
3. The projection of these aneurysms almost always permits an easy distal-to-proximal exposure of the aneurysm-bearing segment and proximal A2. Never hesitate to resect a small amount of the genu of the corpus callosum.
4. The most common source of operative morbidity is excessive retraction of the mesial hemisphere and cingulate gyrus. Never traumatize both cingulate gyri.

9

Aneurysms of the Vertebral Artery at the Origin of the Posterior-Inferior Cerebellar Artery

General

Vertebral artery (VA) aneurysms represent the second most common aneurysm site in the posterior circulation and are the only vascular lesions (aside from vascular cranial nerve compression) commonly occurring in the cerebellopontine angle (CP angle). These aneurysms may originate from the vertebral artery proximal to the posterior-inferior cerebellar artery (PICA) origin, or from the VA distal to the PICA, but the vast majority occur in association with the PICA origin. The PICA, which often shares a reciprocal size relationship with the anterior-inferior cerebellar artery, routinely takes origin from the VA just after it enters the cranial cavity via a short dural tunnel, and aneurysms may arise at any branch point along its course; the second most common site of PICA aneurysms is the posterior medullary segment at the angiographic choroidal point. A constant characteristic of VA-PICA aneurysms is their tendency to incorporate a significant length of the initial portion of the PICA in the aneurysm neck.

Anatomy

The short segment of the intracranial VA proximal to the PICA origin is generally directed superiorly, but as the PICA emerges, the parent artery bends medially toward the midline and its ultimate junction with the contralateral VA (**Fig. 9.1**). Awareness of this change in trajectory becomes important when the surgeon seeks to establish essential distal control of the VA, for as a rule the artery must be identified and isolated medial to the aneurysm-bearing segment, not rostral along the lateral aspect of the medulla.

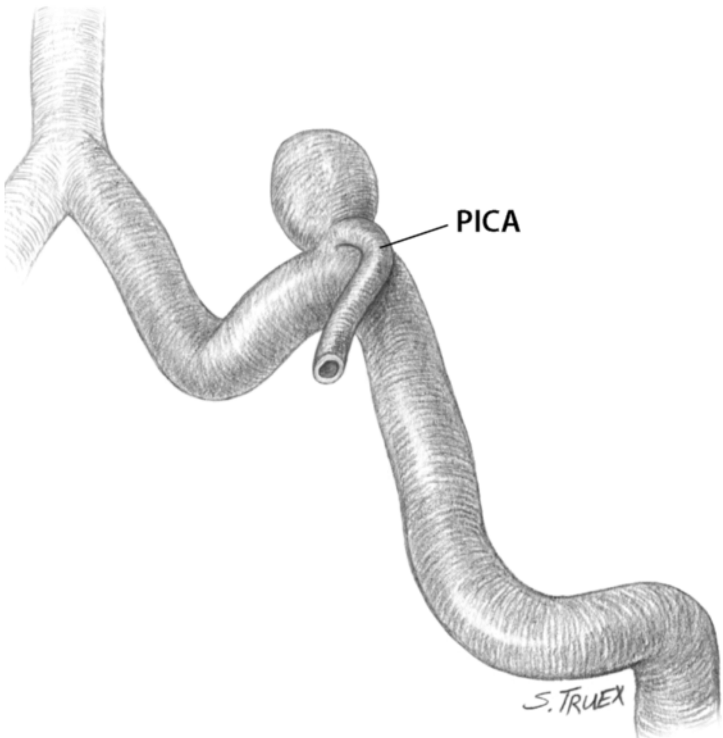


Fig. 9.1 Common orientation of PICA aneurysms.

Although cervical PICA origins are not uncommon, both novice and experienced surgeons often find themselves surprised by the very proximal location of the routine intracranial VA-PICA origin (**Fig. 9.2**). This point is generally found in the inferior aspect of the cerebellopontine angle almost exactly at the rostral-caudal level of the jugular tubercle; the intracranial length of the VA from its exit from the dural tunnel to the PICA origin is generally quite short and is shrouded from view from below by the overhanging posterior lip of the occipital condyle. This shallow intracranial location puts a surgical premium on aggressive exposure of the craniocervical junction prior to dural opening, both for adequate exposure of the aneurysm-bearing segment of artery and for the establishment of proximal arterial control.

The intracranial VA is overlain laterally by the ascending spinal root of the spinal accessory nerve (CN XI) and encircled medially against the stem by the emerging rootlets of the hypoglossal (CN XII), which almost always are found immediately proximal to the PICA origin (**Fig. 9.3**). Slightly more distally, the rootlets of the glossopharyngeal (CN IX) and vagus (CN X) nerves lie suspended superficial to the PICA and the VA in a wide arachnoid sheath that funnels them

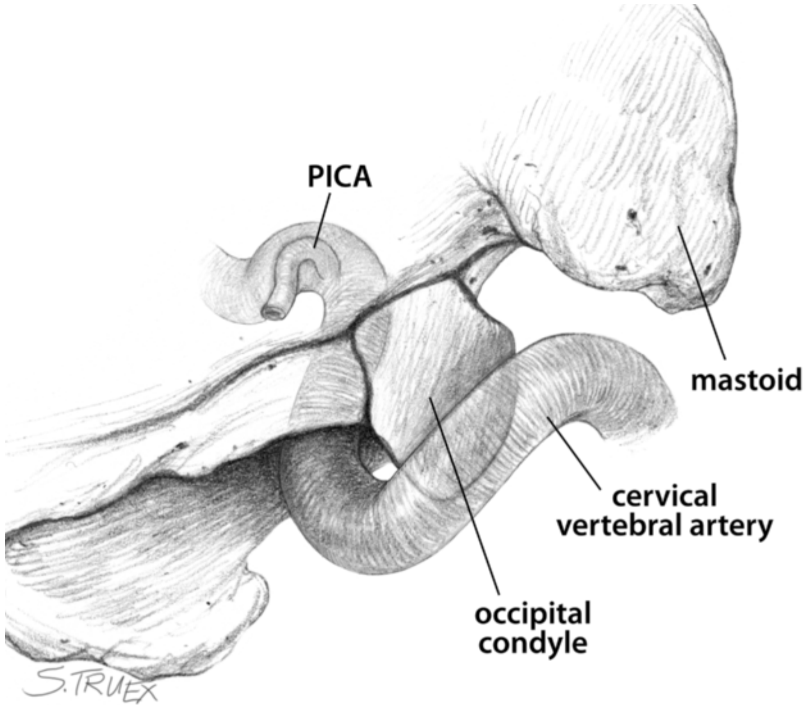


Fig. 9.2 Common bony association of VA-PICA origin.

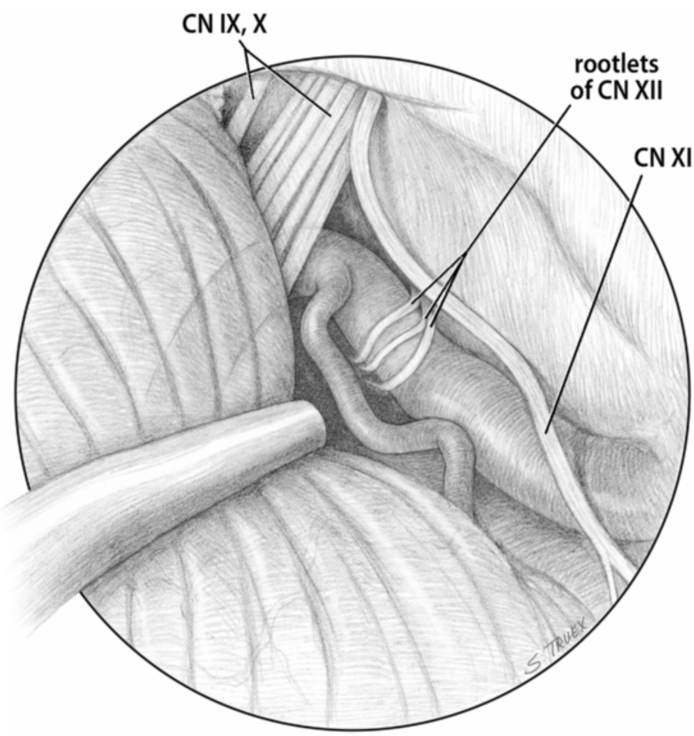


Fig. 9.3 Association of cranial nerve XII and PICA.

to the internal jugular foramen. Immediately superficial to these rootlets, the choroid plexus is invariably seen peeking through the foramen of Luschka. In the rare situation in which a retractor is required for exposure of these aneurysms, it should be placed gently on the cerebellar flocculus at this level.

Projection

VA-PICA aneurysms generally project in a rostral direction to some extent; however, their critical axis of projection is either posteriorly into the medulla itself or anteriorly into the subarachnoid space of the CP angle cistern. Very frequently, the previously described medial bend of the VA, when coupled with the aneurysm's projection, will strongly influence the optimal route of surgical exposure of the VA distal to the aneurysm neck.

Procedure

Positioning

These patients are operated in the lateral, "park bench" position with the operative side superior (**Fig. 9.4**). The neck is fully flexed in the "military brace" position and the vertex inclined toward the floor slightly. The superior shoulder is allowed to slump, and then is drawn and fixed with wide tape anterior to the coronal plane of the body. Each of these maneuvers maximizes the surgeon's access to the lateral subocciput.

Craniotomy and Initial Approach

Patients with VA-PICA aneurysms are operated in the lateral decubitus position (aneurysm side up) via an exposure popularized by Roberto Heros that has come to be known as the suboccipital, far lateral approach (**Fig. 9.5**). This is a difficult exposure to learn, but one that greatly facilitates all exposures of the cerebellopontine angle. Do all the steps correctly and your patients will prosper. In our version of this procedure, the key steps are as follows:

1. Vigorous reflection of the suboccipital muscle bulk inferiorly
2. A generous suboccipital craniectomy that includes the posterior and lateral aspects of the foramen magnum
3. A limited removal of the posterior-medial aspect of the occipital condyle
4. Removal of the ipsilateral lamina of the first cervical vertebra
5. Opening of the dura so as to maximize lateral exposure

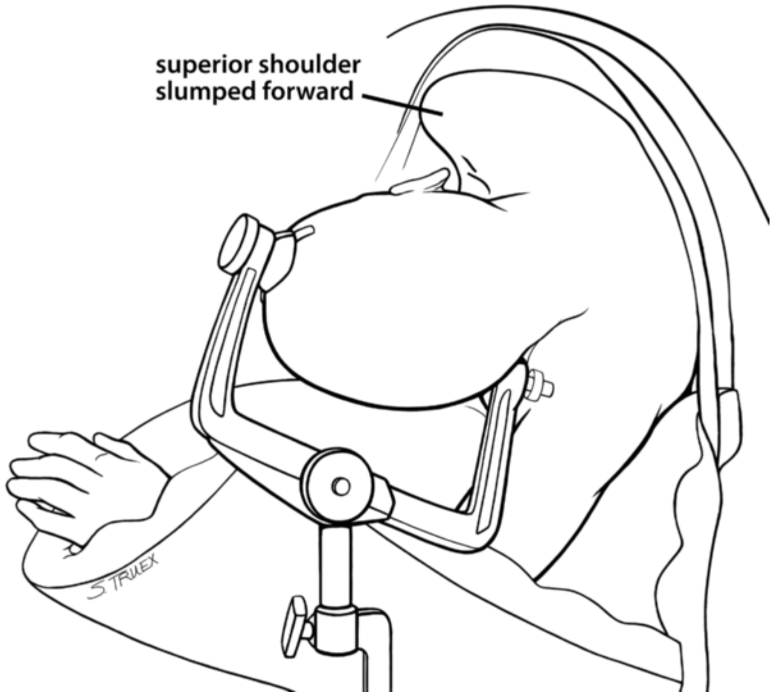


Fig. 9.4 Lateral position for the suboccipital, far lateral approach.

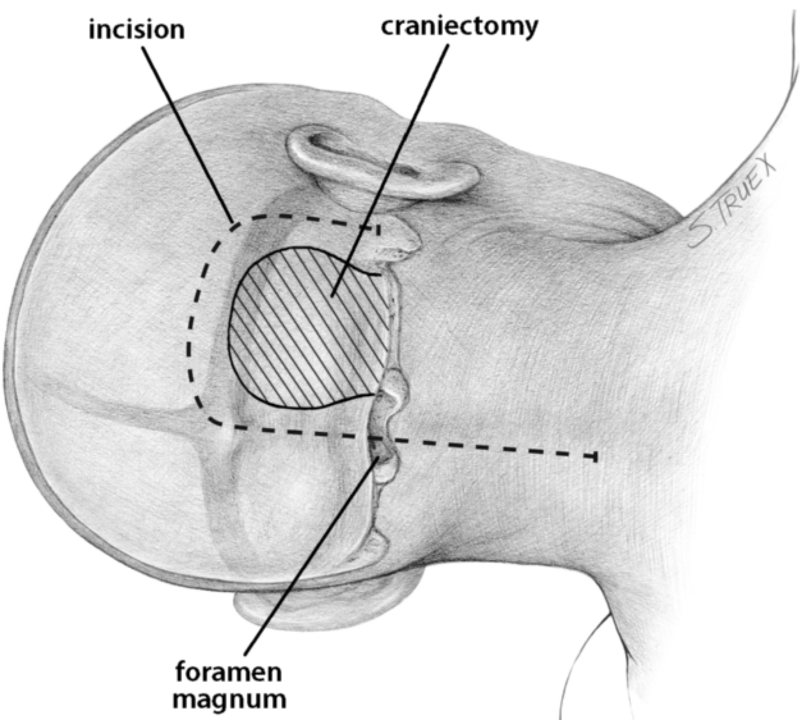


Fig. 9.5 Skin incision and craniotomy for suboccipital, far lateral approach.

Reflection of Suboccipital Muscles

While this procedure can be done via an S-shaped or even a linear incision, we believe a hockey stick or shepherd's crook incision offers the best superficial exposure to the cervical musculature. This incision extends superiorly from the mastoid tip to the inferior nuchal line, then medially to the midline and finally inferiorly to the midcervical area. The skin, subcutaneous tissue, and superficial layer of suboccipital muscles are reflected laterally and inferiorly to be held there with fishhook retractors (**Fig. 9.6**).

The surgeon then palpates the insertion of the inferior oblique and the origin of the superior oblique muscles at the lateral mass of C1, and sections those with the monopolar cautery (**Fig. 9.7**). With careful dissection, both the superficial and the deep suboccipital musculature can then be elevated from lateral to medial while cutting the muscles' attachment to the suboocciput, leaving a fascial cuff superiorly. When the midline is reached, the incision proceeds inferiorly to disconnect the muscular attachments to the arch of C1 and lamina of C2. The entire muscle cuff is then reflected inferiorly below the lamina of C1 to be held by spring-loaded retractors under tension.

The lamina of C1 is cleared of any residual muscle, and the VA is identified in its venous plexus immediately rostral to the C1 lamina and lateral to the lateral

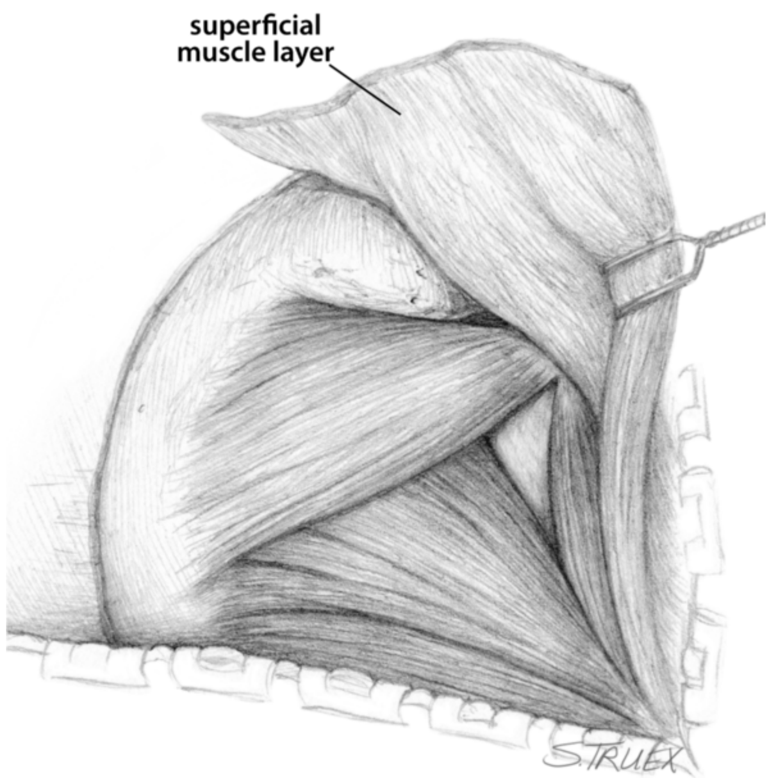


Fig. 9.6 Retraction of the superficial posterior cervical muscle layer.

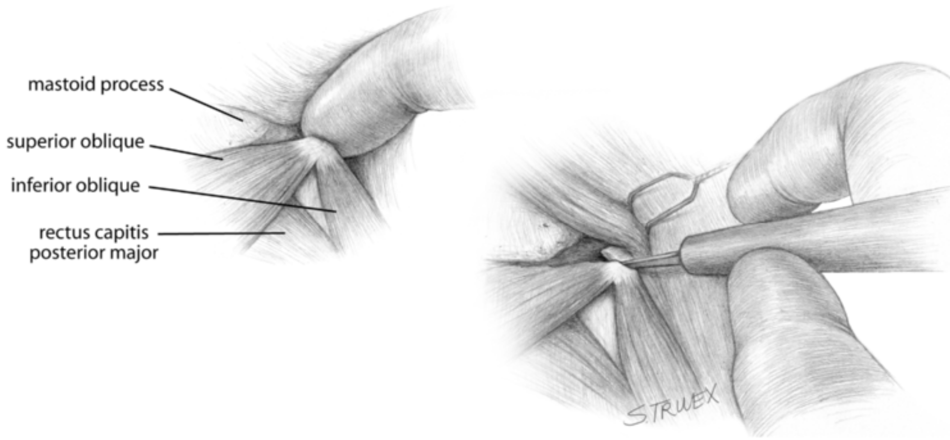


Fig. 9.7 Dissection of deep cervical muscles.

aspect of the foramen magnum. Extracranial control of the VA is recommended before beginning the bony exposure (**Fig. 9.8**).

Craniectomy and Opening of the Foramen Magnum

The bony opening is a straightforward suboccipital craniectomy that should extend laterally from midline to expose the entire sigmoid sinus and inferiorly from the inferior one-half of the transverse sinus to encompass the entire lat-

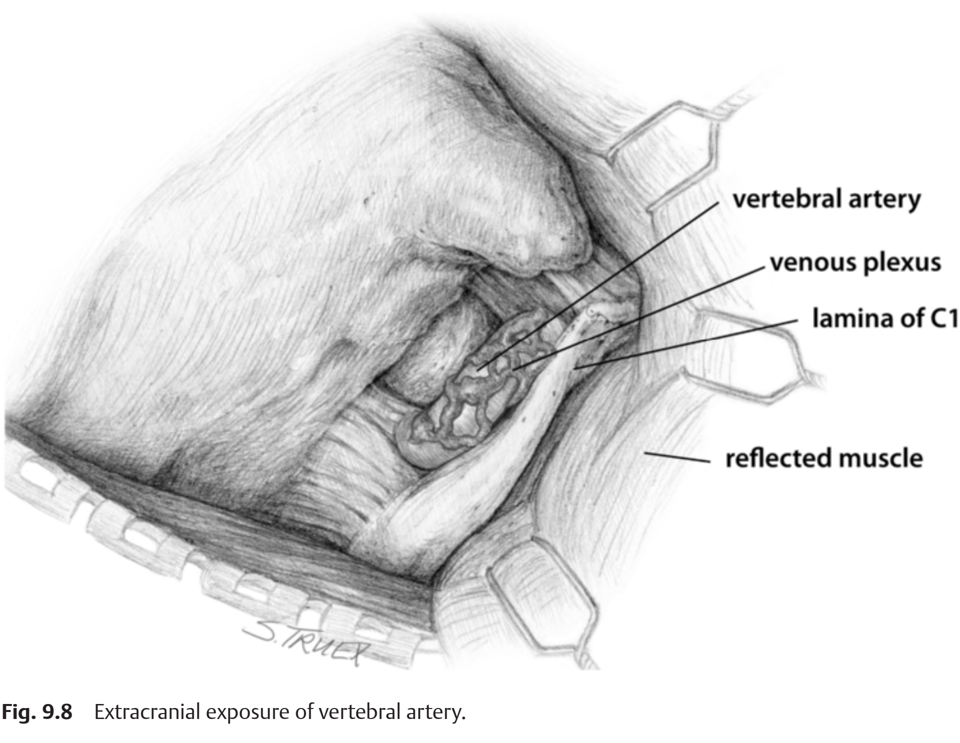


Fig. 9.8 Extracranial exposure of vertebral artery.

eral aspect of the foramen magnum. If the sigmoid sinus is not divested of its bony covering throughout its length, the surgeon will fail to maximize this approach's potential for lateral exposure, a deficit that can only be remedied later by increased and unnecessary cerebellar retraction.

C1 Hemilaminectomy

Theoretically, the laminectomy (**Fig. 9.9**) should be deferred until the entire craniectomy has been completed, so as to avoid any inadvertent injury of the exposed cervical cord with the large drills and cumbersome rongeurs traditionally used for suboccipital exposure. However, the remaining segment of skull base removal—condylectomy—is not done with instruments that place the cord at undue risk, and, more importantly, the condylectomy itself is facilitated by prior laminectomy. Thus we recommend the hemilaminectomy be performed after the craniectomy but prior to resection of the occipital condyle, and that the laminectomy be carried laterally almost to the facet joint.

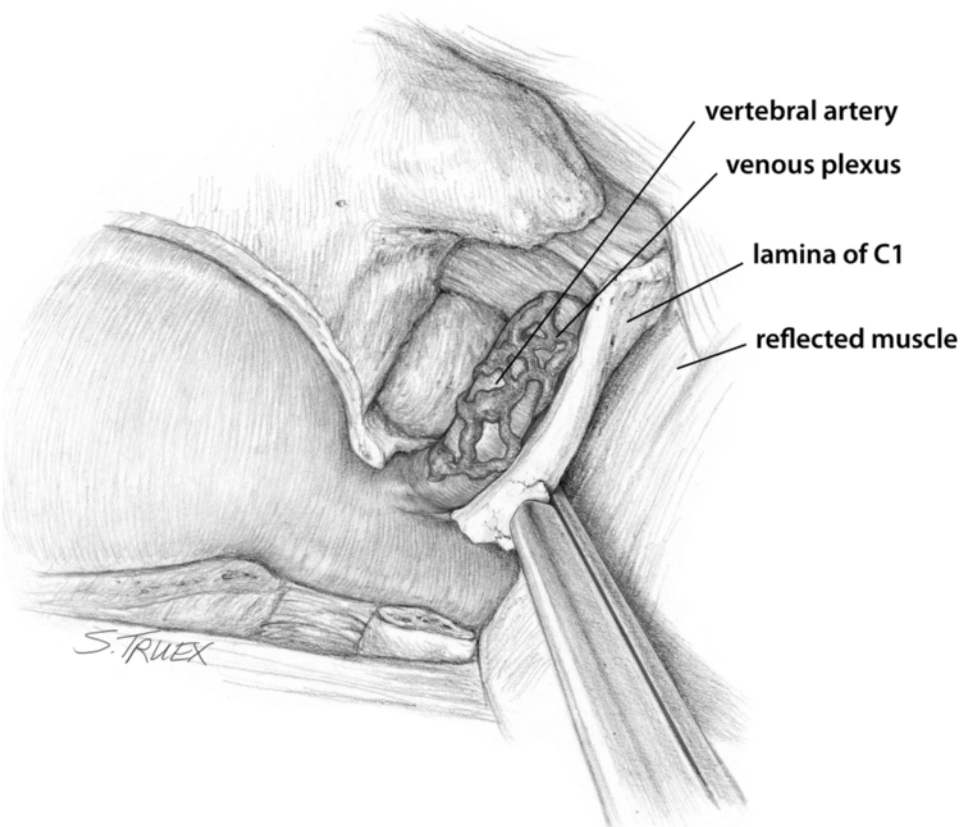


Fig. 9.9 Performance of C1 hemilaminectomy.

Partial Condylectomy

The goal in this important part of the procedure is not to resect as much of the occipital condyle as is humanly possible, but rather to flatten the lateral aspect of the bony craniectomy-laminectomy defect into a smooth contour extending from the exposed junction of the transverse and sigmoid sinuses to the medial aspect of the C1 facet joint (**Fig. 9.10**). This process is a little tedious because the lateral aspect of the bony foramen magnum and the posterior portion of the condyle contain numerous venous channels that must be carefully waxed to obtain hemostasis. Patient drilling, waxing, and more drilling will ultimately efface the protrusion made by these structures into the dura at the skull base; once this aspect of the bony margin is flat, further bone removal is not necessary, as opening the dura will expose the CN XI and underlying VA without retraction of the cerebellar tonsil.

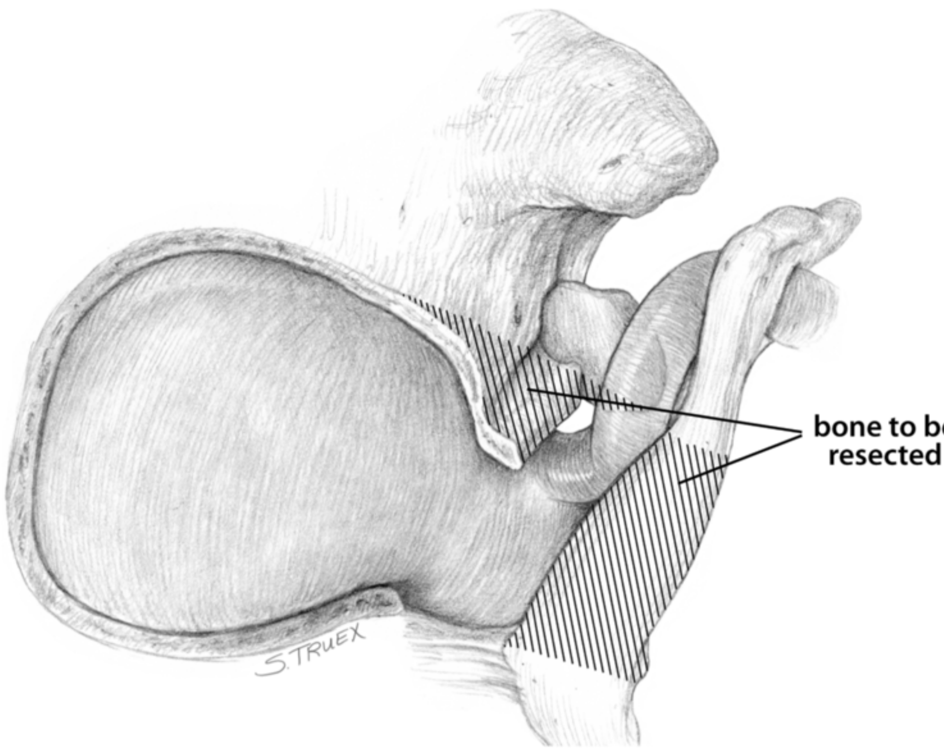


Fig. 9.10 Additional bony resection in suboccipital, far lateral approach.

Dural Opening

This should be done so as to maximize inferior-lateral exposure and simultaneously provide ample access to the cisterna magna. A K-shaped incision on the right (reverse K on the left) serves this purpose nicely (**Fig. 9.11**); the vertical limb of the K is paramedian, extending from the inferior aspect of the transverse sinus through the foramen magnum and down to the C2 lamina. The superior limb extends up to the sinodural angle and the inferior limb down to the bony margin at the site of the condylectomy. The three dural flaps created are then tacked firmly back against the margins of the bony defect.

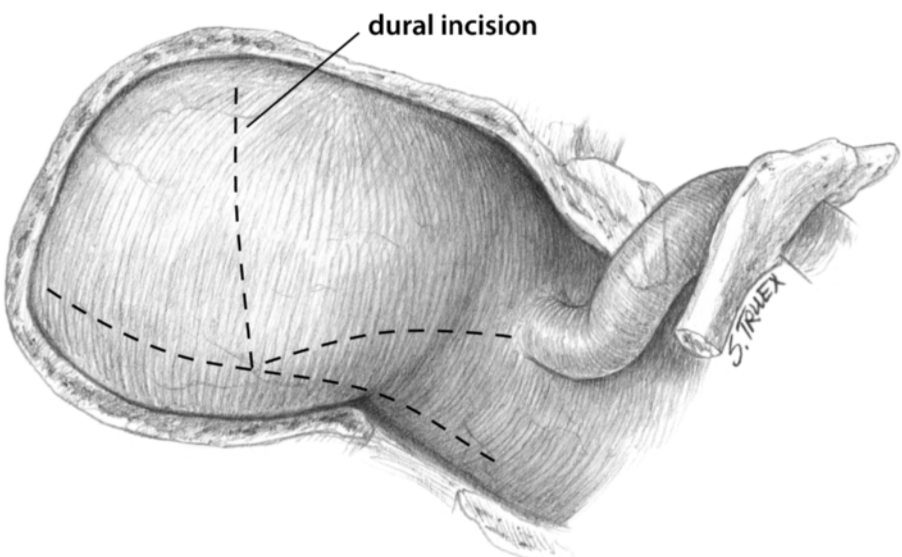


Fig. 9.11 Dural incision for suboccipital, far lateral approach.

Microsurgical Approach and Proximal Control

As the cisterna magna is opened and cerebrospinal fluid (CSF) is released, the cerebellar tonsil will sag toward midline and away from the inner table. Focusing the microscope at the lateral extent of the inferior dural incision, the surgeon will see, through the intact arachnoid, the CN XI entering the cerebellopontine angle, and beneath it, the VA exiting its dural tunnel (**Fig. 9.12**). This proximal portion of the intracranial VA is very laterally located; if you're having difficulty seeing the dural tunnel, you're probably looking too close to the brain stem.

Once identified, the VA should be dissected free of its arachnoid covering (take care to be gentle with the CN XI and CN XII) and prepared for temporary clip placement if necessary.

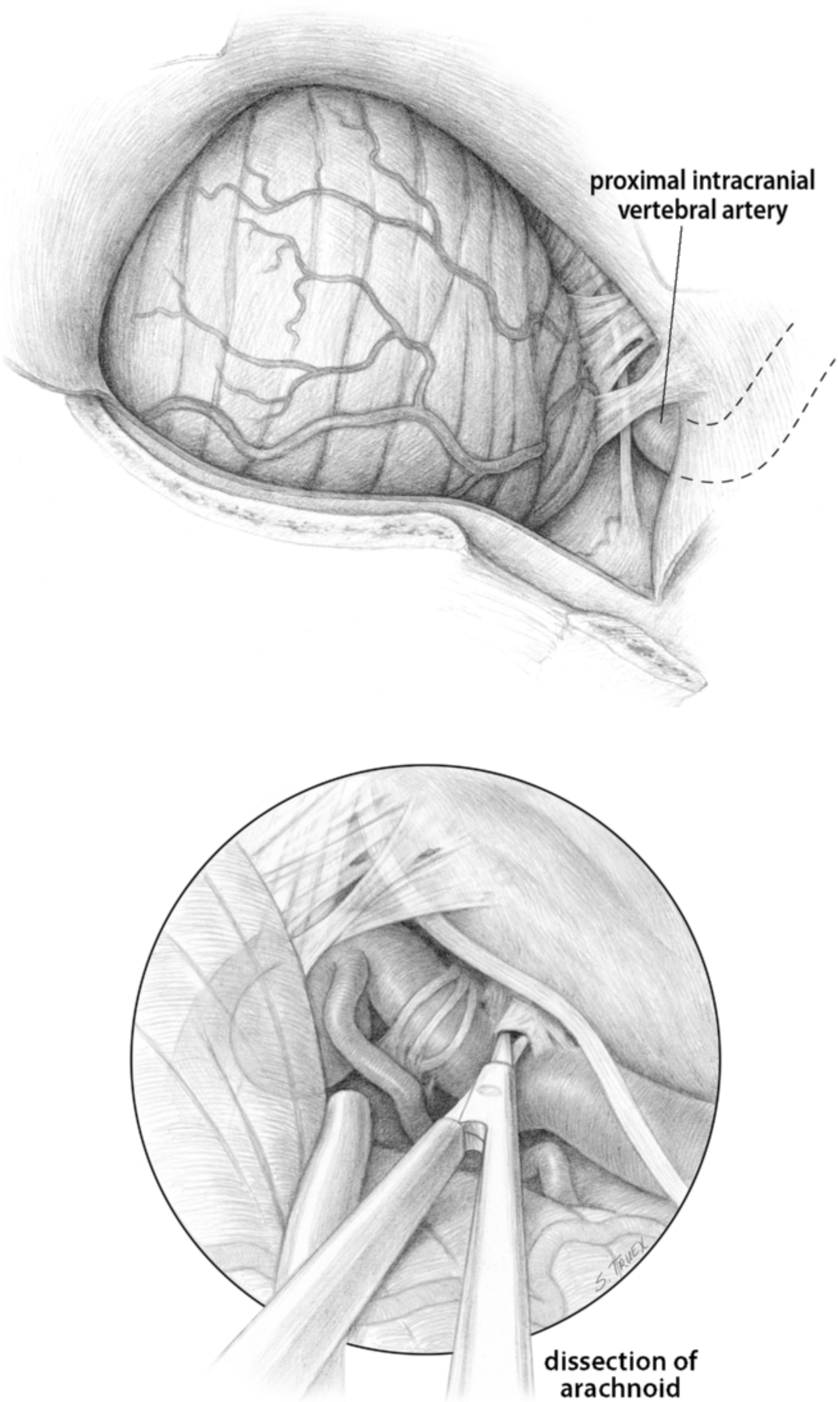


Fig. 9.12 Dissection of the intracranial vertebral artery for proximal control.

Distal Control

Most VA–PICA aneurysms arise as the parent artery makes a sharp medial bend to pass anteriorly en route to the midline. This portion of the artery is often quite close to the skull base but is frequently hidden from the surgeon's view—even after the proximal vertebral has been exposed—by the flocculus and cranial nerves IX, X, and XII.

When dealing with ruptured aneurysms that project medially into the brain stem, distal control can be achieved either by following the inferior aspect of the VA past the aneurysm-bearing segment until the distal vertebral can be seen, or by first opening the arachnoid between the jugular foramen and the internal auditory meatus, retracting the lower cranial nerves inferiorly and exposing the distal VA from a more rostral approach (**Fig. 9.13**).

If the aneurysm projects somewhat laterally into the CP angle, it may obscure any view of the distal VA. In this situation the surgeon can often establish distal control by gently elevating the proximal VA away from the medulla and visualizing the artery distal to the aneurysm-bearing segment where it lies adjacent to the stem in its course to the vertebrobasilar junction (**Fig. 9.14**).

Regardless of aneurysm projection, the trajectory of the distal vessel is almost directly away from the surgeon, which makes establishment of a site for temporary clip placement somewhat difficult; however, it is imperative that this preparation be successfully completed before the aneurysm itself is exposed or manipulated. We can attest—from personal experience—that holding a large suction tube on a PICA aneurysm that is bleeding like gangbusters despite proximal vertebral occlusion, meanwhile

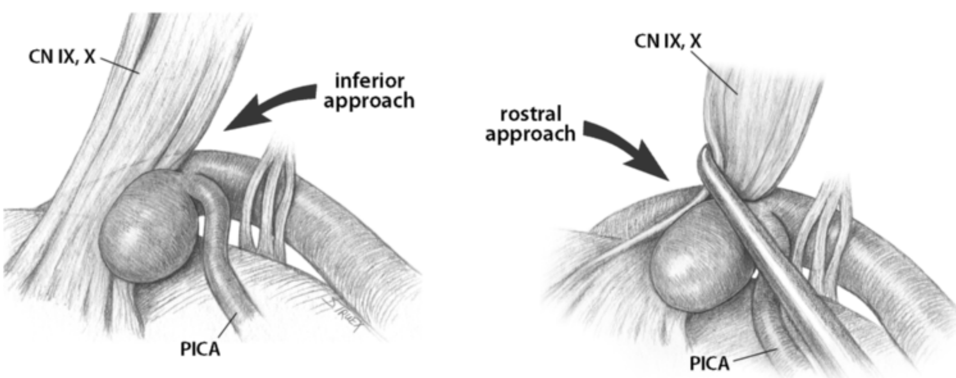


Fig. 9.13 Achieving distal vertebral artery control.

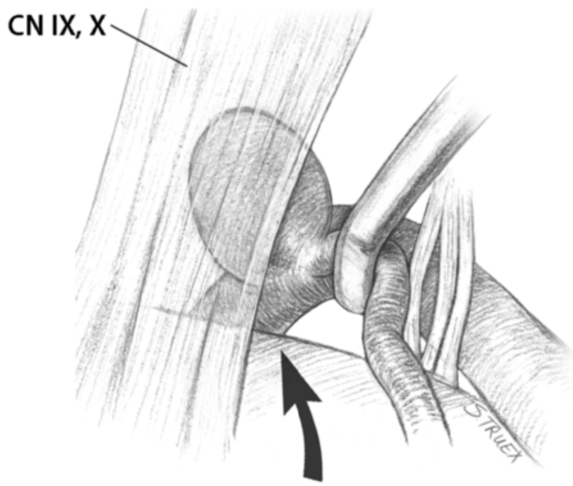


Fig. 9.14 Visualizing distal vertebral artery by artery elevation.

attempting to one-handedly obtain distal control, is a miserable way to spend the afternoon.

If and when temporary isolation of the aneurysm-bearing segment is necessary, placement of the proximal temporary clip rarely poses a problem, although it is advantageous to occlude the parent artery as proximal intracranially as is feasible to facilitate subsequent aneurysm mobilization and permanent clip placement.

Distal temporary clip placement is frequently a different story. Interposition of the aneurysm-bearing arterial segment between the surgeon and the distal artery, coupled with the previously mentioned medial bend of the VA and the tight confines of the cerebellopontine angle combine to hinder access to distal control. Here are three alternative approaches we've found useful in this situation:

1. Pass the clip applier into the CP angle between the cranial nerve IX, X, XI complex "below" and the cranial nerve VII, VIII complex "above," angling the clip caudally to meet the VA (**Fig. 9.15**).
2. Bring the clip applier to the distal artery from inferiorly, "below" the IX, X, XI complex through the caudal aspect of the CP angle. This approach is facilitated by the bony exposure provided by the far lateral craniectomy and C1 hemilaminectomy (**Fig. 9.16**).

Each of these approaches may require that the surgeon apply the temporary clip with the nondominant hand. With a little practice, it's not so difficult, especially if done prior to aneurysm rupture.

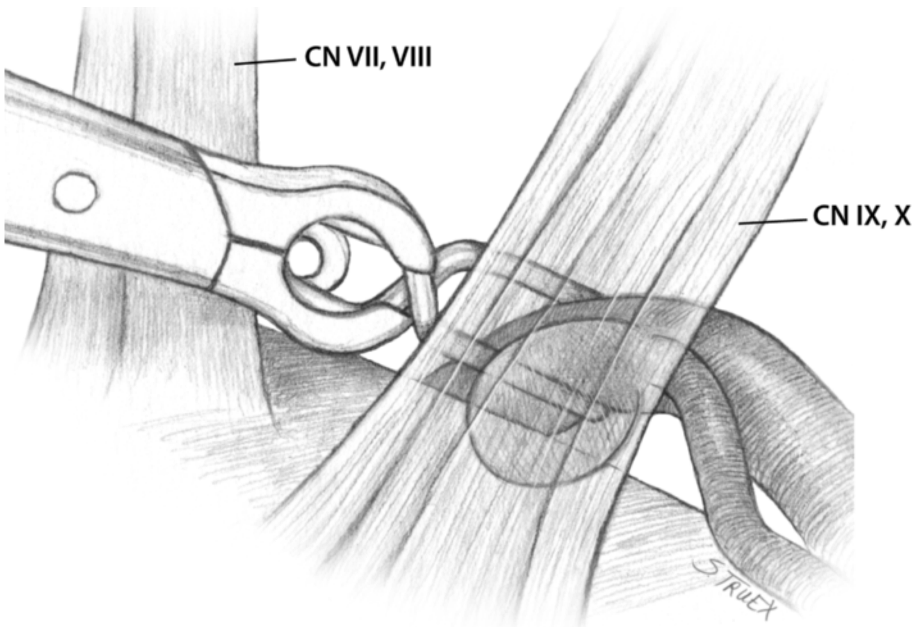


Fig. 9.15 Distal temporary clip strategy for VA-PICA aneurysm.

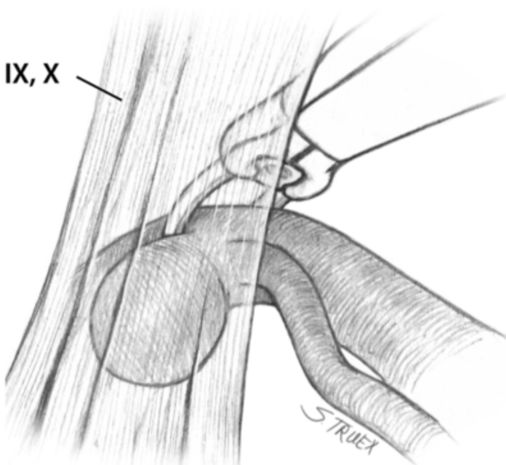


Fig. 9.16 Distal temporary clip strategy for VA-PICA aneurysm.

3. When neither of these approaches is feasible, as often happens when dealing with large or giant aneurysms, the surgeon can use a long “small-hole” fenestrated clip as a distal temporary clip. The clip is applied over the proximal portion of the VA—meaning this portion of the vessel is placed in the fenestration—and the blades then guided on to the distal artery beyond the aneurysm-bearing segment (**Fig. 9.17**).

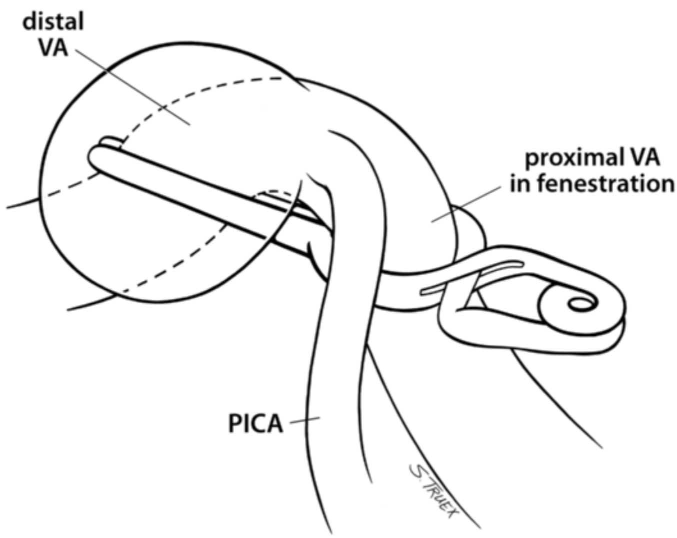


Fig. 9.17 Distal temporary clip strategy for VA-PICA aneurysm.

The final of these alternatives obviously necessitates complete circumferential dissection of the proximal artery, certain knowledge of the location and projection of the aneurysm sac, and at least partial prior dissection of the distal artery at the anticipated site of clip application. It also carries the theoretical risk of injury to the distal arterial intima by virtue of the increased closing force of the permanent clip blades, although in our practice this has not occurred. When operating on complex, large aneurysms this simple maneuver can be extraordinarily useful.

Final Dissection/Clip Application

Most aneurysms at this location require relatively extensive neck dissection because of their propensity to involve a lengthy segment of the branch artery's origin in the aneurysm neck itself. We believe this dissection is generally best accomplished with at least a proximal temporary clip in place (**Fig. 9.18**); if the aneurysm is large or must be tilted out of its bed in the brain stem, total preliminary trapping is preferable (**Fig. 9.19**). As a rule, large aneurysms should be deflated prior to mobilization and final clip ligation; this obviously necessitates a third temporary clip be placed on the PICA itself (**Fig. 9.20**).

Because of the trajectory of the distal VA, the surgeon must take special care to ensure that closure of the permanent clip blades occurs in a plane parallel to the axis of the distal artery. If this is not possible, the blades should be directed away from the artery so as to preclude inadvertent vertebral stenosis, even though this trajectory may leave some portion of the distal neck

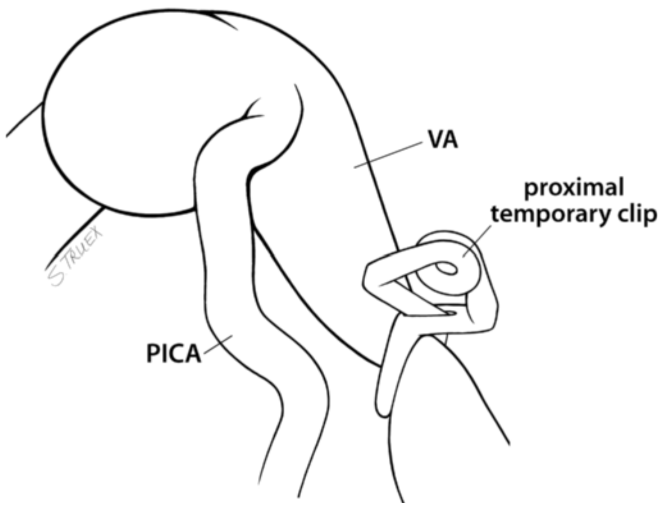


Fig. 9.18 Placement of proximal temporary clip.

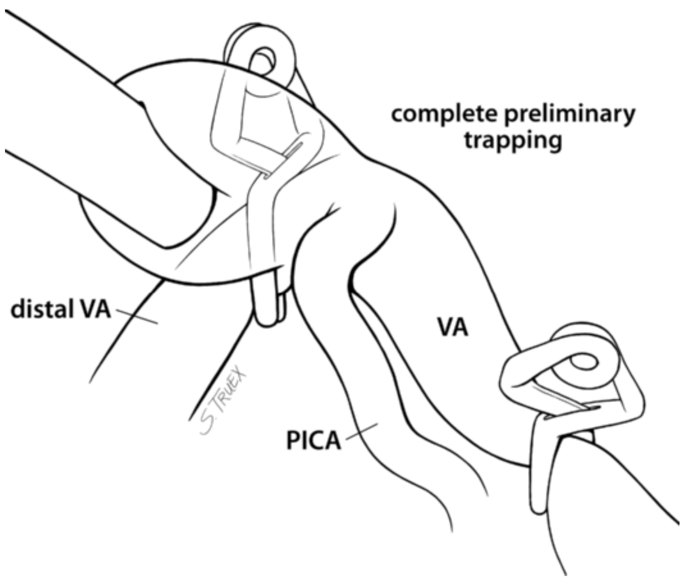


Fig. 9.19 Complete trapping of VA-PICA segment.

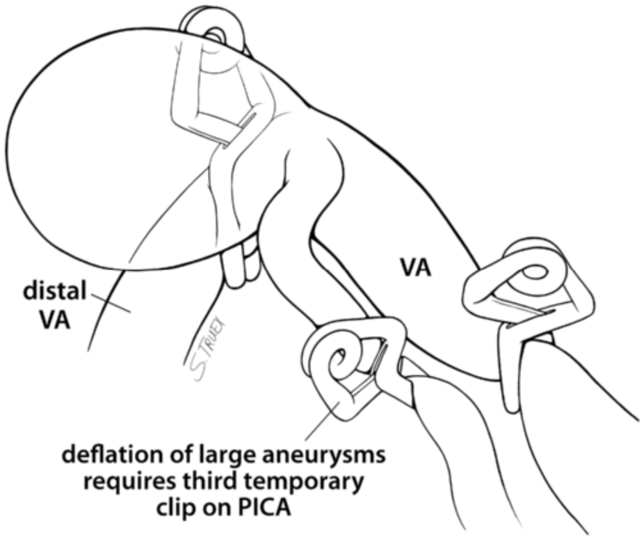


Fig. 9.20 Deflation of large VA-PICA aneurysms.

unsecured. When confronted with this situation, or when the PICA origin cannot be adequately dissected free from the aneurysm neck, an attractive final clip solution is the use of a fenestrated clip with the branch artery placed in the fenestration and the clip blades oriented in parallel with the distal artery (**Fig. 9.21**).

The Unclippable Posterior-Inferior Cerebellar Artery Aneurysm

Occlusion of the PICA proximal to its posterior medullary segment is fraught with risk of brain stem and cerebellar infarction. If the vessel must be sacrificed, there are two reasonable revascularization options, one of which requires significant (as in prior to the skin incision) forethought.

The occipital-PICA bypass usually requires a greater length of donor artery than can be dissected free from the shepherd's crook incision described earlier. If the probable need for this type of reconstruction is considered to be high, an S-shaped incision with preliminary dissection of the occipital artery is preferable, with the artery being freed very proximally from its surrounding soft tissue

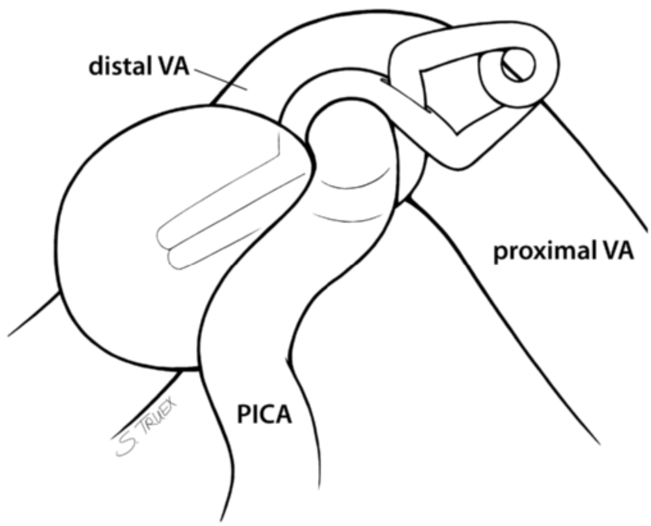


Fig. 9.21 Fenestrated clip strategy for VA-PICA aneurysm.

as the suboccipital musculature is reflected from the bone and retracted inferiorly. If the occipital artery is transected at roughly the level where it pierces the galea, it is generally a good size match for the proximal PICA, with the easiest anastomosis generally being end-to-side in configuration. This reconstruction has proven effective (and patent) in two patients in whom we were unable to avoid PICA occlusion; it has failed in one case.

The second reconstruction option involves a PICA-PICA bypass, usually effected by performing a side-to-side anastomosis joining the two tonsillary segments of the bilateral PICAs within the cisterna magna. Although this procedure theoretically can be done in the lateral position, the amount of brain shift associated with CP angle dissection may make exposure of the contralateral PICA quite difficult unless significant additional bone is removed at the foramen magnum. We personally have never done this procedure for this indication in this position; you're on your own here.

A third option is mentioned only for the sake of completeness; the senior surgeon (DS) has tried without success on two occasions to reimplant a sacrificed PICA into the proximal VA; neither bypass was patent, and one patient developed a permanent and disabling lateral medullary plate syndrome.

Final Thoughts

The far lateral suboccipital exposure is an essential component of every neurosurgeon's operative armamentarium.

1. Every part of this exposure should be done carefully so as to ensure the proximal VA is exposed prior to the aneurysm-bearing segment of artery.
2. Distal control of the VA is difficult but essential to obtain.
3. Regardless of how gentle the dissection of the lower cranial nerves, the surgeon should assume the postoperative patient has an incompetent airway until conclusively proven otherwise.

10

Aneurysms of the Vertebrobasilar Junction

General

There are no more difficult intracranial aneurysms to treat surgically than those that occur at the confluence of the vertebral arteries. These lesions are rare, frequently present with subarachnoid hemorrhage, and often have unique anatomical relationships with the parent artery(ies). Located in the anatomical midline, shrouded by the brain stem and cranial nerves, and only approachable via a deep, narrow, and oblique exposure, they represent a formidable test of the surgeon's skill and good fortune.

Anatomy

Dr. Charles Drake believed "it is likely that a complete, or incomplete, fenestration exists at the origin of all vertebral-basilar junction aneurysms" (**Fig. 10.1**). Certainly all nongiant saccular aneurysms in the senior author's (DS) experience have been associated with such anomalies. In the most fortuitous situation the aneurysm will be found to arise from the proximal carina of the fenestration and to involve only one of the fenestration's two limbs (**Fig. 10.2**). In more complex situations, the aneurysm may appear to engulf one entire limb and involve the other to variable degrees (**Fig. 10.3**); in addition, there may be two separate small aneurysms, each arising from different aspects of the same fenestration, or at least two lobes of a single aneurysm with a broad expansive neck. Recognition of the laterality of origin plays an important role in the selection of appropriate operative approach; we feel the best results are obtained by approaching these lesions from the side of their origin.

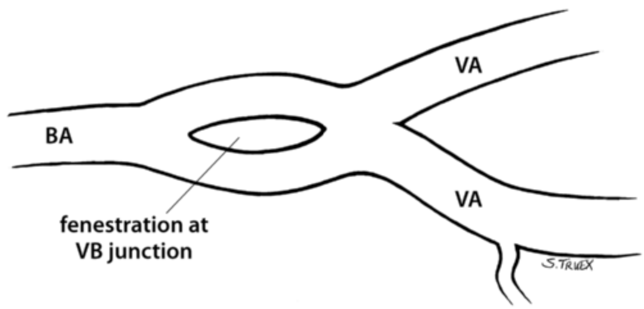


Fig. 10.1 Fenestration of vertebrobasilar junction.

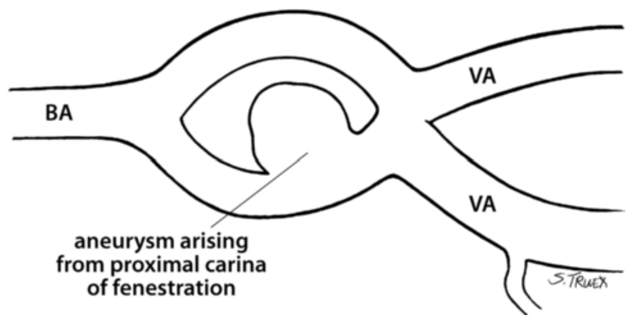


Fig. 10.2 Fenestrated vertebrobasilar junction aneurysm.

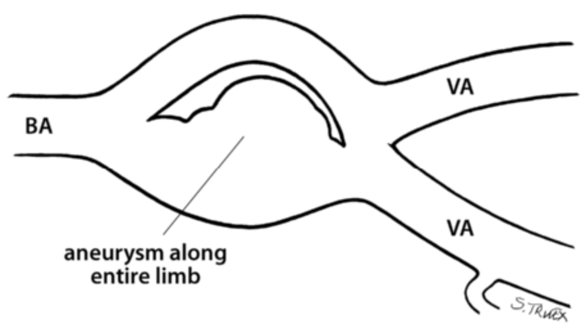


Fig. 10.3 Fenestrated vertebrobasilar junction aneurysm.

Projection

Because these lesions originate at the proximal carina of the fenestration, a portion of their projection will normally be in a superior direction; the critical issue regarding projection relates to the aneurysm's dome orientation in the sagittal plane. This may be posteriorly toward or even into the stem itself, or anteriorly toward the overlying clivus; again, awareness of the orientation of the dome with respect to the axis of the basilar artery is extremely important in design of the operative exposure.

Procedure

Aneurysms of the vertebrobasilar junction are situated near the junction of the proximal and middle thirds of the clivus and are routinely exposed through the cerebellopontine cistern via a far lateral suboccipital craniotomy, as described for aneurysms of the vertebral-posterior-inferior cerebellar artery origin. These patients are operated in the lateral decubitus position, with the neck fully flexed, the vertex tilted slightly toward the floor, and the head held in the true lateral position. The shoulder of the operative side is reflected forward to provide the surgeon an unimpeded vantage point from the lateral foramen magnum up along the petrous ridge through the CP angle.

Craniotomy

A shepherd's crook or hockey stick incision extends superiorly from the mastoid tip to the superior nuchal line, then medially to the midline, and finally inferiorly to the midcervical area. The resultant scalp flap, along with the superficial muscular layer, is reflected laterally, held under tension with fishhook retractors.

The groove between the digastric muscle and the attachment of the sternocleidomastoid muscle is identified, and the lateral mass of C1 is palpated. The attachments of the digastric, the semispinalis, splenius capitus, and both rectus muscles to the subocciput are cut, leaving a healthy cuff for reattachment. The broad muscle flap so formed is reflected inferiorly, and a midline incision in the fascia is made to expose and denude the ring of C1 and spinous process of C2. As the deeper attachments are cut, the flap will be reflected medially away from the mastoid process. Unlike the case of more proximal vertebral aneurysms, it is not necessary to expose and remove the arch of C1, and extracranial dissection of the vertebral artery is not done. The muscle flap is held, reflected inferiorly and medially, by fishhook retractors under tension.

A generous suboccipital craniectomy is performed; the medial aspect of the sigmoid sinus is exposed along with the inferior aspect of the transverse sinus, and the occipital bone is removed almost to midline. The foramen magnum is opened medially and that resection is carried laterally to the level of the condyle, the posterior-medial aspect of which is carefully removed with the drill. The surgeon can expect significant venous bleeding from the bone over the sinuses, the dura itself, and the vertebral plexus between the lamina of C1 and the foramen magnum during the bony exposure, but it's important not to desist until the inferolateral exposure has flattened the condyle sufficiently so that the sigmoid sinus can be seen extradurally passing behind the jugular tubercle.

We open the dura mater in a K-shaped incision, the medial limb of which extends from the transverse sinus inferiorly across the cisterna magna to the lamina of C1. The superior limb of the K extends laterally to the sinodural angle and the inferior limb down to the bony margin of the condylar resection. The two dural flaps are then reflected tight against the lateral margin of the craniectomy defect with stay sutures.

Microsurgical Exposure/Proximal and Distal Control

The microscope is brought to the wound, and once the arachnoid of the cisterna magna has been opened, the tonsillar tip is elevated and the spinal root of cranial nerve (CN) II is identified. This is followed rostrally to the intracranial emergence of the vertebral artery, which in turn is followed to demonstrate the origin of the PICA and the CN XII crossing the vertebral artery. Here the vertebral artery is prepared for temporary clip placement by completely stripping its arachnoid covering immediately distal to the PICA takeoff. The initial millimeters of the PICA are mobilized as well so that the vertebral artery can be elevated against the medulla and the exposure deepened to demonstrate the contralateral vertebral artery.

Prior to approaching the aneurysm, both vertebral arteries should be secured. In some situations this can be accomplished by careful preliminary dissection of the filaments of CN XI, and then by following the inferior aspect of the ipsilateral vertebral artery toward the midline. In other situations, an extensive dissection of all of the lower cranial nerves (CN IX through CN XI) from the brain stem to the jugular foramen is necessary to provide sufficient access across the anterior aspect of the medulla to the contralateral artery.

Once proximal control of both vertebral arteries has been obtained, the basilar artery distal to the aneurysm must be exposed. If the lower cranial nerves have not yet been divested of their arachnoid sheath, that maneuver will be necessary at this time, and it's generally worth the effort to dissect the flocculus away from the underlying nerve roots as well. If a retractor is needed on the cerebellum—and most commonly one is not—it should be placed at the level of the flocculus.

Exposure of the distal basilar can generally be best accomplished above the jugular foramen, in the interval between CN VII/CN VIII and the lower cranial nerves CN IX, X, and XI. Once identified, the basilar artery should be stripped of its arachnoid, gently elevated, and prepared for clip placement at a site unencumbered with perforating arteries. Because the surgeon's view of the artery is very oblique, it's difficult to ensure that a clip will pass completely across the vessel unless the artery has first been lifted free of its attachments to the stem. This maneuver is definitely worth the additional effort because there are few experiences as frustrating as attempting to deflate a large vertebrobasilar junction aneurysm that continues to refill via retrograde flow from an incompletely occluded basilar artery.

Aneurysm Dissection

When dealing with ruptured lesions, an excellent start to the dissection process is the placement of a temporary clip across the contralateral vertebral artery. This will not only soften the aneurysm but will simplify the ultimate temporary trapping, especially if an early aneurysmal rupture occurs. Even if the contralateral vertebral artery is small, early temporary occlusion is beneficial.

For aneurysms with a strong anterior or posterior projection, it's advisable to begin dissection along the ipsilateral aspect of the parent artery and associated neck, working first against the brain stem if the lesion projects toward the clivus, or in the subarachnoid space anteriorly if the fundus projects into the stem. In the rare (and fortuitous) situation when the aneurysm projects directly either anteriorly or posteriorly, the neck itself can be completely defined in this fashion (**Fig. 10.4**). Much more commonly, the lesion will also project superiorly, and this approach may allow the surgeon to actually isolate that segment of the limb from which the aneurysm neck arises. Such exposure will provide an acceptable "trapping" option if the contralateral limb is of sufficient size to adequately perfuse the basilar artery. Unfortunately, quite frequently the aneurysm's neck will involve a portion of both limbs at the proximal carina of the fenestration, obviating the possibility of easily trapping the lesion. When the ipsilateral limb of the fenestration and distal aspect of the neck have been defined and the surgeon acknowledges

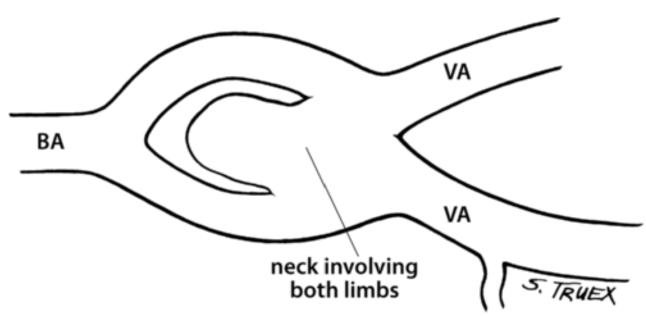


Fig. 10.4 Fenestrated vertebrobasilar junction aneurysm.

that the proximal aspect of the neck which lies in the fenestration itself must be dissected, the patient should be placed in a burst-suppression coma and the remaining vertebral artery occluded with a second temporary clip. Visualization of the remaining proximal (or medial) neck is very difficult because of the surgeon's angle of approach; thus it's generally necessary to compress the fundus to identify the seam between the aneurysm and normal artery (the contralateral limb of the fenestration), a maneuver made much easier and safer if the lesion is slack.

In almost all aneurysms of significant size, the best visualization will be obtained by temporarily trapping the vertebrobasilar junction at the previously mentioned sites, then deflating the lesion to aid in both exposure of the medial aspect of the neck and the placement of permanent clips. A reasonable method to evacuate the aneurysm is to puncture the previously dissected normal limb with a 26-gauge spinal needle and aspirate if necessary (**Fig. 10.5**). There is little chance the needle will injure the normal vessel, and hemostasis is very simple once temporary occlusion has been reversed, neither of which is true if the aneurysm sac itself is perforated.

With the aneurysm-bearing segment deflated, the surgeon should now be capable of either looking across the anterior aspect of the aneurysm and fenestration or of elevating the vertebrobasilar junction away from the pons sufficiently to identify the origin of the aneurysm's neck, its relationship to both limbs of the fenestration, and the contralateral limb of the fenestration itself (**Fig. 10.6**).

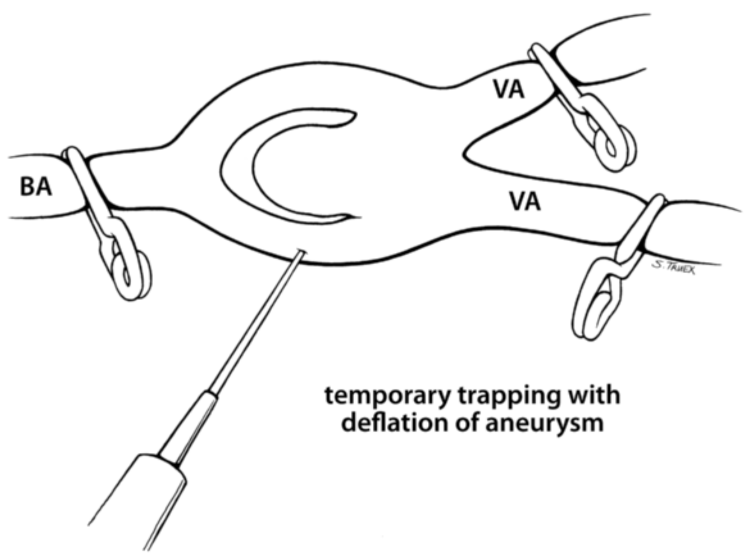


Fig. 10.5 Complete trapping of vertebrobasilar aneurysm.

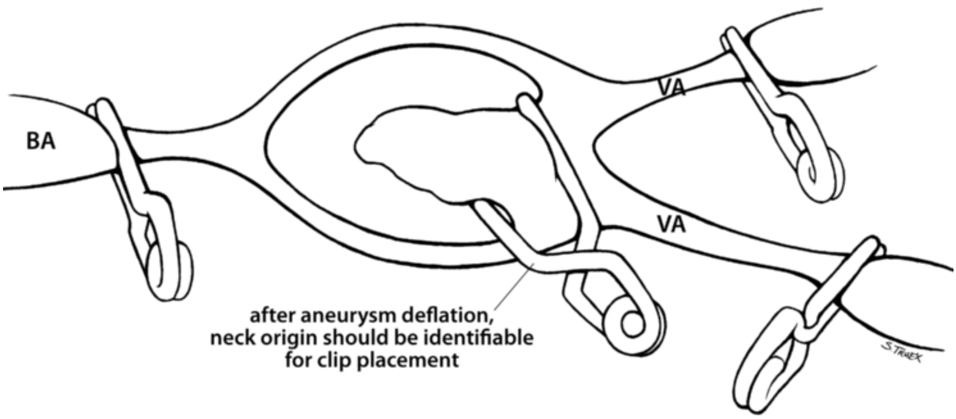


Fig. 10.6 Clip application after deflation of vertebrobasilar aneurysm.

Based on the specific anatomy, there are three potential options for aneurysm closure. The first is definitive clip ligation of the aneurysm neck alone, sparing both limbs of the fenestration (**Fig. 10.7**). The second involves the application of small fenestrated clips, spanning the ipsilateral limb with the fenestrations and occluding the neck with the short blades. The third option is a careful sacrifice of the aneurysm-bearing limb between two trapping clips (**Fig. 10.8**).

Even with the aneurysm deflated, conclusive identification and dissection of the medial neck may be problematic because of the oblique angle; placement of a curved clip that embraces only the aneurysm itself, and extends sufficiently deep within the fenestration so as to completely occlude the neck, will be even more difficult. In our hands this technique has only been successful when applied to relatively small aneurysms that project anteriorly.

The fenestrated clip option is theoretically very attractive; the surgeon should be capable of seeing both the ventral and the dorsal aspects of the deflated aneurysm and ipsilateral limb, meaning the somewhat cumbersome clips can be placed with accuracy, sparing the normal aspect of the artery while the blades close medially on the aneurysm neck and fundus. The problems we've encountered with this construct have related to difficulty with keeping the distal aspect of the blades free from the contralateral limb while ensuring that the somewhat oval aperture of the clip does not allow significant portions of the neck to remain patent. This clip construct seems to work best with larger aneurysms, larger arterial fenestrations, and more expansive necks. However inventive, these clips are much less delicate than the more standard shapes and as a result are awkward to apply with certainty in this very narrow corridor.

The best anatomical option in our experience has been the intentional sacrifice of the aneurysm-bearing limb of the fenestration. Once the entire complex has been deflated, frequently by lifting the ipsilateral limb into the subarachnoid space away from the pons, the surgeon will identify the proximal extent

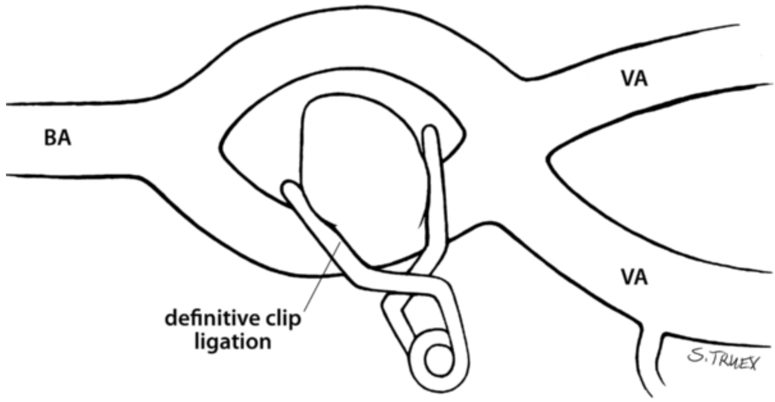


Fig. 10.7 Fenestrated vertebrobasilar junction aneurysm clip application strategy.

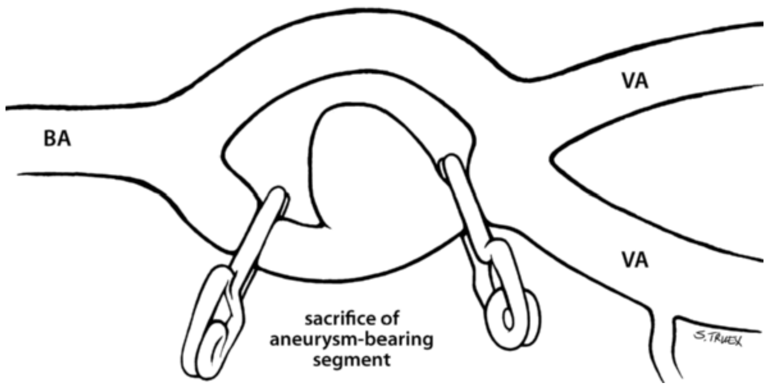


Fig. 10.8 Fenestrated vertebrobasilar junction aneurysm clip application strategy.

of the neck along the contralateral limb. With a small curved clip, that portion of the neck (and the ipsilateral limb) can be closed under direct visualization, while ensuring the clip does not impinge on the lumen of the contralateral limb. The distal aspect of the ipsilateral limb can then be occluded easily with a second distal clip.

The most difficult of all aneurysms at this location are those bilobed lesions that project both anteriorly and posteriorly, making visualization of the medial aspect of the aneurysm impossible without completely deflating both aspects of the aneurysmal sac (**Fig. 10.9**). A theoretical solution to this anatomical variant is to treat the lesion as if it were two aneurysms, one projecting anteriorly, the other posteriorly. Again unfortunately, it is very difficult to effectively clip either lobe in this fashion because, at best, a major portion of the neck and inevitably some portion of the fundus, which lies within the fenestration, will

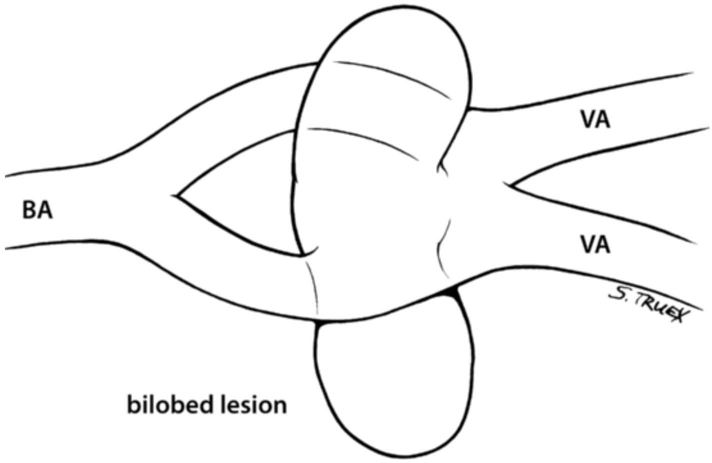


Fig. 10.9 Complex fenestrated vertebrobasilar junction aneurysm.

escape the tangentially applied clip blades (**Fig. 10.10**). More frequently, that portion of the lesion which projects ahead or behind the basilar axis will simply slip out of the clip blades, sometimes with catastrophic results. A trapping solution, such as the one outlined earlier, has been the only practical option we've identified in this situation (**Fig. 10.11**).

Despite the surgeon's best efforts, it is very difficult to be certain that the contralateral limb of the fenestration remains patent following this type of trapping procedure. Visualization after clip placement is completely inadequate and Doppler insonation is very difficult to interpret in the presence of any antegrade or retrograde flow. We would strongly recommend immediate intraoperative angiography in this or similar situations.

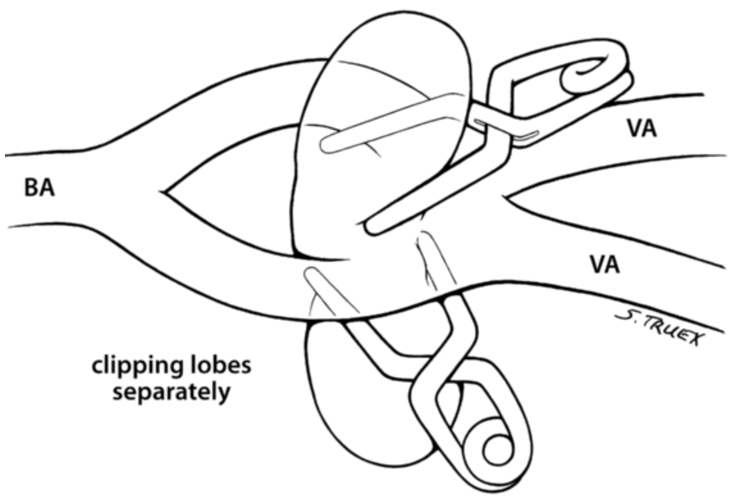


Fig. 10.10 Fenestrated vertebrobasilar junction aneurysm clip application strategy.

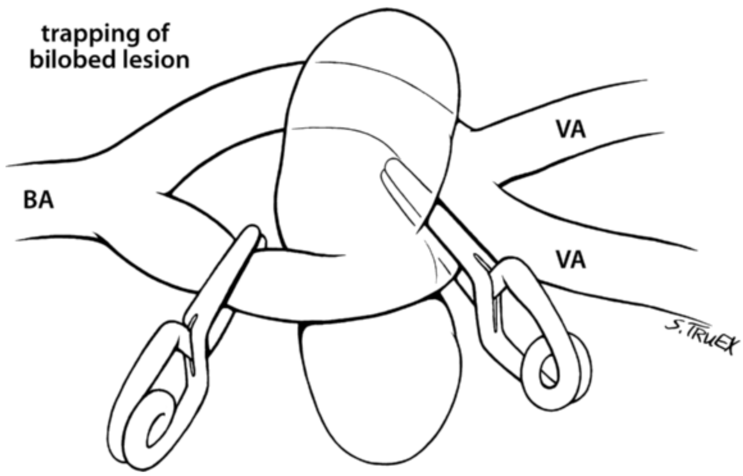


Fig. 10.11 Fenestrated vertebrobasilar junction aneurysm clip application strategy.

Final Thoughts

1. Know the anatomy of the collateral circulation: in the presence of large posterior communicating arteries, proximal occlusion of the very distal aspects of both vertebral arteries is a realistic fallback position.
2. Atraumatic exposure of the vertebrobasilar junction when the CP angle and prepontine cisterns are filled with fresh clot and the brain stem is swollen from a recent hemorrhage is extremely difficult.
3. Maximize the bony exposure by completely unroofing the sigmoid sinus and resecting a portion of the occipital condyle. Every millimeter counts when the bottom of your approach lies anterior to the brain stem in the midline.

11

Aneurysms of the Proximal Basilar Artery

General

These aneurysms are infrequently encountered, even in a busy cerebrovascular practice, and represent the rarest aneurysm location dealt with in this book. Because of their rarity and their relative ease of endovascular access, increasingly they are initially referred for endovascular management, with direct surgery being reserved for the small number failing this approach. Furthermore, their location is not one routinely visited by neurosurgeons in the treatment of other disease processes, making anatomical unfamiliarity an additional deterrent to their surgical management.

Anatomy

Aneurysms of the basilar artery at the origin of its anterior inferior cerebellar branch generally lie in the anatomical midline near the junction of the middle and inferior thirds of the clivus (**Fig. 11.1**). Depending on the anatomical vagaries of the parent vessel, they have been reported to arise as low as the basion and as distally as the tentorial incisura, making an exact understanding of the location of the lesion in question perhaps the most critical single issue in consideration of their treatment. The most consistent neuroanatomical localizer for the anterior-inferior cerebellar artery (AICA) origin is the sixth cranial nerve, which—reliably—lies slightly inferior and lateral to the AICA's emergence from the parent artery. These lesions share with aneurysms of the posterior-inferior cerebellar artery (PICA) and the superior cerebellar artery (SCA) the propensity for involving a portion of the branch artery in their neck; coupled with the small size of the AICA, this may make effective clip placement difficult without endangering the patency of the AICA.

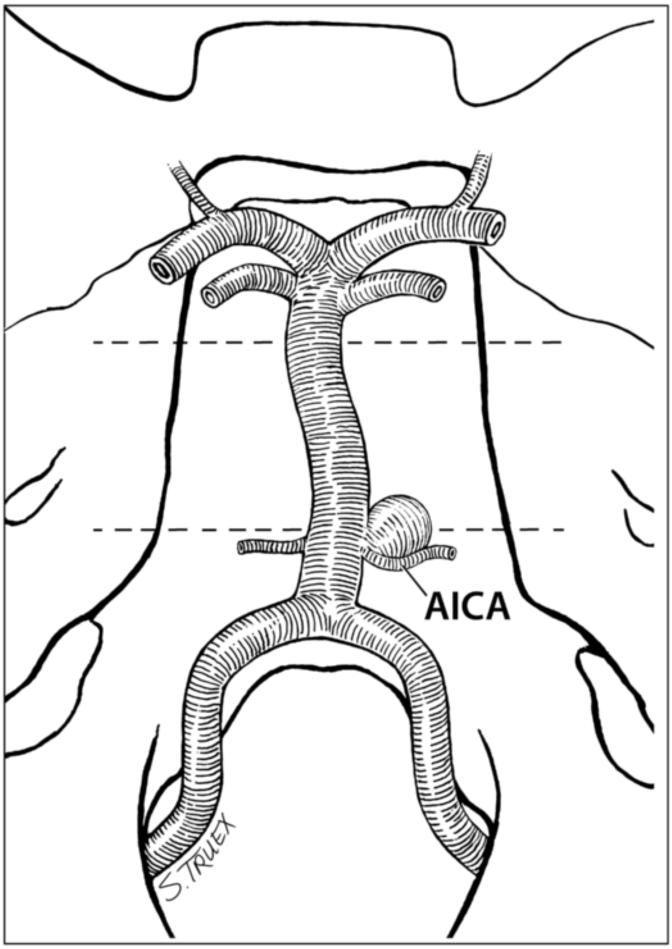


Fig. 11.1 Anatomical configuration of the basilar artery.

Projection

Fortuitously, almost all of these aneurysms in our experience have projected laterally or anterolaterally, although in Drake's far larger series a significant minority projected either directly anteriorly or posteriorly into the underlying brain stem (**Fig. 11.2**). The most common projection routinely brings the dome of the lesion into close proximity with the sixth nerve, which not infrequently (especially following subarachnoid hemorrhage) is tightly bound to the fundus by a tenacious layer of dense arachnoid.

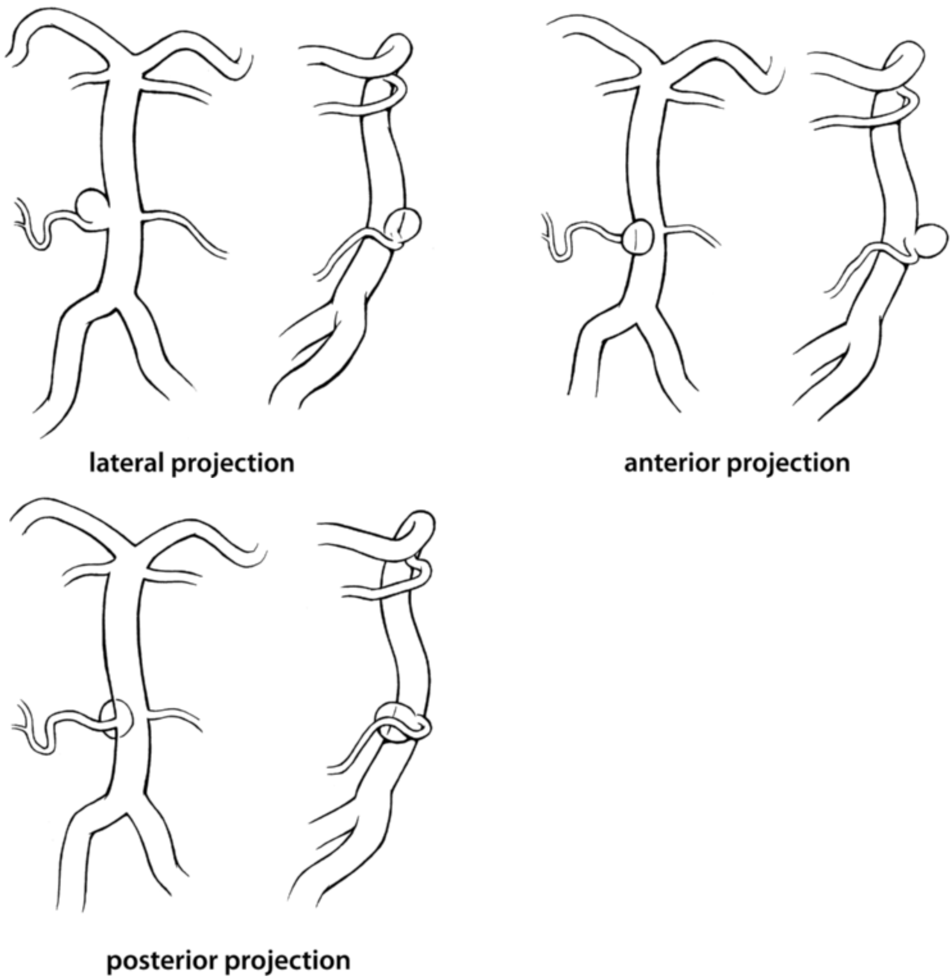


Fig. 11.2 Projections of proximal basilar artery aneurysms.

Surgical Approaches

Historically, these lesions have been approached from almost every imaginable route of access, including transoral transclival exposures; this persistent variety is a testimony to the difficulties associated with their safe, atraumatic exposure and to the ongoing absence of a single optimal operative approach. As already mentioned, a critical issue is the exact location of the lesion under consideration, with aneurysms located very distally being relatively easily exposed by either a presigmoid transtentorial approach or, less commonly, a subtemporal transtentorial route as described by Drake. The low-lying aneurysms, which lie along the inferior third of the clivus, can be easily approached via the far lateral, transcondylar exposure popularized by Heros and described in Chapter 9 dealing with aneurysms of the PICA origin.

Unfortunately, the most common location of AICA aneurysms in our personal experience has been in the relative “no man’s land” at the extremes of these two exposures (**Fig. 11.3**). There is just no easy way to get there, and given that fact, we have been most satisfied with pushing the superior limits of the far lateral exposure as opposed to working inferiorly through a presigmoid approach. The benefits of this choice, which may be purely speculative, include a broader superficial exposure (making easier access for two instruments), earlier proximal control, avoidance of early exposure of the aneurysm dome (we always approach from the side of the lesion), and what seems to be more latitude in the potential directions of clip application. The recognized negatives of this choice involve a greater operative depth, a more oblique approach, greater necessity to manipulate cranial nerves VII and VIII, as well as greater possibility of postoperative lower cranial nerve palsies and more difficult access to distal basilar control.

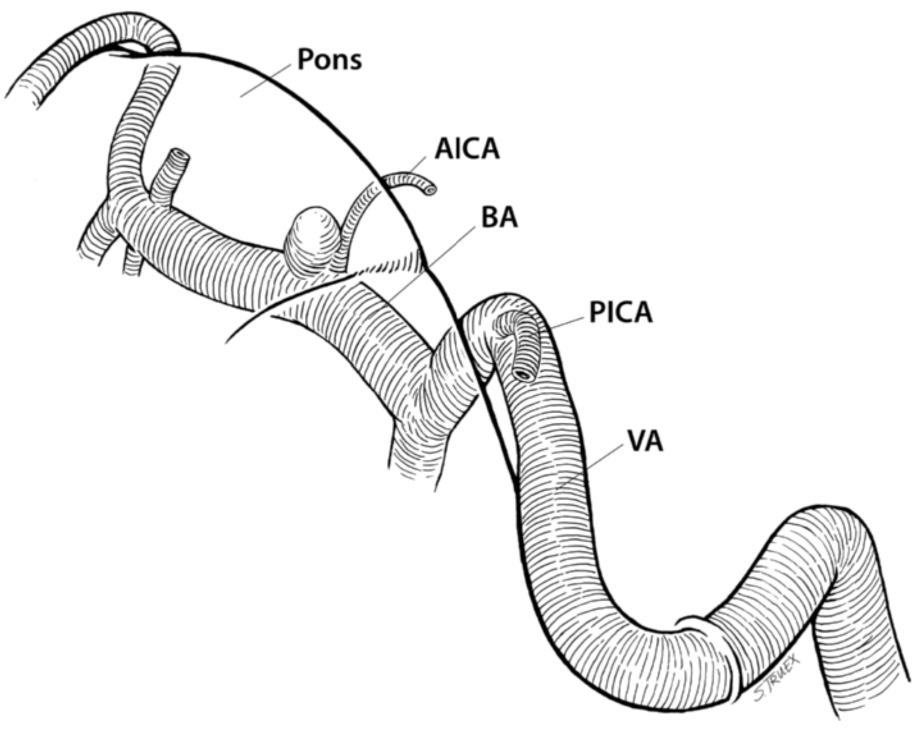


Fig. 11.3 Relation of proximal basilar artery aneurysms to brainstem.

Craniotomy

The routine far lateral suboccipital approach described earlier is used, and despite the height of the target aneurysm, a hemilaminectomy of C1 is done, and the foramen magnum is opened widely. These two components of the exposure minimize the degree of cerebellar retraction and of lower cranial nerve manipulation and facilitate both early demonstration of both vertebral arteries and later dissection through the veil of arachnoid covering cranial nerves VII through XI.

Dissection

The major hindrance in the dissection process is the interposition of the lower cranial nerves (VII–XI) between the surgeon and the proximal basilar artery (**Fig. 11.4**). While the use of a wide entry port through the CP angle permits the introduction of two instruments, it's essentially impossible to employ them

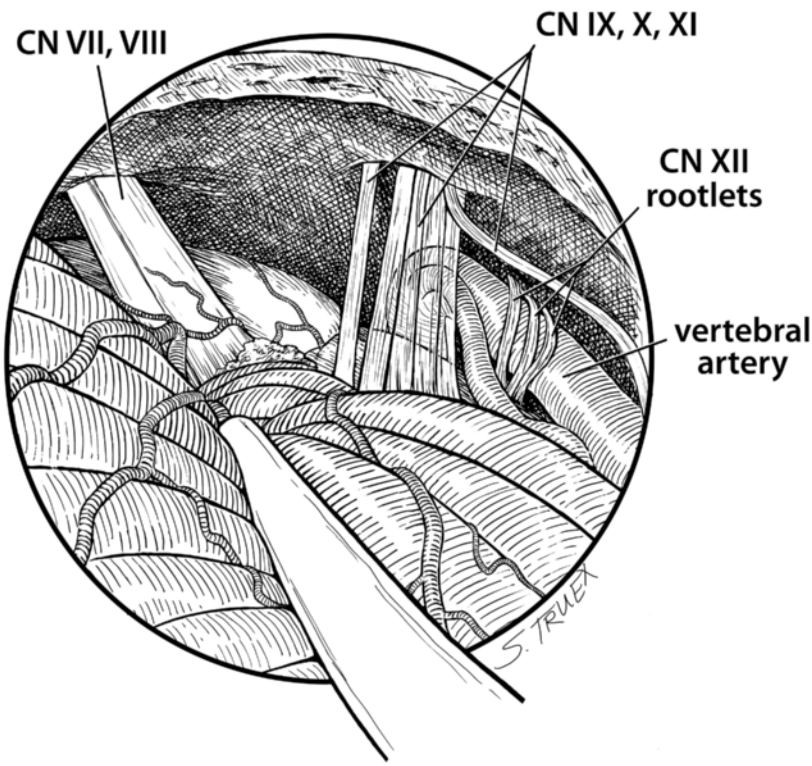


Fig. 11.4 Close relationship of cranial nerves to proximal basilar artery.

both simultaneously, either below CN IX to XI, between VII and VIII and the lower cranial nerve bundle, or between CN V above and CN VII to VIII below. This is a problem described in the chapter dealing with aneurysms of the basilar apex (Chapter 12), when the optimal placement of the operator's instruments sometimes involves simultaneous use of both the corridor between the optic nerve and carotid artery and the corridor posterior to the carotid and anterior to the third nerve (see page 177).

However, when dealing with AICA aneurysms, this two-corridor approach is the rule rather than the exception, mandating that all of the involved cranial nerves be stripped of their arachnoid sheaths prior to beginning dissection of the basilar artery (**Fig. 11.5**). Generally, when using the far lateral approach, the surgeon will find the inferior instrument initially placed below CN IX to XI and the superior instrument between these nerves and CN VII and VIII. As the dissection progresses distally it almost always is necessary to shift the rostral hand into the gap between CN V and CN VII and VIII and to bring the caudal instrument above the jugular foramen (**Fig. 11.6**).

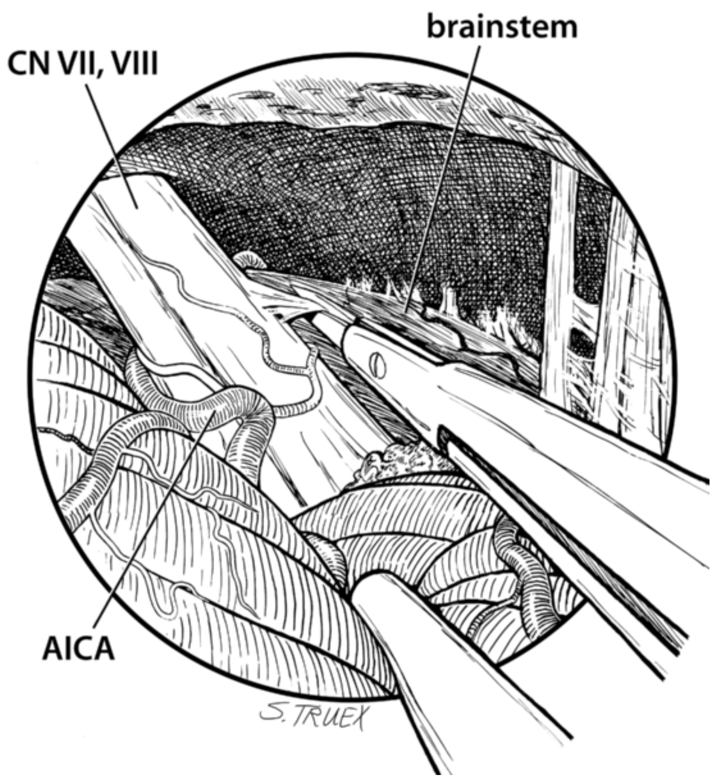


Fig. 11.5 Dissection of cranial nerves before basilar artery dissection.

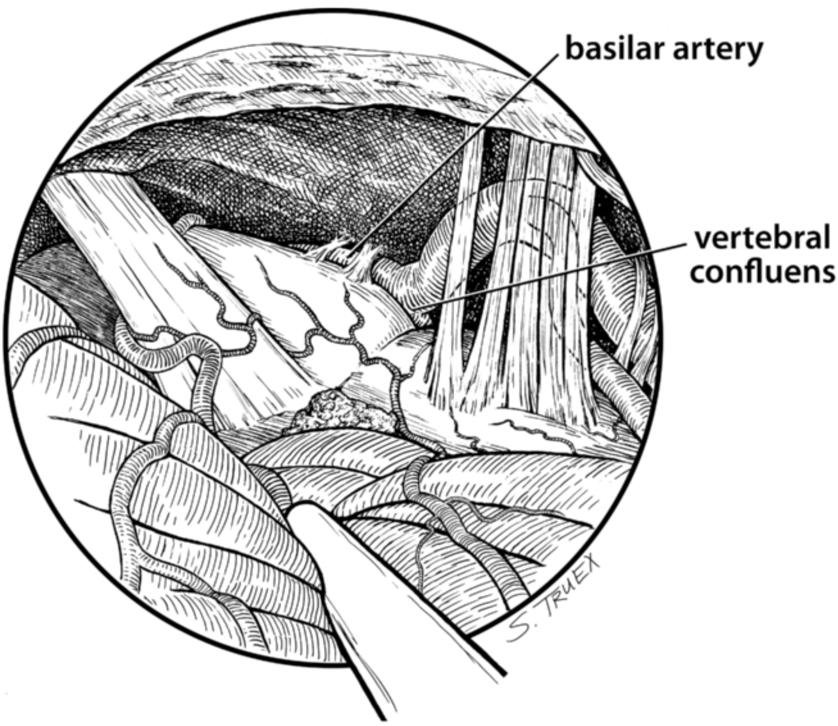


Fig. 11.6 Exposure of the proximal basilar artery.

Obviously, these placements mean the surgeon must exercise extraordinary care in both the introduction and the withdrawal of the instruments; additionally, although retraction of the nerves is always necessary, it must be done as carefully as possible. Cranial nerve monitoring is helpful in providing a continuous reminder that the nerves are under stress.

Once the cerebellopontine cistern has been opened and evacuated, the ipsilateral vertebral artery is identified and then followed distally to the vertebral confluens, which is then dissected and prepared for temporary clip placement (**Fig. 11.7**). If the aneurysm's origin is in very close proximity to the confluens, both distal vertebral arteries are available for temporary occlusion, providing adequate room for the dissection to follow.

The lateral aspect of the basilar origin is then identified and followed rostrally, with careful dissection of the arachnoid layer that binds the artery to the pons. The goal is to arrive at the inferior aspect of the very proximal AICA from a trajectory as parallel to that of the basilar as is possible. Although it may be simpler to first identify the AICA near the porus acousticus, then follow the artery retrograde to its origin, in the case of subarachnoid hemorrhage this approach will generally lead the surgeon into a morass of clot, sixth cranial nerve, and arachnoidal scar that must be dissected to expose the parent vessel and underlying aneurysm (**Fig. 11.7**).

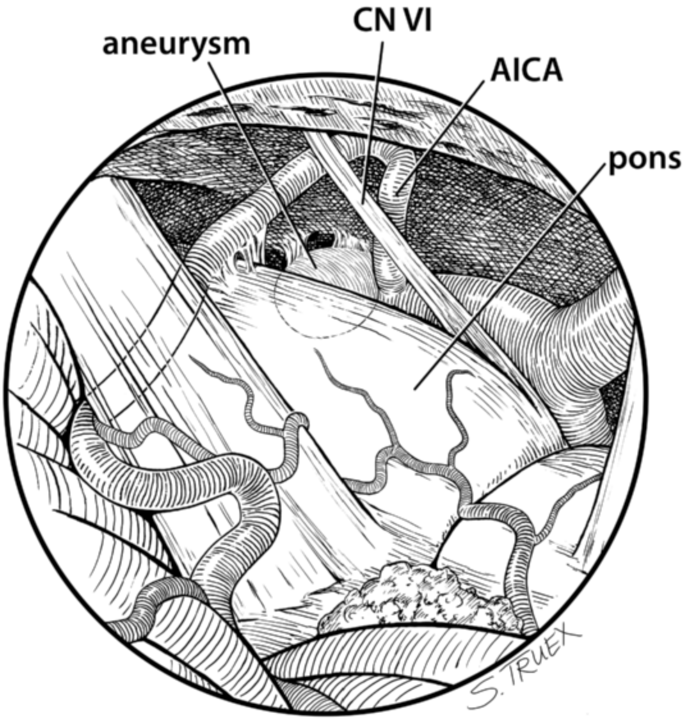


Fig. 11.7 Exposure of proximal basilar artery aneurysm.

With the inferior aspect of the AICA identified, the remainder of the dissection is done under temporary proximal occlusion of the basilar artery, unless the anatomy of both the AICA and aneurysm is completely clear (**Fig. 11.8**). Assuming it is not, and the aneurysm projects laterally, the arachnoid overlying the basilar artery anteriorly is opened, the aneurysm gently compressed into the brain stem, and the basilar artery distal to the aneurysm's neck dissected to provide distal control (**Fig. 11.9**). If the aneurysm projects anteriorly, the basilar exposure proceeds along the artery's lateral aspect in a similar fashion (**Fig. 11.10**).

Clip Placement

The depth of the final exposure and the narrow aperture through which the surgeon sees the aneurysm and AICA origin severely limit clip selection to straight (including bayonet) and slightly curved blades. Although the majority of the aneurysms seem to have relatively small necks, as mentioned earlier they often incorporate the initial millimeters of the emerging AICA. This, coupled with the inferior-to-superior trajectory offered by the far lateral approach, makes the use of a fenestrated clip (AICA in the fenestration) a potentially attractive option, once CN VI has been peeled free of the lesion. The drawback to this specific

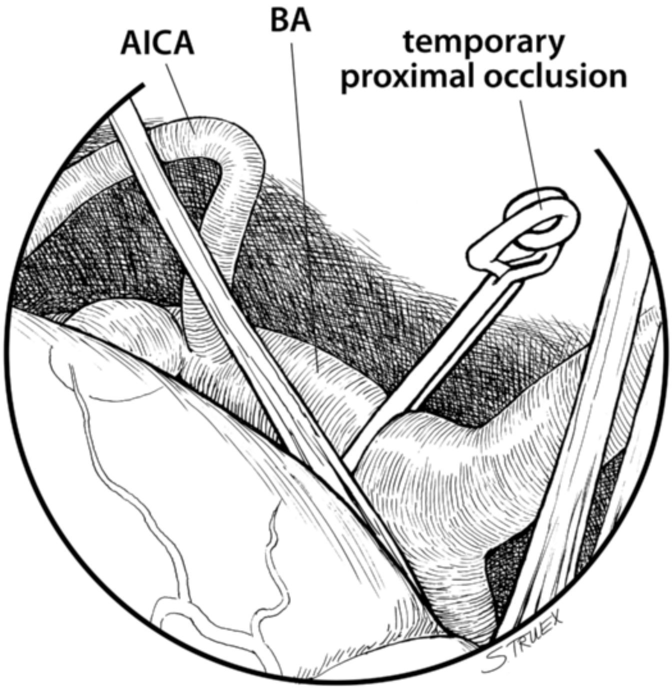


Fig. 11.8 Temporary occlusion of proximal basilar artery.

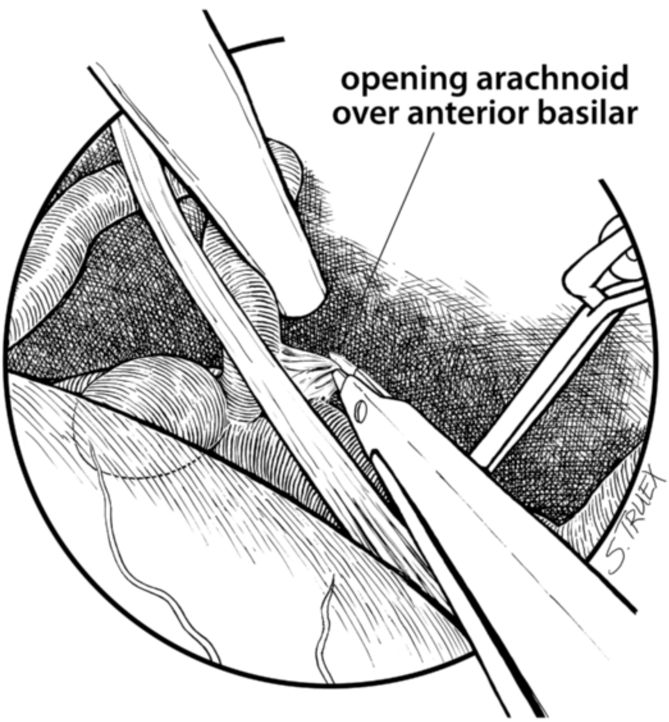


Fig. 11.9 Dissection of anterior basilar artery.

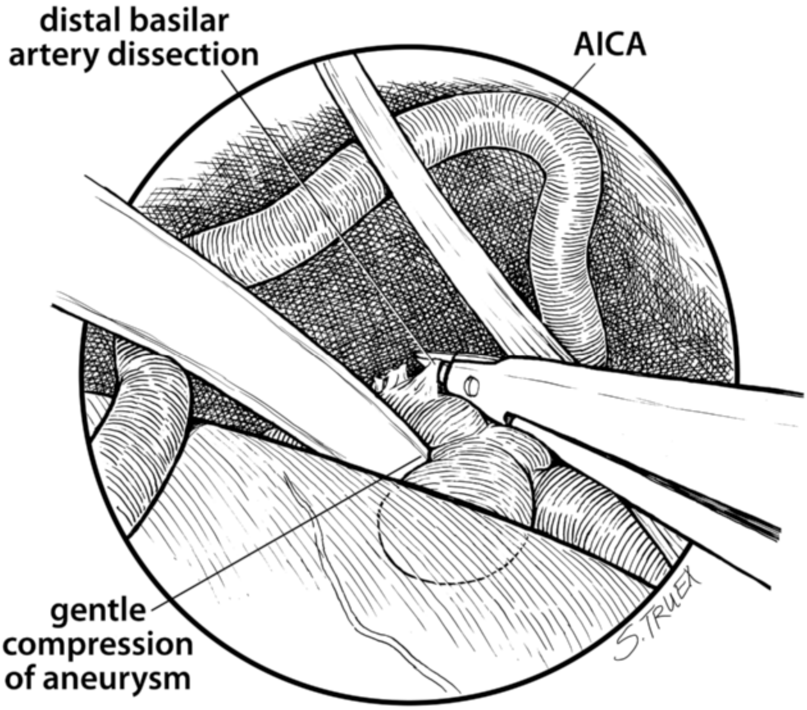


Fig. 11.10 Dissection of lateral basilar artery.

clip selection is that, once in the wound, the jaws of the clip applier will often completely obscure the clip, the AICA origin, and the aneurysm itself. In most situations we've found the best solution is to dissect the AICA distally, freeing it from its arachnoid attachments to the pons, which will then permit the surgeon to return to the proximal artery just distal to the aneurysm and displace it inferiorly, just enough to apply a bayonet clip to the neck (**Fig. 11.11**).

Despite the relatively small size of most of these aneurysms, we strongly encourage the use of long-bladed clips in their treatment. These models obviate the need to put a bulky clip applier into these small, dark exposures, and they generally can be manipulated—along with manipulation of the AICA—to provide adequate obliteration of the aneurysm neck.

Once the clip has been applied, the anatomy becomes even more obscure, making it difficult for the surgeon to determine whether the aneurysm is adequately clipped and the AICA remains patent. Neither ICG angiography nor Doppler insonation is reliable in determining the former: we've had several cases in which both modalities suggested the aneurysm was occluded, only to be disproven by the insertion of a 26-gauge spinal needle. So, if there's enough fundus left to needle and if the clip application could potentially be improved, we'd recommend that the dome be punctured while the basilar is

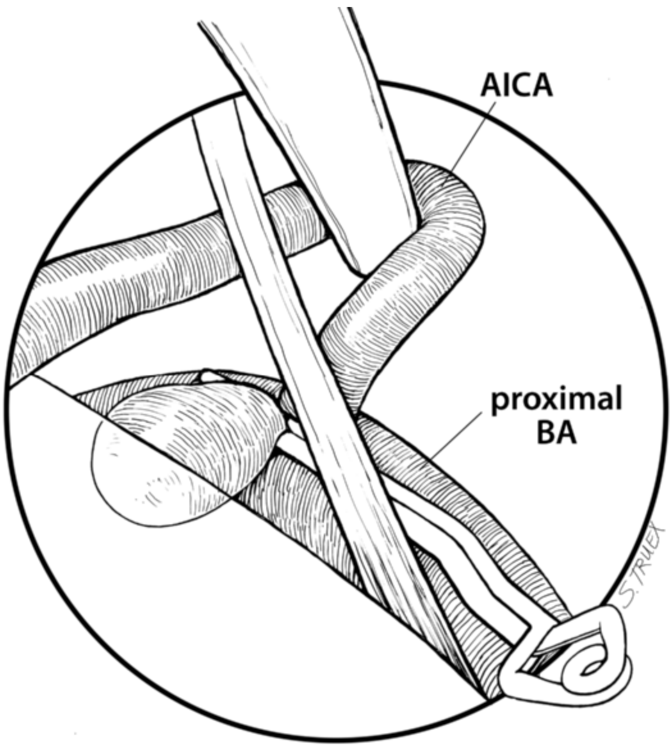


Fig. 11.11 Aneurysm clip application strategy for AICA aneurysm.

still occluded, and the appropriate measures taken if the neck remains patent. If the fundus cannot be visualized or if this is the one and only possible clip position, we'd leave well enough alone and opt for either intraop or immediate postop angiography.

The continued patency of the AICA after clip application of the aneurysm is a somewhat different issue. Interpretation of the Doppler signals may be difficult, but the indocyanine green (ICG) angiogram is very reliable—if the artery fails to fill promptly, odds are good that the clip occludes it. Unless the aneurysm has sheared away from its origin during dissection or clip application, it is always worthwhile to reposition the clip in an attempt to restore AICA patency. Many times the surgeon will be successful in reopening the AICA while maintaining occlusion of the aneurysm, but, unfortunately, this is not always possible. In these situations, especially when dealing with a ruptured aneurysm, the surgeon must decide whether to settle for a less efficacious treatment of the lesion (such as muslin wrapping) or to sacrifice the origin of the AICA to definitively and permanently occlude the aneurysm. There is no uniformly correct answer to this dilemma; however, we have knowingly taken the AICA origin several times, each without neurological consequence: additionally, we've seen the AICA inadvertently and irreversibly occluded on several occasions during endovascular treatment of AICA aneurysms, and none of these patients has suffered a brain stem infarction. We do not imply that ligation of the AICA at its origin is a primary treatment option in the management of these lesions, but we do recognize that sometimes anatomical reconstruction is simply not possible, and our experience suggests that the uncertain risk of AICA occlusion may be preferable to aneurysmal rebleeding.

Distal Anterior-Inferior Cerebellar Artery Aneurysms

The most common site of these aneurysms is at the origin of the auditory artery at or near the porus acousticus (**Fig. 11.12**). Every one we've encountered, except those associated with cerebellar arteriovenous malformations (AVMs), has presented with hemorrhage and none has been amenable to endovascular treatment. A routine far lateral suboccipital approach has been adequate in

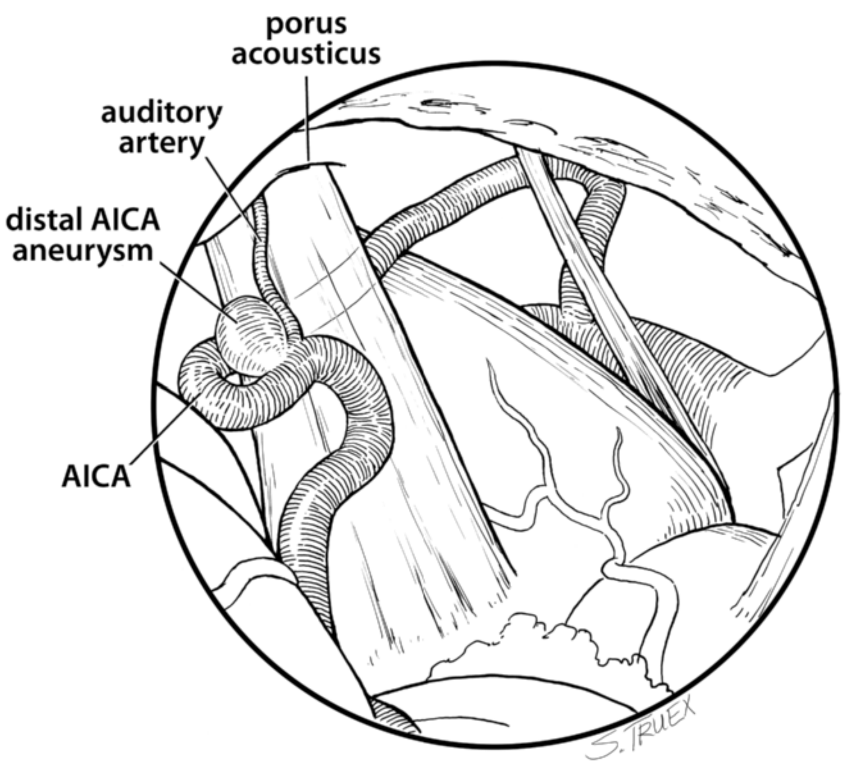


Fig. 11.12 Common location of distal AICA aneurysms.

each case, and the key step has been to achieve proximal control prior to disentangling the aneurysmal segment of artery from the CN VII–VIII complex. These aneurysms seem to be disproportionately large when compared with the size of the parent artery, making definitive obliteration of the aneurysm sac while preserving flow in the distal vessels difficult but not impossible. Cranial nerve dysfunction after treatment has been generally transient; we have no patient with permanent CN VII weakness, although a small number definitely have reduced auditory function unilaterally.

Final Thoughts

1. AICA aneurysms are uncommon lesions that occur in an anatomical location infrequently visited by most neurosurgeons.
2. Exact determination of the specific aneurysm's anatomical locus as related to the skull base and brain stem is critical in the selection of an appropriate surgical exposure.
3. The key to exposure of these aneurysms lies in the appropriate use of the individual subarachnoid corridors between cranial nerves V, VII to VIII, and IX to XI.
4. The constant neuroanatomical localizer for these aneurysms is CN VI.
5. The depth and narrowness of the ultimate exposure necessitate the use of long, fine instruments and generally of long-bladed clips.
6. Because of the problems with visualization, intraoperative or postoperative angiography or both are especially useful.

12

Aneurysms of the Basilar Apex

General

Despite being the most common aneurysm of the posterior circulation, these lesions are distinctly uncommon in the general patient population, a rarity that means relatively few surgeons will develop a large-volume basilar aneurysm experience, especially in the early years of their practice. Furthermore, because the morbidity and mortality associated with the surgical treatment of these lesions are undisputedly high, they are increasingly referred for endovascular treatment as the initial option, which further reduces the volume of surgical experience and ultimately the availability of surgical expertise.

Due to this relative paucity of surgical volume, rather than experiment with a broad variety of approaches, as one might do with aneurysms in "easier," more common locations, basilar apex aneurysm surgeons typically select a single operative approach that fulfills their needs on most occasions, and they subsequently develop minor modifications to more or less meet the exigencies of special situations. As a result, the literature is replete with numerically small surgical series compiled by individual surgeons who document excellent clinical outcomes, each dedicated to one of a variety of the recognized operative approaches. These generally range from subfrontal through transsylvian and pretemporal to subtemporal, and are often further distinguished as orbitozygomatic, transzygomatic, extreme lateral, transcavernous, and transtentorial.

A natural but unfortunate end product of this surgical selection process is the evangelical advocacy of one subspecies of "customized" operative approach, usually by the "customizer" himself. Although individual enthusiasm for personal innovation is understandable, the broad range of exposures currently in use by excellent technical surgeons is practical proof that there is no single "best" way to manage aneurysms located at the apex of the basilar artery.

Young aneurysm surgeons should acknowledge this fact of life, focus their efforts on becoming facile with one standard operative approach to the extent that they recognize its limitations and are cognizant of modifications that will extend its application. For the purposes of this chapter, that standard exposure is the routine “pterional” or frontotemporal, transsylvian exposure.

Rationale for Use of the Transsylvian Approach

The initial, and by far the largest, successful surgical series detailing treatment of these aneurysms was that of Dr. Charles Drake, who employed the subtemporal exposure almost exclusively. Although the results of Dr. Drake’s extensive personal experience remain awe inspiring, most cerebrovascular surgeons were unable to even approach his level of success using this exposure, in part due to Drake’s own technical expertise and in part due to the unfamiliarity of the approach.

With the popularization of microsurgical techniques, the transsylvian exposure rapidly became the most frequently used operative approach to all common aneurysms of the anterior circulation, and very quickly Professor M. G. Yasargil pioneered its extension to lesions of the distal basilar artery during his revolutionary surgical experience at the University of Zurich. Yasargil noted that the basilar apex lay only some 12 to 15 mm deep to the carotid cistern, and that in most situations wide opening of the interpeduncular cistern provided excellent access to the distal basilar artery and the origins of both the superior cerebellar arteries and the posterior cerebral arteries.

An additional advantage of this operative exposure proved to be its unparalleled simultaneous visualization of all four terminal branches of the basilar artery; the corresponding drawback of this approach is the surgeon’s inability to view the dorsal aspect of the basilar bifurcation, and the critically important perforating arteries located there, without first mobilizing aneurysms arising from the basilar bifurcation. Refinement of Yasargil’s original approach has reduced, but not eliminated, this drawback.

Positioning

Laterality

Because the basilar apex generally lies in the midsagittal plane, it can usually be adequately exposed from either side. Most right-handed surgeons, when operating on right-handed patients, choose to employ a right frontotemporal approach through the right sylvian fissure. Even some outstanding left-handed surgeons prefer right-sided approaches when operating on left-dominant individuals because of the lower neurological morbidity associated with manipulation of the nondominant brain and its blood supply.

This right transsylvian exposure allows the surgeon to retract the internal carotid artery anteriorly with the nondominant or "sucker" hand while displacing the temporal tip posteriorly with a self-retaining retractor. This means the surgeon's dominant hand is free for dissection, and that only intermittent retraction/stenosis/occlusion of the carotid artery occurs.

When using a left-sided approach, the surgeon's dominant hand must simultaneously retract the carotid and manipulate the dissecting instruments, a combination that is somewhat more cumbersome and usually provides less adequate visualization than that provided by the contralateral approach. Some surgeons advocate using a self-retaining retractor blade routinely to displace the internal carotid artery (on either side), and on rare occasions we've found this maneuver necessary to obtain adequate visualization; however, if this can be avoided, the risk of inadvertent middle cerebral artery (MCA) ischemia or iatrogenic carotid injury is definitely reduced. Left-sided exposures are indicated when the basilar apex is displaced to the left, when the presence of multiple aneurysms dictates a left-sided approach, when some unique feature of the anatomy (arachnoid cyst) or of the collateral circulation (fetal posterior cerebral artery on the right, small posterior communicating artery [PCOMM] on the left) suggest a left-sided approach to be preferable, or in the presence of a left third cranial nerve palsy.

Rotation, Extension, and Tilt

If the head is rotated 45 to 50 degrees around the long axis of the body, the sphenoid ridge and underlying sylvian fissure will be approximately perpendicular to the horizontal meridian (floor, ceiling, horizon, etc.). This orientation will equalize retraction on the frontal and temporal lobes and maximize the light transmitted to the depths of the exposure. Less rotation (30 degrees) superimposes the optic nerve and carotid artery directly above the basilar apex, necessitating more retraction on these structures or mandating an approach between the nerve and artery; a degree of rotation greater than 50 degrees closes the sylvian fissure by bringing the temporal lobe anteriorly and transforms the oblique view of the distal basilar complex into a more lateral orientation, making visualization of the contralateral P1 segment more difficult.

Once the head is appropriately rotated, the neck should be extended so as to drop the vertex of the skull, elevating the maxillary eminence above the level of the orbital rim. This step is critical to maximizing the beneficial effects of gravity on the frontal and temporal lobes and minimizing the degree of brain retraction necessary to expose the interpeduncular cistern.

From this position, the nonoperative ear should be tilted slightly toward the ipsilateral shoulder, which will have the effect of bringing the floor of the frontal fossa perpendicular to the body's long axis. This, in turn, will permit the surgeon to remain in the patient's sagittal plane throughout the procedure, avoiding the necessity to orient toward the operative shoulder, which further complicates instrument exchanges with the scrub nurse and makes it very difficult for the assistant to access the wound if necessary.

Skin/Muscle Incision

This procedure can be done through any of several scalp incisions designed for frontotemporal exposure centered on/about the pterion (**Fig. 12.1**). It's important the incision begin at the level of the zygoma and terminate in the midline at the hairline; a scalp flap placed too high will not provide adequate access to the skull base and will result in excessive brain retraction. The flap can be turned either as a combined musculocutaneous flap or in two layers, with the scalp flap being elevated in the interfascial plane; the latter alternative generally maximizes the inferior extent of the bony exposure. Using the two-layer approach, once the scalp flap is reflected anteriorly to expose the orbital rim, the attachments of the underlying temporalis muscle to the outer table of the skull are cut in a horseshoe-shaped incision, leaving a cuff along the superior temporal line to facilitate closure (**Fig. 12.2**). Importantly, the fascial incision should extend across the anterior aspect of the frontozygomatic process. The muscle flap is then reflected inferiorly across the zygoma to be held under tension with spring-loaded fishhook retractors.

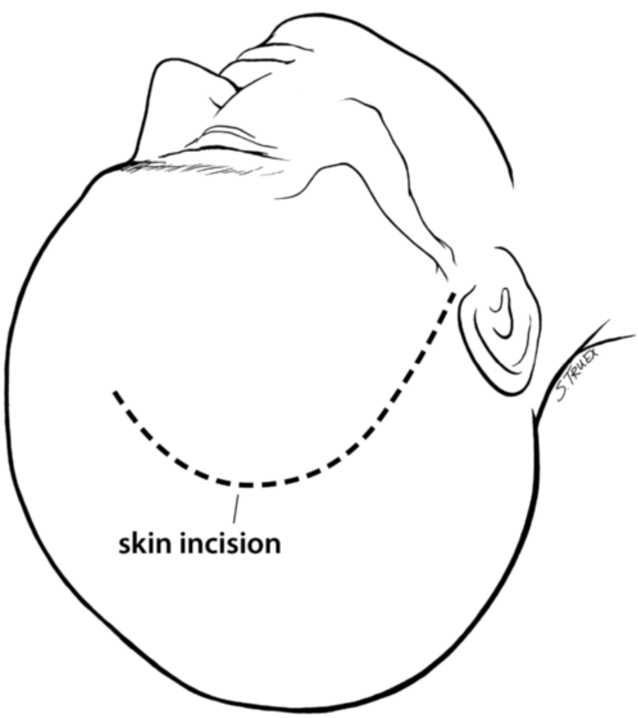


Fig. 12.1 Skin incision for frontotemporal approach to basilar apex aneurysms.

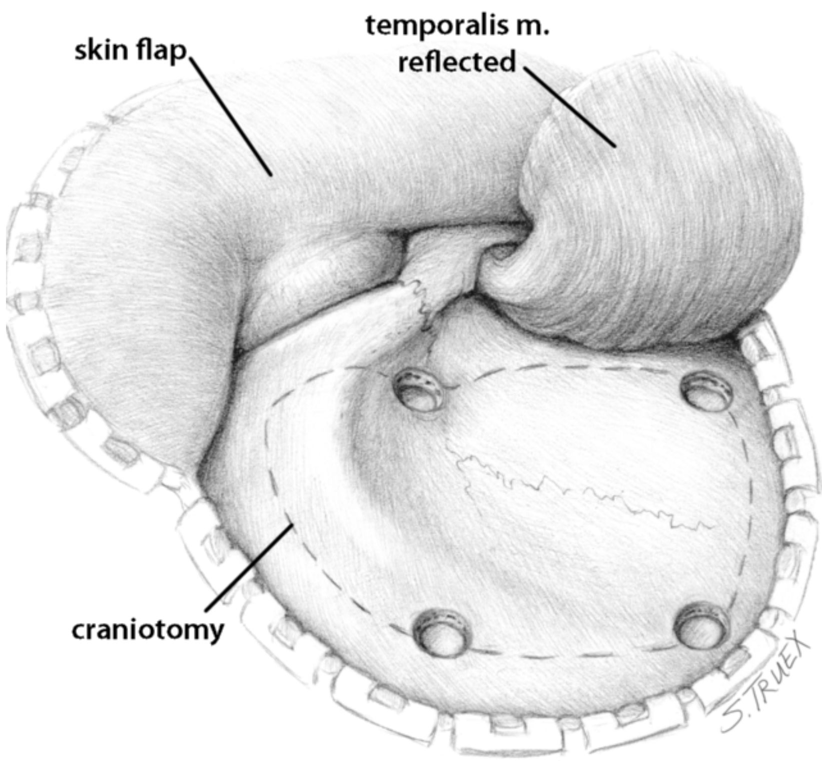


Fig. 12.2 Muscle dissection and craniotomy for basilar apex approach.

Craniotomy/Craniectomy

A relatively large frontotemporal free bone flap (~8 cm × 4 cm) is removed, extending from the midpupillary line to the squamosal portion of the temporal bone and sufficiently superiorly to incorporate the anterior aspect of remaining muscle cuff. Then a generous subtemporal craniectomy is done (**Fig. 12.3**). The inner table of the craniotomy defect above the orbital roof is erased with the drill, and then an aggressive removal of the sphenoid ridge performed. The ridge should be completely flattened at least to the level of the orbitomeningeal artery, and further if the residual wing rides up high into the dural reflection over the sylvian fissure (**Fig. 12.4**). It's neither necessary nor advisable to remove the anterior clinoid process.

Durotomy/Ventriculostomy

The dura mater should either be stellated into the four corners of the craniotomy defect (which is helpful not only for exposure but also for epidural hemostasis) or opened in a lengthy, curvilinear fashion along the inferior margin of the

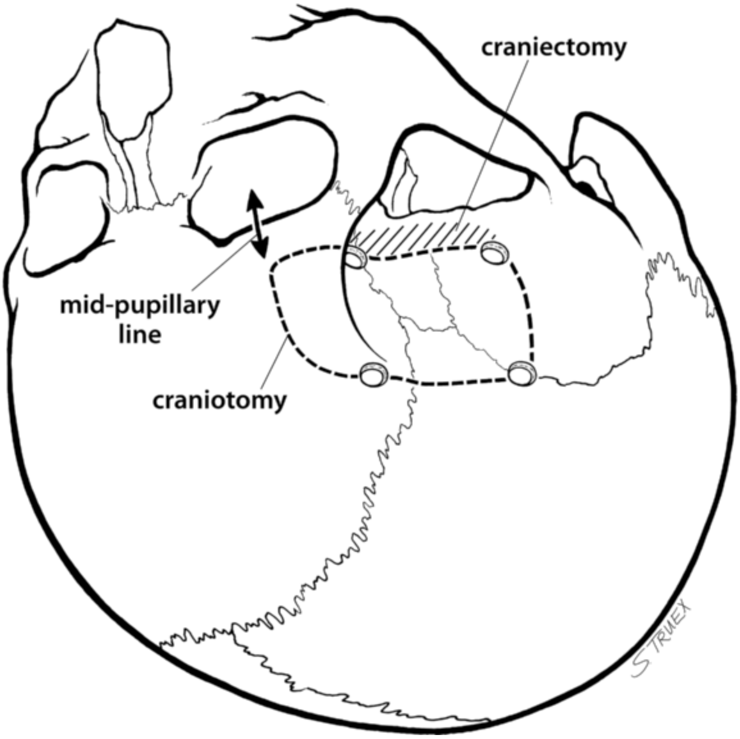


Fig. 12.3 Burr hole placement for craniotomy.

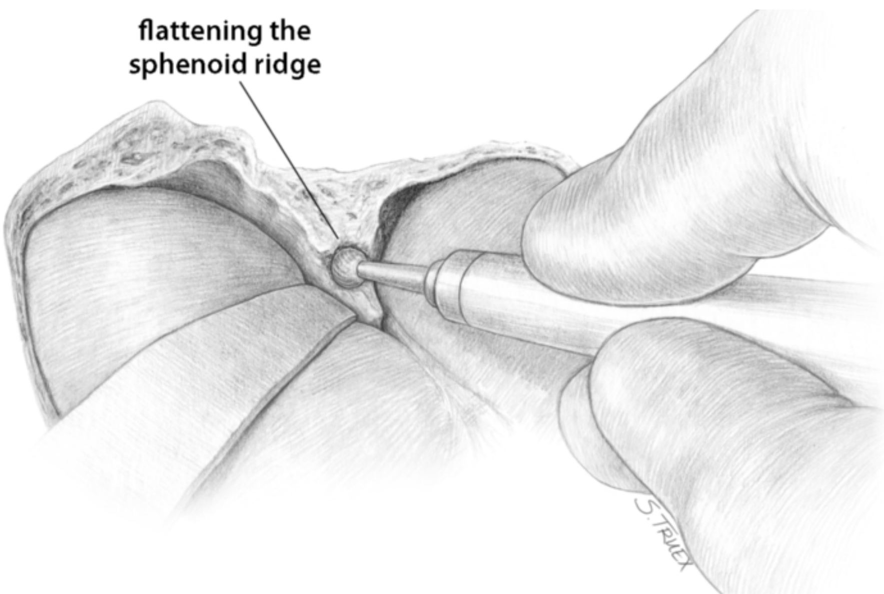


Fig. 12.4 Extradural drill resection of sphenoid ridge.

craniotomy defect. The initial 2 cm of the hemispheric portion of the sylvian fissure must be visible, and if the surgeon plans to use an intraoperative ventricular puncture, an additional portion of the frontal lobe must be accessible. Evacuation of cerebrospinal fluid (CSF), by ventriculostomy or lumbar puncture, is strongly recommended in almost all cases to diminish the degree and force of brain retraction required for adequate exposure of the interpeduncular cistern. Routinely, we insert a “Payne’s point” ventricular catheter and institute CSF drainage at this stage of the procedure (**Fig. 12.5**).

Steps of Exposure

1. *Opening Sylvian fissure-basal cisterns*: A routine retrograde opening of the entire sylvian fissure from the MCA bifurcation to the internal carotid artery (ICA) bifurcation is essential to maximizing the potential of this approach. Once the entire course of the M1 segment is exposed, a self-retaining retractor blade can be placed on the posterior aspect of the orbital cortex at the level of the ICA bifurcation and the

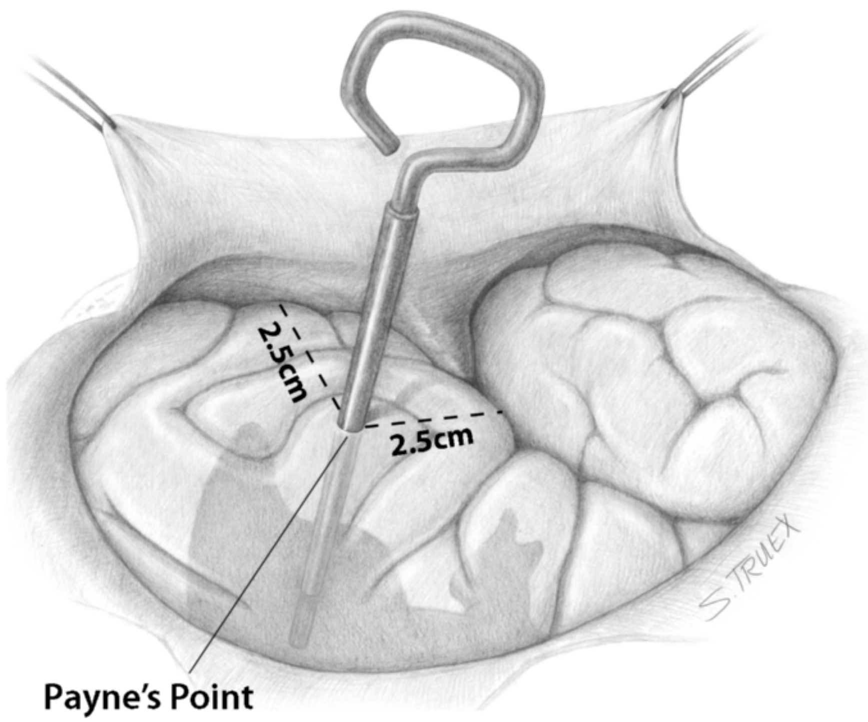


Fig. 12.5 Entry point for Payne’s point extraventricular drain placement.

arachnoid dissection extended anteriorly into the prechiasmatic cistern, freeing the gyrus rectus from its attachments to the optic nerve. When the A1 segment of the anterior cerebral artery is completely exposed, the carotid artery can be skeletonized of its arachnoid covering, and the origins of the PCOMM and anterior choroidal artery (ACHRD) are identified. The frontal lobe retractor is then advanced over the posterior aspect of the gyrus rectus to lie immediately superior to the ICA bifurcation, where it will stay for the remainder of the procedure. Before the exposure is carried deep to the carotid artery, the temporal pole should be mobilized.

2. *Mobilizing temporal pole/resection of uncus*: A second self-retaining retractor blade is placed on the most anterior aspect of the superior temporal gyrus, and the surgeon's view shifts to visualize the anterior aspect of the temporal fossa (**Fig. 12.6**). Veins draining from the temporal tip to the sphenoparietal sinus are cauterized and cut as the retractor is advanced medially, displacing the temporal lobe posteriorly and serving to widen the previously opened sylvian fissure slightly. The retractor tip should ultimately come to rest against the medial dural covering of the temporal fossa slightly inferior to the incisura. If the blade is curved appropriately, the superficial aspect of the retractor will lie parallel to the temporal cortex; with the tip lodged against the temporal dura, the surgeon's right hand can rest safely (but lightly) on the retractor itself, bringing the microscissors to the posterior wall of the carotid via an anterior temporal trajectory. In about half of our cases, especially those with a "high bifurcation," we find it beneficial to resect a portion of the uncus (**Fig. 12.7**). This limited subpial resection can be done later in the procedure, but once the pole has been displaced posteriorly it's very tempting to complete the temporal portion of the exposure immediately. If the uncus is to be removed, the resection should focus on the medial portion of the structure, with special care being taken to remove that superior aspect of the uncus found immediately deep to the carotid bifurcation and origin of the M1 segment. This superior exposure is critical in final visualization of aneurysms located in the rostral aspect of the interpeduncular cistern and should be done with care to avoid inadvertent injury to the anterior choroidal artery. When the entire third cranial nerve is visible through the pia-arachnoid covering the medial aspect of the uncus, the resection is sufficiently expansive.

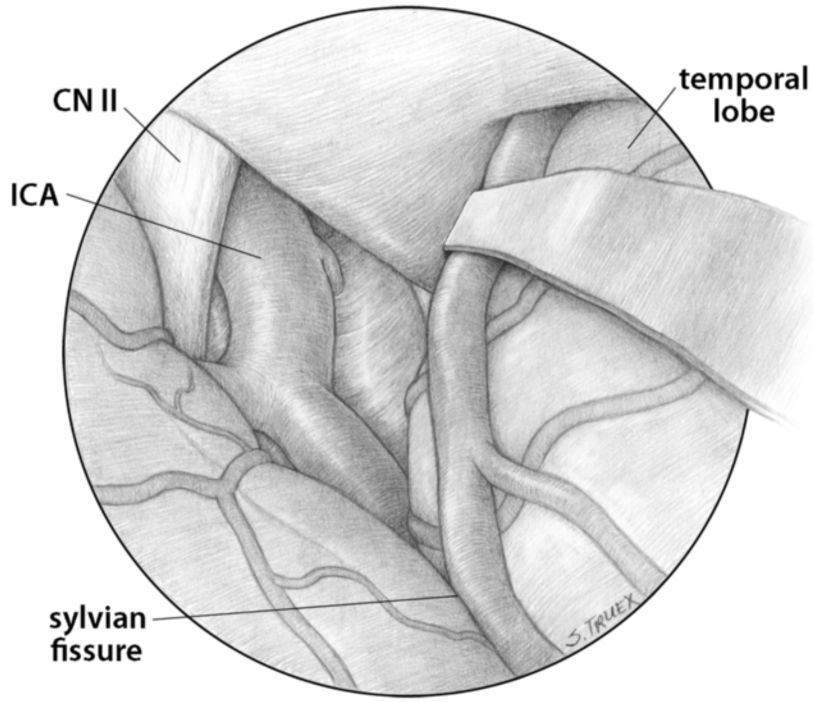


Fig. 12.6 Placement of retractor on anterior aspect of superior temporal gyrus.

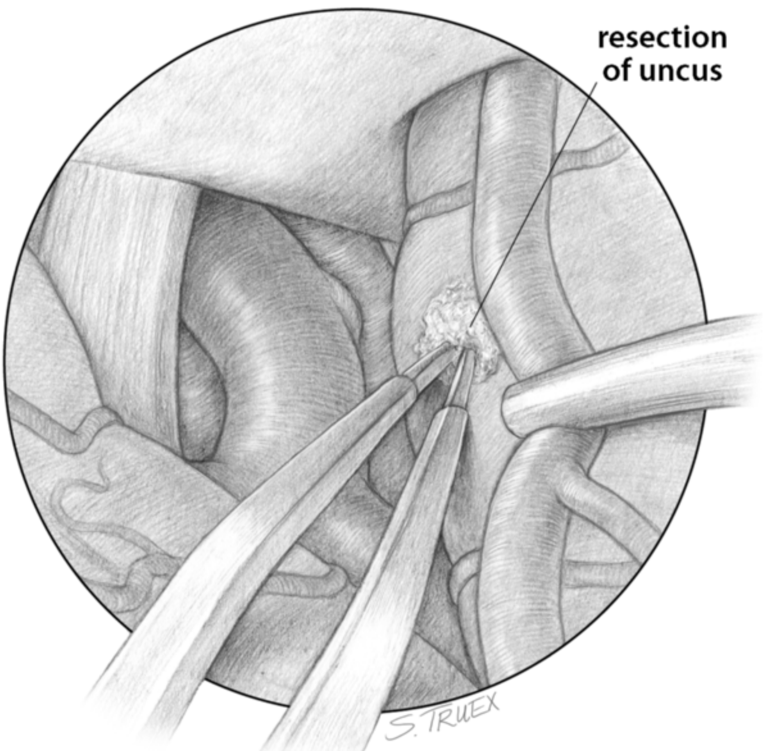


Fig. 12.7 Uncal resection, especially for “high bifurcation” basilar apex aneurysms.

3. *Opening the membrane of Liliequist*: With both frontal and temporal retractors in place, the surgeon can now concentrate on opening the arachnoid boundaries of the interpeduncular cistern. First, the superficial arachnoid layer of the carotid cistern and subsequently the deeper membrane of Liliequist can be identified by following the inferior aspect of the PCOMM as the artery courses posteriorly (**Figs. 12.8** and **12.9**). Each of these thick arachnoid layers should be widely stellated now, and, as the exposure is deepened, the surgeon will find it beneficial to repetitively extend the arachnoid opening laterally over the third nerve, medially across the midline, and inferiorly behind the clivus. With the arachnoid opened widely, the PCOMM, which has no perforating arteries emanating from its inferior aspect, can be followed into the cistern and to the vessel's junction with the posterior cerebral artery—the P1–P2 junction. When the PCOMM is small, this point is readily identifiable, but due to the obliquity of the approach, if the PCOMM is large the transition from PCOMM to P1–P2 may not be obvious. From the P1–P2 junction, the surgeon should proceed along the inferior surface of the P1 segment to the basilar trunk (**Fig. 12.10**). The orientation of the distal basilar artery when first seen through this exposure is somewhat surprising; emerging from the prepontine cistern behind the clivus, the artery seems to run an oblique posterior-to-anterior course, so that the origin of the superior cerebellar artery (SCA) may appear to be posterior, rather than inferior, to that of the P1. Especially in a clot-filled cistern,

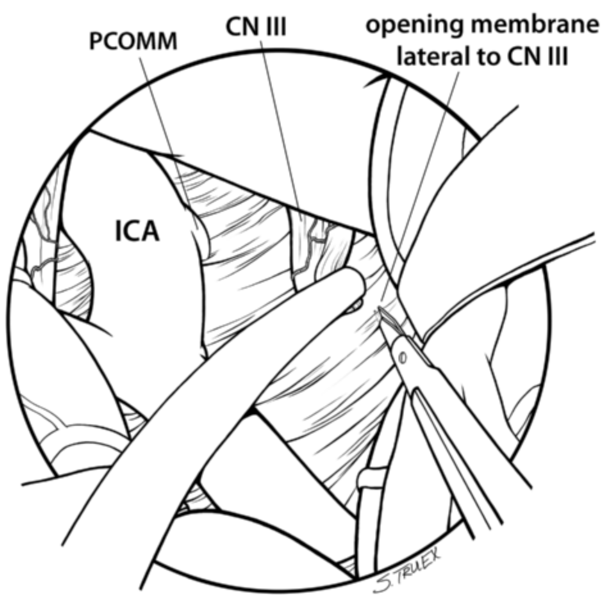


Fig. 12.8 Dissection of superficial arachnoid layer.

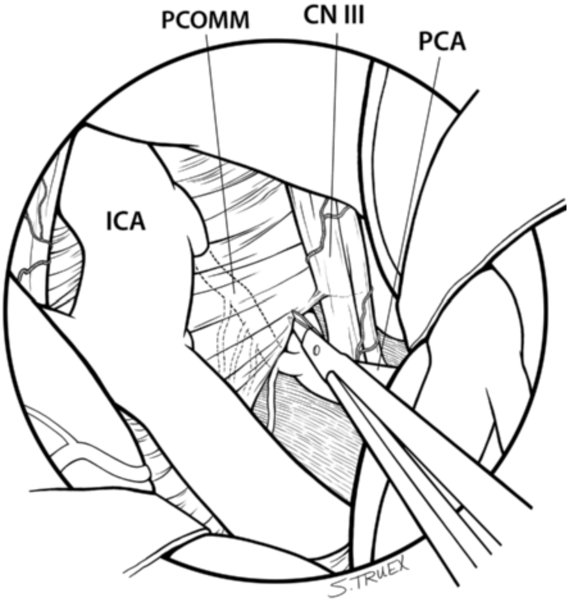


Fig. 12.9 Dissection of deep arachnoid layer, membrane of Liliequist.

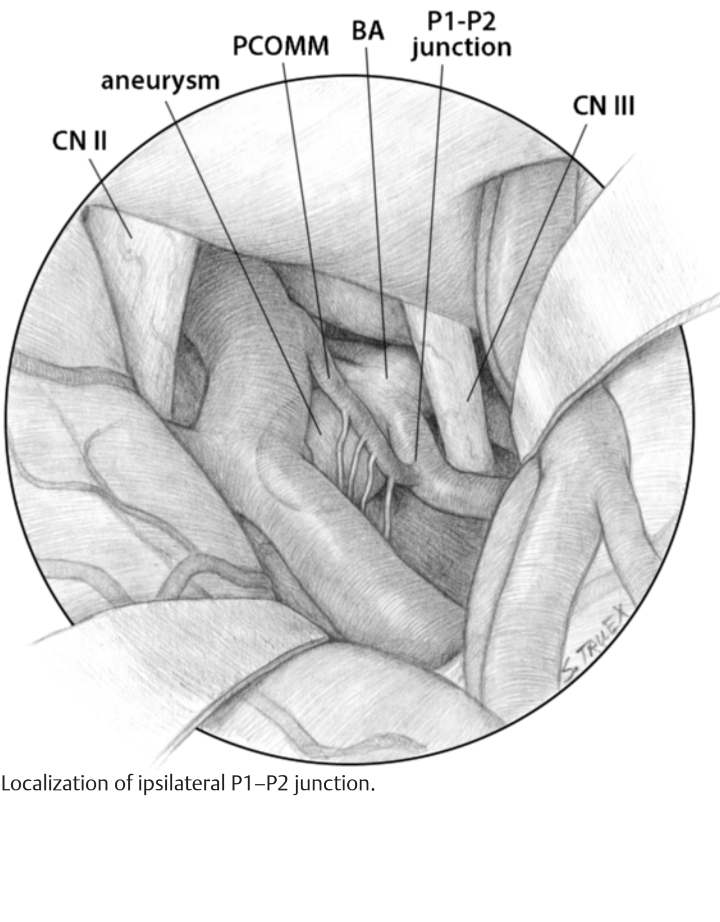


Fig. 12.10 Localization of ipsilateral P1–P2 junction.

this can be disorienting; however, if the surgeon faithfully "connects the dots," following the PCOMM to the P1, then to the lateral aspect of the basilar trunk, proximal control can be safely established. In most situations, it's advisable to follow the trunk retrograde below the SCA origin and prepare the artery here for temporary clip placement; a clip placed more distally (between SCA and P1) both interferes with dissection of the aneurysm and is more likely to encounter small perforating arteries on the posterior basilar wall.

4. *Mobilization of the PCOMM—when, where and how to sacrifice*: In some situations when the carotid artery appears to be tethered posteriorly by a short, taut PCOMM, division of the communicating artery may provide markedly improved access to the basilar apex. Obviously, prior knowledge of the importance of PCOMM input to the PCA distribution is critical to safe sacrifice of this artery; in addition, if the PCOMM is no longer patent, the surgeon has surrendered one of the important reconstruction options often beneficial in dealing with large complex apex aneurysms (vide infra). As a rule, the safest and easiest site for sacrificing the communicator is at the P1–P2 junction, where it is devoid of perforating arteries and can be reliably divided between small arteriovenous malformation (AVM) clips (**Fig. 12.11**). Using the bipolar cautery to secure the artery will invariably produce occlusion of one of the small anterior thal-

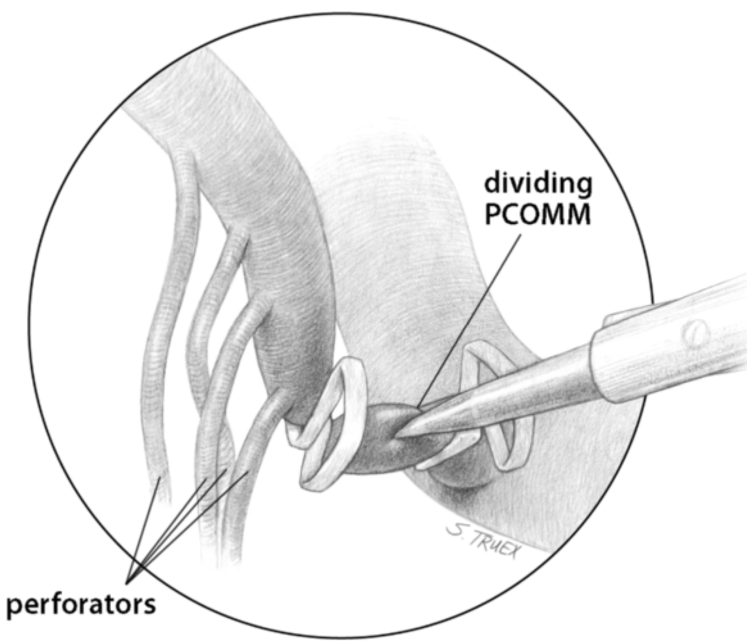


Fig. 12.11 Site of safe sacrifice of PCOMM.

amoperforating vessels; although the subsequent basal ganglia infarction may be well tolerated clinically, it can also result in a permanent hemiparesis. Once the artery has been divided, the proximal remnant retracts nicely superiorly behind the carotid, and the small clip at the P1–P2 junction produces no impediment to further dissection or clip placement.

5. *Dissection of the contralateral SCA and P1*: With the establishment of proximal control along the basilar trunk, the surgeon is ready to move rostrally, exposing the anterior and contralateral aspects of the artery. The opposite SCA origin should be defined and sufficient arachnoid opened to demonstrate the emergence of the contralateral third cranial nerve from the midbrain. Remaining on the ventral surface of the basilar artery the surgeon should move the exposure distally; the contralateral P1 origin can be identified and often easily dissected to the P1–P2 junction, a dissection that provides access to the contralateral P1 and PCOMM arteries for temporary occlusion if necessary. If the projection of the aneurysm permits easy visualization of the origin of the contralateral P1 segment, then the interface of that origin with the aneurysm neck can be gently defined at this time, and the presence and course of the invariable perforating arteries identified. A similar preliminary dissection of the ipsilateral aspect of the neck should follow. Complete dissection of the neck of large aneurysms and most ruptured lesions should generally be deferred until the aneurysm is softened by basilar occlusion.

6. *Institution of temporary basilar occlusion*: It is certainly possible to successfully occlude many basilar apex aneurysms without the use of preliminary temporary occlusion of the basilar trunk (**Fig. 12.12**). Small, anteriorly projecting aneurysms are especially susceptible to the direct approach because the posterior wall of the apex and the initial portions of both P1 segments can frequently be inspected without manipulation of the lesion itself. However, circumferential dissection of the entire neck under direct vision is an *absolute* prerequisite to safe clip-ligation of each basilar apex aneurysm. Iatrogenic occlusion of the adjacent perforating arteries is the single greatest source of morbidity/mortality in this procedure and will occur routinely if the surgeon fails to detach these critically important vessels from their arachnoidal attachments to the aneurysm neck. The safest method to accomplish that goal is to first soften the aneurysm by placing a temporary clip across the previously prepared basilar trunk. Excellent aneurysm surgeons continue to debate the benefits of mild to moderate hypothermia, mannitol infusion, and anesthesia-induced burst-suppression coma in increasing the brain's tolerance of temporary ischemia; without elaborating on the merits of that debate, we routinely use both mild hypothermia and burst suppression in these situations. In our opinion, the "downsides" of this regimen are almost nonexistent, and it's our clinical impression that it may well be very effective. In dealing with most aneurysms of routine size, we've

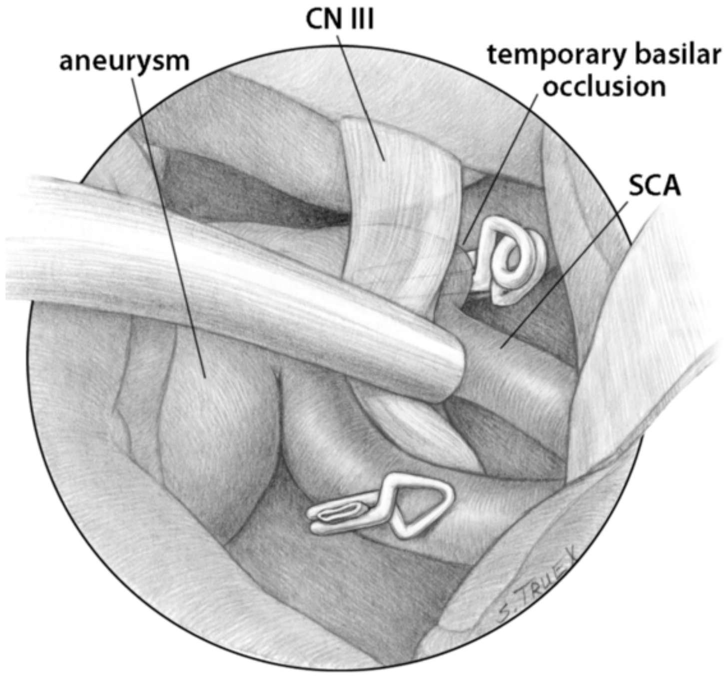


Fig. 12.12 Placement of proximal basilar temporary clip.

found that a single temporary clip will soften the lesion sufficiently to permit its mobilization circumferentially. When that proves not to be the case, or when one is dealing with larger aneurysms, it's beneficial to completely "trap" the lesion, using clips placed on each P1 segment (and sometimes each SCA) as far as possible from the aneurysm itself (**Fig. 12.13**). The confines of the interpeduncular cistern are narrow at best; with as many as five temporary clips clustered around the basilar apex it can be difficult in the extreme to finalize the dissection and accurately apply definitive clips to the aneurysm neck. Tucking the handle of the proximal temporary clip behind the overhanging clivus is one way of reducing the clutter before beginning to mobilize the aneurysm. Our routine is to complete the entire neck dissection after temporary clip application and then, if the period of occlusion has been longer than 15 minutes, to remove the temporary clips and reperfuse the basilar apex for a period equal to the length of temporary occlusion before reapplication of the temporary clips in anticipation of permanent clip ligation of the aneurysm's neck. It's not uncommon for the process of permanent clip application to require 10 to 15 minutes, a period that is much better tolerated after adequate reperfusion than is a period of 30 to 40 minutes of ischemia.

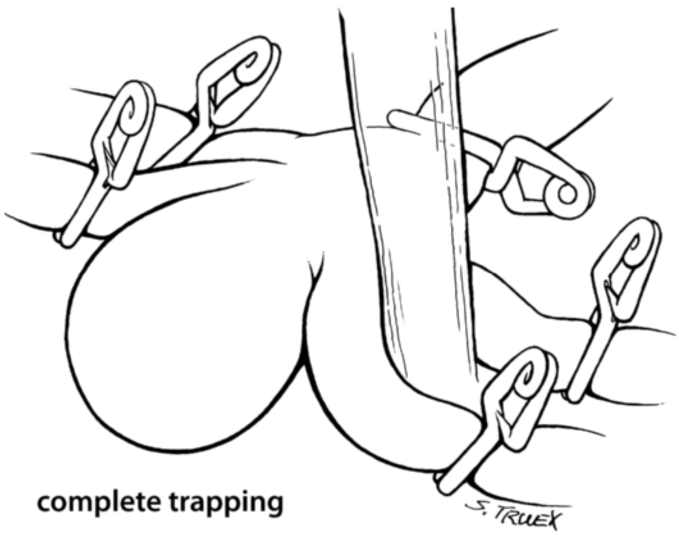


Fig. 12.13 Complete trapping of basilar apex aneurysm.

7. *Mobilization of the aneurysm—different projections*: The overwhelming majority of basilar apex aneurysms project rostrally and somewhat posteriorly, meaning the aneurysm neck must be separated from the dorsal aspect of each P1 origin and then tilted anteriorly out of the interpeduncular cistern to some degree to free the posterior wall from the underlying perforating arteries. Beginning with definition of the contralateral aneurysm–P1 interface, we prefer to complete all of this final dissection with the lesion softened by proximal basilar occlusion. This dissection is almost always best done by compressing the anterior aspect of the aneurysm so that the opposite P1 origin is visible; the aneurysm can then be gently deflected toward the surgeon to permit freeing that portion of the neck from any adjacent perforating vessels (**Fig. 12.14**). Once that plane has been established, the plane of the ipsilateral neck is defined, and any adherent perforating arteries are dissected free from the lateral aspect of the dome and neck. This aspect of the neck is then gently elevated with the surgeon's suction tube as the dissection is moved from the aneurysm's lateral neck to its posterior aspect and gradually deepened to sequentially identify and free the posteriorly lying perforators. When these small vessels have been dissected from the dorsal aspect of the aneurysm, they drop away from the potential trajectory of the clip blades and usually do not need further attention. By patiently increasing the elevation of the proximal neck as the dissection is carried medially, the posterior aspect of the contralateral P1 segment origin can ultimately be identified. At this point, the surgeon will be holding the aneurysm reflected anteriorly with the suction tube; this retraction should be

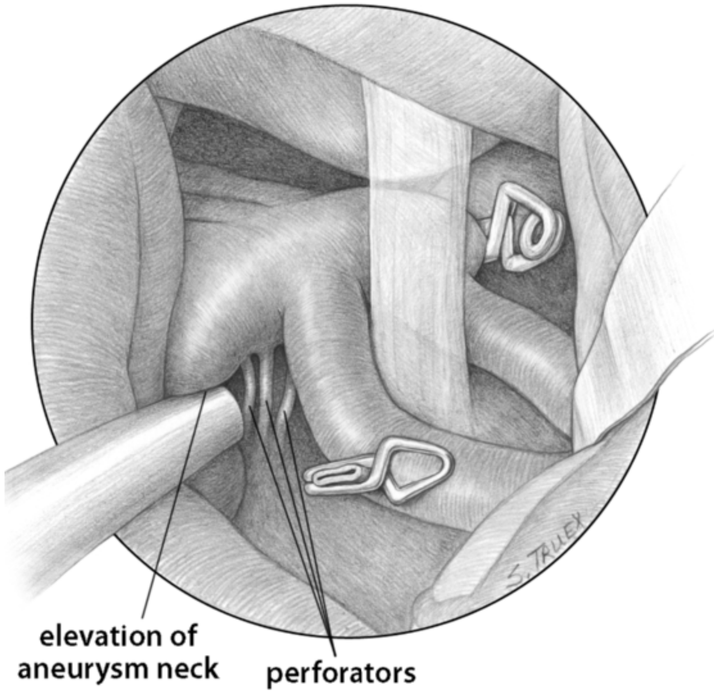


Fig. 12.14 Visualization of perforating arteries.

maintained as a permanent clip is chosen and placed under direct visualization across the basilar apex. The most awkward aneurysm projection in this location is directly posteriorly, but Drake's experience has been a great boon to surgeons faced with this awkward anatomical variant. The superior portion of a posteriorly projecting aneurysm's neck, and the adjacent P1 origins, can be dissected cleanly without difficulty or aneurysm retraction. The surgeon should then mobilize the ipsilateral P1 segment superiorly so as to expose the posterior aspect of the basilar artery between the posterior cerebral artery (PCA) and SCA origins. The inferior aspect of the aneurysm's neck will be encountered almost immediately, and a dissection plane should be developed at that point. As exposure proceeds medially, the perforating arteries adherent to the neck can be displaced posteriorly away from the ultimate path of the permanent clip. When the back wall of the neck has been dissected and the perforators of the P1 artery are finally freed from the superior aspect of the aneurysm neck, there will be two potential options for clip placement. The first involves a clip placed from above the P1 origins down along the back wall of the basilar artery in parallel with its long axis. The second option uses a fenestrated clip placed over the ipsilateral P1 origin, with the blades passing behind the basilar trunk and perpendicular to its long axis (P1 artery in fenestration.) Regardless of its projection, if a basilar apex aneurysm cannot be sufficiently mobilized to permit adequate neck visualization and dissection, the aneurysm-bearing segment should be isolated (trapped) and the sac evacuated (**Fig. 12.15**). While frequently—against all logic—these “trapped” aneurysms will gradually refill, with patience (and intermittent suction), the surgeon can achieve sufficient decompression to complete the dissection under direct vision and then can proceed directly to permanent clip application. Once the aneurysm has been punctured or opened, the surgeon should persist under temporary occlusion until the dissection is finished and the neck appropriately closed with permanent clips; the theoretical benefits of intermittent reperfusion are surpassed in our experience by the likelihood of vigorous bleeding and subsequent obscuration of the critical anatomy surrounding the aneurysm neck.

Clip Placement—Ideal and Options

In a perfect world, every routine basilar apex aneurysm would be clipped in the coronal plane, the clip blades placed parallel and immediately superior to the P1 segments of the posterior cerebral arteries. This clip trajectory permits visualization of at least the anterior clip blade throughout clip placement, and this blade location most effectively closes the aneurysm neck while sparing the previously dissected perforating arteries and avoiding compromise of the P1 segment origins. The most effective clip designs for use in this plane have proven to be the straight, slightly curved, and bayonet models, each applied as illustrated (**Fig. 12.16**). Because of the depth and narrow confines of the interpeduncular cistern, clip blades with more acute angles and greater curvatures are very difficult to successfully manipulate around the basilar apex.

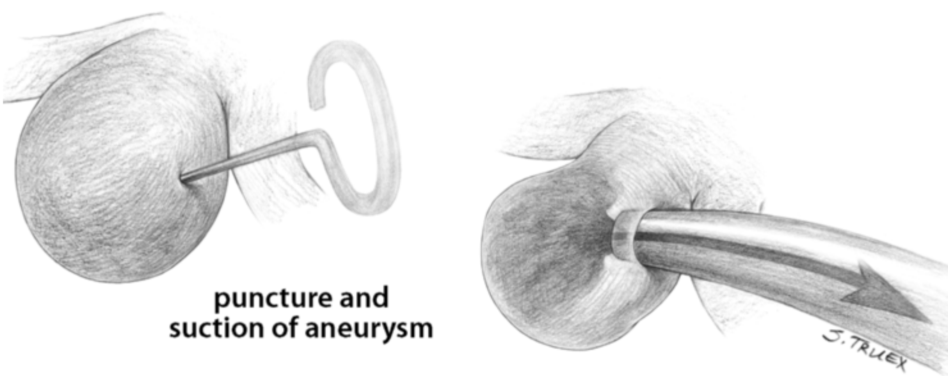


Fig. 12.15 Evacuation of basilar apex aneurysm contents.

When, as is frequently the case, a well-placed clip in this location can be shown to span but not occlude the neck, the surgeon's first printable response should be to place an identical clip tandem to the first. We've used as many as four identical tandem clips on large (but not giant) basilar apex aneurysms before achieving neck closure; in each patient, immediate postoperative angiography demonstrated complete obliteration of the neck at the level of the initial clip.

A second reasonable option in this situation is placement of a straight fenestrated clip distal to and in tandem with the initial clip. As Drake has shown repetitively, distal portions of the first clip's blades may be bridged apart by unseen atheroma in the proximal neck; placing this portion of the aneurysm in the fenestration will usually allow the strong closing force of the distal blades to effectively complete closure of the entire neck.

In reality, the surgeon must rely on a diversity of approaches to deal with the variety of aneurysm projections, neck sizes and extents, and vascular anatomical variants found in this location. One essential alternative is the

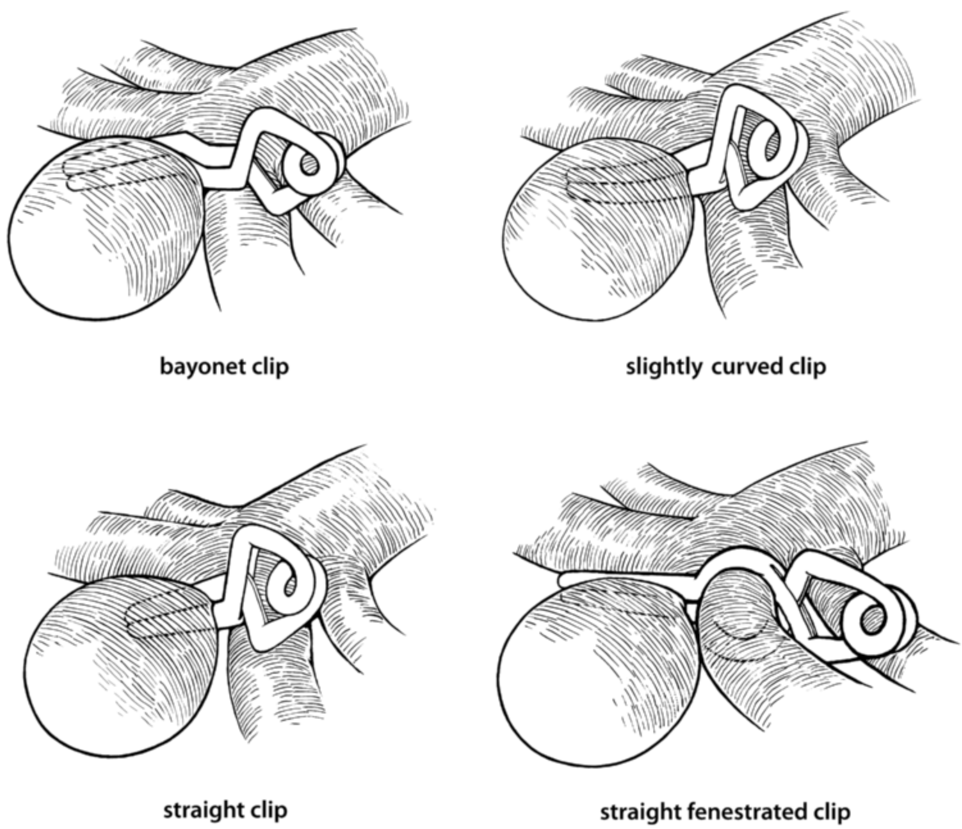


Fig. 12.16 Basilar apex aneurysm clip application strategies.

use of fenestrated clips already mentioned. These versatile clips, initially designed by Drake, are invaluable for posteriorly projecting aneurysms, for the closure of wide, thick-necked lesions, and for the elimination of stubborn residual "dog-ears." Although somewhat awkward to apply, they can be extremely effective, especially when the small-fenestration, very short-bladed models are used either alone, or more commonly, in tandem with other blade configurations. After application of a fenestrated clip, the surgeon must confirm that there is not residual patent neck in the very proximal portion of the fenestration, a common occurrence easily remedied with a distal, tandem short-bladed clip.

When dealing with a posteriorly projecting aneurysm, if a fenestrated clip does not seem appropriate, a good alternative is an "ophthalmic" style clip applied across the anterior aneurysm neck and then manipulated to angle the blades inferiorly down the basilar trunk. Because the distal clip blade is invisible to the surgeon after it passes below the P1 origin, diligent dissection of the posterior perforating arteries in this area is essential prior to clip placement.

As a rule, the larger the aneurysm and the more extensive the neck, the more radical an effective reconstruction may have to be. Drake's expansive experience with large and giant basilar aneurysms is particularly helpful to young surgeons in their search for viable reconstruction options in such situations. An especially beneficial alternative has been the surgical conversion of the basilar "quadrification" into a "trifurcation" via purposeful sacrifice of one of the P1 segment origins. Typically employed when the aneurysm's neck encompasses or "rides out" on one or both P1 segments, or when the neck is so broad it can't be completely spanned by even a long clip, this reconstruction is accomplished by closing the neck and one P1 origin with one clip (or a series of clips) and then by placing a final clip across the P1 segment itself proximal to the P1–P2 junction. It's imperative that the placement of this clip be such as to allow retrograde perfusion of the P1 thalamoperforating arteries via the PCOMM–P1 complex.

Basilar Bifurcation Aneurysms—Useful Modifications to Approach

1. *Aneurysms arising greater than 10 mm above the posterior clinoid*: Although proximal control of the basilar trunk is achieved easily in the interpeduncular cistern, adequate visualization of the neck of high-riding aneurysms is difficult to obtain via a routine transsylvian exposure. Recognized prior to beginning the operative procedure, this problem can be solved in a straightforward fashion by maximizing exposure of the anterior temporal lobe so as to permit a final approach to the aneurysm via a pretemporal route. The most aggressive modification involves cutting the zygomatic arch to produce a true transzygomatic approach; however, this

extreme is rarely necessary if care is first taken to begin the skin incision slightly below the zygoma, to extend the anterior limb of the fascial incision to the bony rim of the zygoma, and then to reflect the muscle flap inferiorly over the bone. After a very generous subtemporal craniectomy and aggressive removal of the sphenoid ridge, the temporal pole is mobilized posteriorly. When the sylvian fissure has been split and the interpeduncular cistern opened, the surgeon's angle of approach gradually shifts from transsylvian to anterior or pretemporal, which permits the surgeon to look superiorly up into the rostral aspect of the cistern. This alteration produces a less oblique view of the bifurcation, meaning that the contralateral P1 and SCA are more difficult to see, whereas the posterior aspect of the artery is somewhat easier to visualize.

2. *Aneurysms located below the posterior clinoid level*: Lesions with necks significantly inferior to the level of the posterior clinoid processes require a more extensive exposure to achieve proximal control of the distal basilar artery; one or a combination of maneuvers will extend the routine exposure sufficiently inferiorly to reach the level of the anterior inferior cerebellar origins. Despite the apparent low level of the basilar apex on preoperative angiography, the surgeon is urged to expose the interpeduncular cistern prior to removing the posterior clinoid process or opening the cavernous sinus; frequently, minor modifications to the routine approach, such as mobilization of the third cranial nerve and a shift in the operator's point of view from transsylvian to pretemporal, will provide adequate proximal exposure. When additional inferior exposure is required, perhaps the most straightforward options involve simple drilling away of the posterior clinoid process after its dural covering has been cut and reflected in a stellate fashion. The posterior clinoid process is often more vascular than the anterior clinoid, requiring frequent applications of bone wax and considerable patience on the surgeon's behalf to ultimately gain the needed 2 to 3 mm of additional exposure. For a more expansive exposure of the prepontine and inferior interpeduncular cisterns, it's necessary to open the posterior aspect of the cavernous sinus and reflect the sinus somewhat anteriorly. This can be done in several ways, the simplest being via a perpendicular incision in the lateral wall of the sinus at or just posterior to the fourth cranial nerve's site of entry into the dural leaflet (**Figs. 12.17** and **12.18**). The nerve can be either dissected free or transected completely; in either case the patient will have a transient fourth nerve palsy postoperatively, which will either disappear or be accommodated for by the end of the first postoperative month. Once the sinus has been opened and its anterior aspect is packed with cotton and oxidized cellulose to obtain hemostasis, the dural incision is then gradually extended. The anterior leaf of the sinus is progressively tacked against the temporal dura to enhance exposure

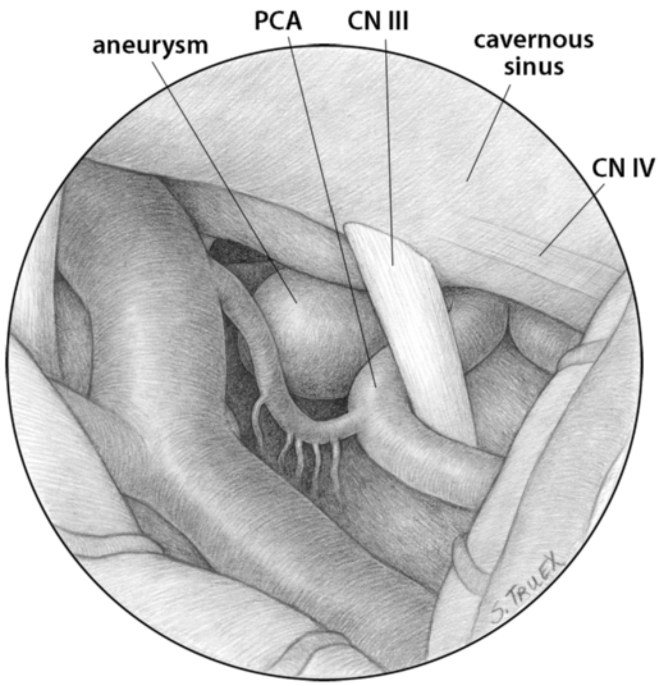


Fig. 12.17 Anatomical relationship of basilar apex to the cavernous sinus.

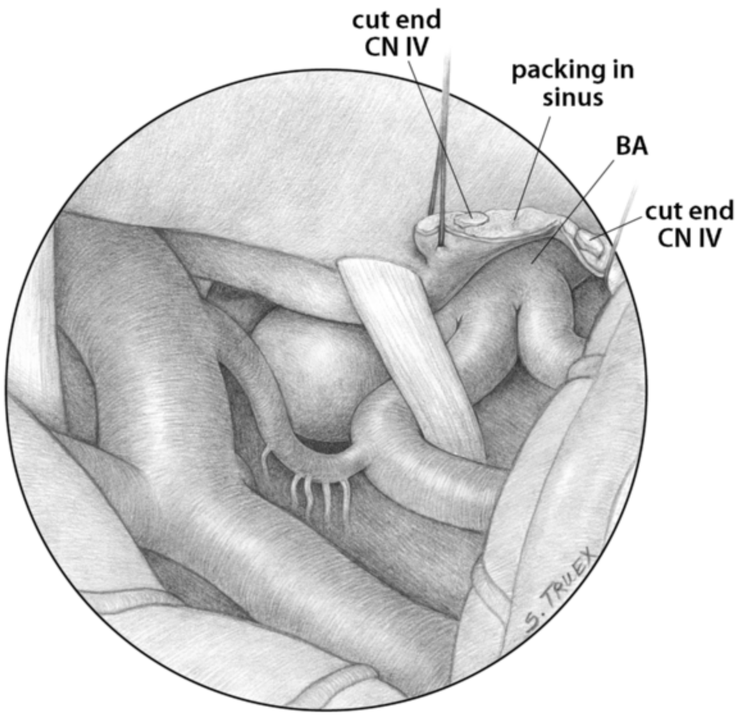


Fig. 12.18 Additional exposure of basilar apex through posterior cavernous sinus.

and improve hemostasis, and the arachnoid over the lateral aspect of the prepontine cistern is opened to expose the basilar artery posterior to the clivus. The inferior extent of the cavernous sinus exposure is marked by the first segment of the trigeminal nerve.

Final Thoughts

1. Adequate exposure of the basilar apex is the culmination of a carefully reasoned series of operative maneuvers, beginning with patient positioning. Don't skip any steps.
2. The anatomy of the interpeduncular cistern is complex, and the oblique angle of approach can be confusing. Never assume you understand the anatomy; always show it to yourself by patient, step-by-step dissection.
3. The final dissection of almost every basilar apex aneurysm is most safely and effectively done with a temporary clip on the distal basilar artery. If this doesn't soften the aneurysm sufficiently to permit manipulation of the neck, the surgeon should move immediately to trapping and evacuating the aneurysm.
4. Freeing each lateral aspect of the aneurysm's neck from the attached perforators, followed by dissection of the posterior aspect of the neck, is the most critical aspect of the procedure. Never put a permanent clip on a basilar apex aneurysm until this has been accomplished.

13

Very Large and Giant Aneurysms

Introduction

In the initial Cooperative Aneurysm study published in 1960, giant aneurysms were defined as lesions with a diameter equal to or greater than 1 inch (25 mm). The reasons behind selection of that diameter are unclear, other than earlier authors in describing small series of very large aneurysms had apparently arbitrarily used these dimensions. In fact, as Roberto Heros points out, as a rule the morphology of aneurysms changes dramatically at diameters of 15 to 17 mm, so that lesions of this size and larger have much more in common with the 25 mm aneurysm than with the much more routine 7 to 13 mm variety. This chapter discusses the unique problems and some potential solutions in the surgical management of aneurysms 15 mm in diameter and larger.

There are three specific factors that set very large and giant (VLG) aneurysms apart from their smaller counterparts, only one of which relates specifically to their diameter. Certainly the sheer *mass effect* of these lesions produces uncommon effects on the surrounding brain tissue, cranial nerves, adjacent dura, and underlying bone. Almost invariably, a large percentage of the circumference of large aneurysms lies not free in the subarachnoid space but rather invaginated into the brain itself, often with significant pial adhesions and parenchymal edema. Symptoms related to cranial nerve compression are a common presentation of these aneurysms, just as permanent cranial nerve injury is one of the most frequent sources of morbidity in their treatment. Extensive and pernicious adhesions to the surrounding dura mater are often themselves hidden by overlying skull base components, both of which require meticulous surgical technique to remove. All of these factors related to size make adequate exposure of the proximal and distal vasculature, and the aneurysm itself, more difficult and fraught with more risk of brain and cranial nerve injury than is encountered in dealing with smaller lesions. More simply said, the aneurysmal mass makes visualization of the pathology harder for the surgeon and more risky for the patient.

Morphology refers to the external shape or configuration of the aneurysm; specifically, the aneurysm's relationship to its afferent and efferent vasculature. There is obviously a continuum ranging from small aneurysms with a dainty, well-circumscribed neck completely discrete from the emerging branch arteries to lesions in which the parent vessel disappears into an aneurysm sac from which emerge, at some distance, two and infrequently three arterial branches; however, some version of the latter scenario occurs with monotonous regularity in larger aneurysms, regardless of the impressions drawn from preop angiography. As a rule, the more expansive the lesion, the more extreme the incorporation of the parent artery terminal end and the origins of the branch vessels. For a surgeon to operate on a VLG aneurysm assuming otherwise is an unfortunate triumph of hope over experience.

The final unique factor that differentiates these aneurysms is the almost uniform presence of *intraluminal thrombosis* and *intramural calcification*. The unique hemodynamic stresses that give rise to these two features are as yet unclear, and the degree and extent of each is variable in almost identical aneurysms; nonetheless, these two anomalies can and do significantly complicate surgical reconstruction. Their presence, if not their actual extent, can routinely be appreciated by review of preop magnetic resonance imaging (MRI) and computed tomographic (CT) studies (only the CT scan accurately demonstrates the degree of calcification), and early recognition can be important in prioritization of the potential alternatives in surgical treatment.

These alternatives include direct reconstruction, proximal (Hunterian) ligation, trapping of the aneurysm-bearing segment, and combinations of the above, plus the addition of one or more revascularization techniques. The possible need for and consequence of each of these approaches should be considered prior to actual operation of each VLG aneurysm; it's almost impossible to "over think" the management of these lesions, unless of course the cognitive process should lead to paralysis by analysis.

Rules to Live By

1. You never have enough information about VLG aneurysms. Furthermore, just having the information won't cut it. Intense study of all of the routine imaging tests, including CT, MRI, and angiograms, is a prerequisite for surgery on the lesions. Often a trial balloon occlusion (TBO) study is also indicated, if the possibility of parent vessel sacrifice exists.

2. With as clear an understanding of the anatomical and hemodynamic realities as the imaging studies can provide, you must evaluate the operative landscape and prepare for the inevitable surprises. This is best done by engaging in a series of “if-this-happens-then-what-do-I-do?” questions and hopefully answers. For example, in dealing with a very large internal carotid artery (ICA)-ophthalmic origin aneurysm, the sequence might go like this:
   a. “If I drill the clinoid, remove the optic strut, open the falciform ligament, dissect the dural ring, and still can’t see the proximal neck, meaning I don’t have proximal control, then what?” (Suggestion: expose the cervical internal carotid artery.)
   b. “If I have the thing exposed and the neck is too broad/atherosclerotic/turgid to close with a clip, what then?” (Suggestion: try temporary proximal occlusion, then crush the neck gently with a fine hemostat, blades sheathed in a fine French catheter.)
   c. “If the neck shears when my clip closes, will the patient tolerate a trapping procedure? With/without a bypass? What caliber of bypass? From where to where?” (Suggestion: your TBO should answer most of these questions and make you prepare the appropriate alternatives.)
3. Take all of the foregoing contingencies into consideration when planning and performing the early stages of the operative procedure. Availability of the ultrasonic aspirator to remove thrombus, draping to allow cervical exposure of the internal carotid artery, femoral catheterization for postclipping angiography, preparation for radial artery or saphenous vein harvest, isolation of the superficial temporal artery—the probable need for each of these preparatory maneuvers can be recognized in step 2 and fulfilled prospectively before the aneurysm is exposed. Better to take your time and get ready now than to waste potentially critical minutes of ischemia time backtracking later.
4. Get lots of room. These are difficult operations. By virtue of the aneurysmal size and the frequent need to combine two procedures (aneurysm clipping and bypass), these lesions require extensive exposure at every level for their successful surgical treatment. Larger craniotomy flaps, generous use of skull base techniques, and extensive subarachnoid dissection all are routinely necessary. “Keyhole” exposures here are only for the most “aggressive” surgeons—and the most unfortunate patients.

5. The surgeon's greatest concern is ischemia: protracted temporary ischemia associated with a difficult clip reconstruction; abrupt, emergent ischemia necessary to control an intraoperative rupture; permanent ischemia due to volitional or inadvertent vessel sacrifice or unrecognized arterial stenosis. In recognition of that danger, the procedure must be performed using every possible means to minimize that risk. That includes the routine use of pharmacological protection, mild–moderate hypothermia, limited lengths of temporary arterial occlusion (whenever possible) interspersed with periods of reperfusion, reliable intraoperative angiography, and early performance of bypass procedures when blood flow is questionable or obviously inadequate.
6. Stay flexible and don't try to make the anatomy correspond to your preoperative concepts. Wide exposures, patient subarachnoid dissection, and complete demonstration of the vascular anatomy will lead to an understanding of the pathological situation that far surpasses that achieved by your study of imaging results alone. Even when it's necessary to use episodes of temporary proximal occlusion to soften the lesion sufficiently to understand the anatomy of the neck and emerging arterial branches, the time and effort are well spent prior to embarking on a sometimes irreversible clip reconstruction.
7. Rely on intraoperative angiography. This modality is increasingly available, accurate, and easy to use, and it has few potentially hazardous consequences for the patient. There is no substitute for imaging the results of your reconstructive efforts immediately, with ample time to safely revise them, rather than 2 hours later in the angiography suite, when reexploration is almost always a futile gesture. The recent introduction of intravenous fluorescein angiography may be the most major technological advance in aneurysm surgery since the development of modern clips.

There are three common varieties of VLG aneurysms, which, for the purposes of this discussion, we'll designate as "The Good, the Bad, and the Ugly."

Although the presenting symptomatology, aneurysm location, and patient-specific comorbidities make every one of these lesions relatively unique, using the characteristics discussed at the chapter's beginning, we can divide them accurately enough for surgical work into one of the above three categories (the categorical names are obviously arbitrary, but qualitatively reflect surgical opinion). This designation carries direct implications for methods, difficulty, and risks of surgical treatment.

The Good

Unfortunately, these are the rarest subset of VLG aneurysms (**Fig. 13.1**). They are simply just that—larger versions of the routine aneurysms found in 2 to 4% of the population. They may present with subarachnoid hemorrhage or mass effect or may be totally asymptomatic. With relatively small necks, they tend to involve a relatively short segment of the termination of the parent vessel and minimal portions of the branch arteries. The principal difficulty in their operative management is adequate exposure, which can frequently be facilitated by the use of temporary arterial occlusion in the later phases of dissection. Clip placement can also present problems with closure of the neck, problems that are relatively simple to ameliorate by either proximal temporary occlusion or trapping followed by aneurysm evacuation using either direct puncture or suction decompression when feasible. It's probably a good rule of thumb that no VLG aneurysm—regardless how discrete the neck—should undergo definitive clip placement without prior proximal temporary arterial occlusion (**Table 13.1**).

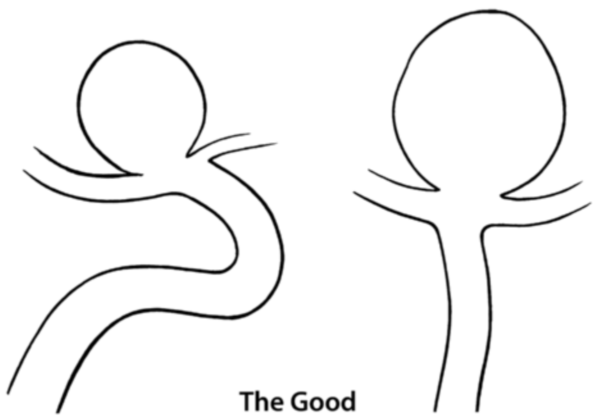


Fig. 13.1 Good configurations of large and giant aneurysms.

Table 13.1 "Good" Very Large and Giant Aneurysms

Characteristics	Consequences
Relatively small necks	Temporary occlusion usually necessary Ischemia times usually brief
Minimal intraluminal thrombosis	Frequently need to evacuate lumen Complex reconstruction probable
Limited intramural calcification	Sacrifice of parent vessel unlikely Rare need for revascularization

The Bad

This category contains the majority of VLG aneurysms (**Fig. 13.2**). In addition to their size, these lesions incorporate one or both of the origins of the emerging branch vessels in the aneurysm's neck. The necks, although identifiable, often contain large amounts of circumferential calcium deposits that are easily recognized by CT scanning. These lesions are also routinely burdened with extensive intraluminal thrombosis. Adequate exposure is compromised by the lesion's size as well as the significant distance separating the origin of the branch arteries from the termination of the parent vessel; the incompressible nature of the thrombus-filled fundus adds to the difficulty (**Table 13.2**).

The extensive, partially calcified necks of these lesions resist clip closure, frequently causing the clip to migrate proximally down onto the parent vessel lumen, with subsequent irreversible injury to the normal endothelium.

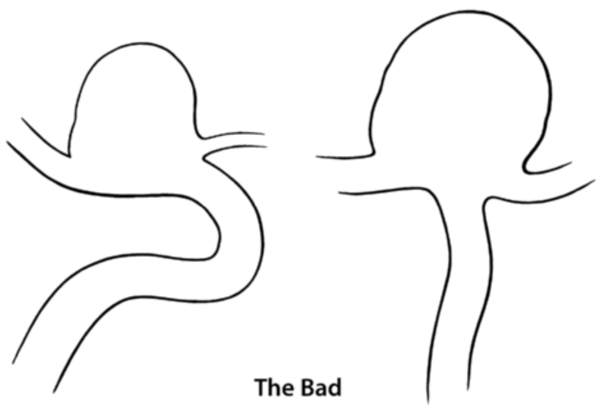


Fig. 13.2 Bad configurations of large and giant aneurysms.

Table 13.2 "Bad" Very Large and Giant Aneurysms

Characteristics	Consequences
Efferent arteries incorporated into neck	Temporary proximal occlusion always necessary Protracted ischemia probable Sacrifice of branch vessel origin frequently indicated Pre-preparation for bypass essential
Extensive intraluminal thrombosis	Aneurysmorrhaphy almost always necessary
Inevitable intramural calcification	Forceful reconstruction of neck may prove essential

The Ugly

This variety of giant aneurysms embodies the extremes of each of the negative characteristics already mentioned (**Fig. 13.3**). There is in fact no identifiable neck because the parent vessel terminates into a broad fundus, which in turn gives rise not only to the major arterial branches but also to often critically important perforating arteries. The lesion almost invariably has significant mural calcification and contains variable amounts of thrombotic material of multiple ages. There are two principal varieties of this aneurysm—globoid and fusiform—along with common hybrids combining some of the morphological features of each. These "ugly" aneurysms present less commonly with bleeding than the other two varieties, but they are more frequently symptomatic by virtue of mass effect or ischemia, the latter secondary either to distal embolization or perforator occlusion.

As a rule, this type of aneurysm cannot be successfully reconstructed in the normal sense of the word, meaning to exclude all abnormal tissue from the circulation. Portions of the entire "fundus" are abnormal, often even those areas at the origins of branch and perforating arteries. Thrombus within the aneurysm is frequently circumferential, changing the course of arterial flow with the dynamic deposition/resolution of clot. The first tissue layer beneath this thrombus is an extremely thrombogenic intima–media combination, and scattered or dense intramural calcification frustrates even the most creative surgeon's attempts to remodel the extensive fundus without iatrogenic occlusion of the emerging arterial branches.

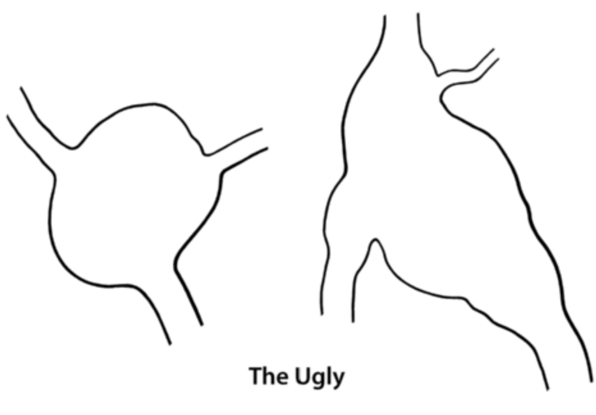


Fig. 13.3 Ugly configurations of large and giant aneurysms.

The therapeutic consequences of these features are as follows:

1. Even protracted proximal occlusion does not render these lesions amenable to clip reconstruction.
2. Aneurysmorrhaphy infrequently is of benefit and runs a serious risk of producing irreversible permanent arterial occlusion.
3. In some cases, planned sacrifice of a major branch artery coupled with an appropriate bypass procedure will permit an adequate clip reconstruction.
4. If endovascular options are not available, Hunterian ligation of the parent artery (with or without distal revascularization) may be a reasonable consideration if the patient is first tested by trial balloon occlusion.
5. Because of the frequent presence of perforating arteries within the aneurysm-bearing segment of vessel, a definitive “trapping” procedure may be disastrous.

Final Thoughts

The surgical treatment of VLG intracranial aneurysms is generally very difficult. Only a small minority of these lesions bear any morphological relationship to the routine small and medium-sized aneurysms surgeons treat with great success every day. The recognized “silver bullets” critical to managing the remainder are few, simple, and frequently inadequate.

1. Make sure you have the skills that may be required for all of the therapeutic options (routine aneurysm exposure and clip ligation, skull base exposures, cervical carotid exposure, donor vessel harvest, microanastomosis).
2. Know everything possible about the patient’s cerebrovascular anatomy and physiology (aneurysm morphology, proximal and distal arterial locations and abnormalities, any other aneurysms, normal collateral sources, toleration of proximal occlusion, blood flow requirements in case of vessel sacrifice, availability of appropriate donor vessels).
3. Have a little more elaborate game plan than the routine: “Let’s just go in there and clip this sucker.”
4. Be flexible: there’s a surprise hidden under every lobe and protrusion. If you can’t adapt on the run with these lesions, you won’t prosper, and neither will your patient.

14

Surgical Management of Previously Coiled Aneurysms

Perhaps we should begin with a general statement regarding the relative merits of microsurgical and endovascular aneurysm treatment. We believe in the optimal situation (ie, these two different approaches are complementary rather than competitive); patients are best served when both treatment modalities are available and the final therapeutic decisions are tailored to best address the specific parameters of individual patients burdened with unique lesions. One size definitely does not fit all when one is dealing with aneurysms, and at University of Texas Southwest (UTSW), the practitioners of each of these modalities are heavily dependent on each other for advice, assistance, and even sometimes for rescue.

It was not too long after the advent of endovascular treatment of intracranial aneurysms in the early 1990s that neurosurgeons began to encounter patients in whom coil embolization had proven inadequate for complete or permanent aneurysm obliteration. In many, the long-term fate of such incomplete therapy was not known, whereas in others, symptoms related to the natural history of the aneurysm itself, mass effect on adjacent structures, or complications related to embolization appeared early in the posttreatment course. Since the emergence and maturation of endovascular techniques, the frequency of these treatment “failures” has markedly decreased, in part because of the dramatic improvements in endovascular technology and in part because there are fewer errors in patient selection by endovascular surgeons, both in our immediate referral base and across North America. As such, endovascular treatment has become the first-line therapy for an increasing proportion of aneurysm patients; however, several patients who require surgical treatment after previous endovascular therapy continue to present themselves. Given that these cases present certain unusual problems with regard to their technical management, we felt a brief chapter dedicated to this issue was appropriate.

General

Operating on a previously coiled aneurysm should generally be avoided for all the reasons that the aneurysm was coiled in the first place, which include patient comorbidities, patient preference, and difficult surgical location. On the other hand, if an aneurysm was coiled out of fear of a "hot brain," which is now resolved, or if based on aneurysm morphology coiling was a misguided decision in the first place, or if attempts at recoiling have failed, surgery may be a practical option. New mass effect symptoms from growth of the previously treated aneurysm, from a new recurrence, or from the coil mass itself may also suggest the need for surgery.

Surgery on a previously coiled aneurysm carries several potential problems not encountered with de novo aneurysm treatment. First, the presence of the coil mass or an intracranial stent may interfere with permanent or even temporary clip placement. Second, the presence of the coil mass also reduces the elasticity of the neck–parent artery interface and thus increases the likelihood that a tear might develop when placing clip(s) across the neck. Finally, in rare cases, the presence of the coil mass may even limit access to the neck of the aneurysm. Nevertheless, with proper patient selection and surgical approach, an open surgical attack may be the patient's best option. If the residual neck is larger than one and a half to twice the height of an aneurysm clip blade, it may be possible to secure the aneurysm without the need to open it or remove the coils. However, when the recurrence is small or the indication for re-treatment is mass effect, trapping the aneurysm, opening and then judicious coil removal may be necessary.

Anatomy

We have treated at least one patient with a partially coiled aneurysm in every location previously mentioned in this text except at the origin of the anterior temporal branch of the middle cerebral artery. The most common previously coiled aneurysm sites re-treated surgically have been the middle cerebral bifurcation, the origin of the ophthalmic artery from the internal carotid, the basilar apex, and the distal anterior cerebral artery. Because the majority of these patients have received their endovascular therapy elsewhere and were then referred to UTSW for consideration of further surgical intervention, a substantial portion of our reoperative experience stems from patients undergoing endovascular coiling at outside institutions. Regardless of origin, in all patients the decision to proceed with microsurgical treatment was made by our own neuroendovascular surgeons because further endovascular management was felt to be either unlikely to result in aneurysm obliteration or to carry more risk than a direct surgical approach. As time has progressed, an increasing number of these patients are being re-treated successfully by endovascular techniques. Besides the patients themselves, no one is happier with this trend than those of us who have had to deal with the peculiar problems posed by previously coiled lesions.

It is almost an axiom at UTSW that, not counting problems with surgical exposure or endovascular access, aneurysms difficult to treat by one modality are very frequently equally difficult to treat by the other. Very small or very large aneurysms, those with extensive necks, incorporation of the parent and branch arteries into the aneurysm's neck/wall, and the presence of intraluminal thrombosis are morphological features that favor neither endovascular nor open surgical treatment. Nevertheless, in many situations the results of the initial intervention may make a "salvage" procedure from the opposite side of the aneurysm wall actually more efficacious and less risky than a virgin operation would have been. Certainly this is not always the case, but if the secondary effort is focused on actually solving the problem at hand rather than making the first guy (and his specialty) look bad, frequently it's surprising how innocuous the definitive operation can be: sometimes not so much.

Approach

One of the important determinants of what the surgeon will find in operating on a partially coiled aneurysm is the length of time from coil embolization to surgery. During the acute postembolization period, the residual patent aneurysm (especially the neck) tends to be quite friable; anchored on one extreme by the parent vessel and on the other by the coil mass, the neck is much less amenable to mobilization—even after temporary arterial occlusion—than in its natural state. This means both neck dissection and clip closure carry greater than routine risks of producing a rent in the aneurysm's wall. The technical implications of this unfortunate fact are twofold:

1. If feasible, a more extensive dissection of the parent and branch arteries and the aneurysm dome should be done to display as much of the aneurysm as possible in all dimensions prior to clip placement.
2. Again, if possible, the clip blades should include a small portion of healthy arterial wall, producing a slight stenosis in the parent vessel at the aneurysm's origin. This will reduce the chance of a "shear" at the junction of aneurysmal and normal tissue as the clip blades close. This is the same concept we've found very effective in dealing with "blister" aneurysms of the anterior or ventral carotid wall.

Incompletely coiled aneurysms operated at a later date have, in our experience, more stable necks, but the fundus of the lesion is generally fused to the surrounding brain, cranial nerves, and vasculature by an intense inflammatory reaction. In many situations, the surgeon will find that the coil mass has actually migrated through the aneurysm wall to lie in the subarachnoid space, where it is densely adherent to whatever anatomical structure has the misfortune to be in the neighborhood. This is especially common when the aneurysm in question is a posteriorly projecting internal carotid artery–posterior communicating artery (ICA-PCOMM) lesion and the adjacent structure is the third cranial nerve (**Fig. 14.1**). In this situation, unlike the protocol for dealing with third nerve palsies and PCOMM aneurysms in their native state, the coil mass must be sharply cut free from the nerve and removed if the palsy is to be cured.

Whether the coil mass remains intraluminal or is in the subarachnoid space, the fundus of an incompletely coiled aneurysm must be frequently mobilized from its attachments, either to permit direct clipping of the neck or to alleviate the mass effect associated with the coil mass. This should always be done sharply under high-power magnification to prevent undue traction on the cranial nerves and vessels involved. When the surgeon deems it necessary to actually evacuate the coil mass, it's important to free up the fundal attachments in the subarachnoid space *prior* to opening the aneurysm and tugging on the coil loops. If the coil mass or fundus is found to be adherent to brain tissue (examples are temporal lobe–PCOMM aneurysms, cingulate gyrus–distal anterior cerebral artery aneurysms, frontal/temporal operculae–middle cerebral artery aneurysms) it is generally simpler to separate the two by a gentle subpial resection.

Based on our experience, there are only two justifications for surgical removal of endovascular coils. The first is to provide room for clip application, a need that is sometimes combined with the need to remove a coil loop protruding into the parent artery. In light of what now appears to be the relatively benign "natural history" of small, stable dog ears left by coil embolization and the now widespread use of stents to deal with protruding loops, this indication should become uncommon in the near future, but there certainly are patients who currently require obliteration of a small residual neck and in whom there is insufficient room for clip placement without producing significant arterial stenosis.

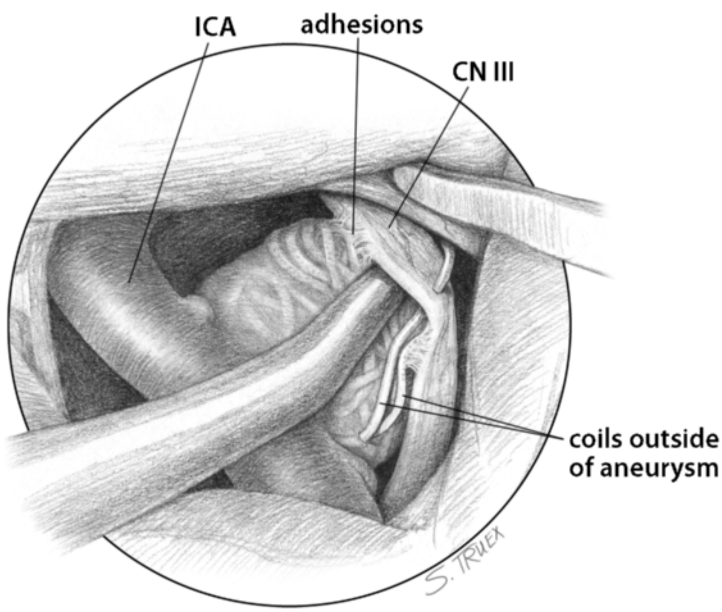


Fig. 14.1 Adherence of exposed coils to neural structure.

The second situation involves partially coiled aneurysms that, by virtue of their size, are producing symptomatic mass effect, generally by pressure on an adjacent cranial nerve. We've seen this on multiple occasions with ICA-ophthalmic aneurysms, and less frequently with ICA-PCOMM and basilar artery–superior cerebellar artery lesions. Occasionally this will occur with giant aneurysms that have invaginated into the brain parenchyma, such as ICA bifurcation, P1–P2 junction, and middle cerebral artery bifurcation, to produce hemispheric neurological deficits.

In the first instance, the surgeon needs another millimeter or two of neck tissue that can be closed with a clip. In the second, theoretically, the more mass that can be safely removed the better. Both situations require temporary trapping of the aneurysm-bearing arterial segment under burst-suppression anesthesia and an acute surgical awareness of the specific goal of coil removal before the aneurysm is opened.

Dissection/Clip Application

To gain additional room for clip placement, we recommend a relatively long incision be made in the aneurysm wall parallel with the axis of the parent vessel and roughly three times the length of desired additional neck. Often, once the surface of the coil mass has been exposed it's possible to place a small dissector between the coils and the aneurysm wall down into the patent neck. At this point, the coils can be gently "compacted" into the fundus, thereby lifting the coil mass first with the dissector and then with the suction tip to free the surgeon's dominant hand. When this maneuver works—and it does most of the time—the surgeon can then slide a clip across the now-exposed neck, carefully remove the temporary clips and, after ensuring patency of the parent and branch vessels, gradually begin to close to the permanent aneurysm clip.

Unfortunately this "compaction" technique is not uniformly successful, but at a minimum it provides ample access to a large surface of the coil mass near its interface with the patent artery neck. At this point, the surgeon needs to remove some of the coil mass to provide additional room for the definitive clip placement—the question is how much? The important answer again is about 2 mm; if the surgeon becomes focused on the somewhat frustrating process of removing the coil mass rather than reconstructing a suitable neck, the surgeon will waste precious minutes of ischemia without accomplishing the ultimate goal until very late in the process.

Beginning at the level of the incision in the aneurysm wall, the surgeon should focus on amputating the very tip of the coil mass that protrudes into the aneurysm neck. This can be done by incising the coil hydra head, usually most effectively with serrated microscissors and carrying that incision circumferentially around the aneurysm neck, which will usually require sequential extension of the opening that has been made into the aneurysm's wall. Don't tug on the cut ends of the coils—just keep cutting until you've shaved off the entire protrusion, which can be removed piecemeal from the expanded neck.

Leave the bulk of the coil mass lodged up in the fundus alone—it's irrelevant to your clip placement, will cost you even more ischemia time, and will bring you nothing but misery if you mess with it (**Fig. 14.2**).

The recommended process for treating a partially coiled aneurysm symptomatic by mass effect is exactly the same as already outlined, except applied to the opposite aspect of the aneurysm. The surgeon's goal here is to eliminate the mass contacting the symptomatic cranial nerve or invaginating deeply into the brain itself; it's definitely not to see how much platinum can be harvested. To that end, the focus should be on the distal aspect of the fundus, where an incision will be made, almost identical to the one described earlier—long, linear, parallel with the long axis of the parent vessel, giving extensive access to the surface of the coil mass in its distal aspect. Again, the coils are cut repetitively with the microscissors (this may be the second set) shaving the mass down a millimeter at a time until the loose shards can be easily evacuated without traction on the aneurysm–cranial nerve interface. It's tedious, frustrating, and hell on your instrument, but you're not subjecting the patient to ischemia and you're not increasing the pressure on the normal neural structures. At the completion of your amputation, it will be necessary to gently and sharply dissect the actual wall of the aneurysm free from the attached cranial nerve to eliminate the foreign body reaction. Once that is done, if you believe more mass should be removed, repeat the shaving process but avoid the temptation to pull on the remaining spaghetti.

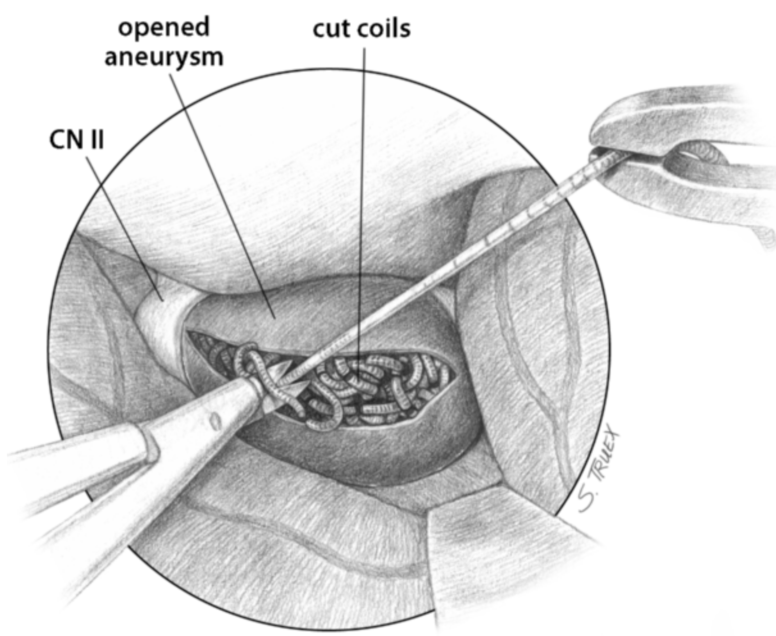


Fig. 14.2 Strategy for removing coils from aneurysm.

Final Thoughts

1. Re-treatment via an endovascular approach should be the first consideration except when the patient presents with mass effect.
2. Allow sufficient exposure not only to have tight proximal and distal control but also to have room to mobilize the aneurysm dome if necessary.
3. Coil removal should be limited to a specific purpose, either to make room for the clip or to relieve mass effect.
4. The most common operative morbidity is tearing the aneurysm neck at its junction with the parent vessel due to the loss of elasticity imparted by the coil mass.

Index

Note: Page numbers followed by *f* indicate figures.