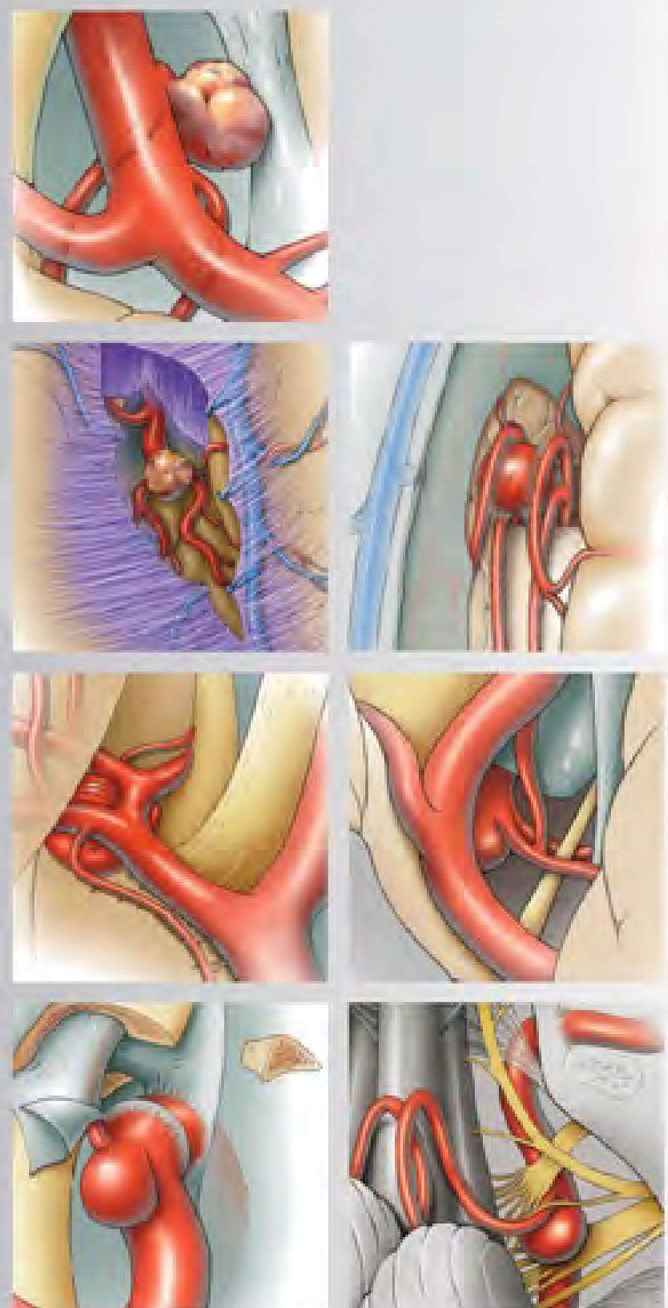
# Seven Aneurysms

## Tenets and Techniques for Clipping

Michael T. Lawton





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*To my sister, Lori Lynn Lawton,*
*whose courageous battle against an anaplastic oligodendroglioma was inspirational,*
*and whose death at age 44 teaches that now is the time to make the most out of life.*

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# Contents

# Foreword

This book is intended to instruct neurosurgeons in the art of performing aneurysm surgery. In one condensed volume, it offers a systematic tutorial to the common aneurysms encountered by neurosurgeons. It is probably as close to a step-by-step description of a process that depends equally heavily on in-depth knowledge of both anatomy and surgical technique and the indefinable quality of surgical finesse as a book will ever be. Trainees, in particular, will long be grateful for Dr. Lawton's clear, concise, and lively descriptions of basic surgical principles, techniques, approaches, and strategies, combined with a generous number of excellent illustrations and intraoperative photographs to underscore his text. This elegant volume by a superb surgeon, in whom I take considerable paternal pride as he did his residency training at Barrow Neurological Institute, is likely to be the standard text for how to clip aneurysms resistant to endovascular approaches for years to come.

*Robert F. Spetzler, MD*
*Phoenix, Arizona*
*May 2010*

# Preface

Endovascular therapy has changed the practice of vascular neurosurgery forever. As the number of aneurysms treated endovascularly grows, the number of aneurysms treated microsurgically shrinks. We are headed toward a future with fewer vascular neurosurgeons, diminishing microsurgical expertise, and possibly the extinction of a surgical art. This book is an attempt to preserve the art of aneurysm clipping. It is designed to impart techniques and nuances to young neurosurgeons and future generations who may have limited open surgical opportunities.

Aneurysms occur at branches or curves in intracranial arteries and, consequently, can be found at more than 20 different locations. Seven of the more common aneurysms were selected for this book: PCoA, MCA, ACoA, OphA, PcaA, basilar bifurcation, and PICA (see **Table P.1**). These seven aneurysms may not be favorable for endovascular therapy (such as an MCA aneurysm or a broad-based basilar bifurcation aneurysm) or may be more favorable for open surgery (such as a ruptured PCoA aneurysm in a 30-year-old patient). No matter how far endovascular techniques and technology advance, some aneurysms will need to be clipped. The seven aneurysms in this book are the ones for which microsurgical clipping should be saved.

In a consecutive, single-surgeon experience with 2500 aneurysms, these seven accounted for three quarters of all aneurysms (**Table P.2**). Therefore, proficiency in managing just these aneurysms will enable vascular neurosurgeons to confidently handle the majority of aneurysms in their practices. AChA aneurysms are anatomically similar to PCoA aneurysms and are clipped with similar techniques; the same is true of SCA and basilar bifurcation aneurysms. Therefore, proficiency in managing the seven aneurysms covered in this book transfers to other aneurysms not covered.

This book is designed as an atlas that is also a textbook. Neurosurgeons learn anatomy, spatial relationships, and operative techniques by studying pictures. However, atlases with sparse text do not convey the thoughts and ideas. Textbooks frequently have too many words and too many contributing authors, resulting in a disjointed collection. This book is written by one author to briefly articulate surgical strategy and distill a decade of experience. This book includes numerous illustrations showing the basics: the common, simple variety of aneurysms, rather than the uncommon, complex aneurysms from the trophy case.

The book is organized in three sections: basic tenets, approaches, and clipping strategies. Tenets are the critical concepts needed to dissect and clip aneurysms, assumed to be understood, but infrequently discussed in depth. Approaches are the craniotomies and exposures needed for these aneurysms. The book culminates with the microsurgical anatomy, dissection strategies, and clipping techniques for each of the seven aneurysms.

The technical challenges and harsh consequences of aneurysm surgery make for a lengthy learning process. It is almost magical to observe a master neurosurgeon who has advanced far beyond his learning curve. His technical prowess is his own and cannot be transferred to others; it cannot be purchased, traded, or preserved. Experience and skill are precious commodities that must be acquired case by case by case. However, experience can be transformed into teachable lessons and insights. The mission of this book is to gather these lessons and insights and pass them on. Hopefully, whatever insight is contained on the following pages will guide other neurosurgeons as they acquire their experience, while also benefiting aneurysm patients and promoting the survival of aneurysm surgery.

**Table P.1 Abbreviations**

| | |
|---|---|
| Arteries | |
| ACA | Anterior Cerebral Artery |
| AChA | Anterior Choroidal Artery |
| ACoA | Anterior Communicating Artery |
| AICA | Anterior Inferior Cerebellar Artery |
| AIFA | Anterior Internal Frontal Artery |
| ATA | Anterior Temporal Artery |
| BA | Basilar Artery |
| CmaA | Callosomarginal Artery |
| FpA | Frontopolar Artery |
| ICA | Internal Carotid Artery |
| IT | Inferior Trunk of MCA |
| LSA | Lenticulostriate Artery |
| MCA | Middle Cerebral Artery |
| MIFA | Middle Internal Frontal Artery |
| MT | Middle Trunk of MCA |
| MTi | Middle Trunk, Inferior |
| MTs | Middle Trunk, Superior |
| OfA | Orbitofrontal Artery |
| OphA | Ophthalmic Artery |
| PCA | Posterior Cerebral Artery |
| PcaA | Pericallosal Artery |
| PCoA | Posterior Communicating Artery |
| PICA | Posterior Inferior Cerebellar Artery |
| PIFA | Posterior Internal Frontal Artery |
| RAH | Recurrent Artery of Heubner |
| SCA | Superior Cerebellar Artery |
| SHA | Superior Hypophyseal Artery |
| ST | Superior Trunk of MCA |
| VA | Vertebral Artery |
| VBJ | Vertebrobasilar Junction |
| Arterial Segments | |
| C1 | ICA, Cervical Segment |
| C2 | ICA, Petrous Segment |
| C3 | ICA, Lacerum Segment |
| C4 | ICA, Cavernous Segment |
| C5 | ICA, Clinoidal Segment |
| C6 | ICA, Ophthalmic Segment |
| C7 | ICA, Communicating Segment |
| A1 | ACA, Precommunicating or Horizontal Segment |
| A2 | ACA, Postcommunicating or Infracallosal Segment |
| A3 | ACA, Precallosal Segment |
| A4 | ACA, Supracallosal Segment |
| A5 | ACA, Postcallosal Segment |
| M1 | MCA, Sphenoidal Segment |
| M2 | MCA, Insular Segment |
| M3 | MCA, Opercular Segment |
| M4 | MCA, Cortical Segment |
| P1 | PCA, Precommunicating Segment |
| P2 | PCA, Postcommunicating Segment |
| P2A | PCA, Crural Segment |
| P2P | PCA, Ambient Segment |
| P3 | PCA, Quadrigeminal Segment |
| P4 | PCA, Calcarine Segment |
| s1 | SCA, Anterior Pontomesencephalic Segment |
| s2 | SCA, Lateral Pontomesencephalic Segment |
| s3 | SCA, Cerebellomesencephalic Segment |
| s4 | SCA, Cortical Segment |
| a1 | AICA, Anterior Pontine Segment |
| a2 | AICA, Lateral Pontine Segment |
| a3 | AICA, Flocculonodular Segment |
| a4 | AICA, Cortical Segment |
| p1 | PICA, Anterior Medullary Segment |
| p2 | PICA, Lateral Medullary Segment |
| p3 | PICA, Tonsillomedullary Segment |
| p4 | PICA, Telovelotonsillar Segment |
| p5 | PICA, Cortical Segment |
| Veins | |
| SSS | Superior Sagittal Sinus |
| ISS | Inferior Sagittal Sinus |
| Bone | |
| ACP | Anterior Clinoid Process |
| PCP | Posterior Clinoid Process |
| SOF | Superior Orbital Fissure |
| Cisterns | |
| AmbC | Ambient Cistern |
| CallC | Callosal Cistern |
| CarC | Carotid Cistern |
| ChiC | Chiasmatic Cistern |
| CruC | Crural Cistern |
| IpC | Interpeduncular Cistern |
| LCmC | Lateral Cerebellomedullary Cistern |
| LTC | Lamina Terminalis Cistern |
| MagC | Cisterna Magna |
| OlfC | Olfactory Cistern |
| PonC | Prepontine Cistern |
| QuadC | Quadrigeminal Cistern |
| SylC | Sylvian Cistern |
| Nerves | |
| CN1 | Olfactory Nerve |
| CN2 | Optic Nerve |
| CN3 | Oculomotor Nerve |
| CN4 | Trochlear Nerve |
| CN5 | Trigeminal Nerve |
| CN6 | Abducens Nerve |
| CN7 | Facial Nerve |
| CN8 | Vestibulocochlear Nerve |
| CN9 | Glossopharyngeal Nerve |
| CN10 | Vagus Nerve |
| CN11 | Spinal Accessory Nerve |
| CN12 | Hypoglossal Nerve |
| Other | |
| CSF | Cerebrospinal Fluid |
| EEG | Electroencephalogram |
| SSEP | Somatosensory Evoked Potentials |
| MEP | Motor Evoked Potentials |
| SAH | Subarachnoid Hemorrhage |
| CT | Computed Tomography |
| ICG | Indocyanine Green |
| IHT | Infra-hypoglossal Triangle |
| SHT | Supra-hypoglossal Triangle |
| Tent | Tentorium |

**Table P.2 Data from the Author's Consecutive, 12-year Experience with 2500 Aneurysms**

| Aneurysms | N | % |
|---|---|---|
| Anterior Circulation | | |
| Cavernous ICA | 25 | 1% |
| * PCoA | 319 | 13% |
| AChA | 98 | 4% |
| Supraclinoid ICA | 86 | 3% |
| ICA Bifurcation | 76 | 3% |
| * MCA | 631 | 25% |
| ATA | 27 | 1% |
| * ACoA | 519 | 21% |
| * PcaA | 53 | 2% |
| * OphA | 132 | 5% |
| SHA | 28 | 1% |
| Posterior Circulation | | |
| * Basilar Bifurcation | 139 | 6% |
| SCA | 39 | 2% |
| PCA | 51 | 2% |
| Basilar Trunk | 29 | 1% |
| * PICA | 85 | 3% |
| VA | 21 | 1% |
| Miscellaneous | 142 | 6% |
| Total Aneurysms | 2500 | 100% |
| *Seven Aneurysms | 1878 | 75% |

# I The Tenets

# 1 Under the Microscope

## The Microscope

The operating microscope is the neurosurgeon's most important tool. It illuminates the operative field, magnifies anatomy, and gives constant visual feedback. Skillful dissection depends on seeing all relevant anatomy and controlling every maneuver, and the microscope empowers us by enhancing sight well beyond the physiologic limit of unaided eyes. However, this unwieldy piece of equipment must be adapted to our individual anatomy and move fluidly with our movements. A finely tuned microscope extends visual perception with imperceptible effort. Therefore, the microscope must be tuned before every case, checking the microscope stand, mouthpiece, oculars, chair, and foot pedals.

The microscope can move fluidly with the neurosurgeon because the counterbalancing stand makes it weightless. Brakes in the stand's joints hold the microscope's position, but the microscope floats when the brakes are released. The microscope must be balanced precisely to keep it from drifting, tipping, or feeling heavy. The microscope balances optimally when the stand's vertical and horizontal beams are at right angles. A stand that overreaches or collapses on itself will drift despite being balanced properly. Therefore, the stand should be positioned beside the patient's head at an appropriate site and distance to achieve this right angle.

## The Mouthpiece

Some who have used the mouthpiece abandon it after a short trial, saying that it is awkward, uncomfortable, and causes gagging. Those who persist in using it find that they can no longer operate without it. The mouthpiece unlocks the microscope's potential, allowing the neurosurgeon to constantly focus and refocus without using hands, thereby increasing operative pace and efficiency. If the microscope is the tool that enables neurosurgeons to see, then the mouthpiece is the tool that enables them to see clearly. It releases the stand's vertical brakes to make fine adjustments that bring the operative target into focus. The target depth changes constantly during the dissection, particularly at high magnification, and the microscope must follow. The mouthpiece enables these adjustments to be made with small head movements without having to put down instruments, change the focal length, or interrupt the rhythm of surgery. The head moves naturally to areas of interest, whereas foot movements on the pedals are not a natural way to refocus. The mouthpiece is not meant for major changes in the microscope's orientation; these movements still require the use of two hands to release all brakes.

The mouthpiece must be carefully fitted with the fixed, upper plate of the mouth switch lying below and in contact with the upper two front teeth. Each neurosurgeon has a unique distance between the interpupillary line and the inferior edge of the front teeth. Another setting adjusts the anterior-posterior position so that it sits comfortably in the mouth. The switch is activated by biting the lower plate with the lower teeth, thereby releasing the stand's brakes and moving the microscope. The line of sight into the ocular lenses must be maintained with both the biting motion and the head movement to maintain visual feedback; the mouthpiece is not properly set if biting the mouth switch compromises vision. Releasing the mouth switch relocks the microscope into the desired position.

Ocular lenses are adjusted for interpupillary distance, length of the tube, and diopters. An inaccurate interpupillary setting can compromise binocular vision. A tube length that is too long can shadow or constrict the visual field, and one that is too short can rub the nose against the ocular's bridge. The diopter setting is individualized to avoid visual straining during long procedures.

## The Chair

Microsurgery is performed best with the neurosurgeon sitting comfortably. This has nothing to do with strength or stamina; sitting in a chair with armrests allows us to relax our hands. Dexterity is necessary for microsurgical proficiency, and it improves when there is no contractile tone in our arm and forearms. The height of the armrest is adjusted to slouch the shoulders slightly and brace the forearms and wrists. The seat height is adjusted relative to the table height to dangle the hands above the operative field with slight wrist flexion. Most chairs allow the arm rests to be angled up or down, and rotated inward or outward. When these adjustments have been made, the armrests are secured tightly. The hands are in optimal position when almost no muscle tone is needed to hold the instruments in the surgical field. A setup that requires wrist extension or any antigravity tone may induce tremor. The movement needed to control the instruments is minimal and comes from the fingers. Armrests alone should stabilize and relax the hands, but the hypothenar eminence or an extended fifth finger can also be used. Gently setting the hands on the edge of the field can further relax the hands.

The chair should roll freely in the space under the microscope. Subtle shifts in body position are necessary to align the hands to the surgical field and keep them relaxed. Power cords and cables are routed behind the chair to keep them from getting in the wheel track and limiting the chair's mobility.

## The Foot Pedals

Microsurgery is performed best at high magnification, requiring constant zoom adjustments with the foot pedal while keeping the hands free to dissect. One foot is dedicated to controlling the microscope's zoom, and the other is dedicated to controlling bipolar cautery. Good chairs have integrated zoom and focus controls that minimize clutter underfoot. Otherwise, the microscope's foot box is placed at the base of the chair. The mouthpiece minimizes the need for focusing with the foot control. The pedals should be positioned comfortably underfoot to be ready at any time and to relax the legs, which helps keep the body core and hands relaxed.

These adjustments and settings are a prerequisite for any aneurysm operation. Performing the various steps described here becomes routine, and they can be done quickly. When fully adjusted, the microscope is tuned to our bodies and moves fluidly with our movements, which keeps the focus on dissecting and clipping the aneurysm.

# 2 Subarachnoid Dissection

## The Subarachnoid Cisterns

The subarachnoid space is the arena of aneurysm surgery because it houses the brain's arteries and provides a navigable labyrinth to deep targets that can be dissected without violating or harming the brain. Subarachnoid dissection, therefore, is a foundation of vascular neurosurgery.

The subarachnoid space is compartmentalized into cisterns built with sheets of arachnoid tissue, bridged by internal arachnoid trabeculations, and filled with cerebrospinal fluid (CSF) (**Fig. 2.1**). Subarachnoid dissection opens and interconnects these cisterns en route to an aneurysm. Intercommunication between cisterns also drains CSF and untethers lobes and lobules of brain, thereby relaxing the brain, facilitating retraction, and widening surgical corridors. Every aneurysm is associated with a cistern. Middle cerebral artery (MCA) aneurysms reside in the sylvian cistern; posterior communicating artery (PCoA) and ophthalmic artery (OphA) aneurysms reside in the carotid cistern; anterior communicating artery (ACoA) aneurysms reside in the lamina terminalis cistern; pericallosal artery (PcaA) aneurysms reside in the callosal cistern (**Fig. 2.2**); basilar

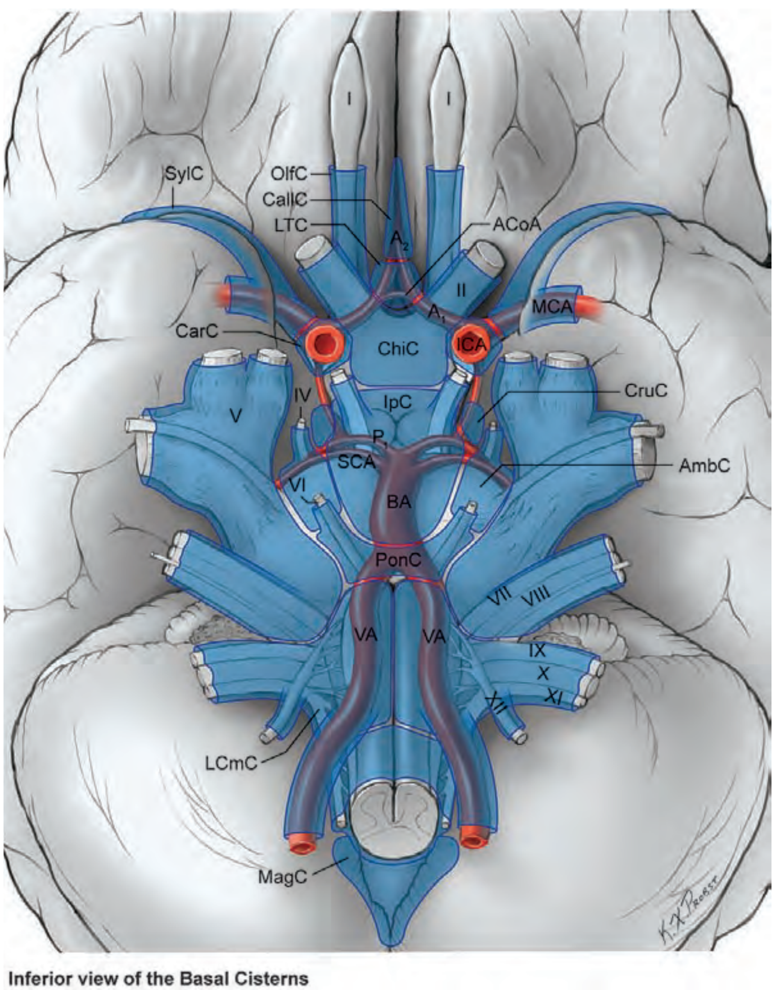



**Fig. 2.1** Basal subarachnoid cisterns, as viewed from beneath the brain. Middle cerebral artery (MCA) aneurysms reside in the sylvian cistern; posterior communicating artery (PCoA) and ophthalmic artery (OphA) aneurysms reside in the carotid cistern; anterior communicating artery (ACoA) aneurysms reside in the lamina terminalis cistern; pericallosal artery (PcaA) aneurysms reside in the callosal cistern; basilar bifurcation aneurysms reside in the interpeduncular cistern; and posterior inferior cerebellar artery (PICA) aneurysms reside in the lateral cerebellomedullary cistern. AmbC, ambient cistern; BA, basilar artery; CallC, collosal cistern; CarC, carotid cistern; ChiC, chiasmatic cistern; CruC, crural cistern; LCmC, lateral cerebellomedullary cistern; LTC, lamina terminalis cistern; MagC, cisterna magna; OlfC, olfactory cistern; PonC, prepontine cistern; SylC, Sylvian cistern.

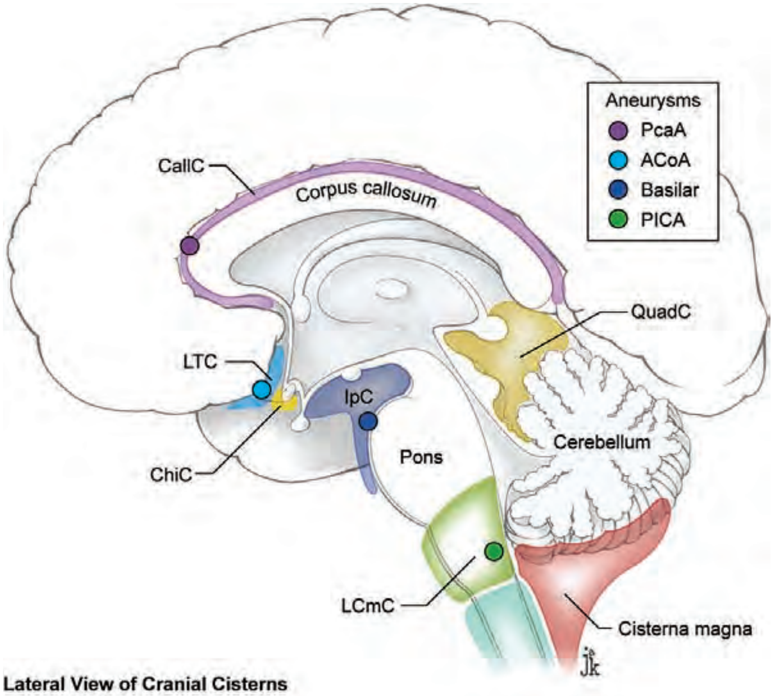



**Fig. 2.2** Midline subarachnoid cisterns, as viewed in the sagittal plane of the brain. The relationship between midline and paramedian aneurysms and their associated cisterns is shown. QuadC, quadrigeminal cistern.

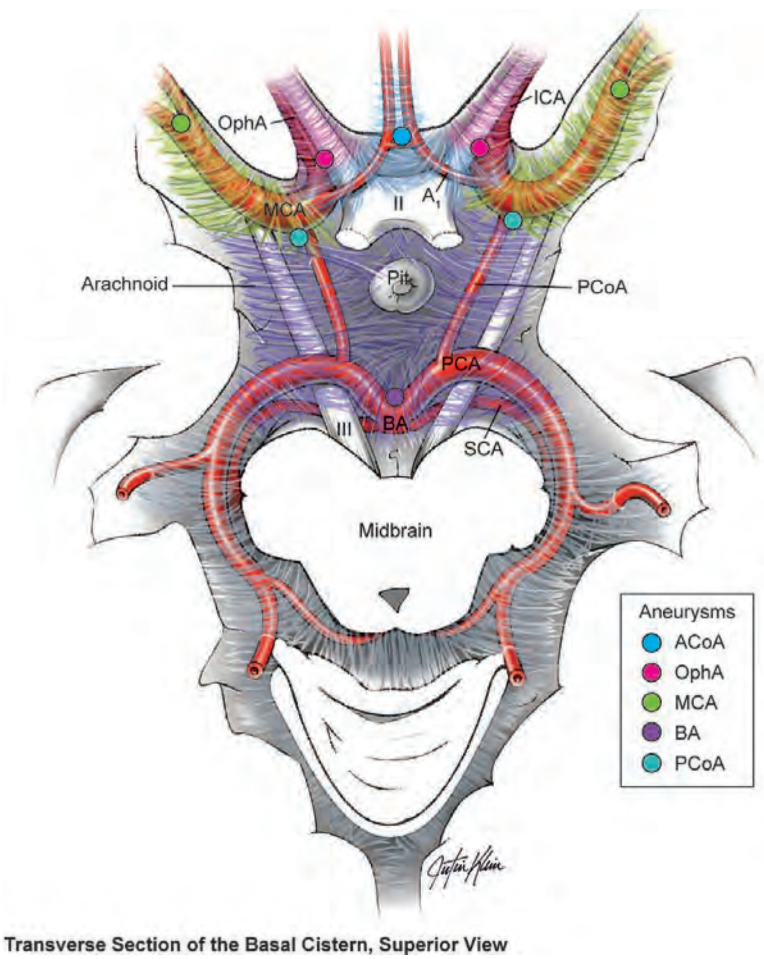



**Fig. 2.3** Subarachnoid cisterns around the circle of Willis, as viewed from above the brain, which has been sliced axially. The relationship between aneurysms in the circle of Willis and their associated cisterns is shown.

bifurcation aneurysms reside in the interpeduncular cistern (**Fig. 2.3**); and posterior inferior cerebellar artery (PICA) aneurysms reside in the lateral cerebellomedullary cistern and sometimes in the cisterna magna. The pathway to some aneurysms traverses several cisterns. For example, the pathway to ACoA aneurysms progresses from carotid to chiasmatic to lamina terminalis cisterns, and the pathway to basilar bifurcation aneurysms progresses from sylvian to carotid to lamina terminalis to crural to interpeduncular cisterns (**Fig. 2.4**). Most of an aneurysm's initial dissection has nothing to do with the aneurysm, and instead deconstructs cisternal architecture to open fissures, separate brain surfaces, and expose normal arterial anatomy.

## Arterial Landmarks

Arteries define a trail through the center of the subarachnoid space that can be dissected continuously from the cortical surface to the circle of Willis. A single cortical artery invariably guides the dissection inward to larger branches and deeper trunks. Arteries are obvious in patients with unruptured aneurysms, untainted CSF, and clear cisterns. However, arteries in patients with subarachnoid hemorrhage (SAH) are buried in dense clot and require some excavation. Clot can be evacuated safely by suctioning outward from an arterial landmark, rather than suctioning inward toward an unidentified artery. Arteries lie centrally in subarachnoid spaces and therefore define the plane of separation between pial surfaces. Larger caliber arteries are identified as the dissection deepens. The angiogram is like a trail map, and angiographic information is translated constantly to the operative field.

Every artery has a safe surface to follow during subarachnoid dissection. Safe surfaces have smooth contours and few branches, whereas dangerous surfaces have perforating arteries, the aneurysm neck, or are poorly visualized (**Fig. 2.5**). For example, the superior surface of the M1 MCA segment gives off lenticulostriate arteries, and dissection along this surface can injure them. In contrast, the inferior surface of the M1 segment gives rise to the anterior temporal artery (ATA), which is easily seen and less vulnerable. Similarly, the superior surface of the P1 posterior cerebral artery (PCA) segment has thalamoperforators and leads directly to the neck of a basilar bifurcation aneurysm, whereas the inferior surface has no perforators. In addition, multiple perforating arteries close the dissection plane between artery and brain. Therefore, an artery's safe surface is dissected preferentially.

Careful subarachnoid dissection should never require division or sacrifice of a small arterial branch. Branches travel

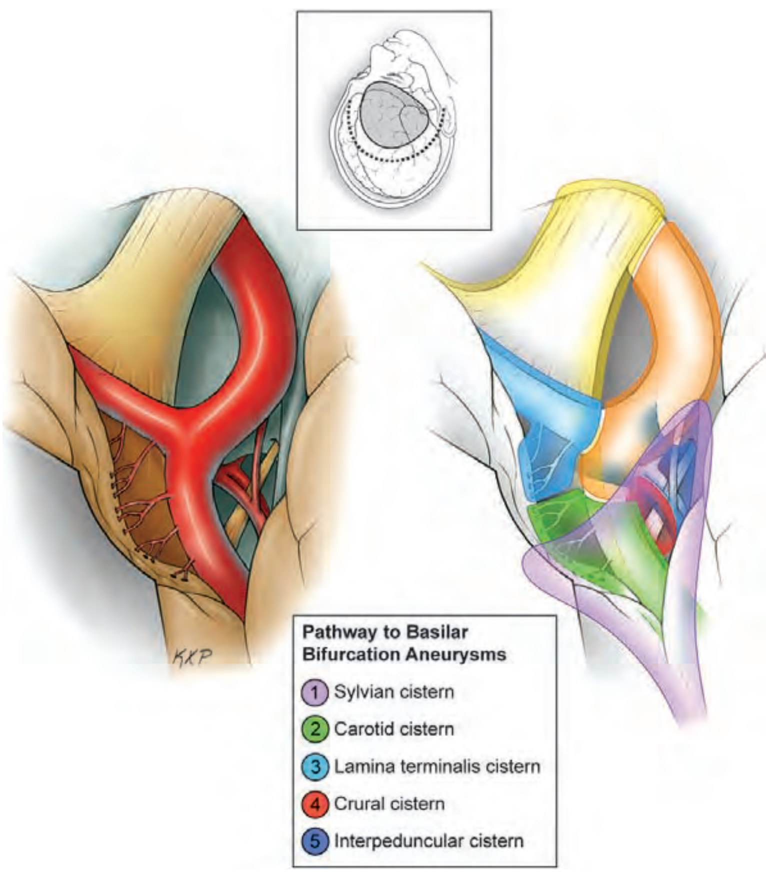



**Fig. 2.4** Pathway of subarachnoid dissection to the basilar apex begins with splitting the sylvian fissure (1) and opening the carotid cistern (2). The lamina terminalis cistern (3) is opened to mobilize the frontal lobe and fenestrate the lamina terminalis, thereby releasing cerebrospinal fluid (CSF) and relaxing the brain. Dissection along the anterior choroidal artery (AChA) opens the crural cistern (4) to detach the medial temporal lobe and facilitate retraction. Finally, the membrane of Liliequist is opened and the interpeduncular cistern (5) is entered to reach the basilar bifurcation aneurysm.

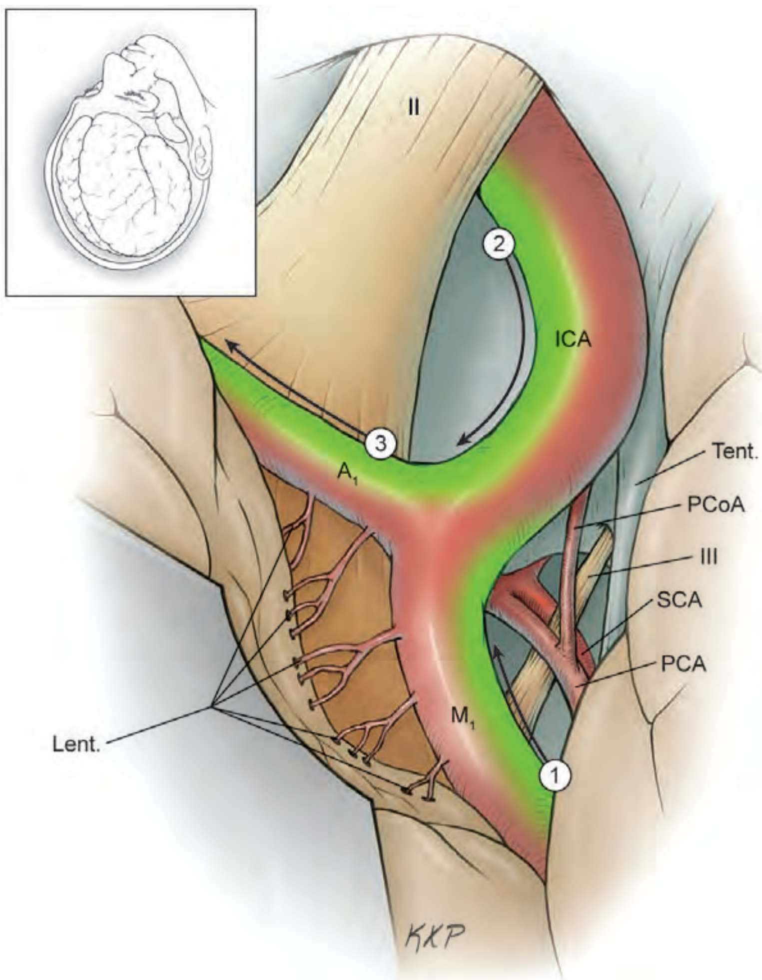



**Fig. 2.5** Every artery has a safe surface to follow during subarachnoid dissection, with smooth contours, few branches or perforators, and opposite the aneurysm neck. The superior surface of the M1 MCA segment gives off lenticulostriate arteries, and dissection along this surface can injure them, but the inferior surface of the M1 segment is safe. Similarly, the superior surface of the supraclinoid internal carotid artery (ICA) and the inferior surface of the A1 anterior cerebral artery (ACA) segment are safe sides for dissection. Lent., lenticulostriate arteries; ON, optic nerve; PCA, posterior cerebral artery; SCA, superior cerebellar artery.

to the brain they supply and can be mobilized in that direction, but sometimes the course may be indirect. Inspection from origin to destination will determine how to mobilize the artery. As a general rule, arteries supply only one lobe and therefore can be swept to that lobe safely. For example, an MCA branch that is adherent to the temporal lobe may appear, at first glance, to send branches to both the temporal and frontal lobes, but thorough dissection may demonstrate a loop that adheres to the temporal lobe but continues to supply the frontal lobe. This artery can be mobilized frontally.

## Dissection Technique

Subarachnoid dissection consists of three basic maneuvers with three simple instruments: cutting with microscissors, spreading with bipolar forceps, and probing with a slightly curved dissector (Rhoton No. 6 dissector; Codman; Raynham, MA). Microscissors incise and open cisternal walls. Blunt probing breaks apart many of the arachnoid webs inside cisterns and identifies resistant bands that require cutting. Subarachnoid tissues cut cleanly when under slight tension, which can be applied with the tip of the sucker or a fixed retractor. Microscissors blades surround the tissue precisely and under full visualization. The deep scissors blade lifts arachnoid away from underlying arteries and veins before cutting it, turning the microscissors into not only a cutting instrument but also a dissecting instrument that sets up its cuts.

Spreading dissection bluntly separates pial planes and opens fissures because pinched bipolar forceps have a gentle opening force that can be applied to brain tissues. Bipolar forceps are aligned parallel to arteries and parallel to pial surfaces, which in turn aligns the forceps' opening force perpendicular to these brain surfaces. The opening force is distributed across a wide area of tissue to gently spread them apart. Bipolar forceps should not be aligned perpendicular to the arteries because the instrument's opening force will not distribute to opposing brain surfaces and its tips might dig into the brain. The microscope and chair must be oriented to bring the bipolar hand and instrument into this parallel alignment. Spreading dissection is useful for splitting tight fissures in swollen brains, like the sylvian or interhemispheric fissures after SAH.

Blunt dissection with a Rhoton No. 6 instrument helps probe anatomy, develop a feel for tissue planes, and mobilize arteries and nerves. This instrument is an extension of one's index finger, and it allows the neurosurgeon to develop natural lines of dissection along arteries. Tight interfaces between arteries, veins, and arachnoid can be opened and enlarged safest with blunt dissection, transitioning to sharp dissection as these interfaces widen. Back-and-forth movements parallel the arachnoidal planes and avoid displacement of neural tissues. For example, the plane between the optic nerve and the inferior frontal lobe is opened with side-to-side movements of the Rhoton No. 6, rather than up-and-down movements. Subarachnoid dissection cycles from blunt to sharp to spreading dissection, and back around again. The Rhoton No. 6 and bipolar forceps each have a discrete function, but the microscissors is more versatile. Closed microscissors can be used as a probing dissector, and carefully opening microscissors can perform spreading dissection. The complex art of subarachnoid dissection reduces to basic maneuvers with a few instruments. A simple routine enables the neurosurgeon to develop an efficient rhythm to the dissection.

Subarachnoid dissection remains “outside” of the brain by respecting and preserving pial boundaries. Pia is delicate, and subpial transgression can cause brain injury, swelling, and contusions. Safe subarachnoid dissection also remains outside of the vessels, respecting and preserving the arteries and veins that course through the cisterns. The neurosurgeon's touch must be gentle and precise as he or she works between these boundaries. Developing the right touch is the biggest challenge with subarachnoid dissection.

# 3 Brain Retraction

## Retraction Without Retractors

Brain retraction is bad. It can raise brain tissue pressure, reduce cerebral perfusion locally, hide critical anatomy, and injure neurovascular structures. However, subarachnoid corridors of the brain are often too narrow to be navigated without some retraction. Therefore, it needs to be applied discriminately and with finesse.

The sucker and suction hand have an underappreciated role as a roving retractor. While drying the surgical field, the sucker also applies countertraction at the point of dissection with its tip and gentle pressure to the brain with its shaft. The bullet-tipped No. 7 or No. 5 microsuction is smooth and atraumatic. Suction strength is regulated by rolling the thumb forward to cover the keyhole fenestration at the thumb grip for more suction, or backward to uncover the fenestration for less suction. The thumb rests in a middle position that partially covers the hole, and a constant whistling noise should be heard at all times. When the whistling disappears, the thumb may be covering the fenestration and suction may draw in adjacent structures. The sucker is malleable; the shaft is straightened to follow the dissection plane and curved gently to the hand. Connecting the sucker to soft silicone tubing keeps it mobile in the hand, whereas stiff plastic tubing creates resistance.

A properly adjusted sucker naturally complements the dissecting instrument. These instruments lie directly opposite one another at the depth of the field; the sucker provides microretraction for each maneuver of the dissecting instrument, and, unlike a fixed retractor blade, the sucker adjusts constantly to the dissection. Lateral pressure with the sucker provides countertraction when cutting tissue, and retracts tissues to facilitate visualizing the dissection plane. The sucker can cross to the side of the dissecting instrument to apply contralateral pressure. A dynamic suction hand substantially reduces the need for a fixed retractor.

In addition to microretraction with the sucker tip, the sucker shaft can function as a slim retractor blade. Instead of positioning the shaft in the dissection corridor, laying the shaft against the brain gently retracts it and opens the corridor like a funnel. The position of the tip is not affected by this lateral hand movement. Like sucker tip retraction, shaft retraction is also dynamic and adapts to the changing needs of the dissection. Dissecting instruments in the dominant hand, like the microscissors or bipolar forceps, can also function as retractors. The shafts of these instruments can retract their side of the surgical corridor by gently lying against brain, opening the other side of the funnel. Some dissection maneuvers do not allow the microscissors or bipolar forceps to double as retractors, but most maneuvers allow the shaft to pivot around the instrument's tips and generate some retraction pressure.

## Retraction with Retractors

Fixed brain retractors are used very sparingly. A basic Greenberg retractor system has two C-clamps that attach to the Mayfield head holder with their posts pointing toward the vertex and the seated neurosurgeon, and with the C-clamps fixed as close to the surgical field as possible. Clamp posts in this position eliminate the need for extender bars that clutter the working area. The Greenberg retractor is mounted on the posts with the flexible arm arcing up from beneath the surgical field in a gentle curve. Greenberg arms that arc down from above the field often interfere with the hands and can be bumped. Retractor blades that are rounded across their width have a more gentle pressure profile against the brain. The blade length from tip to shoulder is minimized to lower clearance above the brain. The brain is irrigated and covered with Telfa strips to keep the blades from directly touching brain.

Retractors should "hold" brain tissue that has already been thoroughly dissected. Extensive preliminary dissection minimizes any "pull" on brain tissue. Maneuvers that slacken the brain also minimize retraction pressure, like evacuating cisternal cerebrospinal fluid (CSF), fenestrating the lamina terminalis, opening the membrane of Liliequist to communicate with posterior fossa cisterns, and lowering external ventricular drains. Lumbar drains are not used during aneurysm surgery because other points of access to CSF are readily available. Mannitol (1 g/kg) is routinely given to dehydrate brain tissue, and Decadron (10 mg) is given to minimize edema from retraction.

The tip of the retractor blade does most of the retractor's work, lifting a lobe or placing arachnoid tissues on stretch. The blade's width at the tip is narrow for precision, but wide enough to distribute retraction pressure. The blade's shoulder gently lays into the brain and opens the working corridor like a funnel. A blade whose shoulder is not angled back will close the mouth of the working corridor and limit maneuverability of the instruments.

## Mobilizing Brain

Retractors move brain, but brain prefers not to be moved. Therefore, the amount of retraction is minimized by skull-base approaches that remove bone along the skull base instead. Drilling the sphenoid wing with the pterional approach or the occipital condyle with the far lateral approach widens the surgical corridor under the brain and reduces retraction. Gravity also minimizes retraction. Patient and head position with some approaches will eliminate the need for retractors, like the anterior interhemispheric approach performed with the patient's head turned laterally 90 degrees and gravity retracting the dependent hemisphere. Similarly, gravity pulls down on the cerebellum during a supracerebellar-infratentorial approach performed with the patient in the sitting position, opening the plane to the pineal region, ambient cistern, and midbrain. Even with more basic approaches like the pterional approach, head extension allows gravity to open the plane between the anterior skull base and inferior frontal lobe, and head rotation vertically aligns the sylvian fissure to allow gravity to pull the frontal and temporal lobes to opposite sides of the fissure.

An escape hatch must be prepared during the craniotomy for brain that will be mobilized later. For example, retraction of the temporal lobe during the transsylvian-pretemporal approach to the basilar bifurcation requires drilling the temporal squamosal bone inferiorly until it is flush with the middle fossa floor, and posteriorly beyond the zygomatic root. Without this egress, retraction would compress temporal lobe against a ledge of bone. Mobilized brain needs complete freedom from arachnoid adhesions that might resist retraction. For example, arachnoid of the sylvian cistern couples the frontal and temporal lobes and resists frontal retraction; arachnoid of the chiasmatic cistern tethers the frontal lobe and optic nerve and resists frontal retraction; and arachnoid of the crural cistern couples the deep frontal and temporal lobes and resists temporal lobe retraction. Subarachnoid dissection removes this resistance before placing a retractor.

Small arteries can also resist retraction. The anterior temporal artery (ATA) can adhere to the temporal lobe; the recurrent artery of Heubner can adhere to the inferior frontal lobe; and the posterior inferior cerebellar artery (PICA) can adhere to the cerebellar tonsil. Failure to release these adhesions can injure or avulse the artery during retraction. Arteries should not be placed behind a retractor blade because they can be occluded by retraction pressure; they should remain in full view and the dissection should progress around them. Retraction can injure bridging veins, particularly those at the temporal pole, tentorium, and interhemispheric fissure. Bridging veins are preserved whenever possible, but aneurysm exposure can sometimes require their sacrifice. Some veins are sacred because they have scant collateral connections and their sacrifice can cause venous infarctions, including veins along the middle third of the superior sagittal sinus (SSS) and the vein of Labbé. Other veins can be taken because of their extensive collateral connections, including the temporal polar vein bridging to sphenoparietal or cavernous sinus, and superior cerebellar and vermian veins bridging to tentorial sinuses. Failure to sacrifice a bridging vein can result in its avulsion with retraction, which can cause brisk bleeding from a venous sinus and be difficult to control. When a vein must be divided, it should be interrupted only at one point to preserve its retrograde connections to collateral veins. Arachnoid granulations also resist retraction. Granulations along the dura of the middle cranial fossa floor and along the SSS can be avulsed with retraction of the temporal pole and medial frontal lobe, respectively. It is easier to release these adhesions before retracting than to chase venous bleeding after retracting.

Most importantly, retraction can avulse an aneurysm's dome. Aneurysms with intraparenchymal hemorrhage often adhere to that portion of brain. Other aneurysms have notorious points of attachment: a superiorly projecting ophthalmic artery aneurysm adheres to the frontal lobe; an inferiorly projecting anterior communicating artery (ACoA) aneurysm adheres to the optic nerve or chiasm; and a laterally projecting posterior communicating artery (PCoA) aneurysm adheres to the temporal lobe. Retraction early in the dissection of these aneurysms can precipitate intraoperative rupture before establishing proximal control or identifying the aneurysm. These specific retraction moves are avoided with their respective aneurysms. In general, the safest retraction with a ruptured aneurysm is a retraction that is avoided completely.

# 4 Vascular Control

## Contingency Planning

A reality of aneurysm surgery is that the technical skill and surgical experience do not eliminate the risk of intraoperative aneurysmal rupture. The dangerous combination of aneurysm fragility and surgical manipulation sometimes precipitates rupture, and the neurosurgeon must prepare for this catastrophe. Vascular control is a simple concept: afferent arteries that supply antegrade blood flow to an aneurysm, and efferent arteries that might supply retrograde blood flow, are exposed for occlusion with temporary clips. In practice, vascular control can be difficult because of limited operative exposure, anatomic obstacles, or interfering aneurysm domes.

Successful aneurysm management begins with the development of a systematic contingency plan. With each case, before entering the operating room, the neurosurgeon must envision intraoperative disaster in every conceivable form and then develop strategies to deal with it. Forethought enables the neurosurgeon to prepare the patient, exposing the patient's neck for proximal carotid control or suction decompression, harvesting a donor vessel for possible bypass, or inserting a groin sheath for intraoperative angiography. Forethought reminds the neurosurgeon early during the dissection to gain proximal and distal control, preselect temporary and permanent clips, and protect the brain with barbiturates. Forethought replays in the neurosurgeon's mind the microsurgical maneuvers to control aneurysmal rupture: direct tamponade with a cottonoid, suction, temporary clipping, trapping, and permanent clipping of the aneurysm. Deliberate thoughts about disaster permeate the operation, readying the neurosurgeon and the operative team for a swift response. Negative thoughts are usually suppressed by surgeons, but must be addressed. Over time, this process of contingency planning becomes instinctive, and the microsurgical mechanics of the rupture response become almost a reflex. Still, we must always pause to consider the elements of vascular control that lie outside of the immediate surgical field to prepare them in advance.

## Proximal Control

Points of proximal control are identified preoperatively on angiography, exposed early, and prepared thoroughly enough to place a temporary clip under duress or under blood. Points of proximal control include the ophthalmic segment of the supraclinoid internal carotid artery (ICA) for posterior communicating artery (PCoA) aneurysms, the M1 segment for middle cerebral artery (MCA) aneurysms, the bilateral A1 segments for anterior communicating artery (ACoA) aneurysms, the A2 segment for pericallosal artery (PcaA) aneurysms, the cervical ICA for ophthalmic artery aneurysms, the basilar trunk for basilar bifurcation aneurysms, and the intradural vertebral artery (VA) for posterior inferior cerebellar artery (PICA) aneurysms. Some aneurysms have additional proximal supply that can feed an aneurysm, like retrograde flow in PCoA with PCoA aneurysms, or retrograde flow in ophthalmic artery (OphA) with OphA aneurysms.

Special moves are needed with some aneurysms to gain proximal control. The falciform ligament can be cut to move proximally on the ICA for proximal PCoA and some OphA aneurysms. The genu of the corpus callosum can be resected to expose the A2 segment for PcaA aneurysms. The posterior clinoid process can be removed to expose the basilar trunk for control of basilar bifurcation aneurysms. The extradural VA can be exposed to control PICA aneurysms that abut the dural ring. There is a range of proximal control, from proximal-proximal control to distal-proximal control. Proximal-proximal control may be distant from the aneurysm and enable collateral arteries to supply it (e.g., cervical ICA occlusion with ophthalmic aneurysms). In addition, temporary occlusion at more proximal points can compromise blood flow in perforators that lie between the temporary clip and the aneurysm (e.g., proximal M1 segment occlusion and diminished perfusion of lenticulostriate arteries with MCA aneurysms). Distal-proximal control adjacent to the aneurysm is usually more complete and preferable.

A dome that lies between the neurosurgeon and the point of proximal control can rupture en route to proximal control. This dangerous relationship exists with inferiorly projecting MCA aneurysms that block the M1 segment, inferiorly projecting ACoA aneurysms that block the contralateral A1 segment, anteriorly projecting basilar bifurcation aneurysms that block the basilar trunk, and anteriorly projecting pericallosal aneurysms that block the A2 segment. The dissection path veers more proximally around these aneurysm domes, or alternatively reroutes to the distal side of the aneurysm. For example, the M1 segment of an inferiorly projecting MCA aneurysm often arcs superiorly and can be accessed from behind the aneurysm, following the superior trunk from distal to proximal to arrive at M1 segment. Similarly, the contralateral A1 segment of an inferiorly projecting ACoA aneurysm often arcs superiorly and can be accessed from behind the aneurysm, following ACoA across to the contralateral A1-A2 junction. Subtle anatomic relationships between proximal arteries and aneurysms domes often dictate dissection strategy. Proximal control gives the neurosurgeon the confidence for the dissection to progress and should be established as early as possible.

## Distal Control

Temporary occlusion of efferent branch arteries is only needed in certain situations: persistent back-bleeding after intraoperative aneurysm rupture controlled with temporary clips on all proximal arteries; persistent aneurysm turgor after temporary occlusion of proximal arteries that prevents aneurysm collapse or further dissection; aneurysm trapping for suction decompression; and deliberate opening of the aneurysm for deflation, thrombectomy, or coil extraction. The ease of gaining distal control depends on aneurysm location and is often inversely related to the ease of proximal control. For example, the proximal control of VA is straightforward with most PICA aneurysms, but the distal VA vanishes into the depths of the exposure and is obscured by lateral medulla. Conversely, the distal PcaA and the callosomarginal artery (CmaA) may be easy to control for most PcaA aneurysms, but the proximal A2 segment may vanish below the genu and rostrum of the corpus callosum. As with proximal control, points of distal control are identified preoperatively on angiography, exposed early, and prepared thoroughly enough to place a temporary clip under duress or under blood. Their exposure does not occur as early as that for points of proximal control. Distal control occurs naturally because dissecting efferent arteries is part of defining an aneurysm neck. Distal control can be challenging when efferent arteries are hidden behind the dome of an aneurysm (like the inferior trunk with laterally projecting MCA aneurysms, or the contralateral A2 segment with superiorly projecting ACoA aneurysms), or when they are deep in the surgical field (like the contralateral P1 segment with some basilar bifurcation aneurysms). As with proximal control, dome avoidance is critical.

## No Control

In some cases, vascular control may be inaccessible. A low-lying basilar bifurcation aneurysm may have a basilar trunk that remains out of reach despite drilling away the posterior clinoid process and the dorsum sella. A calcified, atherosclerotic ICA harboring a PCoA aneurysm may be accessible, but the proximal parent artery wall may not collapse with temporary clipping. Inability to gain control may be disquieting enough to halt the operation. Contingency plans may need to be activated, such as exposing the cervical ICA to control the PCoA aneurysm on the atherosclerotic ICA or deploying a balloon-tipped catheter to temporarily occlude the basilar trunk to control the low-lying basilar bifurcation aneurysm. More elaborate measures, such as using hypothermic circulatory arrest for an uncontrolled basilar bifurcation aneurysm, may require aborting the operation and revising the surgical plan. Alternative therapies, such as endovascular therapy, might have increased appeal at these moments. The neurosurgeon faces a choice between establishing vascular control, aborting the operation, or continuing without control. If the decision is to proceed without vascular control, the dissection must focus on the aneurysm neck and meticulously avoid the dome, and the surgeon must be ready to place a permanent clip if the aneurysm ruptures prematurely.

# 5 Temporary Clipping

## Final Dissection

Temporary clips are used occasionally to control an intraoperative aneurysm rupture, but more often to finish aneurysm dissection and prepare it for permanent clipping. Aneurysm dissection proceeds in an orderly sequence from controlling afferent arteries, finding efferent arteries, and dissecting the neck. Inevitably, this orderly progression is disrupted by the aneurysm dome. A dome that blocks the line of sight will conceal critical aneurysm anatomy in a surgical blind spot. Most of the dissection is performed in open surgical corridors with visible aneurysm anatomy; final dissection is performed in surgical blind spots after all visible anatomy has been prepared. Seeing into a surgical blind spot typically requires mobilizing the aneurysm. Pushing on the aneurysm's base adheres to the policy of dome avoidance, but can avulse a fragile, tethered dome or dislodge a clot at the rupture site. Alternatively, the policy of dome avoidance can be ignored during final dissection, de-tethering and mobilizing the dome to see around it. A turgid, pulsatile aneurysm moves only with great force, whereas a softened aneurysm moves easily. Therefore, temporary clipping enables the neurosurgeon to manipulate the aneurysm aggressively and visualize hidden anatomy.

Temporary clipping is also used for potentially dangerous moves that have nothing to do with surgical blind spots or dome manipulation. An efferent artery stuck to the side of an aneurysm may be completely visible, but peeling this artery off the side wall and developing this cleavage plane may tear into a thin aneurysm wall. These risky maneuvers are deliberately saved for the final dissection. Similarly, delicate perforators stuck to the back of an aneurysm must allow passage of a clip blade. The cleavage plane is developed best with gentle traction on a softened aneurysm, pulling it away from the adherent perforator. Aneurysm traction widens the plane and adhesions are cut under tension. Aneurysm traction relieves a deflected perforator, rather than distorting it further. Temporary clipping and aneurysm softening give the neurosurgeon confidence for these risky moves.

## Extent of Temporary Clipping

One temporary clip proximally is often all that is needed for the final dissection. Aneurysms with only one afferent artery, such as middle cerebral artery (MCA) and basilar bifurcation aneurysms, soften dramatically with a single temporary clip. Aneurysms with contrast jetting into it on preoperative angiography also soften dramatically with a single temporary clip. Aneurysms with several afferent arteries do not slacken with one temporary clip and require additional clips. Ophthalmic artery aneurysms can backfill from the posterior communicating artery (PCoA) or ophthalmic artery (OphA) despite cervical internal carotid artery (ICA) occlusion; an anterior communicating artery (ACoA) aneurysm can cross-fill from the contralateral A1 segment despite ipsilateral A1 segment occlusion; and basilar bifurcation aneurysms can fill from the contralateral PCoA despite occlusion of basilar trunk. The extent of temporary clipping is individualized according to afferent artery anatomy and how much softening is needed.

Distal temporary clips on efferent arteries together with proximal temporary clips on afferent arteries trap the aneurysm and arrest its flow, which may be necessary when final dissection calls for deliberately opening an aneurysm. Thrombotic aneurysms may require thrombectomy to debulk its mass and clip the neck; coiled aneurysms may require removal or mobilization of coils to clip the neck; and giant aneurysms may require suction decompression. Suction decompression takes aneurysm softening one step further, collapsing the aneurysm through an afferent artery outside the cranial field (such as the cervical ICA for an ophthalmic artery aneurysm), through the aneurysm dome with direct puncture, or endovascularly through a balloon-tipped catheter. Suction decompression quickly removes blind spots and greatly facilitates permanent clipping, but it requires complete aneurysm trapping to keep the aneurysm from re-expanding with blood. The aneurysm must also be soft and collapsible, which may not be the case with elderly patients and atherosclerotic aneurysms.

## Neurosurgeon Efficiency

Temporary clipping has disadvantages too. The clip consumes precious space around the aneurysm and can interfere with deep dissection. Interruption of blood flow can cause brain ischemia, depending on the extent of temporary clipping and collateral circulation. Changes in somatosensory or motor evoked potentials may be observed and may elicit warnings from the neurophysiologist. There appears to be a direct relationship between aneurysm softening and brain ischemia: dramatic softening with temporary clipping is often followed quickly by signs of ischemia.

Unquestionably, temporary clipping adds time pressure and stress to the final dissection. Cerebral protection with barbiturates extends patient tolerance to temporary clipping, and so does raising blood pressure. However, neurosurgeon speed is most important. Technical steps during the final dissection must be clear. Contingency plans must be reviewed in advance. Instruments and permanent clips should be preselected. Preparation translates into surgical efficiency. The precious few minutes of final dissection after the temporary clips are applied are the crux of the operation, when exposure is optimized, the aneurysm is slack, risky moves must be made, and the outcome is determined. An aneurysm's tolerance to mobilization is never clear, and a bold maneuver that might cause a catastrophe is not natural for surgeons. However, delicacy vanishes as one appreciates the difficulty of seeing an aneurysm's blind side and the high cost of missing a deep perforator. Intraoperative rupture may be our biggest fear because it causes bleeding and demands an immediate solution. Perforator infarcts may not hurt us in the operating room, but ultimately they have no solution. Performing comfortably under pressure and becoming aggressive with aneurysms is a gradual process. The key to becoming aggressive with aneurysms is the temporary clip. The temporary clip pressures the surgeon to complete the task, but signals the right time to battle the aneurysm.

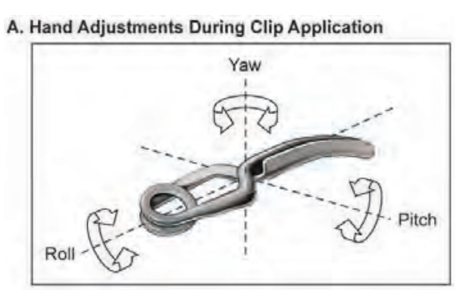
# 6 Permanent Clipping

## Clip Application

Applying a permanent clip on an aneurysm neck is like landing an airplane, requiring just the right "yaw, pitch, and roll" (**Fig. 6.1A**). Pitch refers to the slope of the clip appliers; yaw refers to the side-to-side rotation of the clip appliers about a vertical axis; and roll refers to the side-to-side rotation of the clip appliers about the instrument's axis. Adjustments are made by the wrist while the hand and fingers stabilize the appliers, squeeze it to open the clip blades, and gently release pressure when the clip is in position. With small, sessile aneurysms, downward pressure may also be required as the clip is released.

Permanent clip application demands complete visualization from start to finish, from the introduction of permanent clips into the field to their release from the appliers. Both sides of the aneurysm neck, both clip blades, and the adjacent anatomy are brought into one panoramic view by shifting the microscope, decreasing the zoom, and adjusting retractors. Clip appliers obstruct an established line of sight if they enter the surgical corridor along or near the line of sight; a 15- to 30-degree difference between the appliers' line and the sight line is needed to visualize the blades on the aneurysm neck (**Fig. 6.1B**). The appliers' line is often fixed by the aneurysm anatomy, which requires shifting the microscope to offset the sight line. Clip application should not proceed without complete visualization.

Rhoton introduced four rules about aneurysms: aneurysms arise at branching sites on the parent artery, which may be a side branch or a bifurcation (rule 1); aneurysms arise at turns or curves in the outer wall of the artery where hemodynamic stress is greatest (rule 2); aneurysms point in the direction that blood would have gone if the curve at the aneurysm site was not present (rule 3); and each aneurysm is associated with a set of perforating arteries that needs to be preserved (rule 4). According to rule 1, the clip should be applied perpendicular to the afferent artery and parallel to the efferent branches with bifurcation aneurysms (e.g., middle cerebral artery [MCA] and basilar bifurcation aneurysms). According to rules 2 and 3, the clip is applied parallel to the parent artery with aneurysms at curves (e.g., ophthalmic artery [OphA] and superior hypophyseal artery [SHA] aneurysms). According to rule 4, the clip is applied parallel to the line of perforators across an aneurysm base (e.g., anterior communicating artery [ACoA] and basilar bifurcation aneurysms). Not every aneurysm conforms to Rhoton's rules, but analyzing aneurysm anatomy from this perspective helps envision the repair and select appropriate clips.



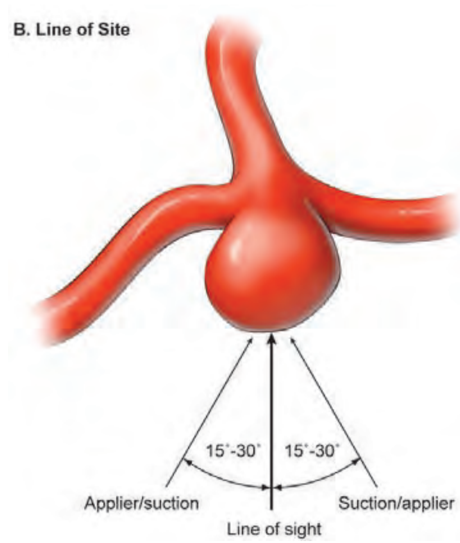




**Fig. 6.1** **(A)** Clip application requires adjusting the yaw, pitch, and roll of the clip. Pitch refers to the slope of the clip appliers; yaw refers to the side-to-side rotation of the clip appliers about a vertical axis; and roll refers to the side-to-side rotation of the clip appliers about the instrument's axis. **(B)** Permanent clip application demands complete visualization of the aneurysm neck, both clip blades, and adjacent anatomy. A line of sight is established that brings these together in one panoramic view. The working line of the clip appliers must be 15 to 30 degrees off of the sight line of the microscope to preserve the view. The appliers' line is often fixed by aneurysm anatomy, which requires shifting the microscope to offset the sight line.

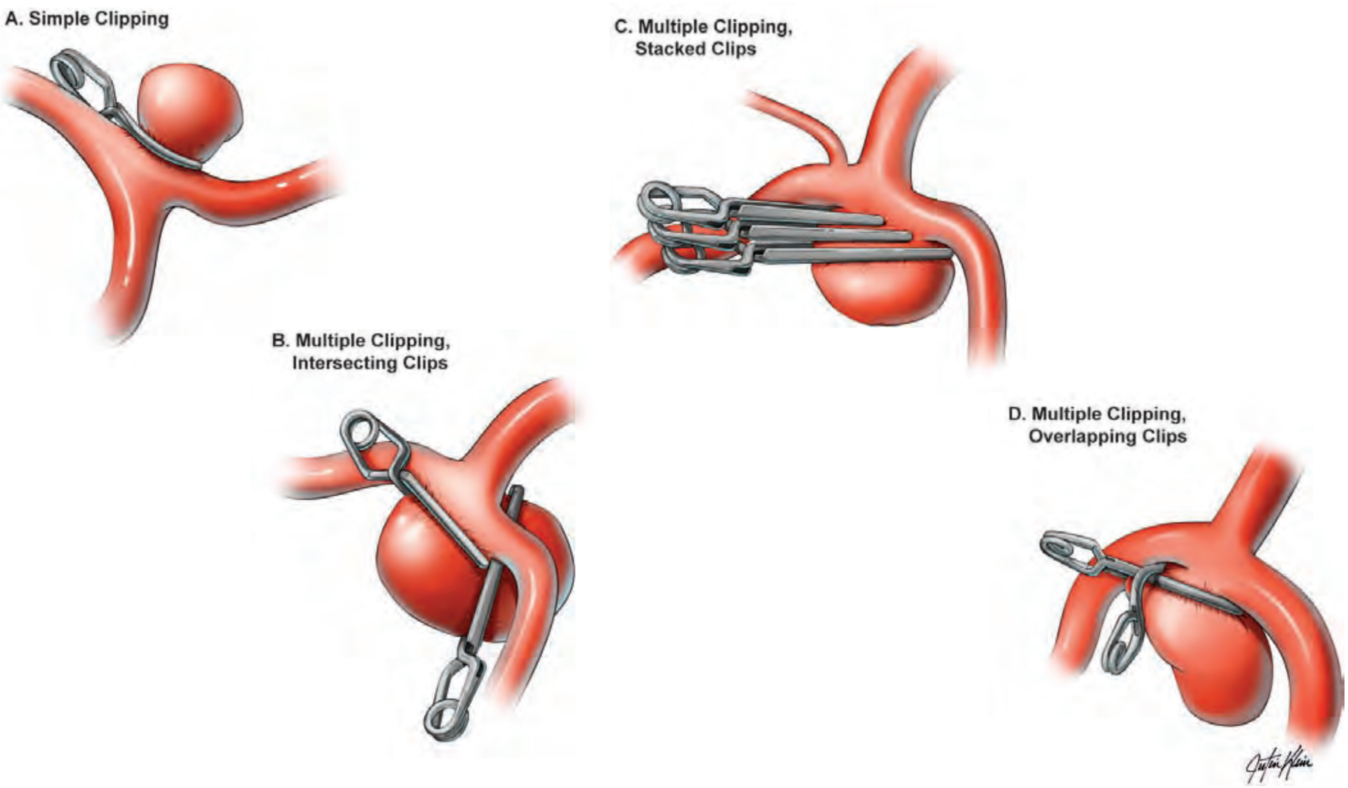



**Fig. 6.2** Basic clipping techniques. **(A)** Simple clipping with a single clip. **(B)** Multiple clipping with intersecting clips. **(C)** Multiple clipping with parallel stacked clips. **(D)** Multiple clipping with an overlapping fenestrated clip closing the posterior lobe of aneurysm.

## Simple Clipping

A basic rule of aneurysm clipping is "simple is best." Simple clipping uses a single clip, usually with aneurysms that are small, have narrow necks, and uncomplicated anatomy (**Fig. 6.2A**). Reliance on a single clip requires the perfect clip size, contour, and configuration. The part of the blade that matters is the part that crosses the neck. Small, deep aneurysms in tight surgical corridors, such as at the basilar apex, may still require long clip blades that move back the clip's coiled spring and keep the head of the appliers from obstructing the line of sight.

## Multiple Clipping

Simple clipping may not be possible with aneurysms that are large, have broad necks, and complex anatomy. These aneurysms require multiple clips, which close an aneurysm neck in sequential steps, progressing from deep neck to near neck and tackling the most difficult, inaccessible part first. Multiple clips can contour the neck reconstruction to match the anatomy of the neck and efferent arteries. Multiple clipping strategies are common and include intersecting clips, stacked clips, and overlapping clips.

Multiple clipping with *intersecting clips* uses a second clip angled into an initial clip, with its tips intersecting the blade or heel of the initial clip at an acute, right, or obtuse angle (**Fig. 6.2B**). Intersecting clips can be simple, such as two straight clips in a T-configuration, or complex, such as multiple straight clips that converge like leaves of a camera's aperture. *Stacked clips* are applied parallel to each other (**Fig. 6.2C**). The initial clip typically closes most of the aneurysm, and tips of subsequent clips precisely contour the remnant beneath the initial clip (understacking). When the initial clip is applied near the neck but does not adequately reconstruct it, subsequent clips stacked above it will complete the closure (overstacking). Stacked clips are all applied in the same direction, which facilitates clipping in tight surgical corridors where the appliers cannot be maneuvered to intersecting angles. Understacking precisely contours the origins of efferent arteries as they exit the aneurysm's base, and understacking with mini-clips eliminates tiny dog-ear remnants. An *overlapping fenestrated clip* can be applied over an initial straight clip at various angles to close a distal neck remnant beneath the initial clip (**Fig. 6.2D**). This overlapping clip reconstruction encircles the initial clip blade, bringing the heel of the fenestrated clip blade against the straight clip blade.

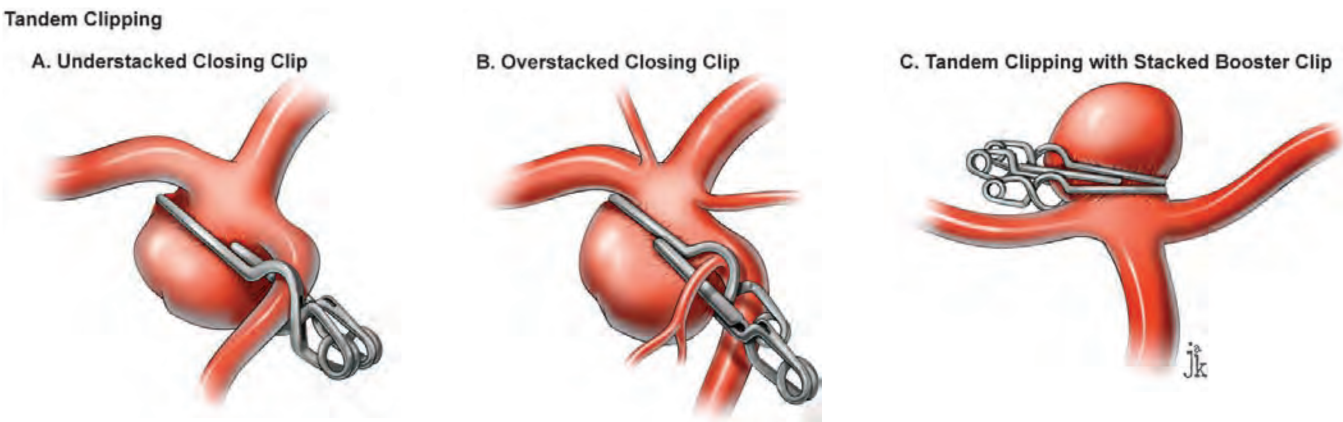



**Fig. 6.3** Tandem clipping techniques. **(A)** Tandem clipping with an understacked closing clip. **(B)** Tandem clipping with an overstacked closing clip. **(C)** Tandem clipping with an overstacked closing clip and a stacked fenestrated booster clip to reinforce the closure at the distal neck.

## Tandem Clipping

Tandem clipping is a technique developed by Drake that uses a straight fenestrated clip to first close the distal aneurysm neck, and then shorter, simple clips to close the proximal neck encircled by the fenestration (**Fig. 6.3**). This ingenious technique effectively closes larger aneurysm necks because the closing force of fenestrated clips is maintained distally near their tips. This clip gathers aneurysm tissue and collapses the neck to visualize deep anatomy. The shorter clips used to close the fenestration contour the reconstruction of the near neck and preserve efferent arteries there. Tandem clipping with an *understacked* clip closes the aneurysm neck below the fenestration, and tandem clipping with an *overstacked* clip closes the aneurysm neck above the fenestration. Tandem clipping with fenestrated clips is superior to simple clipping with longer clips because longer clips can splay at the tips and allow the aneurysm to refill.

## Tandem Angled Fenestrated Clipping

Tandem angled fenestrated clipping is a technique developed by Sugita that uses multiple angled fenestrated clips applied sequentially across a broad neck projecting away from the neurosurgeon, as in many paraclinoid internal carotid artery (ICA) aneurysms (**Fig. 6.4**). This technique typically uses 90-degree angled clips with large fenestrations and blades of varying lengths, curves, and deviations. The clips are aligned with the blade tips in the same direction, and applied toe to heel, progressing from deep neck to near neck. *Tandem counterclipping* techniques align the blade tips in opposite directions, and can be applied toe to toe *(facing)* or heel to heel (*cross-wise*). Tandem angled fenestrated clips should overlap at their interface with the adjacent clip; clips that simply meet at their interface may permit the aneurysm to refill at these points.

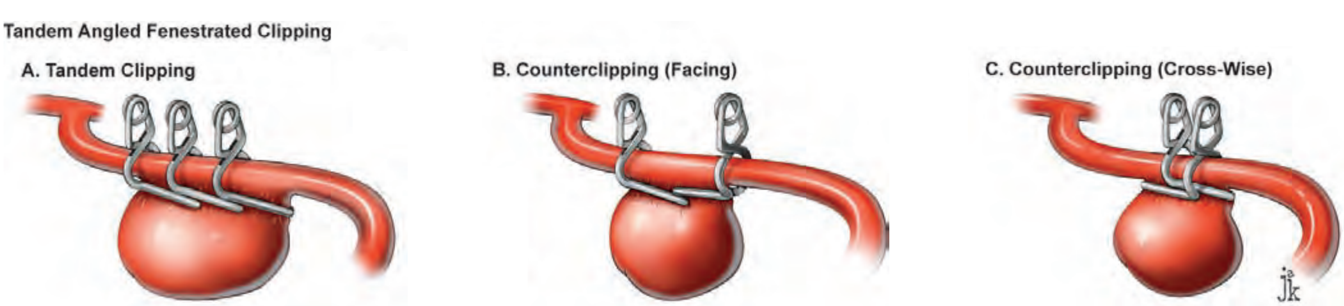



**Fig. 6.4** Tandem angled fenestrated clipping. **(A)** Tandem angled fenestrated clipping with right-angled fenestrated clips placed heel to toe, all in the same direction. **(B)** Counterclipping with facing right-angled fenestrated clips placed toe to toe (facing). **(C)** Counterclipping with crossing right-angled fenestrated clips placed heel to heel (cross-wise).

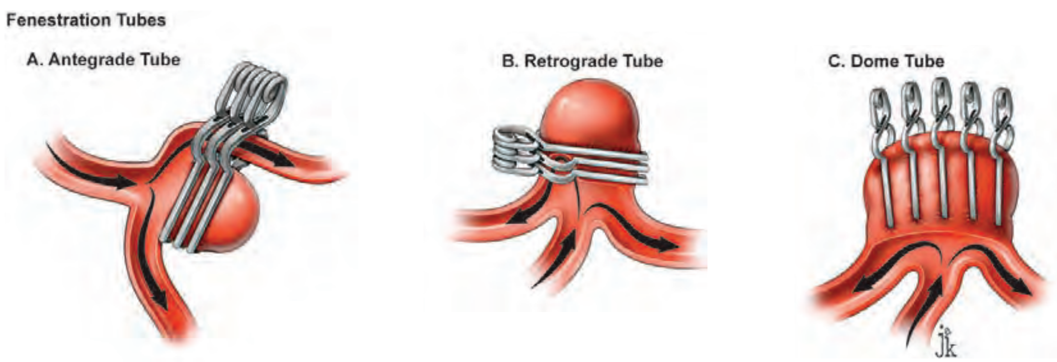



**Fig. 6.5** Clipping techniques with fenestration tubes. **(A)** Antegrade fenestration tube with stacked straight fenestrated clips transmitting an efferent artery with flow antegrade through the tube. **(B)** Retrograde fenestration tube with stacked straight fenestrated clips transmitting an efferent artery with flow retrograde through the tube. **(C)** Dome fenestration tube with stacked straight fenestrated clips over the aneurysm dome with the tips reconstructing and contouring the neck.

## Fenestration Tubes

Straight fenestrated clips can be stacked to close an aneurysm neck and create a tube that reconstructs an efferent artery. These fenestration tubes can be built in three configurations named for the direction of blood flow in the tube (antegrade or retrograde), or the part of the occluded aneurysm in the tube (dome) (**Fig. 6.5**). An *antegrade* fenestration tube builds an open tube oriented perpendicular to the blades and transmits blood flow through the tube antegrade to the efferent artery. A *retrograde* fenestration tube builds a closed tube that turns around its blood flow and redirects it to an efferent artery coursing from the aneurysm's base. A *dome* fenestration tube does not transmit an efferent artery and instead fenestrates the aneurysm dome. The dome tube is built with stacked straight fenestrated clips perpendicular to the aneurysm neck (rather than parallel to the neck as with other constructs), enabling the tips rather than lengths of the blades to reconstruct the neck. Clipping with fenestration tubes is another microsurgical technique that can be used to treat aneurysms with large or giant size, efferent arteries that adhere to the aneurysm, or unusual branch anatomy.

## Clip Reconstruction

Permanent clipping sometimes requires deliberately entering an aneurysm. The neck of a thrombotic aneurysm can be softened with thrombectomy; the neck of a recurrent aneurysm with coil compaction can be softened by mobilizing coils out of the blade pathway; the clipping of some giant aneurysms can be simplified by decapitating the aneurysm. These maneuvers leave a gaping hole in the aneurysm and require a reconstructive repair (**Fig. 6.6**). Techniques for clip reconstruction are selected from the same menu as other aneurysms, but clip reconstruction can be more difficult for

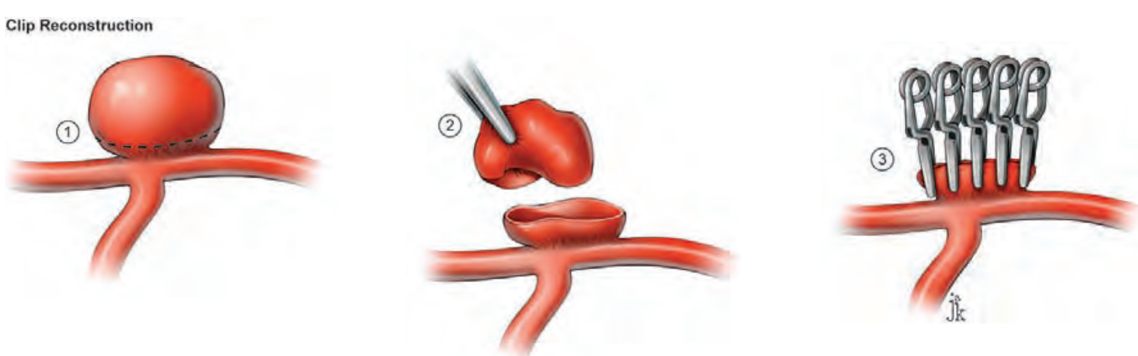



**Fig. 6.6** Clip reconstruction technique. (1) The fundus of an unclippable aneurysm is transected (*dashed line*). (2) The aneurysm is opened and it neck is simplified. (3) The neck is then reconstructed and contoured with stacked straight clips, in this case applied perpendicular to the aneurysm neck.

the following reasons: incomplete proximal and distal control with back-bleeding; adherent perforators and branch arteries that require mobilization; difficulty in reconstructing a neck after transecting the aneurysm; and atherosclerotic tissue at the neck. These reconstructions are performed under the pressure of ongoing ischemia. Unexpected problems must be solved quickly because the brain can be reperfused only after an opened aneurysm has been closed completely. Therefore, opening an aneurysm may facilitate its occlusion and appeals to the neurosurgeon's instinct to attack the aneurysm directly, but it is fraught with uncertainty, tension, and risk. Thrombectomy works best when only a limited debulking is necessary. Concentric thrombotic aneurysms with thin layers of thrombus at the neck require only modest thrombectomy to soften and clip the aneurysm. The same may be true with lobulated and coiled thrombotic aneurysms. Eccentric thrombotic aneurysms with clippable necks may still require thrombectomy to slacken the aneurysm fundus, enable the clips to close the neck, and prevent their migration onto the parent arteries.

# 7 Inspection

## Look, Listen, and Feel

Clipping an aneurysm can be such a relief that it is tempting to consider the operation over. However, post-clipping inspection is an important part of aneurysm dissection. Clipped aneurysms can be aggressively de-tethered, mobilized, and deflated. The added visualization from these maneuvers enables mistakes to be caught.

Inspection checks seven points: (1) aneurysm occlusion; patency of the (2) parent artery, (3) efferent branches, (4) perforating arteries, and (5) adjacent arteries; (6) no neck remnant beneath the clips; and (7) surgical blind spots. The inspection sequence is ordered. A dome should not be mobilized to explore a blind spot until complete aneurysm occlusion is confirmed; additional mini-clips should not be applied to a small neck remnant if primary clips need an adjustment to open an occluded branch.

Visual inspection is most informative: swirling blood is no longer seen through the aneurysm wall; intraluminal red blood cells settle to blanch the aneurysm; afferent and efferent arteries are red and pulsating; the entire path of each clip blade is free of perforators; and clip tips pass beyond the deep portion of the neck. Palpation with a Rhoton No. 6 dissector (Codman; Raynham, MA) on the aneurysm confirms complete clipping when the instrument is still and persistent filling when the instrument pulsates. Auscultation with a Doppler flow probe assesses the patency of critical arteries.

Other adjuncts take post-clipping inspection to another level of sophistication. Indocyanine green (ICG) videography is quick and easy, and it addresses aneurysm occlusion and arterial patency; however, it can only check what is visible through the microscope, and will miss errors that lie outside the field of view. Intraoperative angiography checks arterial anatomy beyond what is visible through the microscope, but it is more complicated and time-consuming than ICG videography, and consequently its use is decreasing.

Neurophysiologic monitoring can detect problems with blood flow in large branch arteries and small perforating arteries to motor and sensory tracts. Somatosensory evoked potentials (SSEPs) measure conduction along the dorsal columns, brainstem, thalamus, and primary sensory cortex. Motor evoked potentials (MEPs) measure conduction along the corticospinal tract, the anterior horn cells, peripheral nerves, and muscle after cortical stimulation. Ischemia resulting from imperfect clip application may produce electrophysiologic changes that lead to the identification of a technical error not detected by inspection. Imperfect clip application can be avoided with most anterior circulation aneurysms because operative exposure is excellent. However, complex aneurysms at the basilar artery apex often do not permit panoramic inspection. Perforators are at greatest risk of occlusion and they hide so well behind the distal neck. Even intraoperative angiography fails to visualize these perforators because of their small size. Missed perforators can cause devastating infarctions in the thalamus, internal capsule, and midbrain, which make neurophysiologic monitoring especially beneficial with basilar artery aneurysms.

A well-clipped aneurysm that passes inspection is punctured away from the neck, just in case it bleeds and an additional clip needs to be stacked. Deflation facilitates the exploration of surgical blind spots and the search for technical errors.

## Persistent Aneurysm Filling

Persistent aneurysm filling is the most common problem, and incomplete distal neck occlusion is the most common reason. This spot is difficult to see because it is furthest from the neurosurgeon and the view is tangential. When applying the clip, the microscope is oriented to bring both sides of the neck and both clip blades into one panoramic view down the blades. The relationship between the blade's tips and the end of the aneurysm neck is difficult to assess from this tangential perspective. An oblique perspective is better, but it sacrifices the view of the other side of the neck, which is unacceptable during clip application. However, this perspective is acquired easily and safely during inspection.

"Ovalization" may also explain persistent aneurysm filling at the distal neck. The circular neck of an aneurysm elongates between clip blades as it is closed by the clip. Mathematically, an aneurysm's original neck width (W) is equal to the diameter of this circle. With clipping, the aneurysm's circumference ($W \times \pi$) is compressed and flattened into two equal lines as the walls of the neck are opposed. Therefore, the new clipped neck width ($W_c$) is equal to half the circumference of the aneurysm [$W_c = (W \times \pi)/2 = 1.5 \times W$]. In other words, the clipped neck width ($W_c$) is 50% longer than the unclipped neck width. As the neck ovalizes, aneurysm tissue is pushed forward and sometimes beyond the clip's tips. This unsecured neck is addressed by advancing the clip or replacing it with a longer clip.

Aneurysms that continue to fill despite well-placed clips that pass beyond the distal neck may not be completely closed at the tips. The weakest part of a straight clip is its tip. In addition, aneurysm tissue between the proximal blades can splay the distal blades, in the same way that a foot in the doorway on the hinge side opens the door wider than a foot in the doorway on the knob side. Splaying is difficult to appreciate visually because the problem is often due to atherosclerosis, calcifications, thrombus, or other intraluminal irregularities. Tandem clipping fixes this problem. A fenestrated clip encircles tissue at the near neck that might splay the tips, and it maintains high closing forces at the blades' tips. After securing the distal neck, the proximal neck is closed with additional clips.

Persistent aneurysm filling can result from incomplete occlusion of the proximal neck with a fenestrated clip. Simple fenestrated clipping is used when an efferent artery lies between the neurosurgeon and the near neck. There is a delicate balance between completely closing the proximal neck with the heel of the blades and compromising the caliber of the artery in the fenestration. This spot can be difficult to see, and imperfections in the clip application might allow aneurysm filling. A simple straight clip might be stacked across this opening, working on either side of the efferent artery. Alternatively, a stacked fenestrated clip with the heel of the blades pulled back will close the leak in the proximal neck, with the fenestrations forming a tube that transmits the efferent artery. This antegrade fenestration tube is useful with adherent arteries that cannot be freed from the aneurysm wall, sparing the neurosurgeon dangerous dissection along a fragile aneurysm wall and difficult repairs when this wall is torn.

The booster clip is an additional clip stacked above the initial clip that reinforces the neck closure at a site of persistent filling. It is often a fenestrated clip that closes strongly at its tips, frequently at the distal neck when the initial clip cannot be advanced. Booster clips can be applied at the interface between two adjacent clips to overlap a site of persistent filling.

## Branch Occlusions

Unintended branch artery occlusions can cause devastating strokes. Clips should ride high on the neck and generously reconstruct the efferent arteries, particularly with atherosclerotic aneurysms and those with aberrant branch angles. These aneurysms have thickened walls and branches that appear to be patent after clipping when viewed externally, but may be narrowed internally with compromised blood flow. ICG videoangiography is particularly useful with these aneurysms.

Clips applied to broad-based, dolichoectatic, and giant aneurysms can slide down the neck and occlude parent and branch arteries. Intraluminal thrombus and coils can hold aneurysm walls apart and transform the neck into a dangerous wedge than can also slide clips down the neck and occlude arteries. A poorly placed clip or one that has migrated can be used as a “tentative clip.” The natural reaction to a poorly applied clip occluding the parent artery is to remove it immediately. However, by leaving it on, it can serve as a scaffold that guides the stacking of permanent clips above it, keeping them off the parent artery. After these permanent clips are secured, the tentative clip is removed and the parent artery reopens. A tentative clip can be used for vascular control when the usual proximal or distal control is inaccessible and the aneurysm needs to be deflated or mobilized. If branch arteries remain occluded, permanent clips should retreat progressively from the neck until patency of the trunks is restored. Aneurysms that continue to slide permanent clips down the neck may require suction decompression, thrombectomy, coil mobilization, or transection to simplify the neck for stable clipping.

# 8 Brain Transgression

## Violation

Vascular neurosurgery is a refined art. The dexterity, grace, and precision of a master neurosurgeon are awe-inspiring; the movement of microsurgical instruments among arteries and nerves is like a ballet; and the otherworld of anatomy underneath the brain is exquisite. Vascular neurosurgeons pride themselves on their ability to reach remote territories through the subarachnoid space without having to violate the brain. Therefore, dissections that violate pia and transgress brain are disappointing and a little embarrassing. Brain transgression stirs an unnatural feeling, but resection of some brain has clear advantages in certain situations.

## Gyrus Rectus

The gyrus rectus resection is the best example of tissue removal that improves access to and visualization of an aneurysm. This gyrus lies in the surgical corridor between the olfactory tract and the interhemispheric fissure and can block exposure of the ipsilateral A2 segment and proximal neck. Gentle retraction with a retractor blade lateral to the olfactory tract causes the brain tissue to bulge over the tip of the blade. Pia is coagulated and incised to enter the brain. Cautery and suction are used to remove tissue. The orbitofrontal artery often courses over the middle of the gyrus rectus, and two pial openings on both sides of the artery preserve it while allowing brain removal beneath it. Resection continues until pia on the opposite side of the lobule is reached or until sufficient room is created around the aneurysm. Bleeding is controlled within the resection cavity with cautery, and the retractor is repositioned with its tip at the deep pial plane.

Brain resection is performed subpially to safely avoid the aneurysm as well as arteries and veins in the subarachnoid space. Any artery of importance, specifically the recurrent artery of Heubner, is identified and dissected away from the lobule before any brain is resected. Inadvertent injury to this artery is the biggest risk of this maneuver, and it should not be performed if the artery cannot be protected. The recurrent artery of Heubner is freed completely from the frontal lobe, following a plane of dissection from the shoulder of its origin from the A2 segment, along the A1 segment, to well beyond the gyrus rectus.

After the gyrus rectus is resected, the subarachnoid plane is reestablished in the interhemispheric fissure. The inner surface of this deep pia is cauterized, inspected, and incised carefully to avoid injury to underlying arteries or the aneurysm itself. The ipsilateral A2 segment is identified in the fissure and traced proximally to the aneurysm.

## Dome Avoidance

Brain transgression removes surgical obstacles such as the gyrus rectus, but is equally important in avoiding dangerous dissection adjacent to aneurysm domes. With middle cerebral artery (MCA) aneurysms, the dome may adhere to the superior temporal gyrus or the posterior pars orbitalis in the frontal lobe, thereby blocking access to the underlying inferior and superior trunks, respectively. With ophthalmic artery aneurysms, the dome may adhere to the medial orbital gyrus and limit frontal lobe retraction needed for an anterior clinoidectomy. With pericallosal artery aneurysms, the dome may adhere to the cingulate gyrus and interfere with the dissection of afferent arteries. By deliberately leaving the subarachnoid space, the sometimes tight plane between a thin aneurysm and the adherent pia is avoided. After reestablishing the subarachnoid plane beyond the point of adhesion, a thin patch of brain and pia remains attached to the aneurysm dome. The aneurysm becomes untethered and can be mobilized safely.

## Brain Relaxation

A swollen brain with an intraparenchymal clot from a ruptured aneurysm is difficult to dissect. Brain transgression may help access the hematoma and relieve intracranial pressure. Hematoma evacuation before securing an aneurysm is a dangerous move, but sometimes is necessary to facilitate the subarachnoid dissection. Dome projection is carefully considered, and clot near the dome is left alone. Clot away from the dome is slowly and gently removed until the brain slackens. Additional clot evacuation can wait until after the aneurysm is clipped. The dome connects with this remaining clot, and evacuation is easily accomplished from this subarachnoid direction.

## Swollen Brain

In some cases of swollen brain without frank hematoma, resection of brain tissue may be needed to expose the aneurysm. For example, with a basilar bifurcation aneurysm and a swollen temporal lobe, the uncus may narrow the surgical corridor of the carotid-oculomotor triangle. Subpial resection of some uncus may facilitate retraction and widen the exposure. The uncus is not eloquent or associated with neurologic deficits after resection. Therefore, the advantages of facilitated dissection, enhanced exposure, and relieved intracranial pressure outweigh any morbidity from limited brain resection. In these instances, our natural aversion to brain transgression can and should be dismissed.

# 9 Intraoperative Rupture

## Ever-Present Danger

Uncontrolled intraoperative bleeding is one of the most feared complications in neurosurgery. It has been said that uncontrolled bleeding is the one factor above all others that unnerves surgeons. As a corollary, surgeons who are agile in handling vascular structures and controlling bleeding can deal with most crises that arise in a neurosurgical procedure. Therefore, managing catastrophic bleeding is an invaluable skill, no matter one's subspecialty or practice.

Intraoperative rupture is an ever-present, unavoidable danger in aneurysm surgery. It occurs in 5 to 10% of aneurysm cases, mostly with fragile, previously ruptured aneurysms in patients with subarachnoid hemorrhage (SAH). It does not diminish with increasing surgical experience of the neurosurgeon performing the operation. However, the timing of intraoperative aneurysmal rupture may well reflect the neurosurgeon's experience. Ruptures occurring during the initial exposure, or predissection, are more frequent early in one's experience, typically due to brain retraction with adherent aneurysms such as superiorly projecting ophthalmic artery (OphA) aneurysms stuck to the frontal lobe, inferiorly projecting anterior communicating artery (ACoA) aneurysms stuck to the optic chiasm, or posterior communicating artery (PCoA) aneurysms stuck to the temporal lobe. Avoiding retraction or using it sparingly eliminates these mistakes. Similarly, rupture during clip application becomes less frequent with experience, reflecting the developing sense for when an aneurysm is ready to be clipped. Inadequate dissection of the aneurysm's neck and poor clip application are responsible for ruptures during clipping that occur in procedures performed by inexperienced neurosurgeons, reflecting a natural fear of intraoperative rupture. The seasoned neurosurgeon is more likely to aggressively manipulate the aneurysm and precipitate rupture during the final dissection maneuvers, preferring an expected rupture of a fully prepared aneurysm over an unexpected rupture during clip application of an underprepared aneurysm.

## Visceral Response

Intraoperative aneurysm rupture elicits an intense rush of emotions: surprise, confusion, regret, tension, frustration, anger, excitement, and desperation. This visceral response can be overwhelming and crippling for neurosurgeons early in their surgery experience. These moments demand calm, clarity, and confidence. The adrenaline rush can interfere with microsurgical mechanics. The situation can force dangerous or hasty maneuvers. Calm is needed to quiet the hands and emotions and to execute the plan methodically. In addition, calm benefits everyone in the operating room, from the nurses passing instruments, to the anesthesiologists administering pressors or blood, to other surgeons assisting with the procedure. Clarity is the quality that enables the thinking required in performing the operation. Confidence is the quality that infuses composure and assures that the sequence of technical steps will lead to a successful aneurysm repair. Calm, clarity, and confidence translate into a swift and efficient rupture response. Over time, the technical response to intraoperative rupture becomes reflexive, and the cognitive response becomes intuitive, but the visceral response to rupture does not seem to vanish. Its intensity fades with experience and anticipation, but it remains a factor to deal with.

## Technical Response

The technical response to intraoperative aneurysm rupture is an ordered sequence of steps: tamponade, suction, proximal control with temporary clipping, distal control with temporary clipping, and permanent aneurysm clipping. A small cottonoid is used to cover the rupture site. Gentle pressure and suction effectively clear the surgical field, but firmer pressure and a larger suction may be needed with large tears and brisk bleeding. Bleeding can almost always be controlled with tamponnade and suction, and should not require additional suction from an assistant. Tamponade ties up the suction hand but frees the other hand to place temporary clips on proximal afferent arteries. One-handed clip application is difficult if the point of proximal control has not been adequately dissected. Proximal control slows the bleeding and is often sufficient to finish dissecting and apply permanent clips. Temporary clips on distal efferent arteries may be necessary with brisk back-bleeding.

An aneurysm that has ruptured intraoperatively is no longer untouchable, as it once was. A torn aneurysm trapped with temporary clips can be collapsed and mobilized aggressively. The sac can be entered, suctioned down, and manipulated. The operation accelerates into “final dissection” mode with the urgency normally associated with temporary clipping and cerebral ischemia. As contrarian as it may seem, intraoperative rupture creates opportunity. For example, an ophthalmic artery aneurysm that ruptures before anterior clinoidectomy can sometimes be clipped without clinoidectomy by aggressively mobilizing the aneurysm away from the anterior clinoid process (ACP). The stress of the situation should not force the permanent clipping before the aneurysm is adequately prepared. An imperfectly placed clip may be used as a tentative clip to control bleeding from the rupture site, remove temporary clips, and reperfuse the brain. Additional permanent clips can be stacked below the tentative clip, or the tentative clip can be readjusted to finalize the repair.

Cerebral protection with hypothermia and pharmacologic agents is maintained by the anesthesiologists during an intraoperative rupture, and normal or slightly increased blood pressure is maintained during temporary clipping to augment collateral blood flow.

## Cognitive Response

The neurosurgeon must continue to think and operate. Intraoperative rupture elicits many questions in the neurosurgeon: Why did the aneurysm rupture? Where is the hole? Why is the aneurysm still bleeding? Where is the other branch artery? How can this be repaired? What was my contingency plan? What did I do when this happened before? All these questions arise while working to control the rupture. Work must continue in order to discern the cause of an aneurysmal rupture, to visualize anatomy under adverse conditions, and to devise a solution. In a surgical field suddenly suffused with blood before an aneurysm has been fully dissected, critical anatomy becomes obscured. The neurosurgeon must see through the blood to find the problem, the undissected anatomy, and the solution. Visual and cognitive insight comes from an appreciation of arterial anatomy and aneurysm pathology. It comes from past aneurysm cases and averted catastrophes during which techniques and tricks have been tried and abandoned or embraced. Every operation on an aneurysm contributes collectively to insight, generating knowledge of aneurysm anatomy that can guide the neurosurgeon when conditions are not so favorable. Answers and solutions during an intraoperative rupture are cognitive, and this cognitive response has to dominate the emotions and guide the hands through critical steps leading from rupture to final clipping. Over time, experience transforms the cognitive response from a forced process to an intuitive one.

# II The Approaches

# 10 Pterional Approach

## Position

The patient is positioned supine with a bolster under the shoulder ipsilateral to the aneurysm. The head is rotated 15 to 20 degrees away from the side of the aneurysm. The head is extended approximately 20 degrees, allowing gravity to retract the frontal lobe away from the anterior cranial fossa floor and making malar eminence the high point in the surgical field. The head is then lifted above the level of the heart, out of a dependent position. The neck is maintained in a neutral position, avoiding lateral flexion that might close the angle between the shoulder and head, and take away valuable working space. This head position aligns the plane of sylvian fissure vertically, allowing frontal and temporal lobes to fall away naturally to either side as the fissure is split later, like pages in a book that rests on its binding. Retractors become unnecessary during the sylvian fissure dissection. This head position and some lateral rotation of the operating table will adjust for most variability in the plane of the sylvian fissure. A conventional head position with 30 degrees of lateral rotation often leaves the temporal lobe overlying the sylvian fissure and closes the plane, even with full table rotation toward the side of the aneurysm.

## Incision

A curvilinear skin incision begins at the zygomatic arch 1 cm anterior to the tragus and arcs to the midline, just behind the hairline at the widow's peak (**Fig. 10.1A**). These two endpoints define the linear fold of the scalp flap, which barely crosses the pterion. Therefore, additional inferior retraction of the scalp flap with "fish hooks" on a Leyla bar (Aesculap; San Francisco, CA) is needed to expose pterion thoroughly. A semicircular incision maximizes the scalp flap. An incision placed too anteriorly along the hairline, having a **J**- rather than a **C**-shape, results in a smaller craniotomy because the bone flap conforms to the scalp flap. A foreshortened craniotomy might limit exposure of the posterior sylvian fissure or mobilization of temporal lobe.

## Extracranial Dissection

The scalp is elevated only enough to expose the zygomatic root posterior-inferiorly and the keyhole anteriorly. The superficial fat overlying the temporalis fascia should not be entered because the frontalis branch of the facial nerve lies in this tissue plane and can be injured with additional elevation of the scalp flap. The temporalis muscle is incised from the zygomatic arch to the superior temporal line along the skin incision, then anteriorly to the keyhole, running 1 cm below the superior temporal line. The temporalis is flapped anteriorly, leaving a cuff of fascia and muscle along the superior temporal line to suture the muscle to during closure. The fish hooks are repositioned to retract the temporalis muscle as well as the scalp flap.

Patients with large frontal sinuses that will be violated by the craniotomy will require a vascularized pericranial graft for the repair during closure. Head computed tomography (CT) scans or scout films from the angiogram demonstrate the frontal sinus size. It is easier to harvest this pericranial flap during the opening than later during the closure. The depth of the skin incision stops short of the cranium to preserve pericranium, going only through galea and deep connective tissue. The scalp flap is elevated away from the pericranium, opening a white, avascular tissue plane sharply with upward traction on the scalp. The pericranium can be incised well behind the skin incision, extending posteriorly and across midline to enlarge the flap's size, if necessary. Pericranial flaps elevate cleanly from the bone with blunt dissection and can be preserved during the procedure in moist sponges. Cerebrospinal fluid (CSF) leaks through the frontal sinus are unwanted complications that may require repeat craniotomy, direct repair, and sometimes ventriculoperitoneal shunting. It is far better to prevent this complication than to have to deal with it later when tissues are scarred and the pericranium is compromised.

## Craniotomy

A frontotemporal craniotomy is made using a single temporal bur hole (**Fig. 10.1B**). The craniotomy follows the temporalis incision posteriorly, then curves anteromedially to the foramen of the supraorbital nerve and inferiorly to the floor of the anterior cranial fossa. This spot is often covered by the fold in the scalp flap, which requires additional retraction during the craniotomy. This seemingly small corner of bone, if it remains, can narrow the outer opening of the operative corridor and limit the maneuverability of instruments held on this side.

Dural preservation is particularly important along the inferior bone cut, which is where dura is thinnest. The frontal lobe behind this dura is retracted when pterion is drilled, and tears in this dura can expose brain, leading to injury, swelling, and contusions. Dural integrity is checked by irrigating through the bony cut and shining light directly down on the dura. If there is any suggestion of a dural tear, an additional bur hole can be made at the keyhole, and the dura can be dissected from the inner table of skull. Dural tears are avoided by not crossing pterion with the drill, instead following the floor of the frontal fossa posteriorly. If this dura is torn, intact dura over the orbital roof deep to the tear is elevated and the tear is either repaired primarily with suture or covered with Telfa to protect exposed brain.

## Drilling the Pterion

The pterion is located at the intersection of the frontal bone, the parietal bone, and the greater wing of the sphenoid bone. Pterion lies at the point where the coronal suture intersects with the greater wing, providing an identifiable landmark. Although this point lies on the flat outer table of bone externally, internally the lesser wing of the sphenoid joins the inner table of bone here and is continuous with the orbital surface of the frontal bone, or orbital roof. The inner surface of pterion is a complex three-dimensional structure that prevents its crossing with the foot plate of a drill, and instead requires that it be snapped or cracked to remove the bone flap.

The drill is used to remove pterion and the lesser wing of the sphenoid medially to the superior orbital fissure (SOF), with the goal of making a flat surface over the orbit connecting the anterior and middle cranial fossae (**Fig. 10.1C**). The

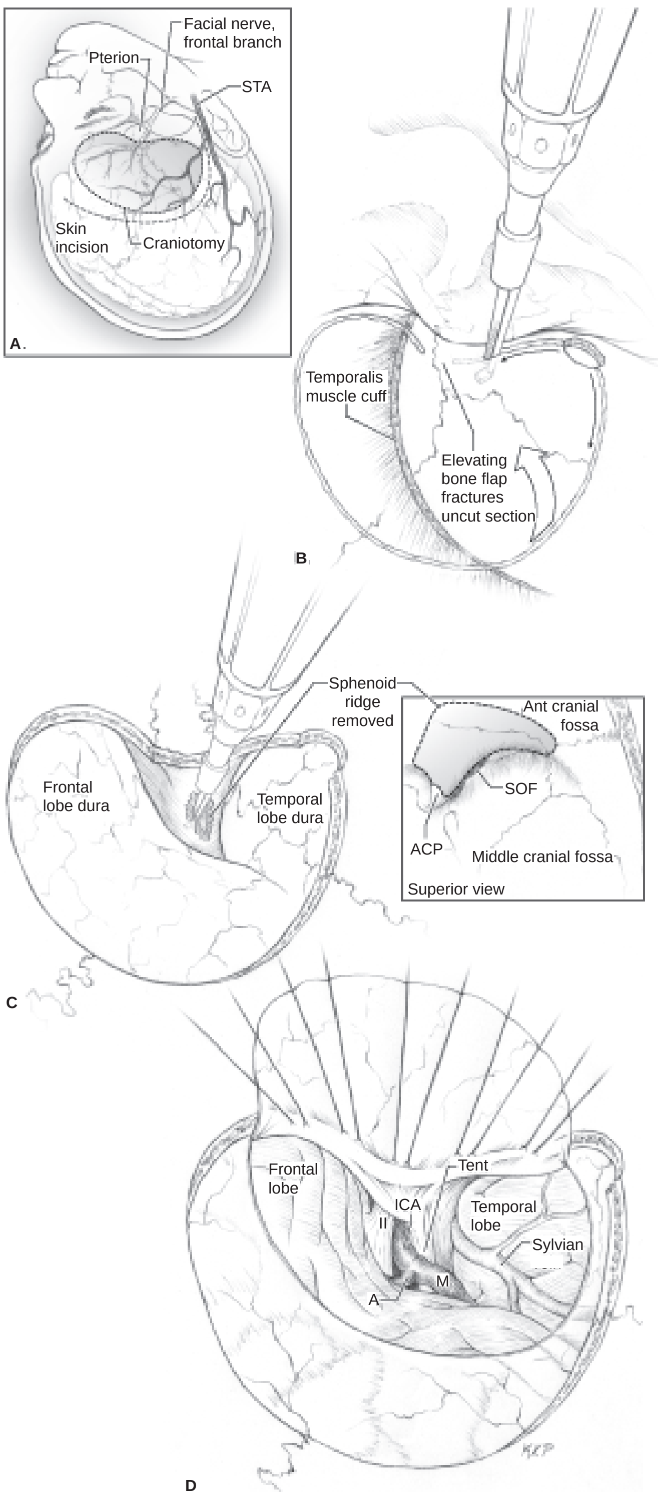



**Fig. 10.1** **(A)** Head position, skin incision, and craniotomy for the pterional craniotomy (right side). The superficial temporal artery is preserved posterior to the incision in case it is needed for a bypass. Superficial fat overlying the temporalis fascia is not entered because the frontalis branch of the facial nerve lies in this tissue plane. **(B)** A craniotomy flap for the pterional approach. Dural preservation is particularly important inferiorly where the dura is thinnest and where the pterion is drilled. Dural tears are avoided by not crossing the pterion with the drill. Instead, bone is cut on either side of the pterion and cracked by elevating the bone flap. **(C)** Drilling the pterion. Removing the pterion and lesser wing of the sphenoid medially to the superior orbital fissure (*inset*) flattens the surface over the orbit connecting the anterior and middle cranial fossae. **(D)** Final exposure of the pterional approach. Thorough resection of the pterion opens an unobstructed view along the dural flap into the carotid cistern. Multiple tacking sutures placed deeply on the dural flap pull it snugly against the pterion.

orbital plate of the frontal bone has ridges and irregularities that mirror the sulci and gyri of inferior frontal lobe. The frontal sinus lies between the inner and outer tables of frontal bone and can extend laterally to the craniotomy cut. Although the frontal sinus should not be entered if possible, the craniotomy and overall exposure should not be compromised by its avoidance either.

The lesser wing of the sphenoid bone is flattened until the lateral edge of the SOF is reached. The bone opens like a Gothic arch to transmit a fold of dura containing the oculomotor, trochlear, and abducens nerves, as well as the superior ophthalmic vein and ophthalmic nerve. With most aneurysms, skeletonization of the dural fold of the SOF is sufficient to flatten the pterion. With some patients, the lesser wing of the sphenoid bone and the base of the anterior clinoid process create a prominent bony hump that can obscure the view into the carotid cisterns intradurally. These structures can be drilled down or rongeured past the lateral extent of the SOF, along the dural fold. The dural fold can be mobilized laterally by removing bone that forms the lateral or temporal border of the SOF, opening into the lateral orbit. Once removed, the dural fold mobilizes laterally and the base of the clinoid can be rongeured. This deep bone is often a conduit for emissary veins, and bleeding is controlled with bone wax.

The squamosal portion of the temporal bone is drilled inferiorly to the middle fossa floor. The endpoint for removal of bone from the skull base is a flat surface upon which to reflect the dural flap.

## Dural Opening

The dura is opened with a semicircular incision, extending from the floor of the middle cranial fossa at the posterior-inferior aspect of the exposure to the floor of the anterior cranial fossa at the anterior-inferior aspect of the exposure. Multiple stay sutures flatten the dural flap. The hinge point is the anterior clinoid process, so this point requires adequate bony reduction extradurally. Thorough resection of the pterion opens an unobstructed view along the dural flap into the carotid cistern (**Fig. 10.1D**).

# 11 Orbitozygomatic Approach

## Rationale and Indications

The orbitozygomatic approach dramatically enhances the standard pterional craniotomy. When a patient's head is rotated away from the aneurysm and extended, the superior and lateral orbit becomes the roof of the operative corridor. Drilling down the pterion raises this roof, but not nearly as much as removing orbital walls completely and depressing the eye with the dural flap. Zygoma resection increases the mobilization of the temporalis muscle inferiorly, which opens the middle fossa to facilitate mobilization of the temporal lobe in a posterolateral direction. A widened operative corridor improves illumination, reduces brain retraction, and improves maneuverability. A good orbitozygomatic approach gives the neurosurgeon a wide sweep of surgical trajectories ranging from supraorbital to transsylvian to pretemporal to subtemporal. Surgical trajectory can then be tailored to the pathology. In addition, the orbitozygomatic approach extends the upward view of the basilar apex. The line of sight through the microscope intersects with the orbital rim and eye as the viewing target rises in the interpeduncular cistern. The orbitozygomatic approach eliminates the shadow that would otherwise be cast over high-riding basilar apex aneurysms with a pterional approach.

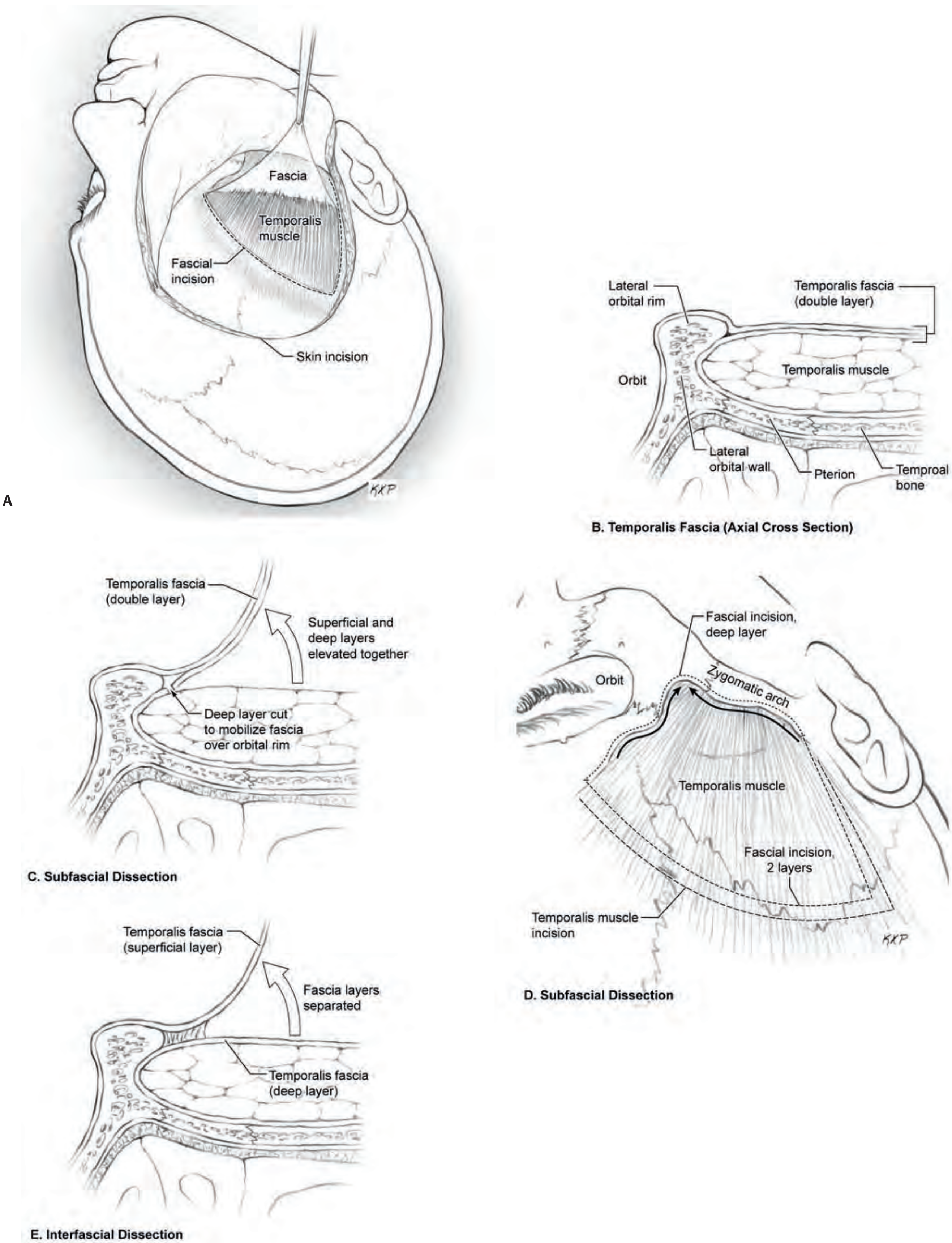
The orbitozygomatic approach is routinely used for basilar apex aneurysms. It is used selectively in the anterior circulation, primarily with giant and complex aneurysms. Deep bypass procedures benefit from the additional working room of this approach. Enhanced exposure is always advantageous, but it can cause subtle orbital asymmetries that bother some patients. There are other risks, including frontalis nerve injury, pulsatile enophthalmos, orbital entrapment, diplopia from extraocular muscle or nerve injury, blindness, and communication with frontal or ethmoidal sinuses with potential routes of infection or cerebrospinal fluid (CSF) leakage. The incidence of these complications is low.

## Extracranial Dissection

Patient position and skin incision are the same with the orbitozygomatic approach as with the pterional approach. The first difference is the soft tissue dissection to expose the orbitozygomatic unit. The zygoma and orbital rim are ensheathed in two layers of temporalis fascia (**Fig. 11.1A**), and elevating the superficial layer exposes bone (**Fig. 11.1B**). Subfascial dissection elevates both fascial layers off the temporalis muscle, and then cuts the deep layer along the posterior edge of the lateral orbital rim and the superior edge of the zygoma, allowing it to mobilize with the superficial layer over the orbitozygomatic unit (**Fig. 11.1C,D**). Interfascial dissection separates these two layers, leaves the deep layer on the temporalis muscle, and mobilizes just the superficial layer over the lateral orbital rim and zygoma (**Fig. 11.1E**). The subfascial dissection is simple, fast, and preferred.

Both layers of fascia are incised from the zygomatic arch to the superior temporal line along the skin incision, then anteriorly to the keyhole, running 1 cm below the superior temporal line (**Fig. 11.1A**). Temporalis muscle is not incised because the fascial flap elevates easily when underlying muscle remains attached to the skull. A round-tipped dissector

**Fig. 11.1** (*opposite*) **(A)** Dissection of the temporalis fascia. The temporalis fascia is incised from the zygomatic arch to the superior temporal line along the skin incision, then anteriorly to the keyhole. The facial flap elevates easily when the muscle is not incised and is left attached to the skull. **(B)** Anatomy of the temporalis fascia. The zygoma and orbital rim are ensheathed by the fascial layers. The superficial temporalis fascia covers the zygoma and orbital rim, extending inside the orbit where it transitions to the periorbita. Deep temporal fascia envelopes the temporalis muscle in the temporalis fossa, remaining outside the orbit. These fascial layers are separated to expose the orbital walls and zygoma for osteotomies. **(C)** Subfascial dissection technique leaves the superficial and deep temporalis fascia together over the muscle, but cuts the deep fascia along the posterior edge of the lateral orbital rim and superior edge of zygoma. These cuts release the superficial fascia, allowing it to elevate over the orbital rim and zygoma. **(D)** The deep layer of the temporalis fascia is incised by following the superior edge of the zygoma to the maxilla (*right arrow*) with a sharp round knife or dissector. Similarly, the contours of the posterior edge of the lateral orbital rim are followed to the maxilla (*left arrow*) with a sharp round knife or dissector, joining the other fascial incision. **(E)** The interfascial dissection technique separates the superficial and the deep fascia over the muscle. The superficial fascia peels over the orbital rim and zygoma, and deep fascia remains around the temporalis muscle. The subfascial dissection is simple, faster, and preferred.


Fascia
Temporalis muscle
Fascial incision
Skin incision
KKP
A
Lateral orbital rim
Temporalis fascia (double layer)
Temporalis muscle
Orbit
Lateral orbital wall
Pterion
Temproal bone
B. Temporalis Fascia (Axial Cross Section)
Temporalis fascia (double layer)
Superficial and deep layers elevated together
Deep layer cut to mobilize fascia over orbital rim
C. Subfascial Dissection
Fascial incision, deep layer
Orbit
Zygomatic arch
Temporalis muscle
Fascial incision, 2 layers
Temporalis muscle incision
KKP
D. Subfascial Dissection
Temporalis fascia (superficial layer)
Fascia layers separated
Temporalis fascia (deep layer)
E. Interfascial Dissection

with a sharp edge advanced along the superior edge of the zygoma to the maxilla, and along the posterior edge of the lateral orbital rim to the maxilla, cuts the deep fascial layer and releases the fascial flap. A deep fat pad lies beneath this fascial flap, with an outer layer that mobilizes with the fascial flap and an inner layer that travels under the zygoma with the temporalis muscle. These fat pads are separated with blunt dissection strokes from the zygoma superiorly into this plane.

The fascial flap is elevated to the anterior edge of the lateral orbital rim and the inferior edge of the superior orbital rim, where superficial fascia transitions to periorbita and folds into the orbit. Periorbita is a delicate lining, but when carefully stripped from the orbit's interior, it retains periorbital fat to better visualize orbital osteotomies. Periorbita can be preserved by beginning the dissection where it is thickest inferolaterally near the inferior orbital fissure, by using side-to-side sweeps with a round-tipped dissector, and by advancing circumferentially along the orbital roof and the lateral wall. This dissection deepens 3 cm toward the orbital apex. Once the orbitozygomatic unit is exposed, the temporalis muscle is mobilized inferiorly.

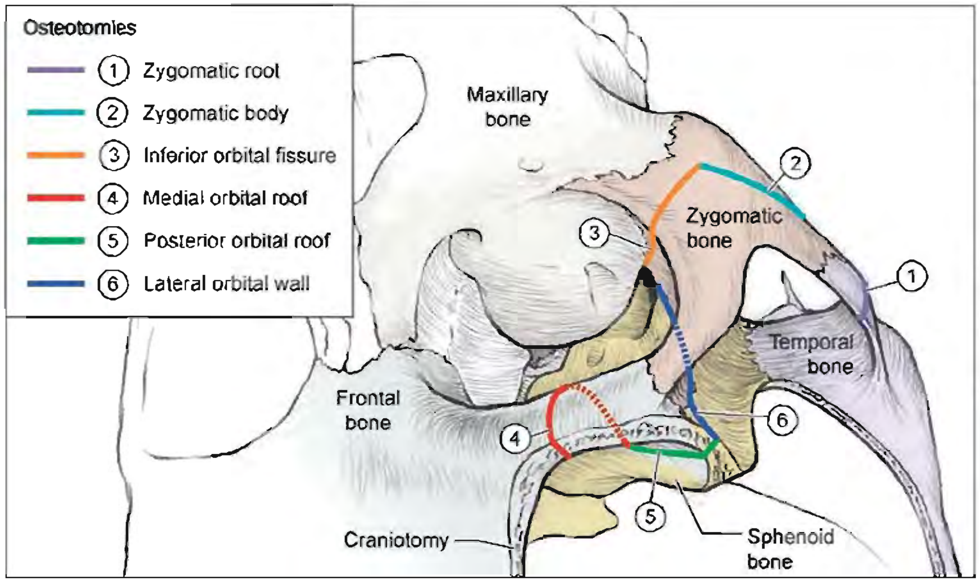
## Craniotomy and Osteotomies

The orbitozygomatic unit consists of the orbital rim, orbital roof, lateral orbital wall, and zygomatic arch. This orbitozygomatic unit is removed in several ways: with the cranial flap as one integrated piece; separate from the cranial flap as two pieces; and separate from the cranial flap as two pieces, with a modified orbital unit that does not include the zygoma. The two-piece approach with the complete orbitozygomatic unit is the standard technique used most often. The one-piece orbitozygomatic approach gives a better cosmetic result but the osteotomies are more difficult to perform. The modified orbital approach is used when the zygoma resection would not add meaningfully to the exposure. The frontotemporal craniotomy resembles that of the pterional approach, but the anteromedial corner extends more medially beyond the supraorbital notch. Dura of the frontal lobe is elevated 3 cm posteriorly to visualize the orbital roof. The pterion does not need to be drilled because it is removed with the orbit. Before making any osteotomies, the inferior frontal dura and periorbita are protected from the saw blade with strips of Telfa.

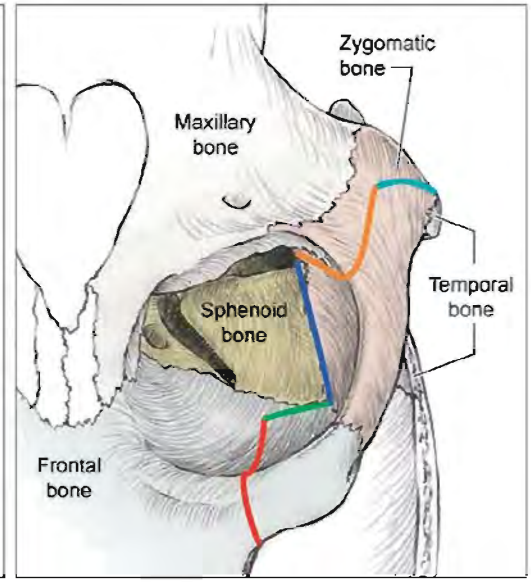
The orbitozygomatic unit is released by a series of six osteotomies (**Fig. 11.2**) made with a reciprocating saw, which minimizes bone loss from the cuts. The first cut is made across the root of the zygomatic process of the temporal bone (zygomatic root), angling the saw blade away from the temporomandibular joint that lies on the inferomedial surface of zygomatic root (**Fig. 11.2**, osteotomy 1). This cut in the root is made with two perpendicular cuts, creating a notch that seats the zygoma more securely than would one straight cut. A fixation plate is placed in the zygoma and registered with a drill hole in the root to improve the cosmesis of the repair. The second and third cuts are made across the temporal process of the zygomatic bone (malar eminence), first from the inferolateral margin of the zygomatic arch continuing halfway across the zygomatic bone (**Fig. 11.2**, osteotomy 2), and then from the inferior orbital fissure through the zygomatic bone to the same endpoint (**Fig. 11.2**, osteotomy 3). The inferior orbital fissure is difficult to visualize directly but can be palpated with a thin dissector, which also guides the tip of the saw blade into the fissure and protects the eye. When these two osteotomies connect, the resulting V in the zygomatic bone secures the fragment into position when replaced.

The fourth cut is along the medial orbital roof in an anterior-posterior direction, just lateral to the supraorbital notch (**Fig. 11.2**, osteotomy 4). The frontal dura is protected with Telfa strips and gentle retraction, and the saw is angled as the cut deepens to keep the teeth at the heel of the blade from contacting dura. The eye is also protected with Telfa strips and gentle retraction. The fifth cut crosses the posterior orbital roof in a medial-to-lateral direction, approximately 2 to 3 cm posterior to the inner table of the frontal bone (to preserve the orbital roof), and finishes laterally in the thick bone of the sphenoid ridge and pterion (**Fig. 11.2**, osteotomy 5). The sixth cut crosses the lateral orbital wall, beginning in the inferior orbital fissure from outside the orbit and connecting in the sphenoid ridge and pterion with the previous

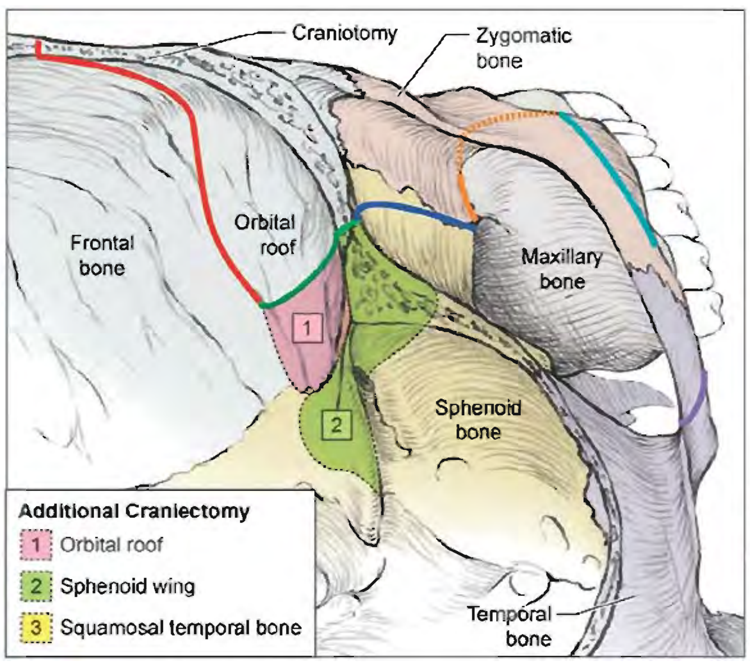
**Fig. 11.2** (*opposite*) Osteotomies for the right orbitozygomatic craniotomy, as seen in anterior-superior oblique **(A),** anterior **(B),** posterior-superior oblique **(C),** and lateral **(D)** views. The orbitozygomatic unit is released by a series of six osteotomies. The first cut crosses the zygomatic root, usually with two perpendicular cuts that notch the zygomatic root and seat the zygoma securely (osteotomy 1). The second cut extends from the inferior margin of the zygomatic arch halfway across the zygomatic bone (osteotomy 2). The third cut extends from the inferior orbital fissure to the same endpoint (osteotomy 3). The fourth cut is made along the medial orbital roof in an anterior-posterior direction, just lateral to the supraorbital notch (osteotomy 4). The fifth cut crosses the posterior orbital roof in a medial-to-lateral direction, approximately 2 to 3 cm posterior to the inner table of frontal bone (to preserve the orbital roof), and finishes laterally in the thick bone of the sphenoid ridge and pterion (osteotomy 5). The sixth cut crosses the lateral orbital wall, beginning in the inferior orbital fissure from outside the orbit and connecting the previous cut (osteotomy 6). The orbitozygomatic unit can then be removed as a single piece. **(C,D)** After removing the orbitozygomatic unit, additional bony exposure includes (1) resecting the orbital roof, (2) resecting the medial sphenoid wing, and (3) drilling down the squamosal portion of the temporal bone.



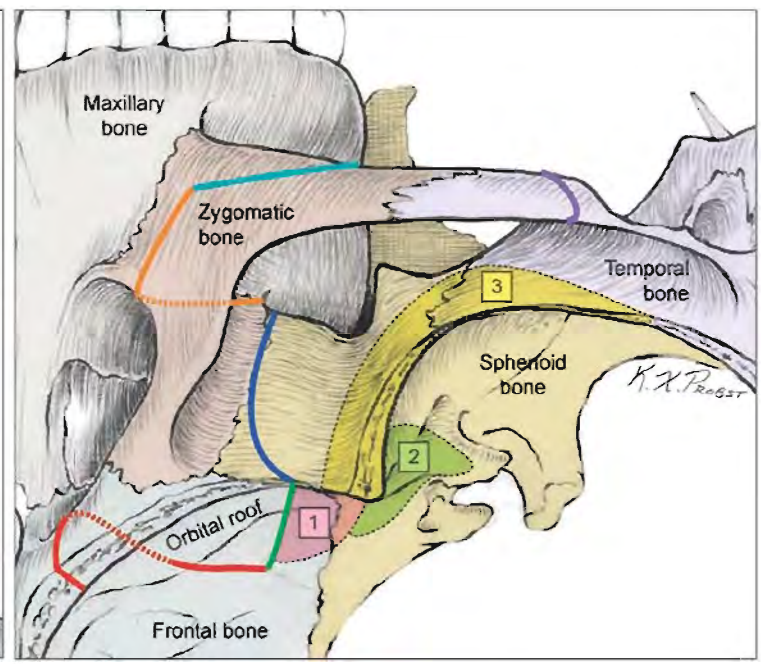

A. Orbitozygomatic Osteotomies




B. Orbitozygomatic Osteotomies




C. Orbitozygomatic Osteotomies and Additional Craniectomy




D. Orbitozygomatic Osteotomies and Additional Craniectomy

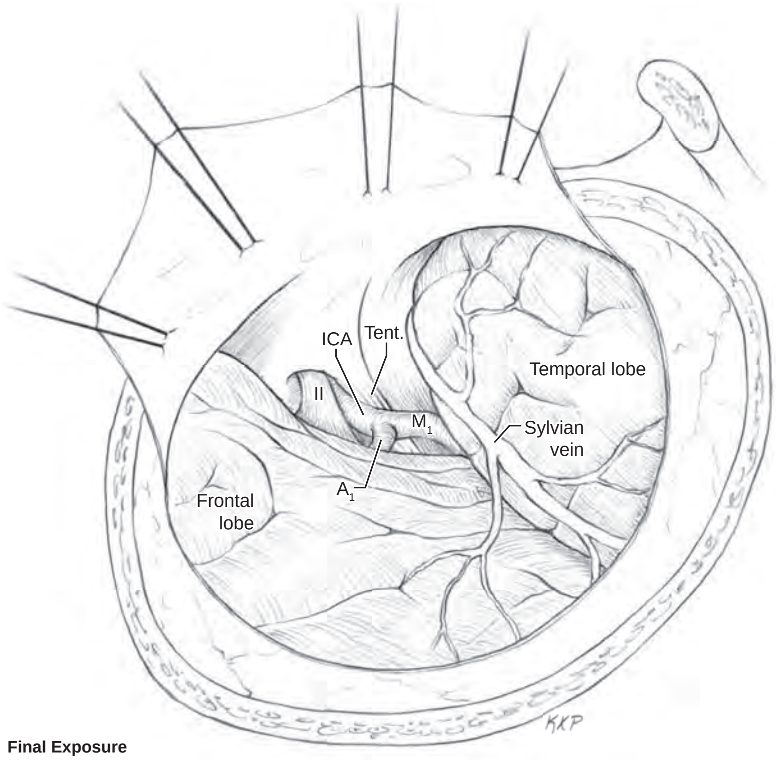



**Fig. 11.3** The final exposure of the orbitozygomatic-pterional approach. With the orbit and zygoma removed, the dural flap and its tacking sutures depress the globe gently and open a wide exposure of the sylvian and carotid cisterns. ICA, internal carotid artery; Tent., tentorium.

cut (**Fig. 11.2**, osteotomy 6). The orbitozygomatic unit can then be removed as a single piece.

Additional bone is removed around the orbital apex, resecting what remains of the orbital roof, lateral orbital wall, and medial sphenoid wing, back to superior orbital fissure (**Fig. 11.2C,D**, craniectomies 1 and 2). Bony resection continues to the base of the anterior clinoid process, which is left in place.

## Subtemporal Exposure

The temporal lobe mobilizes posterolaterally after splitting the sylvian fissure, thereby opening the important pretemporal corridor. However, the temporal lobe must have an unobstructed pathway to retract this way. The inferior margin of the temporal squamosal bone is drilled inferiorly until the cranial exposure is flush with the floor of the middle fossa, all the way back to zygomatic root (**Fig. 11.2C,D**, craniectomy 3). With this inferior barrier removed, the temporal lobe retracts smoothly.

A dural flap based over the orbit is tented forward with tacking sutures to depress the globe gently and thereby gain a wide exposure of the sylvian region. It often takes a dozen sutures to maximally flatten the dural flap; any less and swollen orbital tissue can bulge into the surgical corridor. With the orbit and zygoma removed, a wide corridor is opened to the sylvian and carotid cisterns (**Fig. 11.3**).

# 12 Anterior Interhemispheric Approach

## Position, Incision, and Extracranial Dissection

Pericallosal artery (PcaA) aneurysms originate from a right- or left-sided bifurcation of the anterior cerebral artery (ACA), but are midline aneurysms deep to the falx. Therefore, the anterior interhemispheric fissure needs to be accessed only on one side, and the craniotomy is eccentric to that side. The right side is chosen for these aneurysms to avoid complications in the dominant hemisphere resulting from the craniotomy, venous sacrifice, or retraction.

The patient is positioned supine with the head in neutral position (nose up) and the neck extended slightly (**Fig. 12.1A**). A bicoronal skin incision is needed to mobilize the scalp flap inferiorly enough for a craniotomy cut that runs across the anterior cranial fossa floor (**Fig. 12.1B**). The incision begins at the right zygoma and ends at the contralateral superior temporal line because the craniotomy is eccentric to the right side. The scalp is folded to expose supraorbital frontal bone from the ipsilateral superior temporal line to the contralateral glabella. Pericranium is harvested during the opening to make it available during the closure to cover the frontal sinus, if it has been entered. It is easier to harvest pericranium as a separate layer as the scalp flap is elevated, rather than to peel it away from a folded scalp flap at the end of the procedure.

## Craniotomy

Pericallosal artery aneurysms are exposed optimally with a craniotomy flap whose medial border crosses the superior sagittal sinus (SSS) to the contralateral (left) side (**Fig. 12.1C**). Midline exposure enables the dura to be opened to the edge of the SSS and directly accesses the interhemispheric fissure without any overhanging bone. The craniotomy flap is extended inferiorly as close to the anterior cranial fossa floor as possible. Crossing the midline with this cut sometimes requires drilling down the ridge of bone on the inner table in the midline. The lateral cut extends to the superior temporal line, and the temporalis muscle is left undisturbed. The posterior cut extends to the coronal suture.

The SSS is crossed carefully with the craniotome. Its epidural location is established visually before crossing the sinus by aiming light into the cut of bone and irrigating enough to see intact dura. If a dural tear is detected, the flap is taken in two pieces. The craniotomy flap can be raised safely as one flap in younger patients with dura that is not adherent to the inner table of the skull, and in many women with a shallow bony sulcus of the SSS. However, this craniotomy flap is raised in two pieces in elderly patients or those with thin, adherent dura. The first piece is a unilateral (right) frontal flap taken up to, but not across the SSS. After removing this bone flap first, dura containing the SSS is dissected from the inner table of the skull under direct visualization to minimize the risks of sinus injury or excessive bleeding from the emissary veins. The second portion of the craniotomy safely crosses the SSS twice, with the dura retracted away from the skull.

The inner table of the frontal bone in the inferior midline is drilled until flat (**Fig. 12.1D**), in a manner analogous to drilling the sphenoid bone for a pterional approach. This additional bone removal increases visualization along the anterior cranial fossa floor for accessing proximal control of low-lying PcaA aneurysms. This bone removal may also enter and cranialize the frontal sinus, which requires coverage with a pericranial graft during the closure.

## Dural Opening

Dura is opened with a semicircular flap based against the SSS. Bridging frontal veins are preserved when they are large and more posteriorly located. A vein that fuses with the dura before reaching the SSS can be saved by dividing the dural flap on both sides of the vein and elevating two flaps instead of one. These cuts fashion a sleeve of dura over the vein that preserves the vein. Venous infarction is a potentially devastating complication that is difficult to predict, which means that bridging veins should be preserved whenever possible.

## Gravity Retraction

Pericallosal artery aneurysms that lie along the A4 or A5 segments are rare, but their distal location on the body of

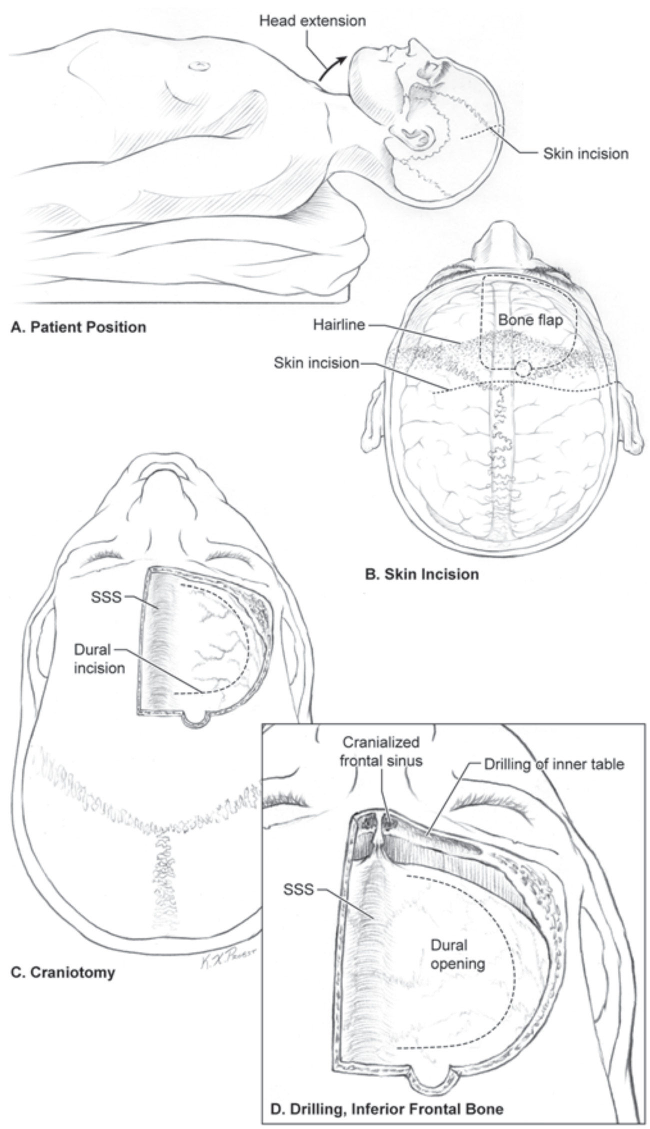



**Fig. 12.1 (A)** Patient position for proximal pericallosal artery (PcaA) aneurysms, with the nose up, slight head extension, and the midline oriented vertically. **(B)** A bicoronal skin incision mobilizes the scalp flap inferiorly enough for a craniotomy cut across the anterior cranial fossa floor. The skin incision begins at the right zygoma and ends at the contralateral superior temporal line because the craniotomy is eccentric to the right side. **(C)** The craniotomy is usually made with a single bur hole. The craniotomy crosses the midline and exposes the superior sagittal sinus (SSS), eliminating any bony ledge that might obscure access to the interhemispheric fissure. The craniotomy flap extends inferiorly to the anterior cranial fossa floor, and laterally to the superior temporal line, leaving the temporalis muscle undisturbed. The posterior cut extends to the coronal suture. **(D)** The inner table of the inferior frontal bone is drilled until flat, in a manner analogous to drilling the sphenoid bone for a pterional approach. This additional bone removal increases visualization along the anterior cranial fossa floor for proximal control of low-lying PcaA aneurysms.

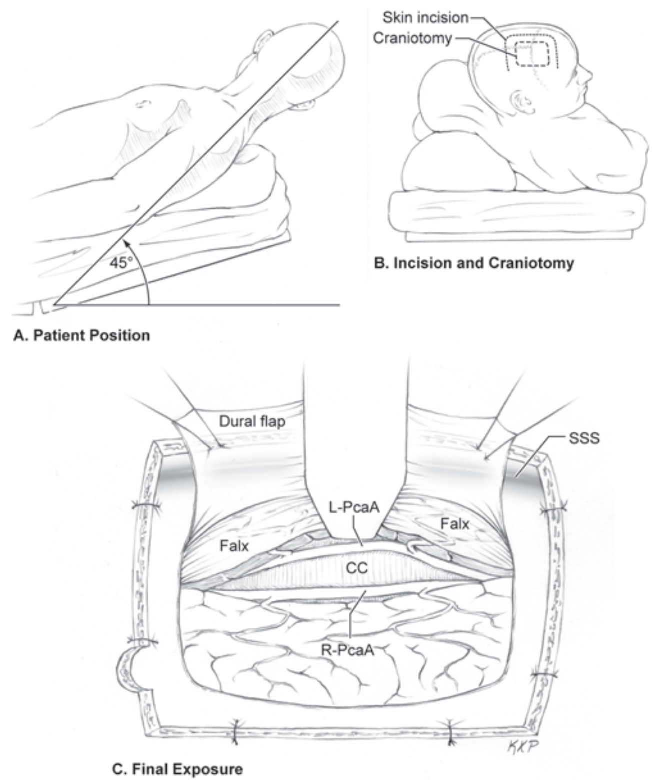



**Fig. 12.2 (A)** Patient position for distal PcaA aneurysms, with the head turned 90 degrees to the right, and the head and neck angled up 45 degrees. This position orients the midline horizontally, allowing gravity to retract the right frontal lobe and open the anterior interhemispheric fissure. **(B)** A "trapdoor" skin incision is used instead of a bicoronal incision, with the anterior limb placed along the hairline (not on the forehead), the posterior limb behind the coronal suture, and the connecting limbs parasagittally just across the midline. The craniotomy is two thirds anterior and one third posterior to the coronal suture, and crosses the SSS to expose the left side. **(C)** The dural flap is the same as with the "nose up" approach: a semicircular flap based against the SSS. Gravity pulls the right hemisphere down away from the falx to open the interhemispheric fissure without a retractor. A retractor may be needed on the inferior free edge of the falx to better expose the PcaA and corpus callosum (CC).

the corpus callosum allows for a modified anterior interhemispheric approach that uses gravity to retract the right hemisphere. The patient is positioned supine with bolsters under the left shoulder. The head is turned 90 degrees to the right with the sagittal midline parallel to the floor, and angled 45 degrees upward (lateral neck flexion) (**Fig. 12.2A,B**). This position allows gravity to retract the dependent right hemisphere and open the interhemispheric fissure.

A “trapdoor” incision is used instead of a bicoronal incision, with the anterior limb placed along the hairline (not on the forehead), the posterior limb behind the coronal suture, and the connecting limbs parasagittally just across the midline (**Fig. 12.2B**). This incision accommodates a craniotomy flap that is two thirds anterior and one third posterior to the coronal suture, and crosses the SSS to expose the opposite side. The dural flap is a semicircular flap based against the SSS. Gravity pulls the hemisphere down away from the falx to open the interhemispheric fissure without a retractor (**Fig. 12.2C**). A retractor may be needed on the inferior free edge of falx to better expose the PcaA and corpus callosum.

# 13 Far-Lateral Approach

## Position

The far-lateral approach is also called the lateral suboccipital approach, the extreme lateral approach, and the extreme lateral inferior transcondylar exposure (ELITE).

A modified park-bench or three-quarter prone position is used with the patient placed with the lesion side upward (**Fig. 13.1A**). The operating table is extended by placing a 3/4-inch-thick plastic board under the mattress and pulling both the mattress and board 6 inches beyond the edge of the table. This extender creates a gap between the Mayfield head holder and its attachment to the table, allowing the dependent arm to hang comfortably over the extended end of the table, cradled in a padded sling. By dropping the patient's arm and shoulder down, the head can be rotated effectively into position. This position minimizes brachial plexus compression and improves venous return compared with the full prone position.

Three maneuvers position the head optimally: *flexion* in the anteroposterior plane until the chin is one finger's breadth from the sternum; *rotation* of 45 degrees away from the side of the lesion, bringing the nose down toward the floor; and lateral flexion 30 degrees *down* toward the floor. These maneuvers position the clivus perpendicular to the floor, allowing the neurosurgeon to look down the axis of the vertebral and basilar arteries and to work between the lower cranial nerves. The ipsilateral mastoid process becomes the highest point in the operative field, and the posterior cervical-suboccipital angle is opened maximally to increase the neurosurgeon's operating space. The patient's up shoulder is taped to keep the cervical-suboccipital angle open.

## Incision and Extracranial Dissection

A "hockey-stick" incision is made beginning in the cervical midline over the C4 spinous process (**Fig. 13.1B**). It extends cephalad to the inion, courses laterally along the superior nuchal line to the mastoid bone, and finishes inferiorly at the mastoid tip. A cut just below the superior nuchal line is made, paralleling the superior nuchal line and leaving a 1-cm cuff of fascia to reattach the muscle during closure. The midline nuchal ligament is identified by continuing this cut across the midline and inspecting the suboccipital muscles. The paraspinous musculature is split in this avascular plane of the nuchal ligament. The cut just below the superior nuchal line extends laterally to the mastoid bone and inferiorly to its tip, detaching the paraspinous muscles. The myocutaneous flap is then mobilized inferolaterally to expose the occipital bone and foramen magnum. Mobilization of the paraspinous musculature in this manner provides adequate exposure of the lateral foramen magnum; the muscles need not be dissected or transected, thereby eliminating a significant source of postoperative pain. Retraction of soft tissue is facilitated by exposure down to and around the C2 spinous process. The vertebral artery (VA) is identified and protected as it courses from the transverse foramen of the lateral mass of C1, through the sulcus arteriosus of the C1 vertebral arch, to its dural entry point. The lateral epidural venous plexus can cause troublesome bleeding and is best preserved by blunt dissection.

## Craniotomy

Bone removal consists of three parts: C1 laminotomy, lateral occipital craniotomy, and condylectomy (**Fig. 13.1B**). The arch of C1 is removed with the drill, making a cut just medial to the sulcus arteriosus and another across the contralateral arch. These cuts are made in a rostral-to-caudal direction to keep any lurching of the drill away from the VA. Additional atlantal bone can be removed under the VA laterally to the transverse foramen. The foramen can be opened dorsally and the artery mobilized, but this maneuver is rarely needed for intradural aneurysms.

Dural adhesions around the foramen magnum are stripped with angled curettes, and a craniotomy is performed using the lip of the foramen magnum as the epidural access for the drill. A suboccipital craniotomy is extended unilaterally from the foramen magnum in the midline, up to the muscle cuff at the level of the transverse sinus, as far laterally as possible, and then back around to the foramen magnum. In elderly patients with adherent dura, a suboccipital bur hole with subsequent cuts down to the foramen magnum may help to preserve dura. The rim of the foramen magnum is

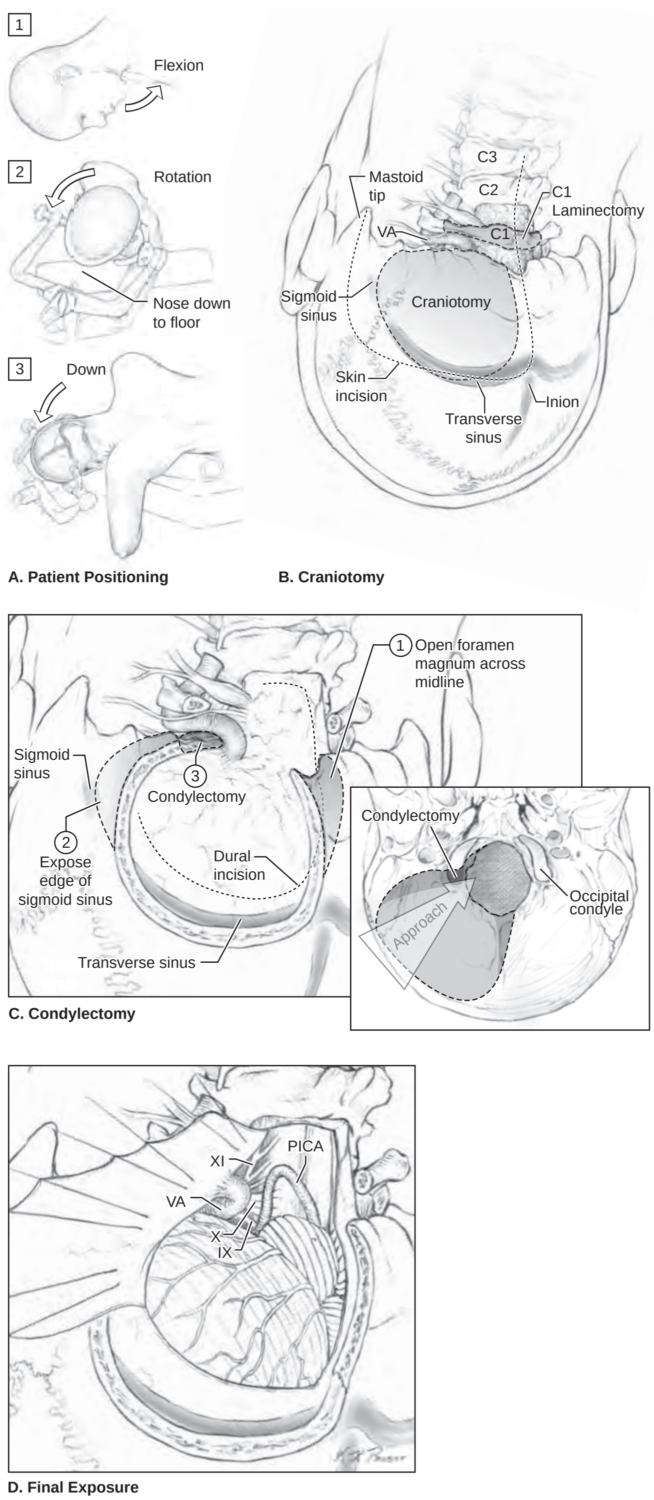



**Fig. 13.1** **(A)** A modified park-bench or three-quarter prone position is used with the patient placed with the lesion side upward. The dependent arm hangs over the end of the table, cradled in a padded sling. Three maneuvers position the head optimally: (1) *flexion* in the anteroposterior plane until the chin is one finger's breadth from sternum; (2) *rotation* 45 degrees away from the side of the lesion, bringing the nose down toward the floor; and (3) lateral flexion 30 degrees *down* toward the floor. These maneuvers put the clivus perpendicular to the floor, allowing the neurosurgeon to look down the axis of the vertebral artery. The ipsilateral mastoid process becomes the highest point in the operative field. The patient's up shoulder is taped to open the cervical-suboccipital angle. **(B)** A "hockey-stick" incision is made beginning in the cervical midline over the C4 spinous process, extending cephalad to the inion, coursing laterally along the superior nuchal line to the mastoid bone, and finishing inferiorly at the mastoid tip. The myocutaneous flap is mobilized inferolaterally to expose the occipital bone and foramen magnum. Bone removal consists of a C1 laminotomy and a lateral suboccipital craniotomy. The suboccipital craniotomy is extended unilaterally from the foramen magnum in the midline, up to the muscle cuff at the level of the transverse sinus, as far laterally as possible, and then back around to the foramen magnum. VA, vertebral artery. **(C)** Additional bone removal is needed after the craniotomy: (1) The foramen magnum and midline suboccipital bone are rongeured to extend the opening across midline. (2) The foramen magnum and lateral suboccipital bone are rongeured or drilled to extend the opening laterally toward the occipital condyle and sigmoid sinus. (3) The posteromedial two thirds of the occipital condyle are drilled away. The anterior extent of the condylar resection is defined either by the condylar emissary vein or by the dura that begins to curve anteromedially, giving a tangential view along this dural plane. Condylar resection enables the dural flap reflected against the condyle to be completely flat. The dural incision curves from the cervical midline, across the circular sinus, to the lateral edge of the craniotomy. An inferior dural incision laterally under C1 mobilizes the flap further laterally against the margin of the craniotomy. A condylectomy is sufficient if there is no bony prominence obstructing the view of the lateral medulla (approach trajectory, *inset*). **(D)** Final exposure offers a view down the barrel of the vertebral artery and working space in the angle between the lateral medulla and inferior cerebellum. PICA, posterior inferior cerebellar artery.

rongeured to extend the opening across the midline and laterally toward the occipital condyle (**Fig. 13.1C**).

## Condylectomy

The lateral aspect of the foramen magnum and the posteromedial two thirds of the occipital condyle are removed with a drill using a round, 3-mm-diameter, diamond-tipped bit to minimize injury to the adjacent emissary veins (**Fig. 13.1C**). The anterior extent of the condylar resection is defined either by the condylar emissary vein or by dura that begins to curve anteromedially, giving a tangential view along this dural plane. Only rarely does condylar resection extend anteriorly to the hypoglossal canal. Condylar resection enables the dural flap reflected against the condyle to be completely flat. In general, when you think you have drilled enough condyle, drill some more. Bleeding from the condylar emissary veins should not deter further condylectomy because this bleeding is easily controlled with bone wax and Surgicel Nu-Knit (Ethicon, Somerville, NJ) packing.

## Dural Opening

The dural incision curves from the cervical midline, across the circular sinus, to the lateral edge of the craniotomy. An inferior dural incision laterally under C1 mobilizes the flap further laterally against the margin of the craniotomy (**Fig. 13.1C**). Multiple dural tacking sutures hold the flap against the condyle under tension. Condylectomy is sufficient if there is no bony prominence obstructing the view of the lateral medulla (**Fig. 13.1D**). The arachnoid of the cisterna magna is preserved until the microscope is brought into the field to keep blood out of the subarachnoid space.

## Extended Far-Lateral Approaches

The exposure of the far-lateral approach can be combined easily with the exposure of the extended retrosigmoid approach, removing additional suboccipital bone superiorly to the junction of the transverse and sigmoid sinuses. The retrosigmoid addition enables the cerebellopontine angle to be entered and large VA aneurysms to be accessed. The trajectories from the far-lateral and extended retrosigmoid approaches are almost perpendicular; consequently, the retrosigmoid extension does not improve the exposure of the far-lateral approach. It does, however, provide an additional vantage point on the anatomy, which can help clarify the operative strategy.

The approach is identical to the far-lateral approach, but the superolateral edge of the craniotomy is defined by drilling through the mastoid bone to the transverse-sigmoid junction. The sigmoid sinus is skeletonized down to the jugular bulb. The subsequent far-lateral craniotomy then connects to this exposed dura, and the craniotomy flap is enlarged. The dura is opened with a **C**-shaped flap based along the sigmoid sinus, which, when tacked anteriorly, pulls the sinus forward to open the route into the cerebellopontine angle. The standard far-lateral dural flap then connects with this flap.

# III The Seven Aneurysms

# 14 Posterior Communicating Artery Aneurysms

## Microsurgical Anatomy

The posterior communicating artery (PCoA) bisects the supraclinoid internal carotid artery (ICA) into an *ophthalmic segment* from the distal dural ring to the PCoA, and a *communicating segment* from the PCoA to ICA bifurcation. The PCoA arises from the posterior carotid wall, courses posteriorly and medially along the superior surface of the oculomotor nerve, and intersects the posterior cerebral artery (PCA) to mark the end of the P1 segment and the beginning of the P2 segment (**Fig. 14.1**). Approximately eight anterior thalamoperforating arteries originate from the superior surface of the PCoA along its course and ascend to the hypothalamus, anterior thalamus, internal capsule, tuber cinereum, floor of third ventricle, posterior perforated substance, optic chiasm and tract, and pituitary stalk.

The anterior choroidal artery (AChA) is the most important branch associated with PCoA aneurysms, lying adjacent to the distal neck. The AChA arises from the posterior wall of the communicating segment, but can also arise from the PCoA, the ICA bifurcation, and the proximal M1 segment. The AChA is usually a single artery, but it can originate as two arteries. Its initial *cisternal segment* runs posteromedially behind the ICA, following the contour of the medial uncus through the crural cistern and supplying the optic tract, lateral thalamus, and internal capsule (genu and posterior limb). The AChA can assume PCA territories and supply the medial temporal and occipital lobes. The cisternal segment ends at the plexal point where the AChA pierces the telae choroidea of the temporal horn of the lateral ventricle. The *plexal segment* runs in the temporal horn to the atrium and has diminishing surgical significance. The territory of the cisternal segment makes the AChA so critical, and its compromise causes deficits out of proportion to its small size; these deficits include hemiplegia, hemianesthesia, and hemianopsia.

The *fetal PCA* is an important variant (**Fig. 14.2**). During embryogenesis, the PCoA initially supplies the occipital lobe, but the P1 segment enlarges to annex this territory and the PCoA shrinks to produce the classic circle of Willis anatomy. The transformation fails to occur in as many as 20% of patients, and the P1 segment remains hypoplastic or atretic. The fetal PCA must be recognized and preserved when clipping PCoA aneurysms because its compromise can result in occipital lobe infarction.

The *PCoA infundibulum* has a “funnel-shaped” PCoA that is dilated at its origin and tapers triangularly, with an artery of normal caliber emerging from the tip rather than from the base, as with true aneurysms (**Fig. 14.3**). Seen in as many as 10% of patients, this anatomic variant has no proven risk of rupture and is not treated unless it enlarges. Intraoperatively, an infundibulum with a thinned or protuberant posterior wall can be clipped to pinch off this portion of the infundibulum while preserving PCoA flow.

The course of the oculomotor nerve parallels the PCoA, and aneurysms projecting posteriorly and inferiorly will impact the nerve, accounting for the third nerve palsies that many patients present with (pupil dilatation and eye deviation laterally and inferiorly, or the “down and out” eye). The nerve originates from the interpeduncular fossa of the midbrain, courses between the P1 PCA and superior cerebellar artery (SCA), attaches to the membrane of Liliequist, and climbs to the oculomotor triangle, a dural space bordered by the tentorial edge laterally, the petrous apex posteriorly, and the interclinoidal line medially (the line between the anterior and posterior clinoid processes). The nerve enters its dural sleeve at the triangle’s anterior apex to exit the subarachnoid space and travel in the roof of the cavernous sinus, just below the anterior clinoid process.

The optic nerve overlies the supraclinoid ICA at the point of proximal control. A small space is needed for the upper blade of a temporary clip between the inferolateral aspect of the optic nerve and the superomedial aspect of the ICA. The falciform ligament is a dural fold that runs from the medial side of the anterior clinoid process (ACP) to the roof of the optic canal and tuberculum sella. A small incision in the ligament parallel to the lateral edge of the optic nerve expands the space for a temporary clip. The lower blade of a temporary clip fits into the space between the inferolateral aspect of the ICA and the parasellar dura. A large ACP can obscure this space, and its removal helps in visualizing the ICA and facilitating temporary clip application.

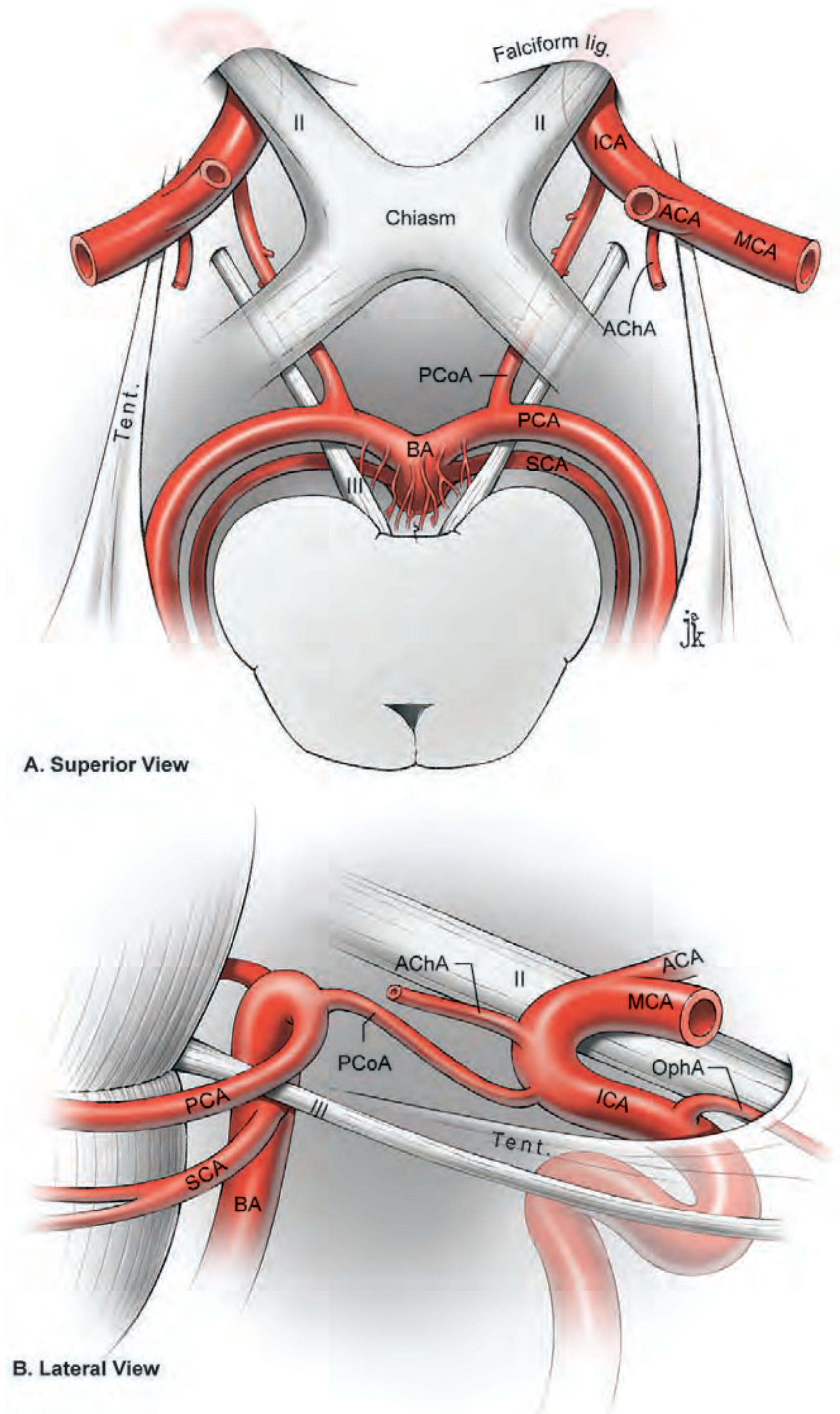



**Fig. 14.1** Microsurgical anatomy of the posterior communicating artery (PCoA), as seen in superior **(A)** and right lateral **(B)** overviews. The PCoA bisects the supraclinoid internal carotid artery (ICA) into an ophthalmic segment and a communicating segment, and gives rise to the anterior thalamoperforators. ACA, anterior cerebral artery; AChA, anterior choroidal artery; BA, basilar artery; MCA, middle cerebral artery; OphA, ophthalmic artery; PCA, posterior cerebral artery; SCA, superior cerebellar artery; Tent., tentorium.

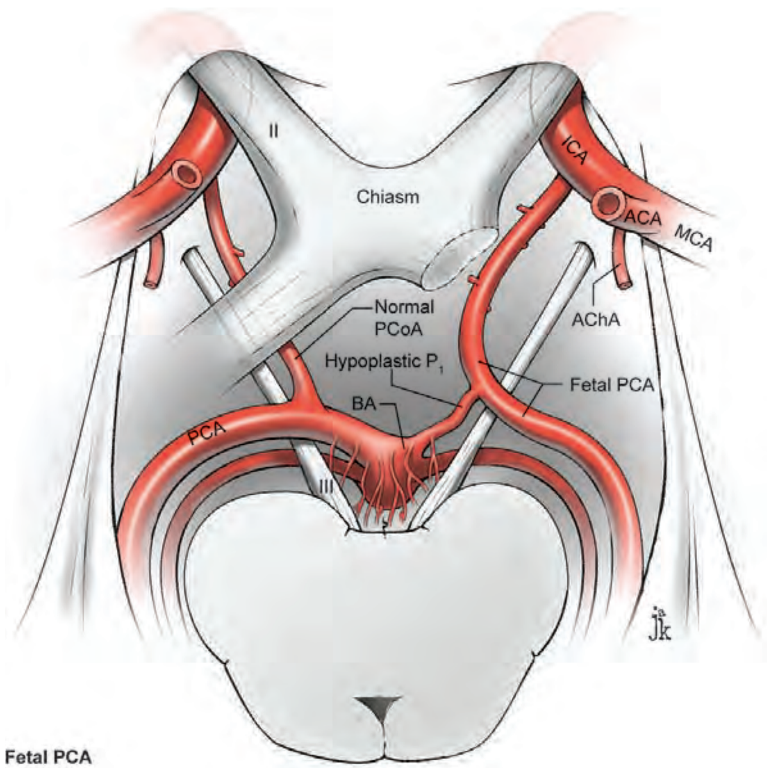



Fig. 14.2 Microsurgical anatomy of the fetal posterior cerebral artery (superior overview).

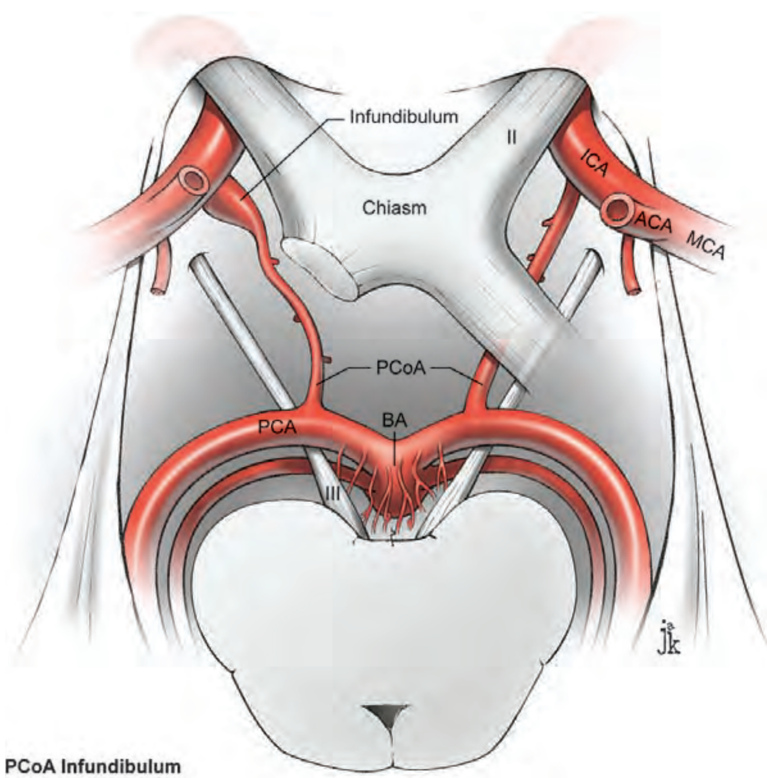



Fig. 14.3 Microsurgical anatomy of an infundibular origin of the posterior communicating artery (superior overview).

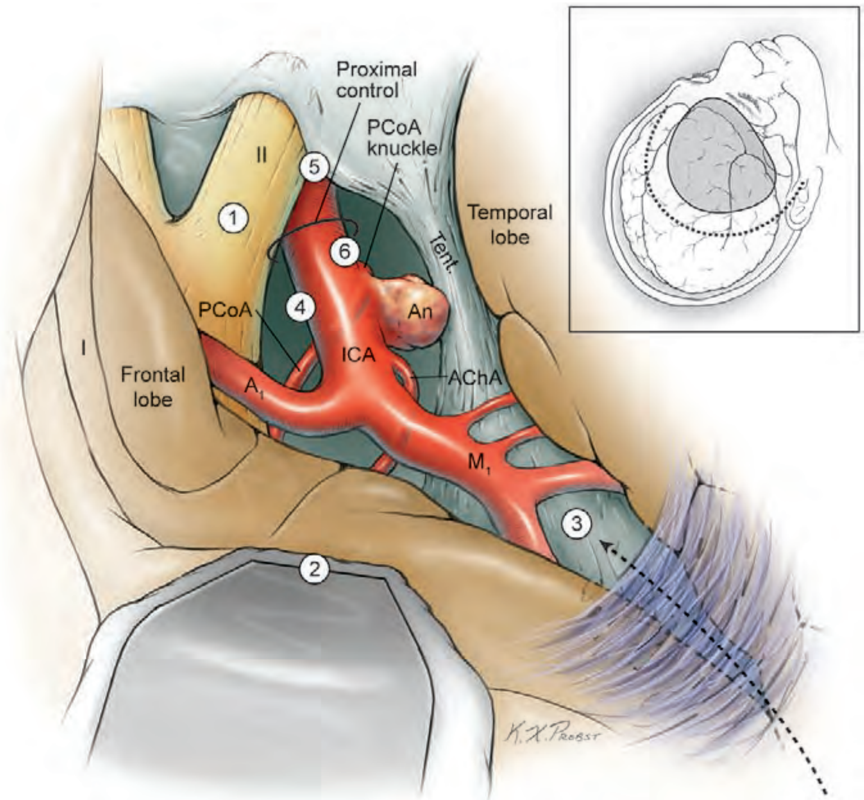



**Fig. 14.4** Dissection strategy for PCoA aneurysms. Step 1, identification of the optic nerve; step 2, placement of the frontal retractor; step 3, splitting the proximal sylvian fissure; step 4, opening the optic-carotid triangle; step 5, proximal control; step 6, exposing the proximal ICA inferiorly. An, aneurysm.

## Aneurysm Dissection

The prevailing surgical attitude toward PCoA aneurysms can be summarized as: "It's just a P-comm." Although these common aneurysms require minimal microdissection and have simple anatomy, they should be taken seriously. Their fragile domes have numerous points of adhesion (oculomotor nerve, tentorium, and temporal lobe); the ACP can obscure the PCoA's origin and the proximal neck; and AChA complications can be devastating.

Microdissection begins by identifying the optic nerve through the arachnoid of the chiasmatic cistern (**Fig. 14.4**, step 1). Even in patients with significant subarachnoid hemorrhage, the optic nerve is recognizable where dura of the anterior cranial fossa floor converges with the cisternal arachnoid. Rotate the table to orient the axis of the ipsilateral optic nerve vertically. A frontal lobe retractor is positioned with the blade's tip lateral to the olfactory tract as it merges with the optic nerve (**Fig. 14.4**, step 2). The chiasmatic cistern is opened with a No. 11 blade and the incision is extended with microscissors along the superior surface of the optic nerve and anteromedially to the interoptic triangle. Posterolateral incisions open the carotid and sylvian cisterns.

A wide sylvian fissure split is not needed with PCoA aneurysms. Opening the proximal or sphenoidal segment of the sylvian fissure (**Fig. 14.4**, step 3) separates the frontal and temporal lobes enough to visualize ICA's communicating segment and proximal M1 segment. Without some sylvian fissure split, the arachnoid of the sylvian cistern overlies this spot. The sylvian arachnoid is lifted and cut with the tip of a No. 11 blade. The sylvian veins emerging from the cistern provide a point of incision into these layers. Blood in the sylvian cistern helps separate the arachnoid from underlying arteries. This sylvian dissection progresses medially to join the earlier dissection of the carotid cistern.

This limited dissection of the proximal sylvian fissure and a frontal lobe retractor on the medial orbital gyrus brings the entire supraclinoid ICA into view. This retraction places no traction on the aneurysm. The temporal lobe forms a steep posterior wall in the surgical corridor, and any temptation to retract the temporal lobe should be resisted because PCoA aneurysms projecting laterally above the tentorium often adhere to the uncus and can rupture with such a maneuver.

The superior ICA surface is traced anteriorly (**Fig. 14.4**, step 4) to the apex of the optic-carotid triangle for proximal

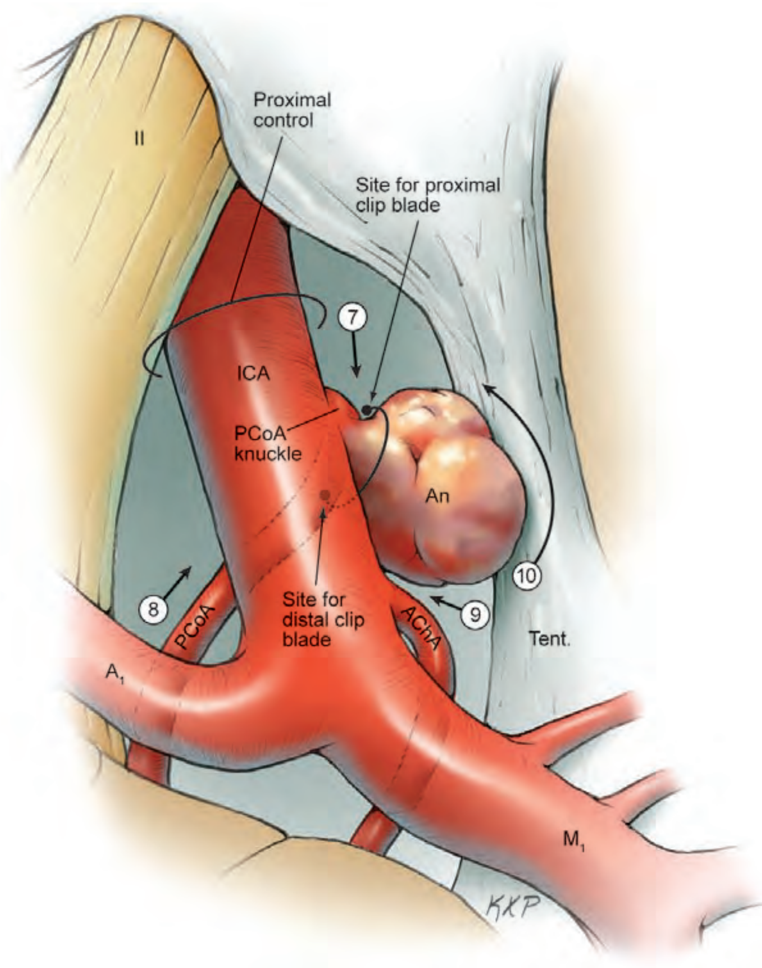



**Fig. 14.5** Dissection strategy for PCoA aneurysms. Step 7, identifying the spot between the PCoA origin and the proximal neck; step 8, tracing the distal course of the PCoA; step 9, identifying the spot between the AChA and the distal neck; step 10, releasing the tentorial adhesions.

control (**Fig. 14.4**, step 5), and if necessary, the falciform ligament is incised to widen the interval between the ICA and the optic nerve. The dissection proceeds laterally around the ICA to its inferior surface (**Fig. 14.4**, step 6), where there is a space for the lateral blade of a temporary clip proximal to the PCoA origin.

Two spots are carefully explored: the spot between the PCoA origin and the proximal aneurysm neck (**Fig. 14.5**, step 7), and the spot between the distal aneurysm neck and the AChA (**Fig. 14.5**, step 9). The PCoA origin is often difficult to see because it is on the posterior carotid wall, courses medially out of view, and is obscured by the aneurysm. Consequently, only a knuckle of artery proximal to the aneurysm neck can be seen. Trace the aneurysm's anterior wall down to the neck, and trace the inferior surface of the ICA back to the PCoA, and these pathways converge at the PCoA origin. The optic-carotid triangle can be widened with some lateral and downward traction on the ICA, and the distal PCoA can be followed proximally to confirm the PCoA origin (**Fig. 14.5**, step 8). The small depression between the knuckle of the PCoA origin and the aneurysm is the seat for the proximal clip blade.

The PCoA aneurysms project inferiorly and posteriorly, but their relationship to the tentorium and oculomotor nerve varies. Domes that project medial to the oculomotor nerve abut the posterior clinoid process, and this bony prominence can narrow the space for the proximal clip blade. Domes that project on the oculomotor nerve are common and typically have ample room between the tentorial edge and the ICA to access both sides of the neck. Gentle handling of the aneurysm minimizes irritation of the oculomotor nerve. Domes that project more laterally can be infratentorial, supratentorial, against the tentorial edge, or split by the tentorium with a portion or lobule on either side (**Fig. 14.6**). Domes that impact the tentorium develop adhesions that pull on the dome as the neck is dissected or clipped. Releasing these adhesions (**Fig. 14.5**, step 10) makes it easier for the clip to close the neck, but must be weighed against the risk of dome dissection. Domes that project above the tentorium develop adhesions to the temporal lobe and often present with intracerebral and subarachnoid hemorrhage. Laterally projecting domes above the tentorium lie in the line of dissection and are prone to rupture if not carefully avoided.

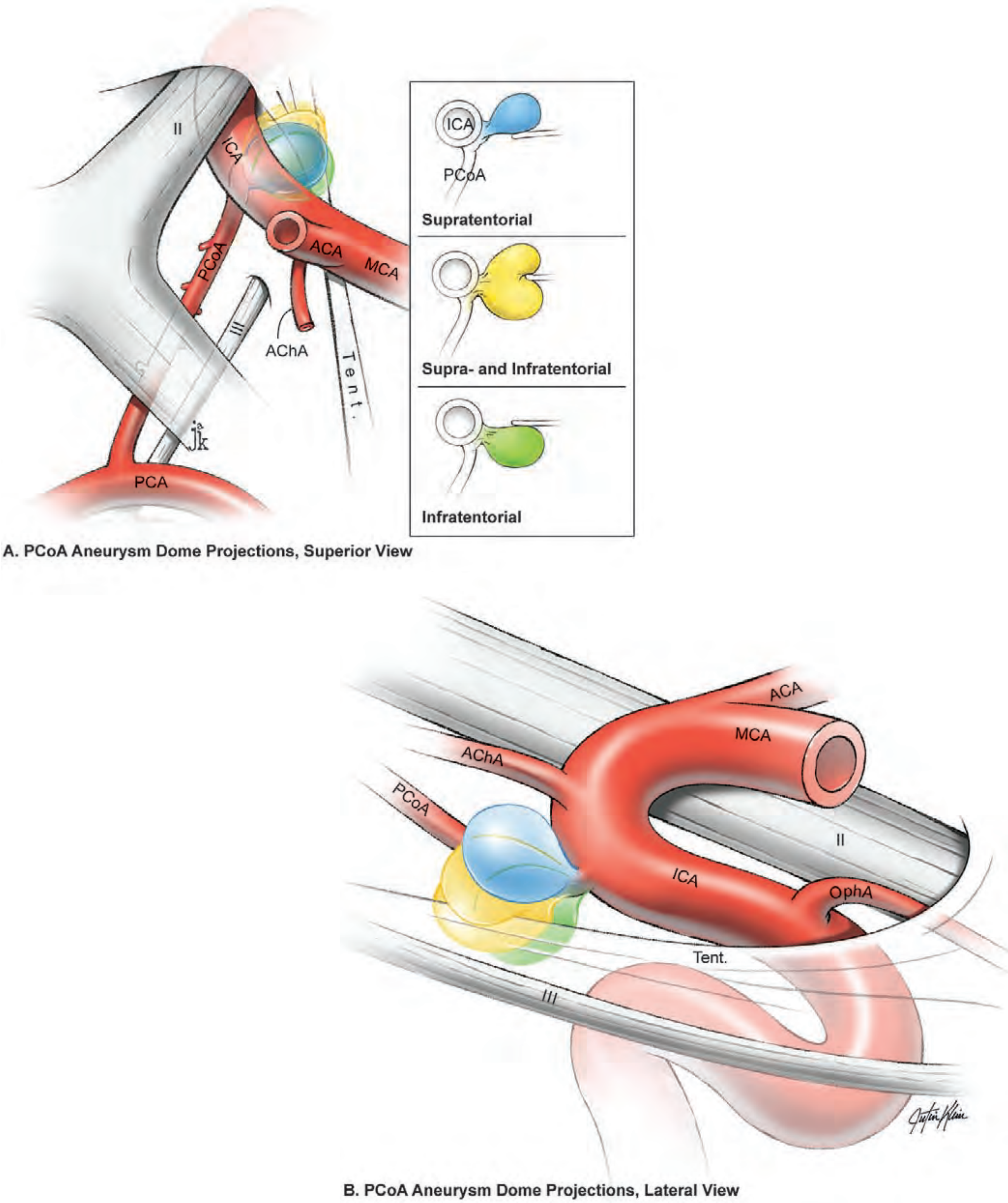



**Fig. 14.6** Domes of PCoA aneurysms project supratentorially, infratentorially, against the tentorium, or around the tentorium, with lobules both supra- and infratentorially, as seen in superior **(A)** and lateral **(B)** views.

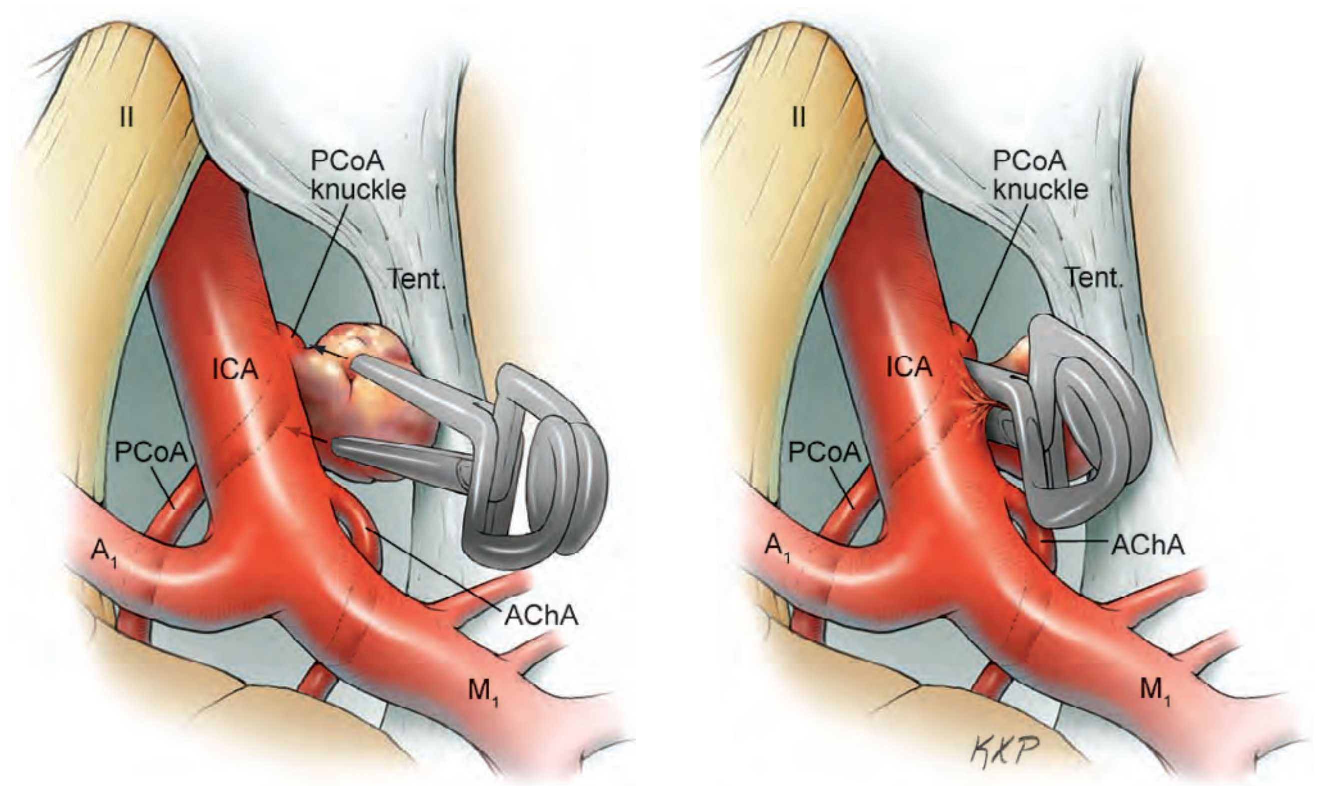



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**Fig. 14.7** Clipping technique for PCoA aneurysms. **(A)** Clip alignment. **(B)** Final application, with preservation of the PCoA and AChA.

## Clipping Technique

The PCoA aneurysms are usually occluded with a simple straight clip (**Fig. 14.7**). The proximal blade is applied over the shoulder of the PCoA origin at the anterior neck, and the distal blade is applied in front of the AChA at the posterior neck (**Figs. 14.8, 14.9, 14.10, 14.11, and 14.12**). The tips are advanced until they pass the neck. The angle of clip application is adjusted to seat the blades squarely against the ICA. Slow release of the clip eases it onto the aneurysm neck. Fragile domes that are stuck to the tentorium sometimes rupture during the closure of the clip. Clip position is optimized before releasing the clip, and steady release should continue even if the aneurysm tears.

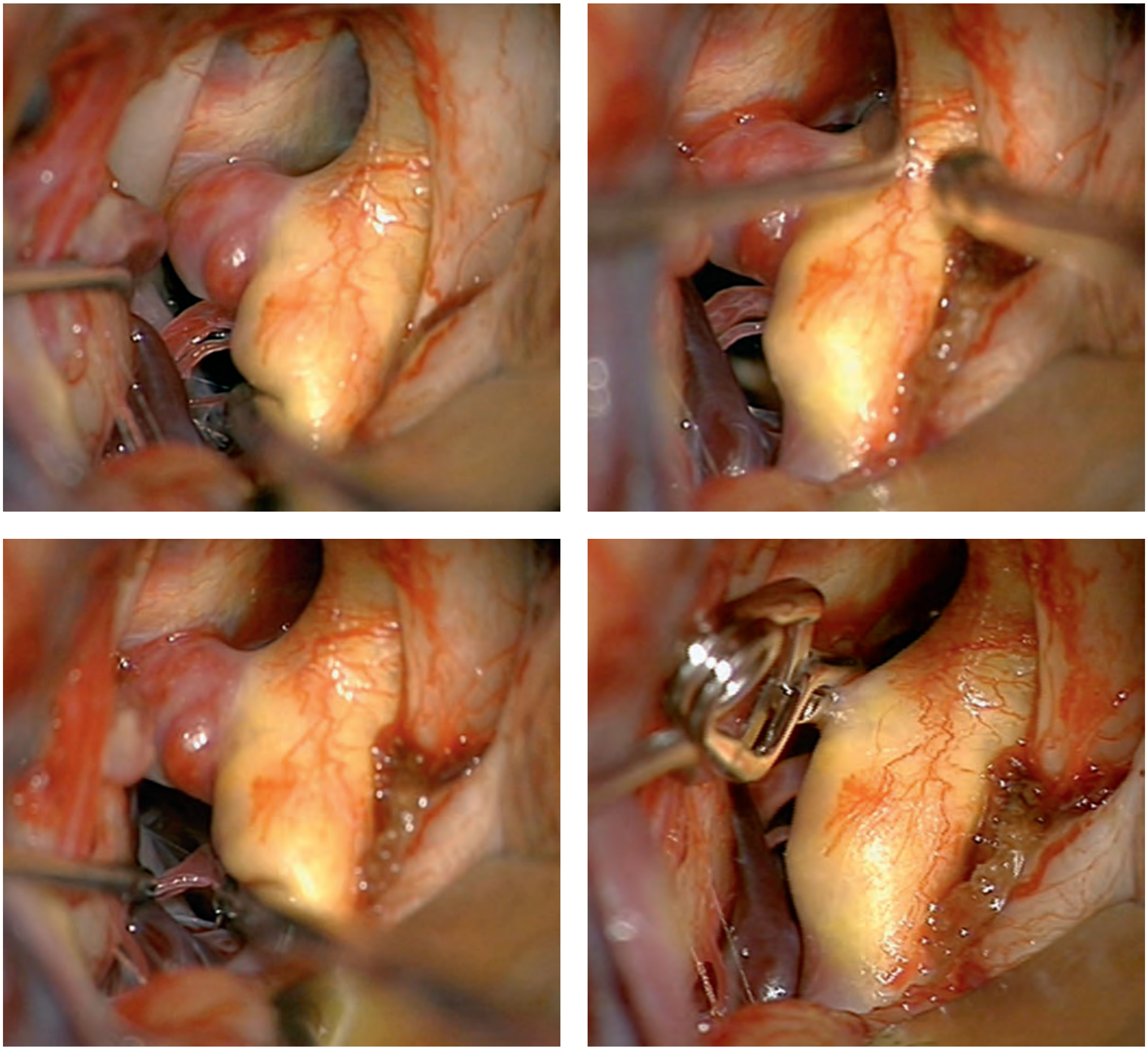

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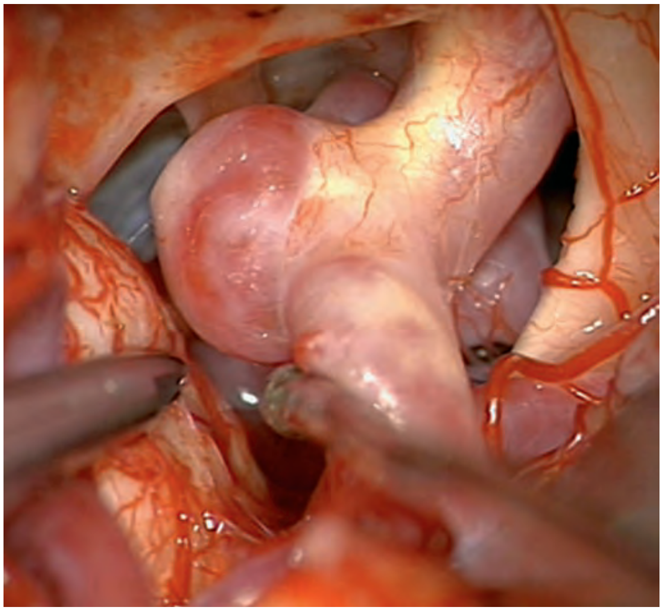
**Fig. 14.8** This small, unruptured left PCoA aneurysm in a 67-year-old woman demonstrates simple anatomy. **(A)** The aneurysm projected inferiorly, barely touching the oculomotor nerve. **(B)** Gentle upward pressure on the ICA with a No. 6 dissector demonstrated the spot between the proximal aneurysm neck and the PCoA origin, which appears only as a small knuckle. **(C)** The AChA was separated from the distal aneurysm neck. **(D)** The aneurysm was clipped with a simple straight clip. Note the atherosclerotic discoloration of the ICA. Atherosclerosis and heavy calcification of the proximal ICA can take away proximal control, because a temporary clip may not occlude the ICA. Exposure of the cervical ICA may be necessary in older patients if the intraoperative rupture risk is high or if temporary clipping is necessary to complete the aneurysm dissection and clipping.



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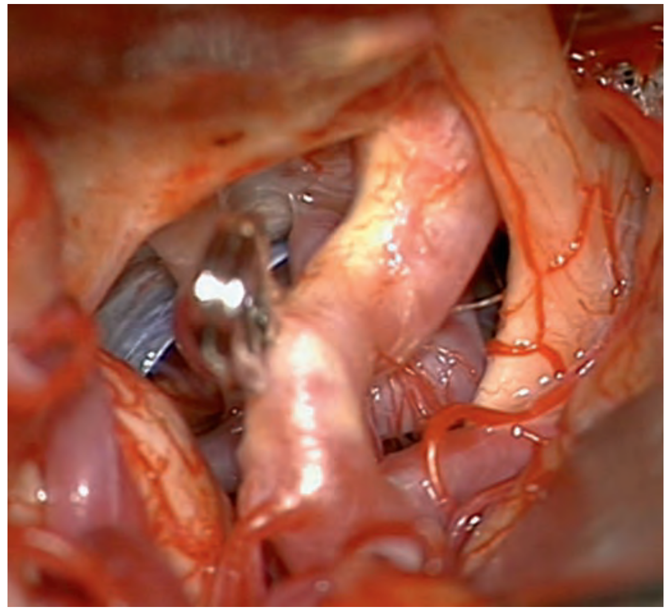

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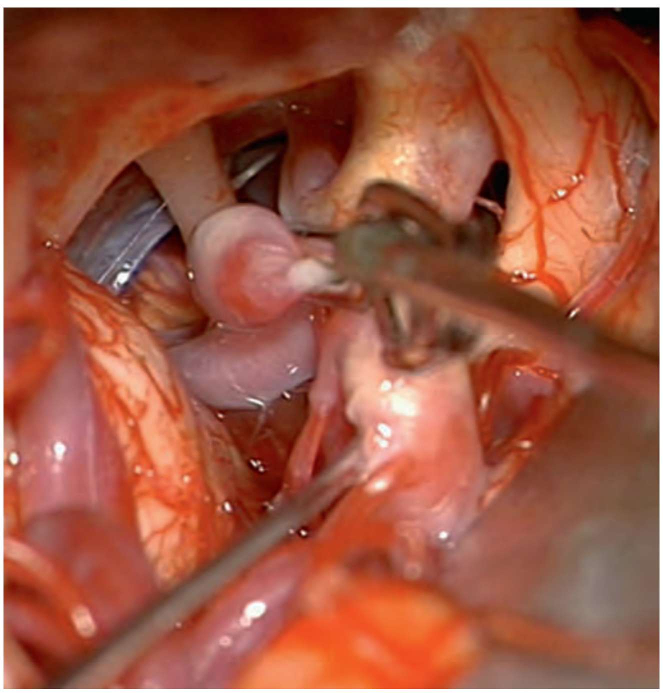

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**Fig. 14.9** This 67-year-old woman had a broad-based left PCoA aneurysm. **(A)** A large PCoA was seen in the angle between the ICA and the proximal neck, coursing medial to the oculomotor nerve. The PCoA joined the PCA behind the ICA, and the P2 segment of the PCA was seen in the optic-carotid triangle. **(B)** A temporary clip on the ICA softened the aneurysm and enabled clipping with one straight clip. **(C)** Deflecting the aneurysm clip enabled inspection along the length of the clip blade, with good visualization of the PCoA origin proximally and the P2 PCA segment distally. Note the AChA was preserved distal to the clip.

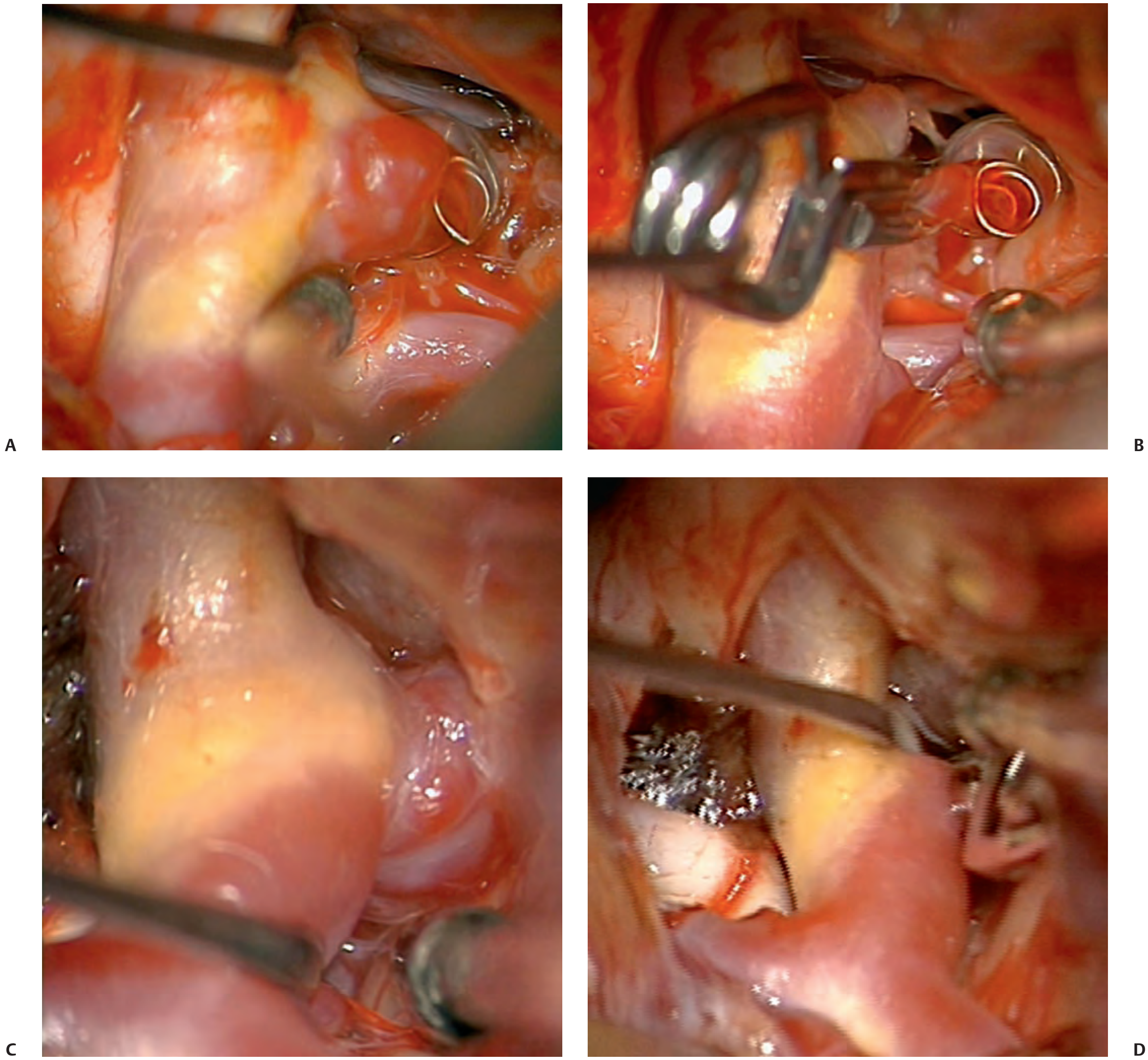
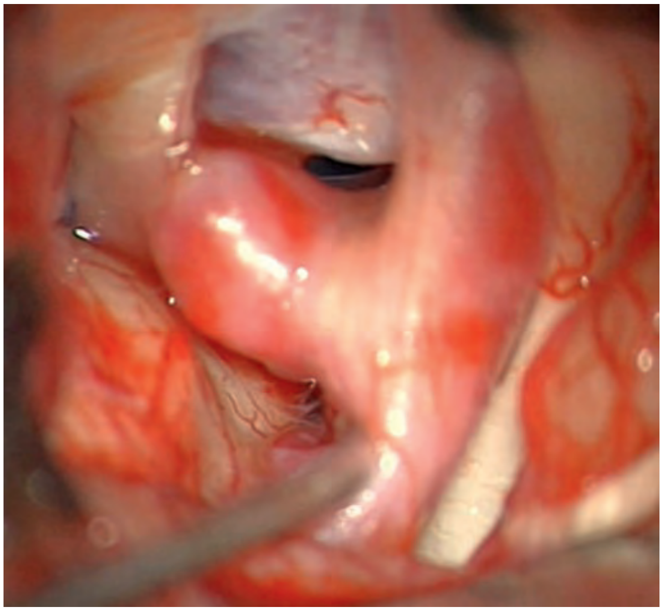


**Fig. 14.10** The tip of the anterior clip blade is applied at the spot between the PCoA origin and the proximal aneurysm neck. **(A)** In some cases like this, in which a right PCoA aneurysm recurred after endovascular coiling, the PCoA is prominent and this spot is easily identified to guide clip placement **(B)**. **(C)** In other cases like this right PCoA aneurysm, the PCoA origin appears as only a small knuckle between the ICA and the proximal aneurysm neck. **(D)** This knuckle is better visualized after permanent clipping and with upward retraction on the ICA.



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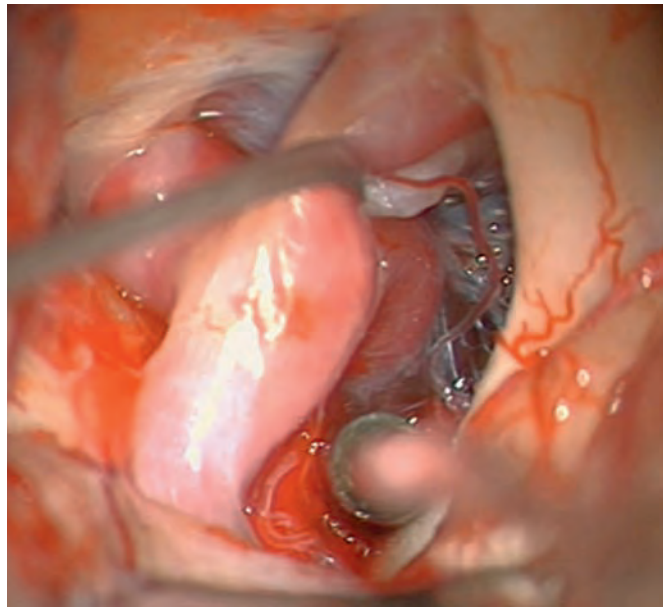

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**Fig. 14.10** (*Continued*) **(E)** In cases where the PCoA or its knuckle cannot be found, the artery often courses medially. **(F)** The left PCoA is seen in the optic-carotid triangle with some downward deflection of the ICA with a No. 6 dissector. Note the posterior clinoid process separating the inferiorly projecting aneurysm from the medially coursing PCoA, and note a small superior hypophyseal artery (SHA) anterior to the PCoA running to the sella and pituitary stalk.

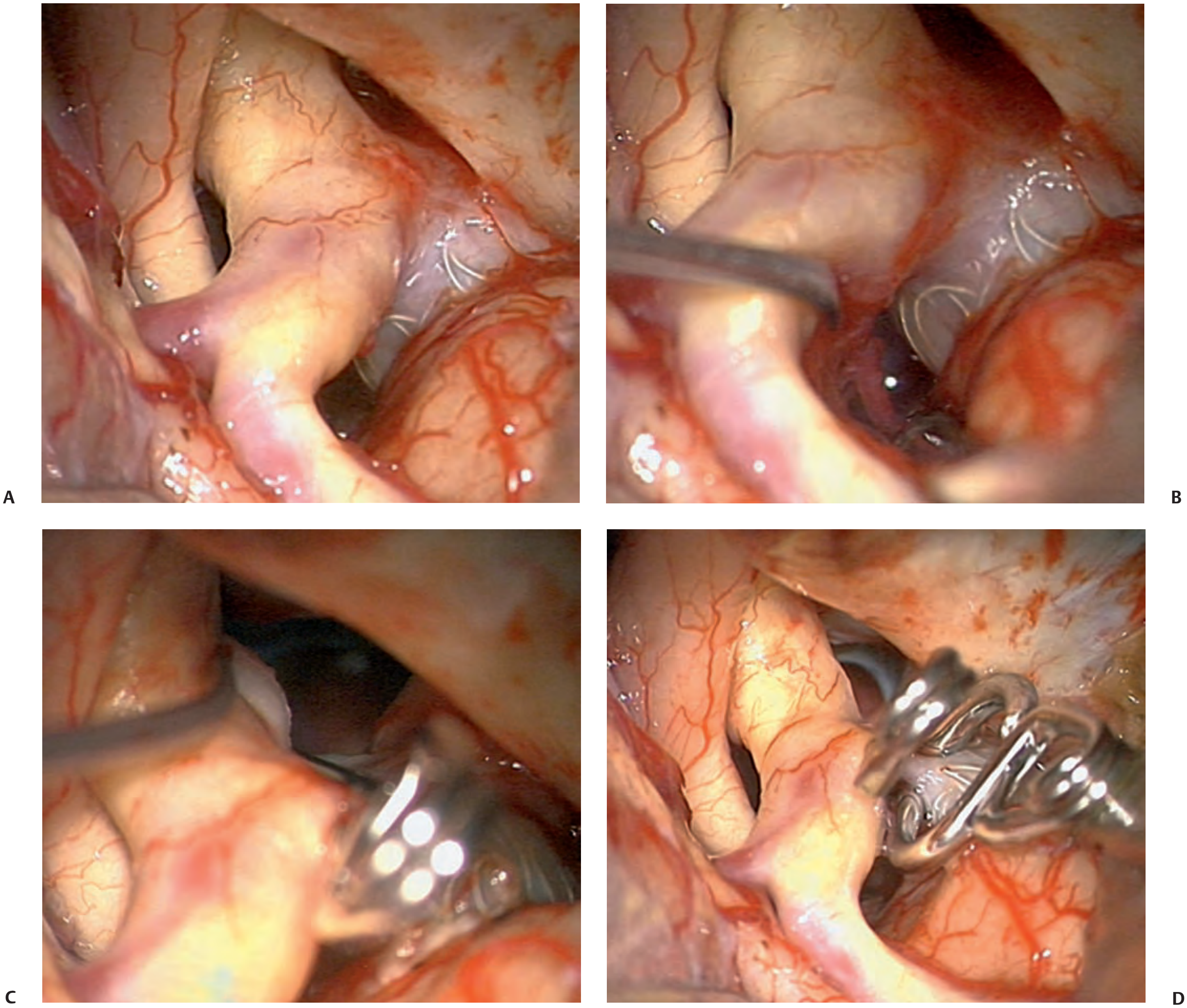


**Fig. 14.11** **(A)** This 64-year-old woman had a large right PCoA aneurysm that recurred after endovascular coiling. **(B)** The AChA was easily separated from the posterior wall of the aneurysm. **(C)** The straight clip was applied, with preservation of the PCoA seen as a knuckle at its origin. **(D)** Indocyanine green videoangiography showed some residual aneurysm filling through the distal neck, and a straight fenestrated clip was stacked on top of the straight clip to close the distal neck.

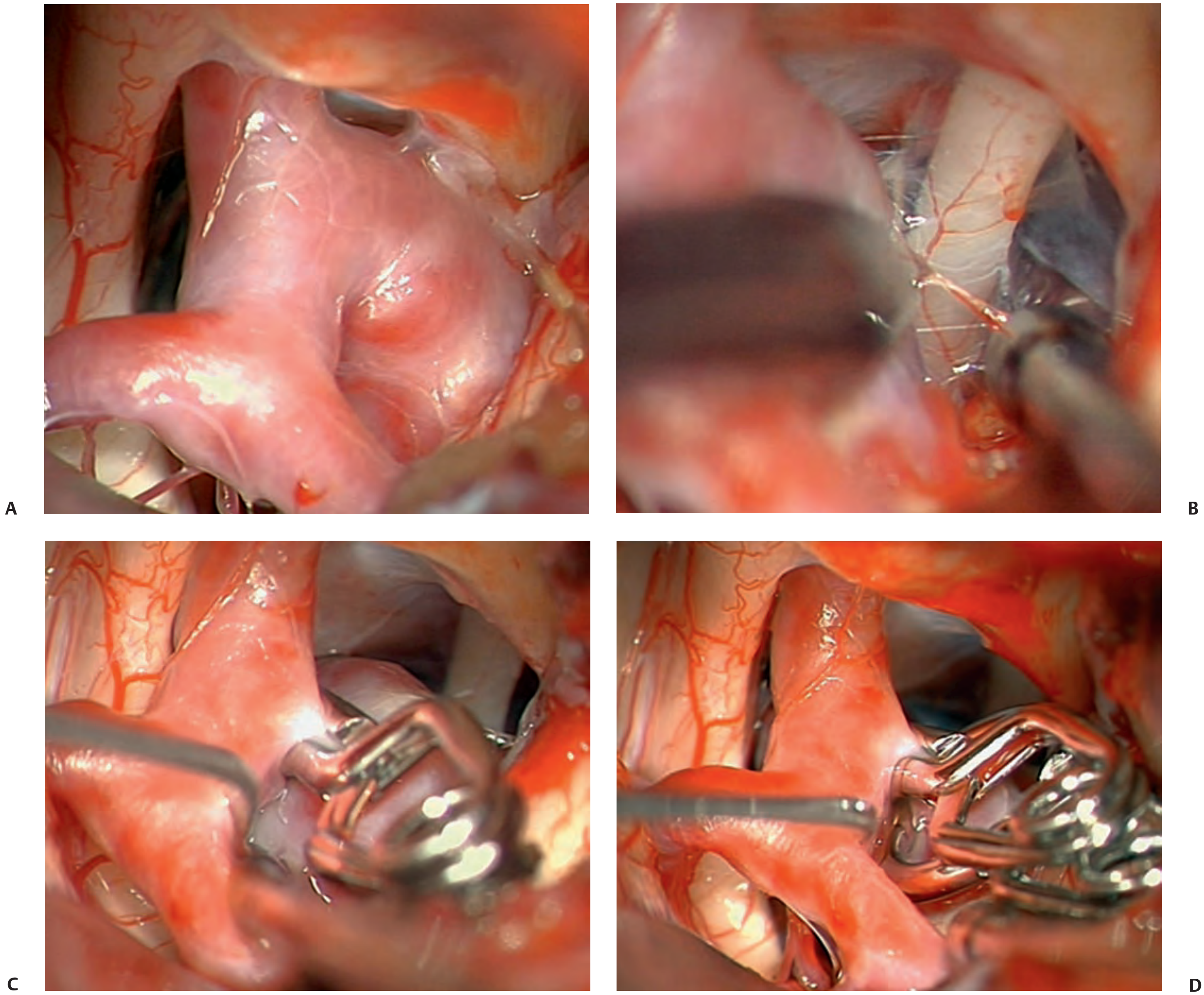

Fig. 14.12 This 47-year-old woman had a large right PCoA aneurysm. **(A)** The aneurysm projected against the tentorium. **(B)** Release of the tentorial adhesions visualized the oculomotor nerve and the PCoA origin. **(C)** A straight clip fit nicely in front of the AChA, seen as a knuckle posterior to the clip. **(D)** A stacked straight fenestrated clip was needed as a booster clip to close the proximal deep portion of the neck.

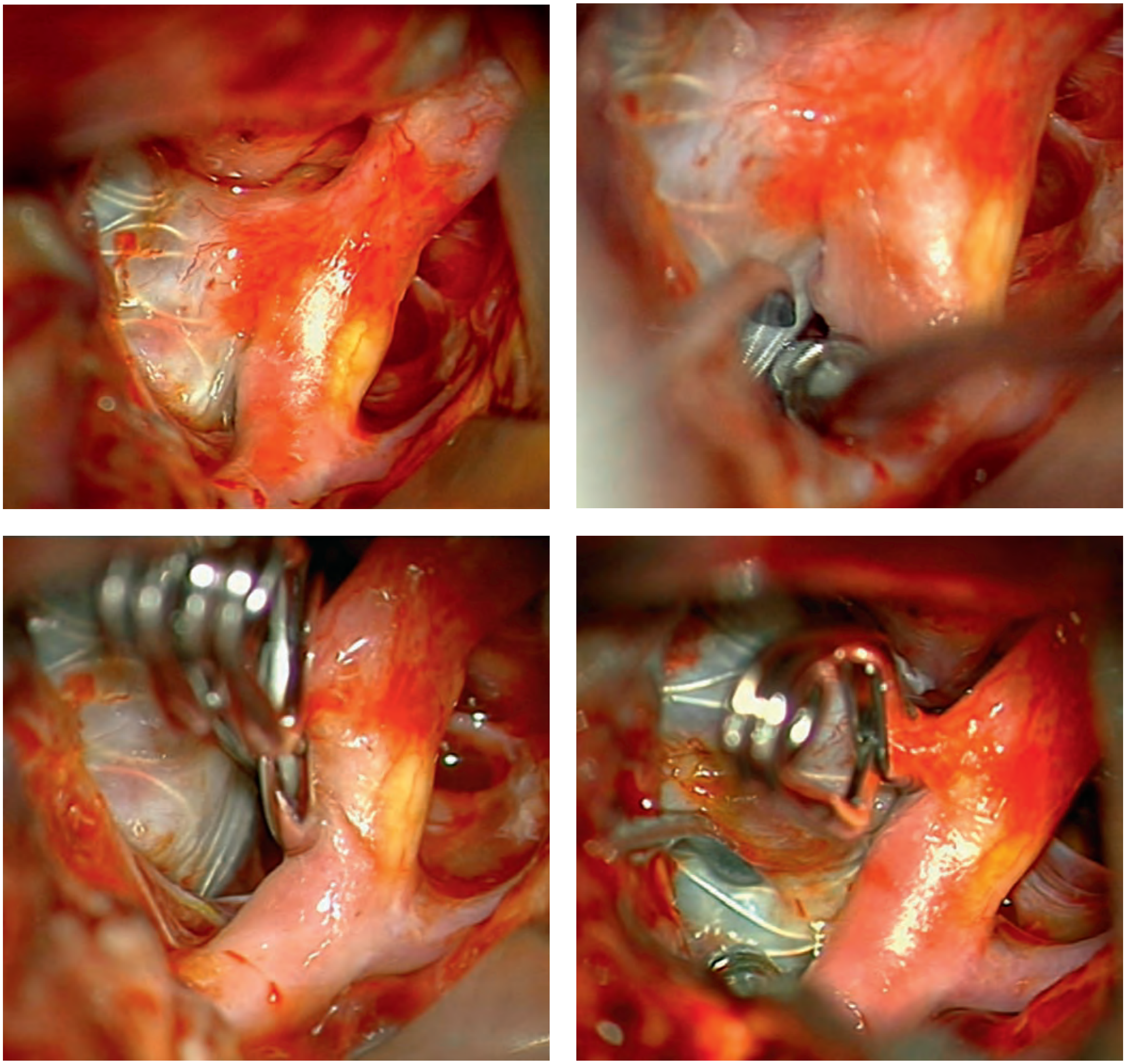

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**Fig. 14.13** This 49-year-old woman presented with a subarachnoid hemorrhage from a large left PCoA aneurysm that was coiled 2 years earlier. **(A)** The PCoA origin was identified as a knuckle at the proximal neck. **(B)** The AChA origin was identified as a knuckle at the distal neck. **(C)** The tandem clipping technique was used to keep the AChA open, but the clips pinched the ICA, occluded the AChA, and the motor evoked potentials (MEPs) were lost. **(D)** The tandem clips were replaced with one straight clip that preserved the AChA and restored the MEPs.

The safety of the AChA is critical to successful clipping, and it is inspected closely after clipping. With larger PCoA aneurysms, even a perfectly placed clip can lie against the AChA origin and obstruct the blood flow (**Fig. 14.13**). An adherent AChA that cannot be stripped from the aneurysm neck can be left on the aneurysm and encircled with a fenestrated clip or stacked fenestrated clips (**Fig. 14.14**).

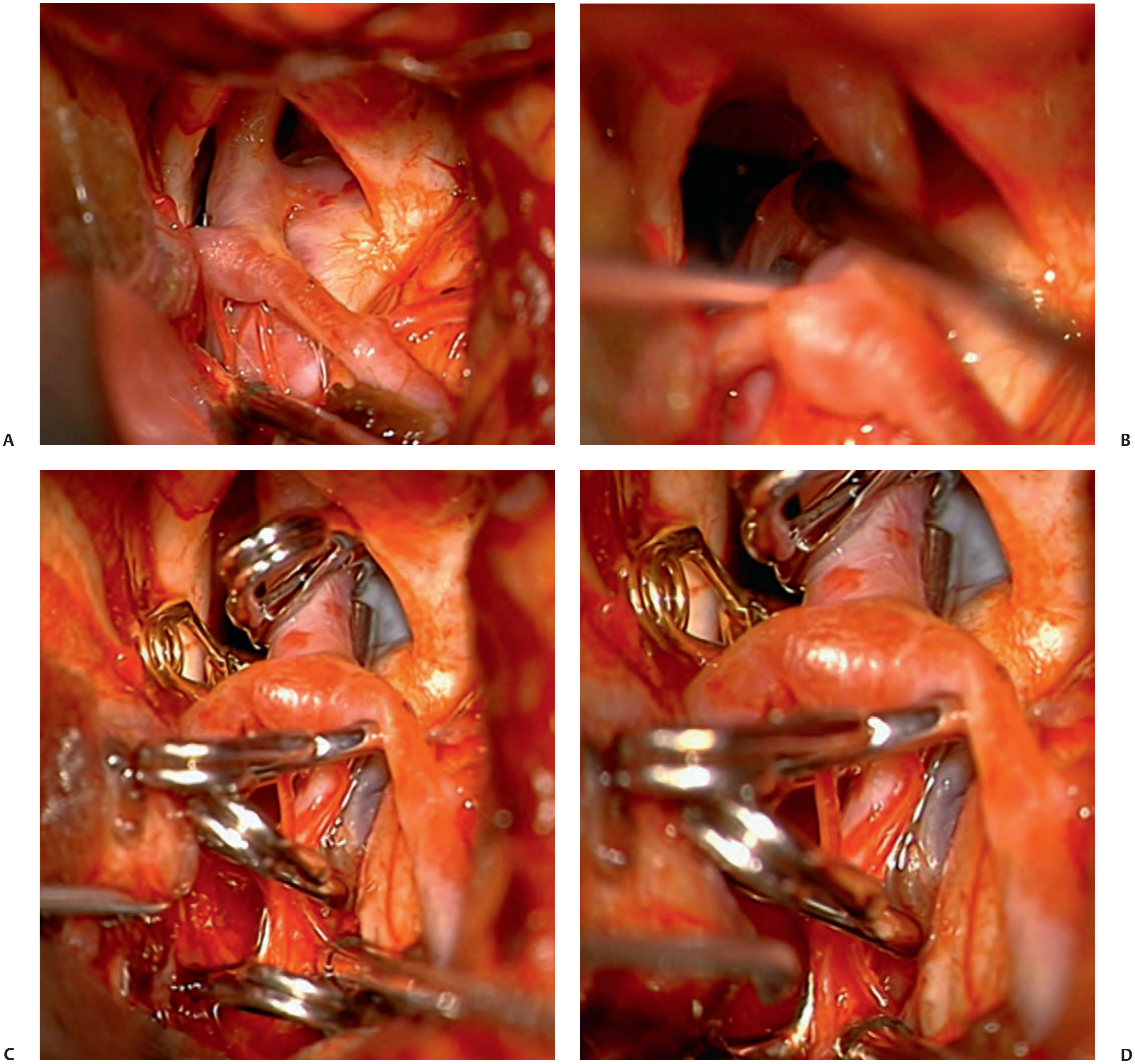
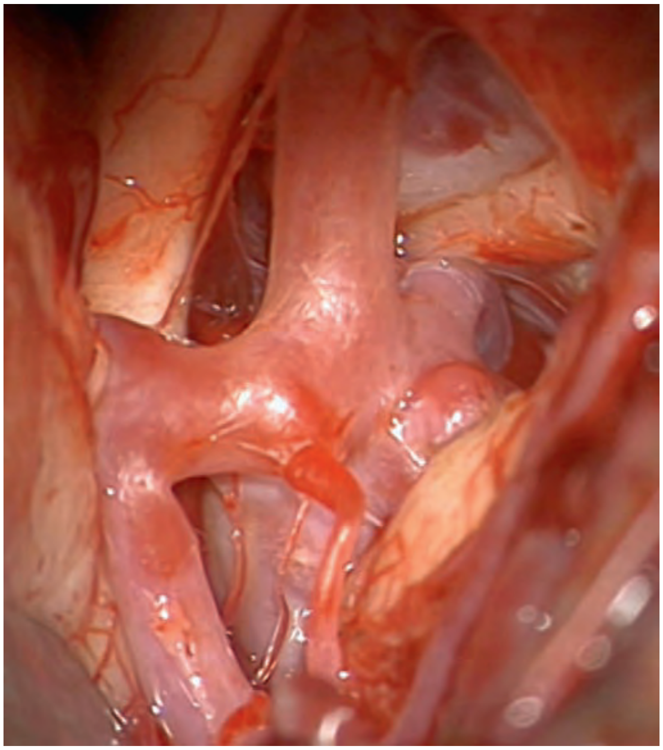


**Fig. 14.14** PCoA aneurysms are more difficult to clip when they are giant in size. **(A)** This giant right PCoA aneurysm in a 55-year-old woman projected infratentorially and filled the space behind the ICA, medial to the tentorial edge. The AChA arose 1 cm distal to the PCoA origin and the proximal neck, but it adhered to the posterior aneurysm wall and could not be dissected free. **(B)** The PCoA was also adherent to the aneurysm, seen here coursing along its medial wall. **(C)** The giant size and a broad neck required tandem angled fenestrated clipping, applying the distal clip blades beneath the adherent AChA and transmitting the AChA through the fenestration when it finally detached from the aneurysm. The initial clip configuration compromised flow in AChA and the patient's MEP and somatosensory evoked potential (SSEP) signals were lost. Adjusting the clips downward on the neck restored flow in this small but critical artery and the MEP and SSEP signals returned. **(D)** Higher magnification view demonstrated the sliver of aneurysm wall that was preserved to save the AChA as it coursed across the aneurysm, above the blades of the last two angled fenestrated clips.



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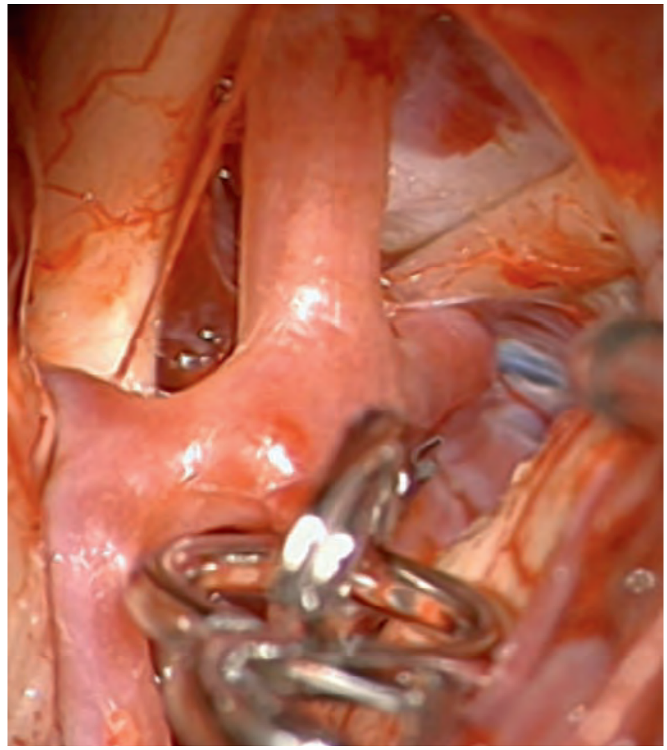

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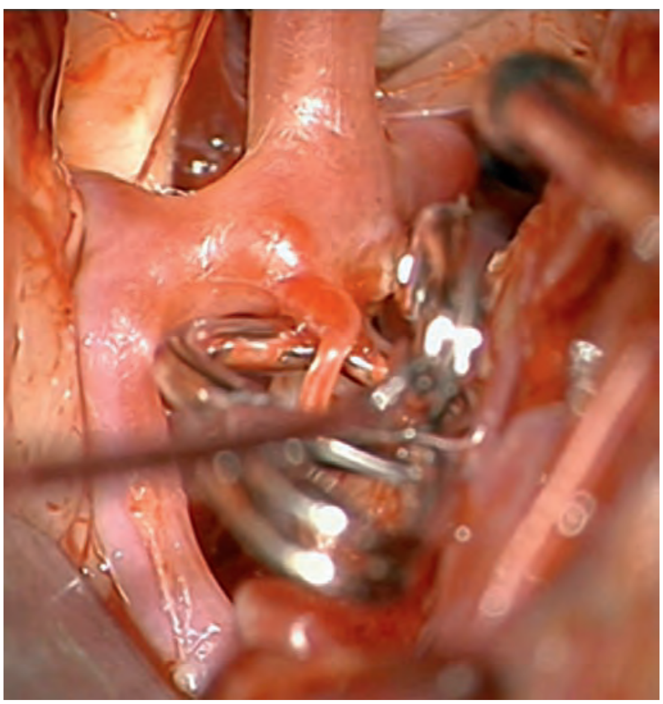

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**Fig. 14.15** This 55-year-old woman presented with a subarachnoid hemorrhage from this large right PCoA aneurysm. **(A)** She had an accessory M1 MCA originating from the lateral aspect of the ICA terminus, and an AChA originated from the main M1 MCA (not shown). **(B)** Using 4 minutes of temporary occlusion time to soften the aneurysm, the neck was closed with a straight fenestrated clip, with the blade tips lying on the shoulder of a large PCoA. **(C)** The fenestration transmitted the accessory M1 MCA.

Puncturing and deflating PCoA aneurysms is common practice because decompressing the oculomotor nerve gives patients with preoperative palsies the best chance for recovery of function. Aneurysm tissue should be left on the nerve because additional dissection and removal might aggravate it or compromise the penetrating arteries that supply it.

Deflating the aneurysm after clipping opens the view behind it. A medially directed PCoA that might have been

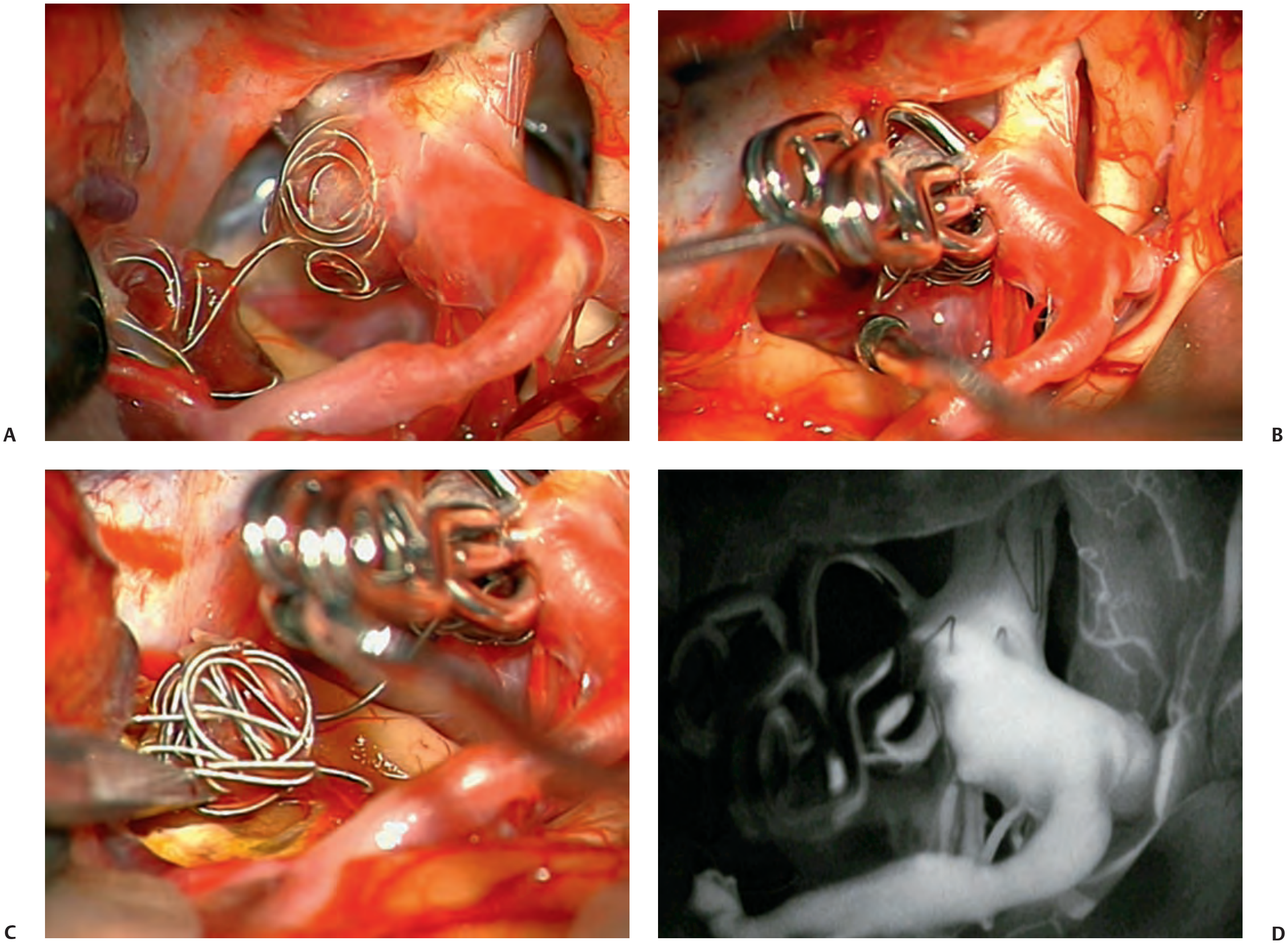

**Fig. 14.16** This 49-year-old woman had a broad-based, bi-lobed left PCoA aneurysm treated with stent-assisted coiling after a subarachnoid hemorrhage 6 months earlier. **(A)** The stent's tines were seen through the wall of the ICA, and the coils were seen in the posterior lobe of the aneurysm. Note the coil extrusion through the dome into the subarachnoid space. **(B)** Tandem clipping was used, with an understacked straight clip closing the fenestration of the clip. **(C)** The tight coil mass in the subarachnoid space and surrounding hemosiderin suggested that an associated pseudoaneurysm was coiled, with subsequent reabsorption of hematoma. **(D)** Indocyanine green videoangiography demonstrated the stent intraluminally, no residual aneurysm filling, and preservation of the AChA and its branches.

obscured by the aneurysm is often easily seen after clipping. Clip tips can sometimes catch the PCoA or its perforators as it courses behind the aneurysm. After deflating the aneurysm, the clip can be viewed fully and its position adjusted if necessary. The PCoA aneurysms that bleed after clipping may have a proximal blade on the wrong side of the PCoA origin. When inadvertently placed on the anterior surface of the PCoA origin, between the PCoA and the ICA, the PCoA can fill retrograde from the posterior circulation and also fill the aneurysm. The clip requires repositioning on the posterior surface of the PCoA origin, between the PCoA and the proximal neck, to properly occlude the aneurysm.

Some large PCoA aneurysms that persistently fill after clipping with a simple straight clip may require tandem clipping or a booster clip to reinforce the closure of the distal neck (**Figs. 14.15 and 14.16**). The PCoA aneurysms with intraluminal thrombus, previously placed coils, or atherosclerosis may also require tandem or boosters clips.

The PCoA aneurysm anatomy can be hidden by the anterior clinoid process when the aneurysm lies proximally on

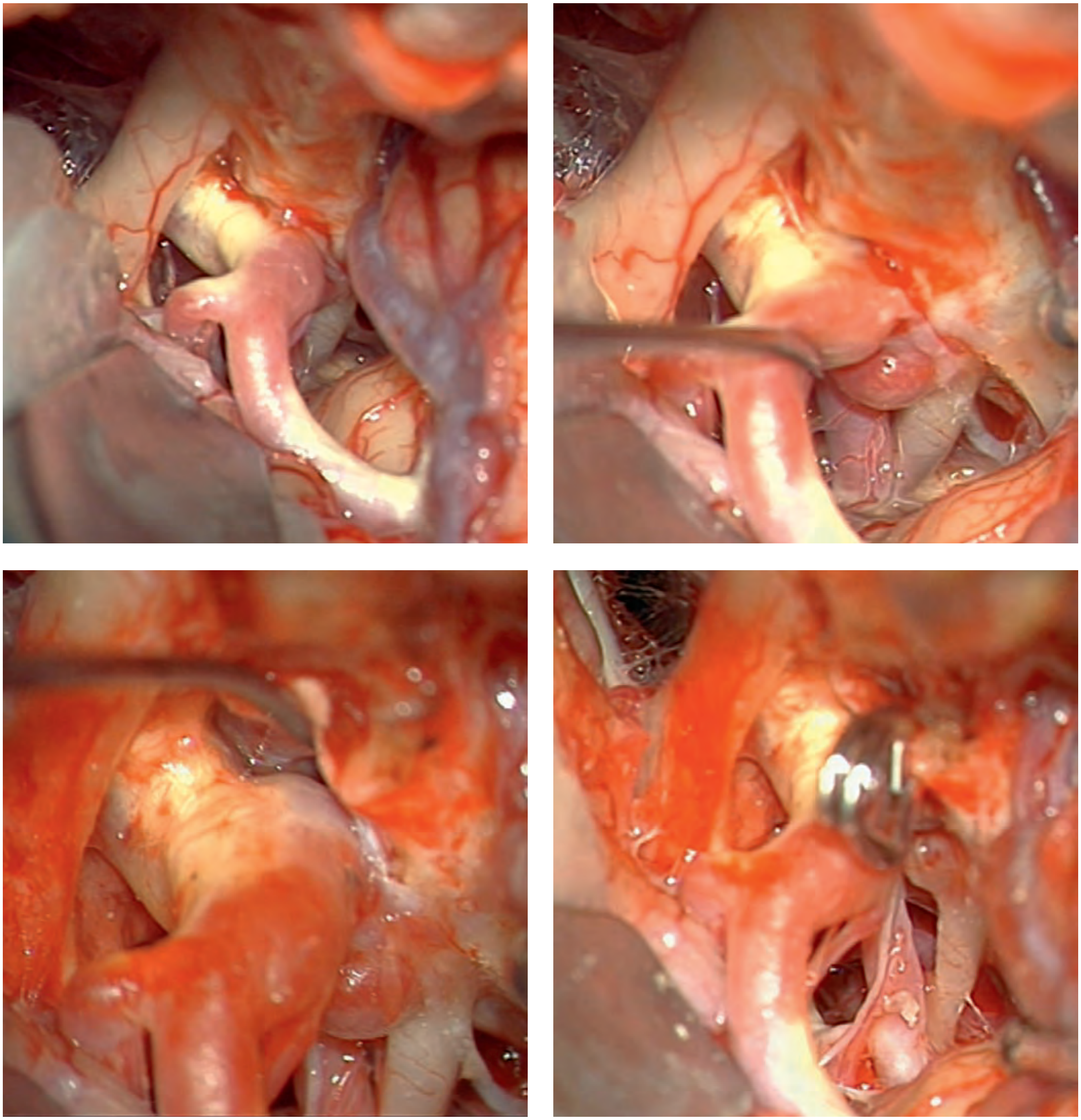

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**Fig. 14.17** This elderly woman presented with a progressive right oculomotor nerve palsy from the PCoA aneurysm. **(A)** A prominent anterior clinoid process covered the proximal neck and a bend in the ICA hid the aneurysm. **(B)** With some medial ICA deflection, the aneurysm was seen impacting the oculomotor nerve. **(C)** Limited anterior clinoidectomy exposed the proximal neck. **(D)** The aneurysm was clipped with a slightly curved clip, preserving the PCoA and AChA and decompressing the oculomotor nerve.

the ICA or the clinoid process is large. Limited removal of the tip and body of the anterior clinoid process, without drilling the optic strut or dissecting the distal dural ring, exposes this hidden anatomy and facilitates clipping (**Fig. 14.17**). A complete anterior clinoidectomy is rarely needed for PCoA aneurysms.

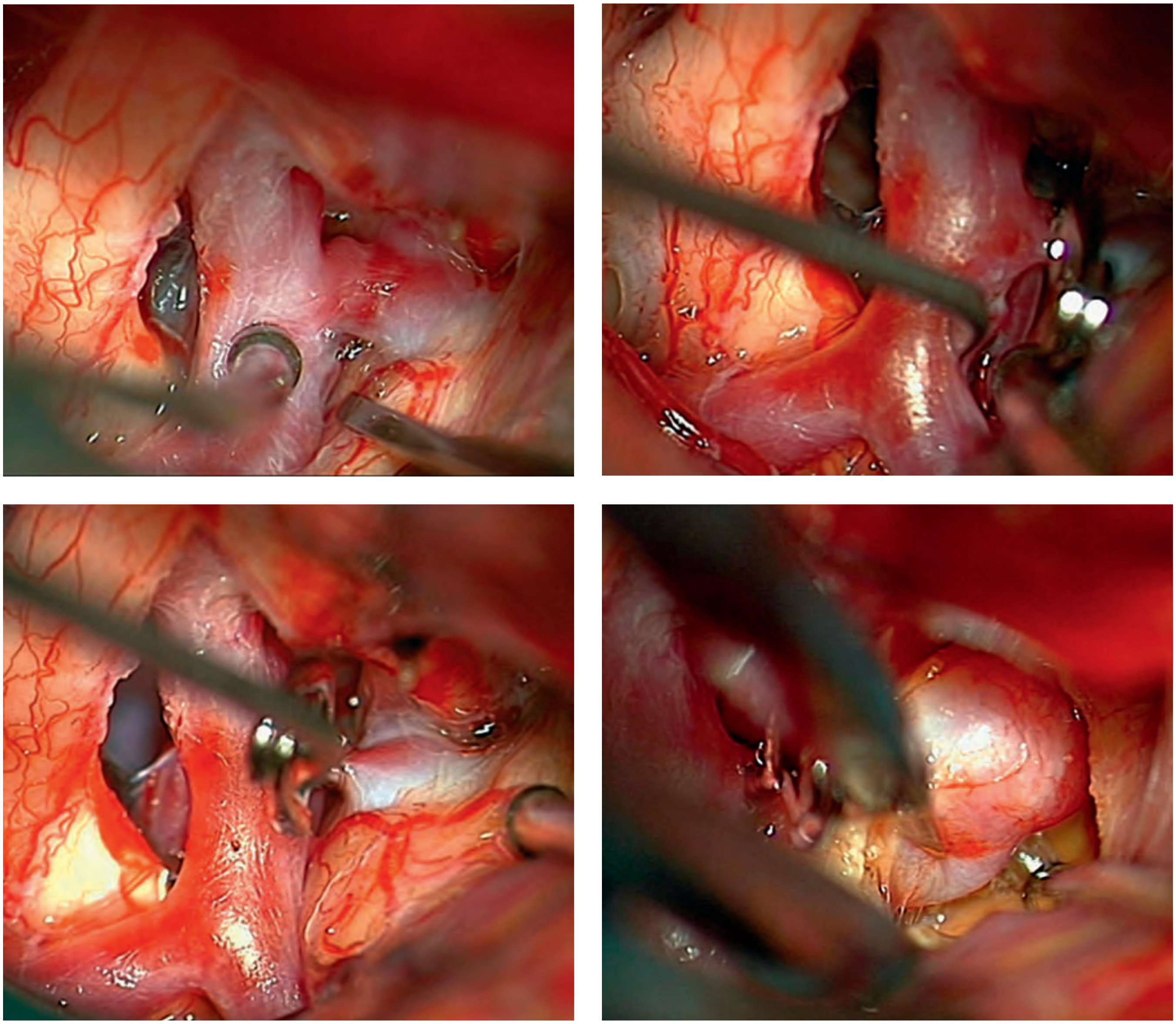

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**Fig. 14.18** The principles of PCoA aneurysm surgery are applicable to AChA aneurysms. This 40-year-old woman had a sudden, severe headache associated with a right oculomotor nerve palsy 1 year previously. Her palsy resolved gradually and she presented with a new seizure. Further evaluation diagnosed an AChA aneurysm and some surrounding encephalomalacia, suggesting an unrecognized intraparenchymal rupture. **(A)** The AChA aneurysm projected supratentorially into the uncus. The PCoA origin was identified proximally, and the AChA origin was seen as a knuckle at the base of the aneurysm. **(B)** The neck was closed with a straight clip, and the distal AChA was visualized coursing posteriorly beneath the clip blades. **(C)** The dome projected into brain parenchyma. **(D)** The surrounding gliotic cavity was consistent with her previous hemorrhage.

The principles and steps for PCoA aneurysms also apply to AChA aneurysms (**Fig. 14.18**). Patients with multiple aneurysms and a PCoA aneurysm contralateral to a ruptured or primary aneurysm can often be clipped simultaneously during the same surgery, sparing the patient a second intervention. The *interoptic triangle* provides access to the medial ICA below the contralateral optic nerve, through which small, unruptured PCoA aneurysms with medial and inferior projection can be clipped (**Fig. 14.19**). The PCoA aneurysms that are ruptured, large, or project laterally are not favorable for

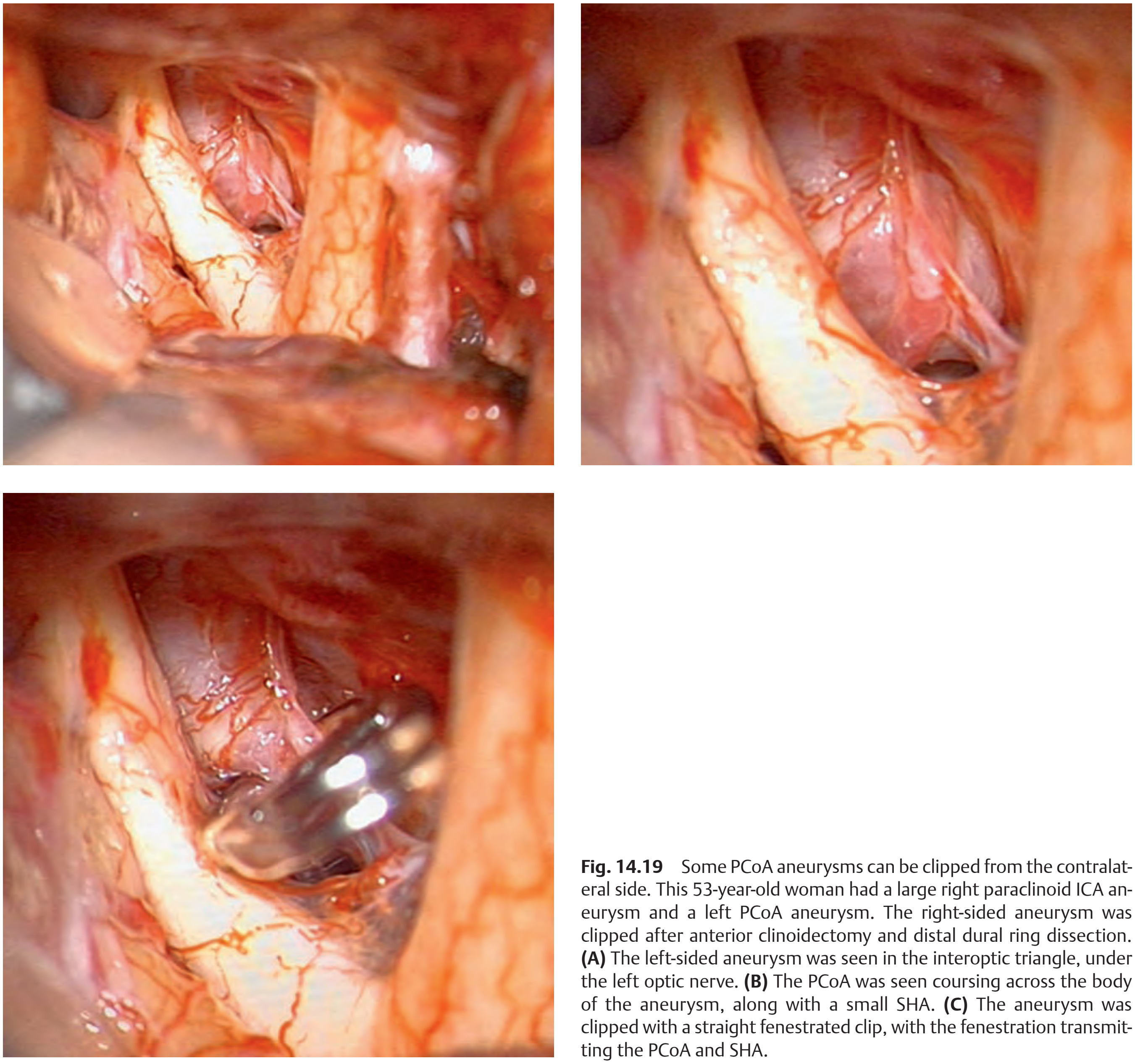


**Fig. 14.19** Some PCoA aneurysms can be clipped from the contralateral side. This 53-year-old woman had a large right paraclinoid ICA aneurysm and a left PCoA aneurysm. The right-sided aneurysm was clipped after anterior clinoidectomy and distal dural ring dissection. **(A)** The left-sided aneurysm was seen in the interoptic triangle, under the left optic nerve. **(B)** The PCoA was seen coursing across the body of the aneurysm, along with a small SHA. **(C)** The aneurysm was clipped with a straight fenestrated clip, with the fenestration transmitting the PCoA and SHA.

contralateral clipping because the view of AChA may be inadequate.

The PCoA aneurysms often have an anatomy that is favorable for endovascular coiling, such as small size, a narrow neck, and easy accessibility. However, these aneurysms are also favorable for microsurgical clipping. They require minimal microdissection and often have simple anatomy. Low surgical risk, ability to decompress the oculomotor nerve, and durability of clipping are the real advantages of clipping over coiling with this straightforward and common aneurysm.

# 15 Middle Cerebral Artery Aneurysms

## Microsurgical Anatomy

Segmental anatomy is defined by the middle cerebral artery's (MCA) complex curvature rather than its branches. The M1 segment begins at the terminal bifurcation of the internal carotid artery (ICA) and ends at the genu, a right-angle bend in the artery as it courses over a small gyrus of insular cortex, the limen insulae (**Fig. 15.1**). The M1 segment is named the *sphenoidal segment* because it parallels the course of the sphenoid ridge. The M2 segment, or *insular segment*, begins at the genu, runs in the insular cleft, and terminates at the circular sulcus of the insula where the arteries make their next right-angle turn. The turn in the circular sulcus may be exaggerated (90 to 180 degrees) as arteries transition from the insular surface to the medial frontoparietal opercular surface. The M3 segment, or *opercular segment,* begins at this genu where arteries leave the insular surface, run in the opercular cleft, and terminate at the cortical surface of the sylvian fissure. The M4 segment, or *cortical segment*, consists of branches supplying the lateral convexity from their emergence from the sylvian fissure to their final territory. The MCA therefore courses through the sylvian fissure from the ICA terminus to the lateral convexity, has four segments, makes three right-angle bends, alternates its orientation between horizontal and vertical, and branches distally to resemble a candelabra.

The MCA bifurcates into *superior* and *inferior trunks* (**Fig. 15.2**), with the bifurcation located on the M1 segment if it is proximal to the genu at the limen insulae, on the M2 segment if it is distal to the genu, or at the M1-M2 junction if it is at the genu. Most MCA aneurysms are located at MCA bifurcations into superior and inferior trunks. MCA trifurcations into superior, middle, and inferior trunks are observed in less than 20% of patients, and MCA quadrifurcations are rare. Bifurcations with early secondary bifurcations of trunks can appear as quadrifurcations. Trunks can be symmetrical, but size relates to the number of distal branches, and one trunk often dominates. Anterior branches include the orbitofrontal artery, operculofrontal artery, and central sulcus artery; posterior branches include the posterior parietal artery, angular artery, and posterior temporal arteries. Trunks do most of their branching along the M2 segment, which removes these branches from the aneurysm dissection.

The anterior temporal artery (ATA) originates from the inferior surface of the M1 segment and ascends the temporal lobe in the sylvian fissure. The ATA can also arise from the inferior trunk of the MCA bifurcation or from a common temporal trunk proximal to the MCA bifurcation that also gives rise to uncal and temporopolar arteries. Uncal and temporopolar arteries are normally small branches from the M1 segment proximal to the ATA. Although the common temporal trunk can create a "false bifurcation" and be misinterpreted as an early MCA bifurcation, the ATA usually is a reliable landmark during the dissection along the M1 segment toward the aneurysm. As the ATA courses over the surface of the temporal lobe to supply the temporal pole, it can drape the dome of a large or inferiorly projecting aneurysm and be misinterpreted as an inferior or middle trunk ("false trunk"). The ATA is not directly related to MCA aneurysm necks. It can be dissected off the dome to mobilize the aneurysm, or left on the dome with permanent clips applied around it.

The lateral lenticulostriate arteries originate from the superior surface of the M1 segment, enter the lateral two thirds of the anterior perforated substance, and ascend to deep white matter structures that include the caudate, putamen, globus pallidus, superior half of the internal capsule, and corona radiata. Lenticulostriate arteries may be large stems with multiple secondary branches, solitary arteries that parallel the M1 segment, or small twigs perpendicular to the M1 segment. There are, on average, 10 lenticulostriates, and most arise from the pre-bifurcation portion of the M1 segment. Lenticulostriates can arise from the post-bifurcation M1 segment or the M2 segment, depending on where the MCA bifurcates. The eloquent territory of lenticulostriate arteries demands careful preservation.

A duplicated MCA is a second M1 segment that arises either from a supraclinoid ICA or its terminal bifurcation (**Fig. 15.2**). An accessory MCA is a second M1 segment that arises from the A1 anterior cerebral artery (ACA), usually near the anterior communicating artery (ACoA), resembling the recurrent artery of Heubner but for the presence of cortical branches (**Fig. 15.2**).

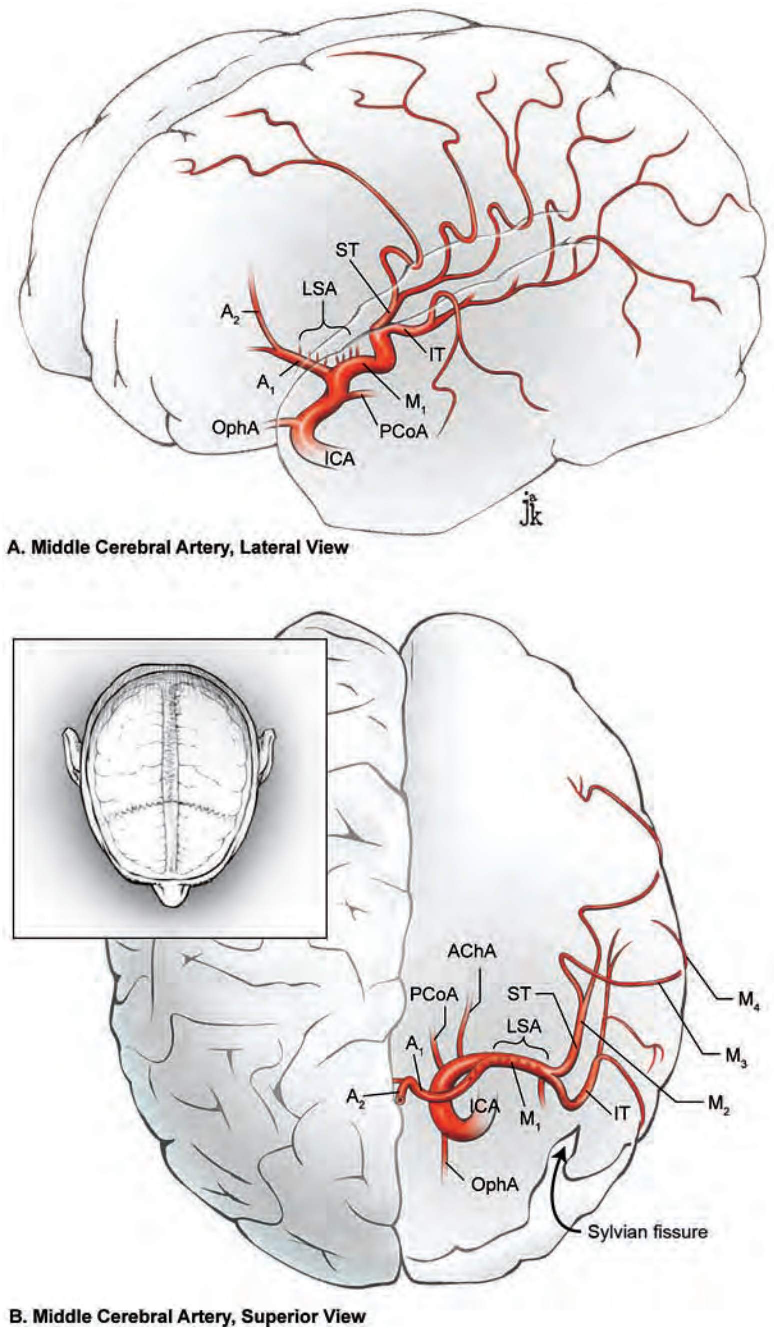



**Fig. 15.1** Microsurgical anatomy of the middle cerebral artery (MCA). Lateral **(A)** and superior **(B)** views showing the MCA segments: M1, sphenoidal segment; M2, insular segment; M3, opercular segment; and M4, cortical segments. AChA, anterior choroidal artery; ICA, internal carotid artery; IT, inferior trunk; LSA, lenticulostriate artery; OphA, ophthalmic artery; PCoA, posterior communicating artery; ST, superior trunk.

## ■ Splitting the Sylvian Fissure

### Veins and Superficial Dissection

The sylvian fissure is the gateway to aneurysms around the circle of Willis. Separation of the frontal and temporal lobes opens the subarachnoid network unlike any other maneuver, making the sylvian fissure split one of the aneurysm surgeon's most important techniques.

Superficial sylvian veins are the guardians of the sylvian fissure. Some patients have no veins, and an inviting sheet of arachnoid between the frontal and temporal lobes is all that covers the lateral sylvian cistern. Other patients have a complex of frontal, parietal, and temporal veins that course

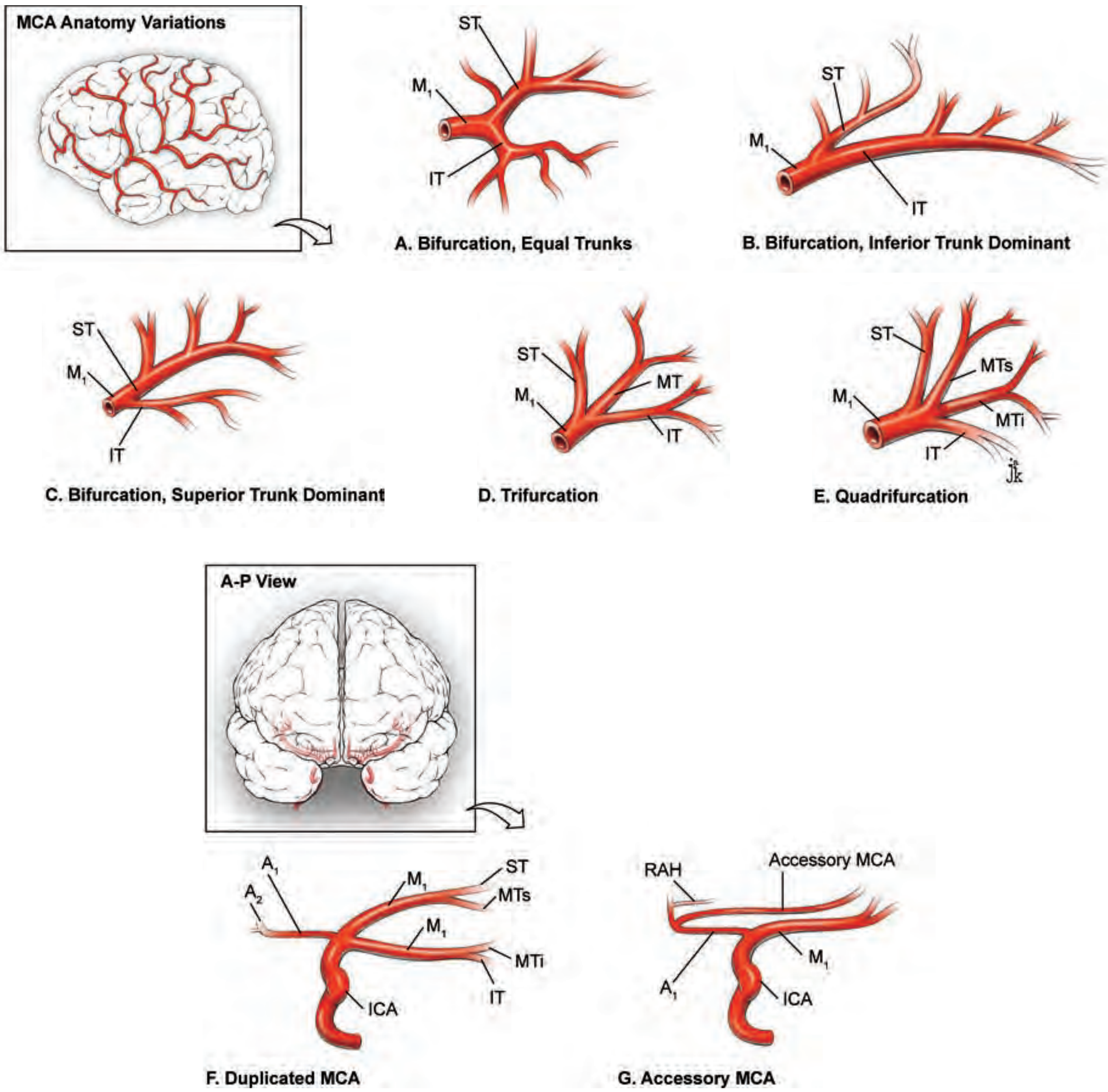



**Fig. 15.2** Normal variations of middle cerebral artery anatomy. **(A)** MCA bifurcation, equal trunks. **(B)** MCA bifurcation, inferior trunk dominant. **(C)** MCA bifurcation, superior trunk dominant. **(D)** MCA trifurcation. **(E)** MCA quadrifurcation. **(F)** Duplicated M1 MCA segment. **(G)** Accessory M1 MCA segment. Anterior branches include the orbitofrontal artery, operculofrontal artery, and central sulcus artery; posterior branches include the posterior parietal artery, angular artery, and posterior temporal arteries. A-P, anteroposterior; MT, middle trunk; MTi, middle trunk, inferior, MTs, middle trunk, superior; RAH, recurrent artery of Heubner.

along the lips of the sylvian fissure (**Fig. 15.3**). The first step in splitting the sylvian fissure is to dissect beyond the veins. In general, superficial sylvian veins are mobilized to the temporal side of the fissure because they course inferiorly and bridge to the sphenoparietal sinus under the sphenoid ridge. Dissection along the temporal side of the veins would ultimately cross their outflow connections, whereas dissection along the frontal side can preserve these connections.

Cortical arachnoid is incised with the tip of an up-facing No. 11 scalpel blade, lifting this layer off the underlying veins and nicking it. One blade of a short microscissors enters the subarachnoid space through that nick and continues the incision, again lifting the arachnoid with the scissors blade to clear the underlying veins. Arachnoid is incised along the superficial sylvian vein from distal to proximal, coagulating and cutting venous tributaries from the frontal lobe (**Fig. 15.4**,

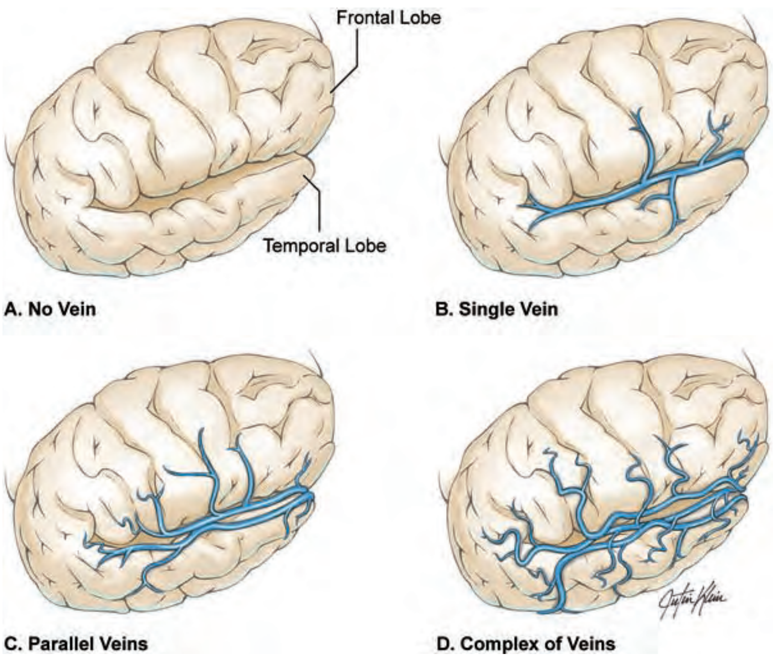



**Fig. 15.3** Normal variations of the superficial sylvian vein anatomy (right side). **(A)** Absence of superficial sylvian veins. **(B)** Single superficial sylvian vein. **(C)** Parallel superficial sylvian veins. **(D)** Complex network of superficial sylvian veins.

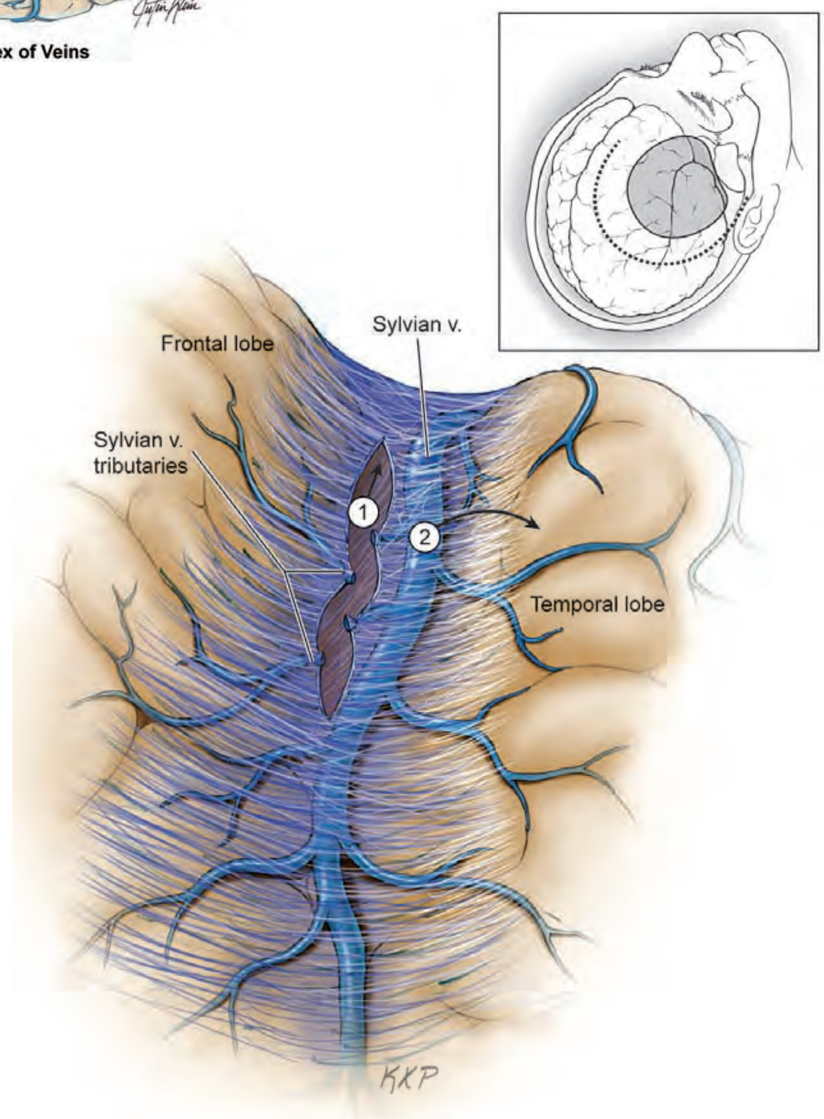



**Fig. 15.4** Dissection steps in splitting the sylvian fissure (veins and superficial dissection, right side). Step 1, cortical arachnoid incision; step 2, temporal mobilization of the sylvian veins.

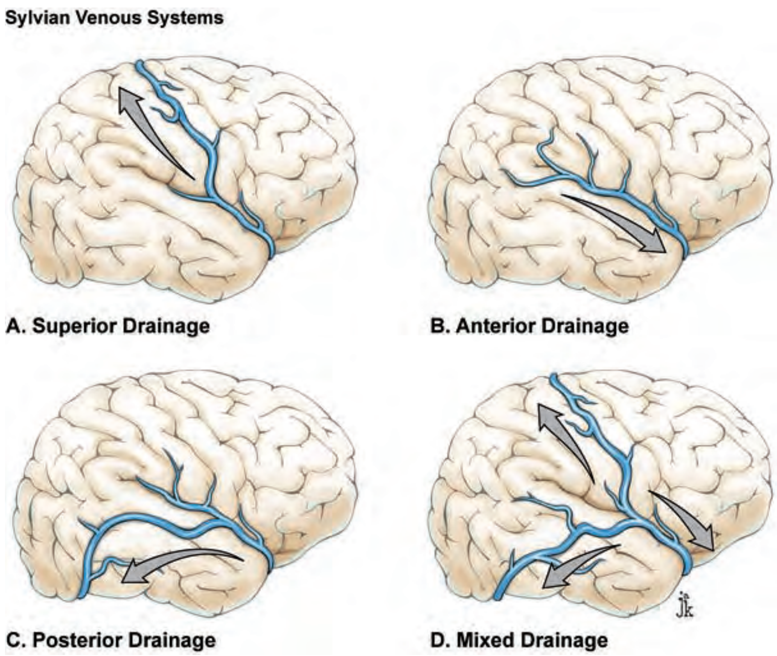



**Fig. 15.5** Venous systems draining the sylvian fissure: **(A)** superior, **(B)** anterior, **(C)** posterior, and **(D)** mixed systems.

step 1). The superficial sylvian vein is gradually detached from the frontal lobe and mobilized temporally (**Fig. 15.4**, step 2).

The superficial sylvian venous complex is composed of three interrelated venous systems (**Fig. 15.5**). An *anterior sylvian venous system* drains to the sphenoparietal sinus, cavernous sinus, and sphenobasal or sphenopetrosal sinuses; a *posterior sylvian venous system* drains to the lateral temporal veins, vein of Labbé, and transverse sinus; and a *superior sylvian venous system* drains to the frontoparietal veins, vein of Trolard, and the superior sagittal sinus (SSS). Convergence of these three venous systems along the sylvian fissure can create an obstructive tangle of veins, but it also establishes collateral venous connections that allow patients to tolerate sacrifice of a vein. Most of the time, a large sylvian vein can be rolled away from the frontal lobe and preserved. Sometimes the plane between paired sylvian veins may be the easiest pathway into the fissure. Occasionally, an adherent vein does not mobilize temporally and may need to be divided, provided that the dominant sylvian trunk is preserved and that it connects with other venous systems. Veins should be protected, but opening the sylvian fissure can require some venous pruning. The rarity of venous complications after splitting the sylvian fissure attests to the interconnections between the sylvian venous systems. Venous sacrifice can increase venous pressure in the sylvian veins and increase their fragility, so it should be delayed until the sylvian fissure split is further along.

As dissection along the superficial sylvian vein reaches the temporal pole, cortical arachnoid of the distal sylvian cistern transitions to sphenoidal arachnoid of the proximal sylvian cistern. From the surgeon's perspective, this sphenoidal arachnoid is vertically oriented, and cortical arachnoid is horizontally oriented (**Fig. 15.6**). Sphenoidal arachnoid should be opened before proceeding to deep sylvian dissection because it couples the frontal and temporal lobes and resists deep spreading dissection. The steep view down this plane may require some frontal retraction with swollen brains.

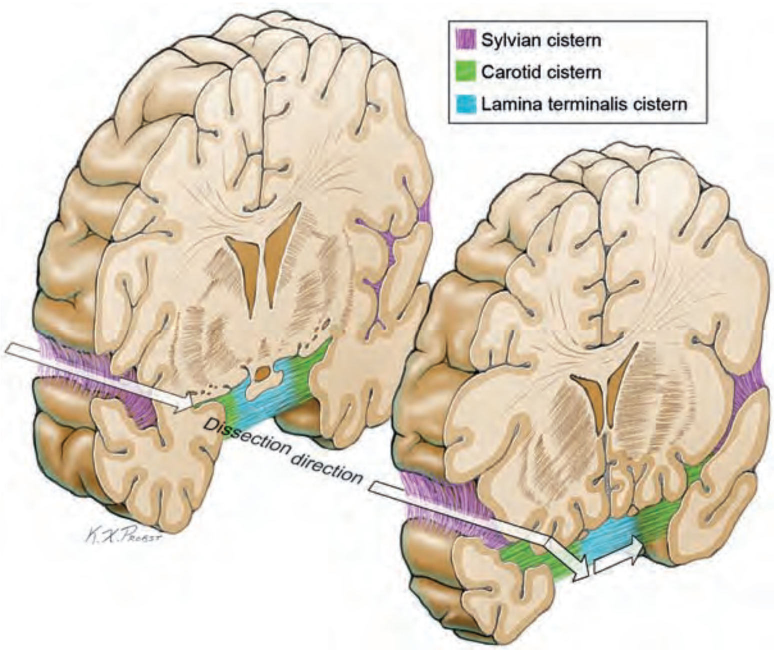



**Fig. 15.6** Subarachnoid dissection during the sylvian fissure split progresses from the distal sylvian cistern and its horizontal cortical arachnoid, to the proximal sylvian cistern and its vertical sphenoidal arachnoid. Opening the sylvian cistern leads to the carotid and lamina terminalis cisterns more medially.

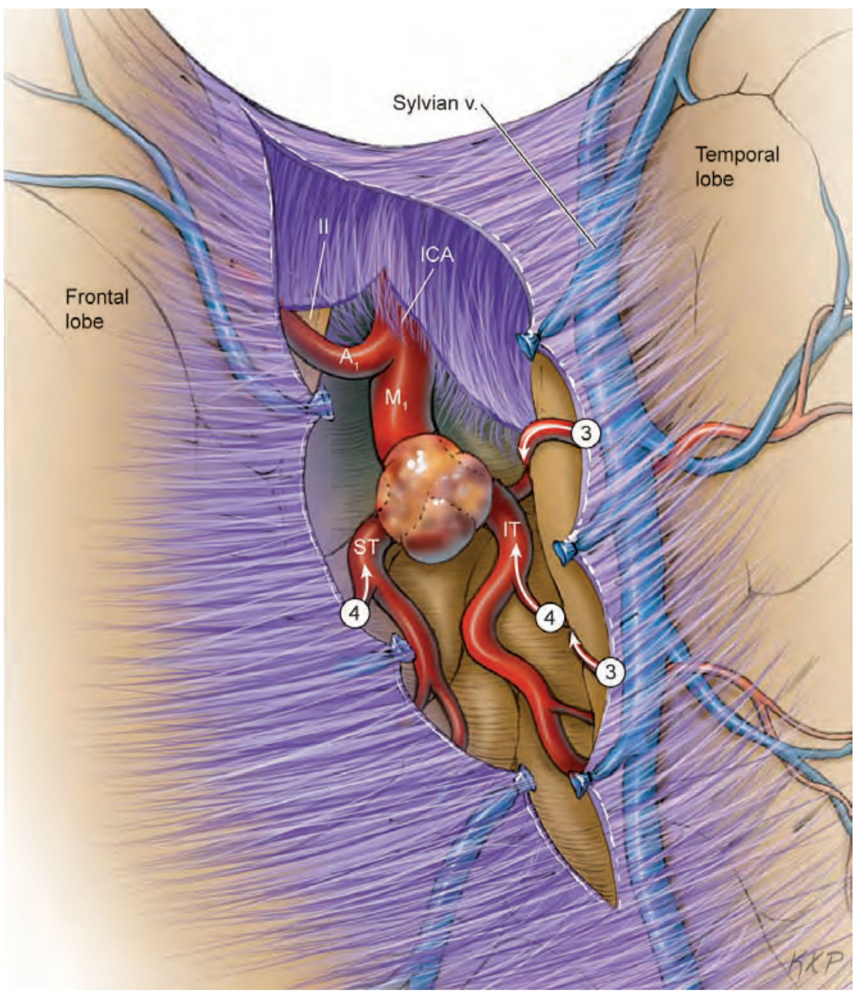



**Fig. 15.7** Dissection steps in splitting the sylvian fissure (arteries and deep dissection). Step 3, following the cortical MCA branches to the opercular MCA branches; step 4, following the opercular MCA branches to the insular MCA branches.

The sylvian veins frequently lie beneath sphenoidal arachnoid or can penetrate it en route to the sphenoparietal sinus. Subarachnoid hemorrhage can hide these veins, but lifting dissection with the microscissors protects underlying veins.

## Arteries and Deep Dissection

After mobilizing the superficial veins temporally and opening the sylvian cistern, an artery is identified as it emerges from the fissure. Arteries naturally separate the frontal and temporal lobes to define the dissection plane. This cortical artery is followed into the operculum of the sylvian fissure to develop the plane further (**Fig. 15.7**, step 3). Superficial sylvian dissection along the veins aligns the microscope at a shallow angle, whereas deep sylvian dissection along the opercular segments of the MCA branches aligns the microscope at a steep, downward angle, almost back toward the neurosurgeon. Cutting arachnoid bands between the frontal and temporal lobes initiates this dissection. The working area around an artery should be widened circumferentially like a funnel, rather than like a cylinder, to avoid constricted corridors. Similar working areas around adjacent opercular arteries can be developed and connected to neighboring areas of dissection (**Fig. 15.7**, step 3).

Small opercular arteries lead to larger insular arteries, and insular arteries lead to the trunks of the MCA bi- or trifurcation (**Fig. 15.7**, step 4). The dissection becomes easier as it deepens because insular arteries widely separate the frontal and temporal lobes. Spreading dissection along the arteries parts the lobes from "inside out," following a wide plane of separation deep in the sylvian fissure to narrow, more adherent areas superficially. Yasargil analogized this dissection to splitting an orange, where radial force directed outward from the center easily separates the orange wedges. The sylvian fissure is often most adherent superficially near the pterion where there are few arteries between the frontal and temporal lobes to separate the lobes. Lobules can even interdigitate, adding a rolling contour to this plane of contact (**Fig. 15.8**, frontal-herniating or temporal-herniating fissures). Spreading dissection from inside out is the best method for opening these difficult tissue planes. When tissues still do not separate easily, an artery might be found under sphenoidal arachnoid in the proximal fissure to re-establish the subarachnoid plane.

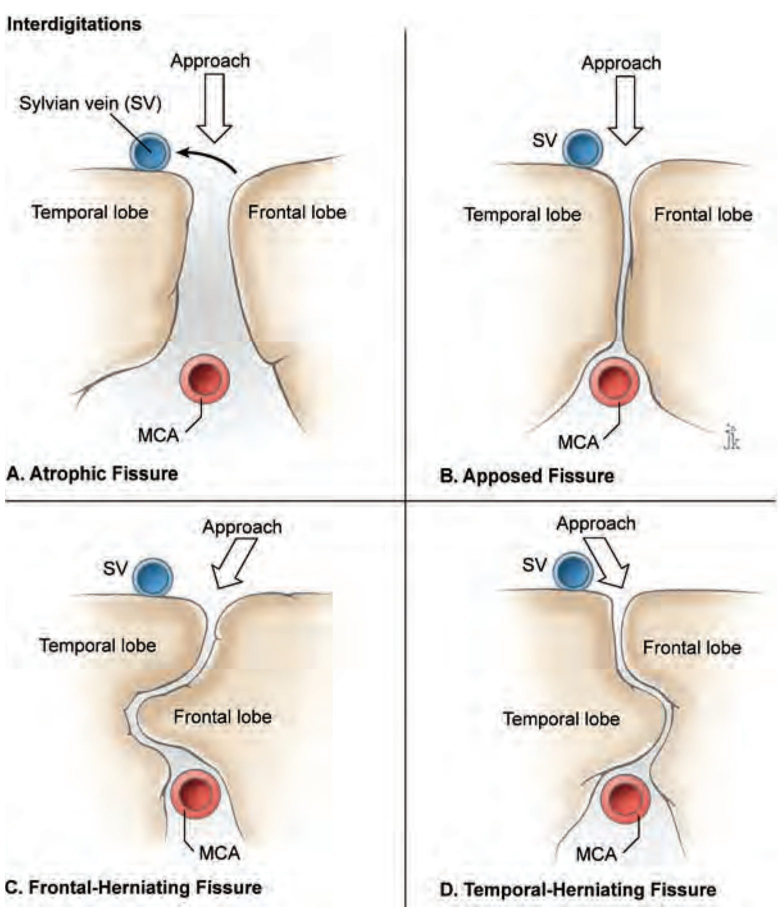



**Fig. 15.8** Types of sylvian fissures. **(A)** Atrophic fissures in older patients are wide open with minimal contact between the frontal and temporal lobes. **(B)** Apposed fissures are more common with large areas of contact between the frontal and temporal lobes. Interdigitated fissures, either frontal-herniating **(C)** or temporal-herniating **(D)**, are tightly apposed with contoured areas of contact, and the angle of approach must follow this rolling contour.

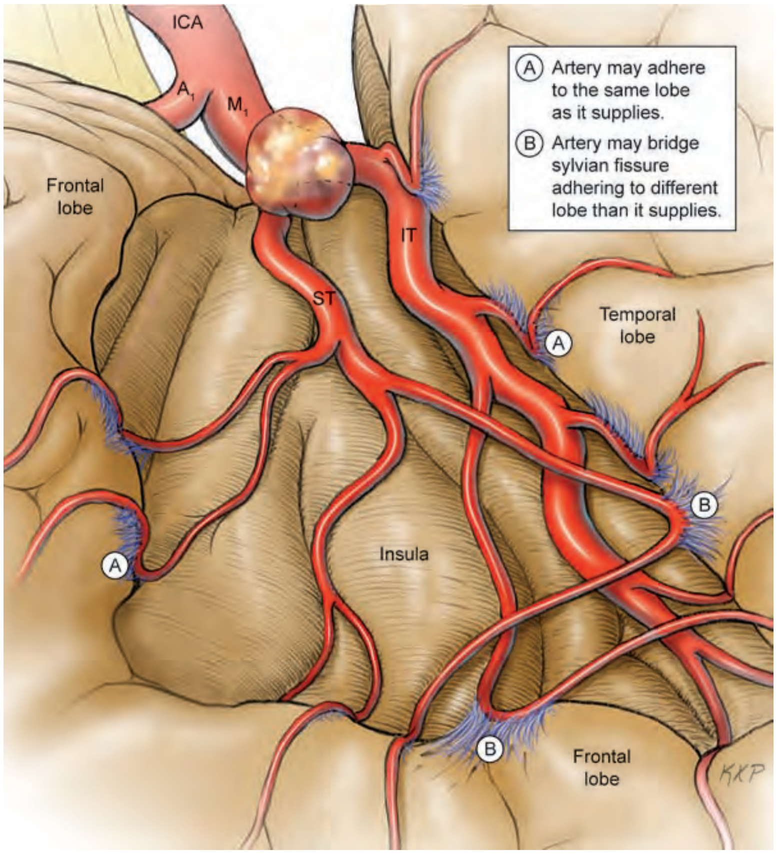



**Fig. 15.9** Dissection steps in splitting the sylvian fissure (inside the sylvian cistern). Arteries branch temporally or frontally, but never to both lobes. Consequently, arteries in the sylvian fissure move to one side or the other. Some arteries lie on the same lobe they supply (A), and other arteries lie on the opposite lobe (B). A temporal artery that adheres to the frontal lobe bridges the fissure and is mobilized temporally. Branch arteries are traced from their origin to their final destination to interpret and unscramble them correctly.

## Inside the Sylvian Cistern

Once inside the sylvian cistern, the challenge shifts from separating lobes to unscrambling arteries. Inferior, middle, and superior trunks of the MCA, the ATA, the lenticulostriates, and other branch arteries must be untangled to complete the fissure split. Arteries faithfully serve one lobe, branching temporally or frontally, but never branching to both lobes. Consequently, arteries in the sylvian cistern move to one side or the other. The anatomy is easy to decipher when an artery lies on the same lobe it supplies (**Fig. 15.9A**), but is difficult to decipher when an artery lies on the opposite lobe (**Fig. 15.9B**). A temporal artery that adheres to the frontal lobe before looping back to the temporal lobe will bridge the fissure and might be compromised if this anatomy is not appreciated. Branch arteries are traced from their origin to their final destination to interpret and mobilize them correctly. Bridging arteries with confusing anatomy require more dissection and another read.

Unlike arteries that faithfully serve one lobe, veins can branch to both lobes and frequently bridge the sylvian fissure. Deep sylvian veins encountered at the end of the fissure dissection overlying the M1 segment are often small and can be divided. Large deep sylvian veins should be mobilized temporally and preserved. Thick arachnoid between carotid and sylvian cisterns is the final tether between the frontal and temporal lobes. Once cut, the sylvian fissure split is completed and the vasculature can be followed from the supraclinoid ICA to the MCA bifurcation.

Brain retractors are not used during the sylvian dissection. When the frontal lobe finally separates from the temporal lobe, a retractor can be positioned on the posterior portion of the medial orbital gyrus with the retractor tip right above the A1 segment. Retraction is light, holding apart tissues that are thoroughly disconnected.

Splitting the sylvian fissure from distal to proximal in the manner described is easier than from proximal to distal. Distal-to-proximal dissection proceeds sequentially to deep arterial trunks; inside-out dissection is effective; brain retraction is not necessary; and cerebrospinal fluid (CSF) remains in the sylvian cistern to separate the lobes. In contrast, proximal-to-distal dissection follows the M1 MCA segment; it may require frontal lobe retraction; and CSF is released early to collapse the sylvian cistern. Distal-to-proximal dissection approaches MCA aneurysms without proximal control, which can be dangerous with ruptured aneurysms but is safe with unruptured aneurysms. Sylvian dissection with ruptured aneurysms often begins distally to establish dissection planes, but quickly shifts proximally to establish control of the aneurysm.

## Aneurysm Dissection

The MCA aneurysms obey Rhoton's third rule better than most aneurysms: they point in the direction that blood would have gone if the curve or bifurcation was not present. Consequently, most MCA aneurysms project laterally along the axis of the M1 segment (**Fig. 15.10A**). In addition, they have some inferior or superior tilt that depends on the M1 segment's arc in a coronal plane: an upward arc ends with downward flow at the bifurcation and an aneurysm projecting inferiorly, whereas a downward arc ends with upward flow at the bifurcation and an aneurysm projecting superiorly (**Fig. 15.10B,C**). Similarly, MCA aneurysms have some anterior or posterior tilt that depends on the M1 segment's arc in an axial plane: a posterior arc ends with anterior flow at the bifurcation and an aneurysm projecting anteriorly, whereas an anterior arc ends with posterior flow at the bifurcation and an aneurysm projecting posteriorly (**Fig. 15.10D,E**). Preoperative angiography demonstrates M1 segment curvature and dome orientation, and helps in planning a dissection route that avoids the dome.

A wide opening of the sylvian fissure is required with MCA aneurysms. Opercular branches lead to insular branches, which lead to trunks and the aneurysm neck. MCA aneurysms projecting laterally in the sylvian fissure typically hide one of the trunks behind the aneurysm, and most often it is the inferior trunk. From the neurosurgeon's vantage point looking into an opened sylvian fissure, the temporal lobe is deep in the field and the aneurysm lies between the surgeon and the inferior trunk. The frontal lobe is shallower, and its superior trunk lies superficial to the aneurysm. Therefore, the superior trunk tends to be more apparent during

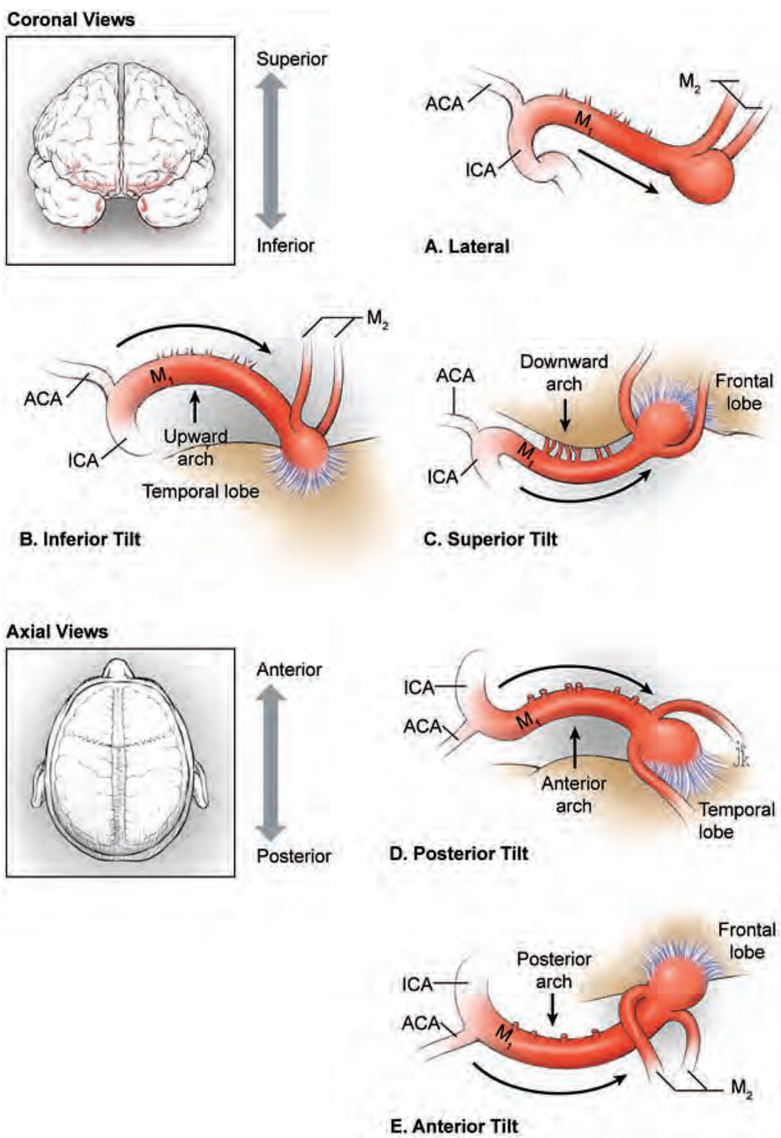



**Fig. 15.10** MCA aneurysm dome projections. Coronal views: lateral **(A),** inferior **(B),** and superior **(C)** projection. Axial views: posterior **(D)** and anterior **(E)** projection. ACA, anterior cerebral artery.

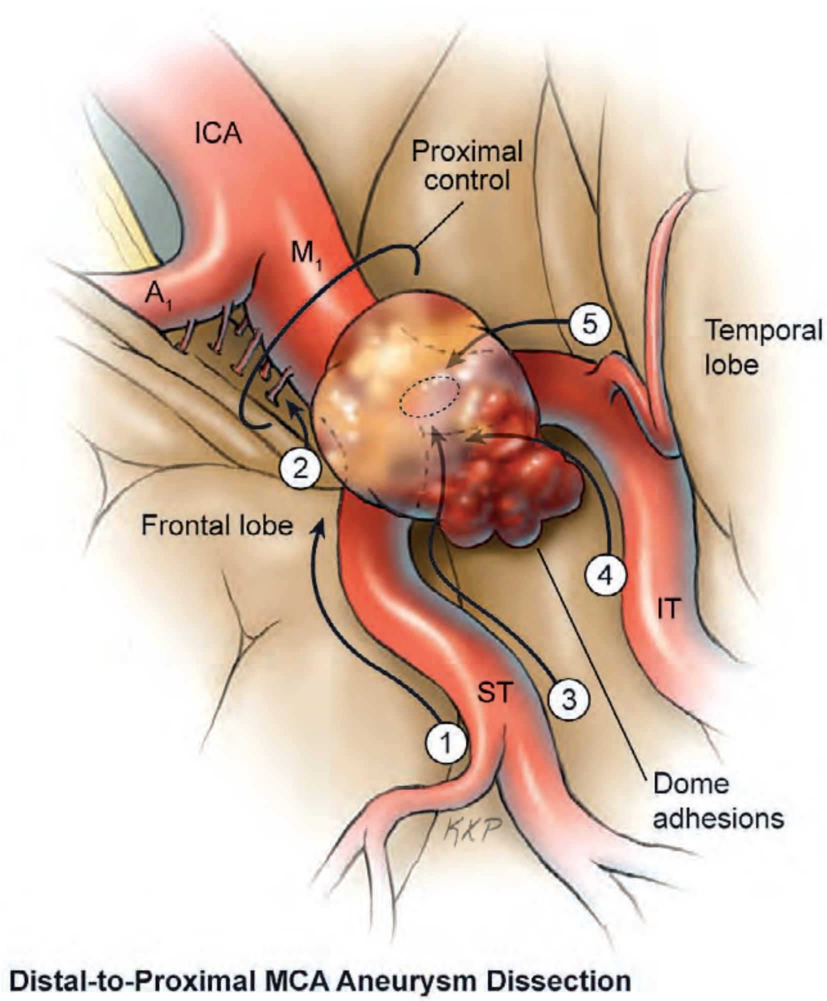



**Fig. 15.11** MCA aneurysm dissection strategy, distal-to-proximal dissection. Step 1, following the superior trunk (outer surface); step 2, preparing the M1 segment for proximal control; step 3, following the superior trunk (inner surface); step 4, following the inferior trunk (inner surface); step 5, dissecting the distal neck (blind spot).

the dissection and can be followed proximally to the aneurysm and its neck (**Fig. 15.11**, step 1). Tracing the superior trunk puts the dissection distal, superior, and medial to the aneurysm. The outer surface of the trunk, opposite the cleavage plane between the inner surface and the aneurysm neck, is the safest to follow and will clarify the junction between the superior trunk and the afferent M1 artery. Additional retrograde dissection exposes the M1 segment where proximal control is prepared (**Fig. 15.11**, step 2). With the added security of proximal control, the inner surface is dissected down to the proximal neck and across the neck of the aneurysm to the opposite side (**Fig. 15.11**, step 3). The hidden trunk can often be found by working behind the aneurysm neck in the insular recess of the sylvian fissure. Once found, the hidden trunk converges on the neck as it is followed retrograde (**Fig. 15.11**, step 4). The operative perspective facilitates dissection of this deep trunk along its inner surface and develops the appropriate cleavage plane at the distal neck.

Laterally projecting MCA aneurysms tend to have a blind spot at the distal neck. Dome adhesions from the thrombus, arachnoid, draped arteries such as the ATA, or draped sylvian veins tether the aneurysm to the temporal lobe and make the blind spot difficult to explore. A clear view may be present along one side of the neck, but dome adhesions may impair the view along the other side of the neck. When shifting the microscope fails to provide the necessary view, the dome can be untethered or the aneurysm mobilized after softening it with temporary clipping. These final dissection maneuvers should visualize the pathway for the other clip blade. Final efforts are typically devoted to opening the cleavage plane between the distal neck and the hidden trunk that lies in the surgical blind spot (**Fig. 15.11**, step 5). This is the spot for the tip of the permanent clip.

This distal-to-proximal dissection heads directly to the aneurysm's base and avoids its dome, but proximal control of the M1 segment is lacking early in the dissection, which can be risky with ruptured aneurysms. The alternative approach is proximal-to-distal dissection. This antegrade approach gains early proximal control by opening the carotid cistern and dissecting the supraclinoid ICA to its bifurcation (**Fig. 15.12**, step 1); identifying the A1 ACA and clearing a spot just above it for the anterior blade of the temporary clip (**Fig. 15.12**, step 2); identifying the anterior choroidal artery (AChA) laterally and dissecting along the M1 segment (**Fig. 15.12**, step 3); and clearing a spot for the posterior blade of the temporary clip (**Fig. 15.12**, step 4). This dissection requires minimal splitting of the sylvian fissure. However, proximal dissection in this direction requires some frontal lobe retraction, splits the sylvian fissure inefficiently (from "outside-in" rather than "inside-out"), and can be close to an inferiorly projecting aneurysm dome. Once this proximal

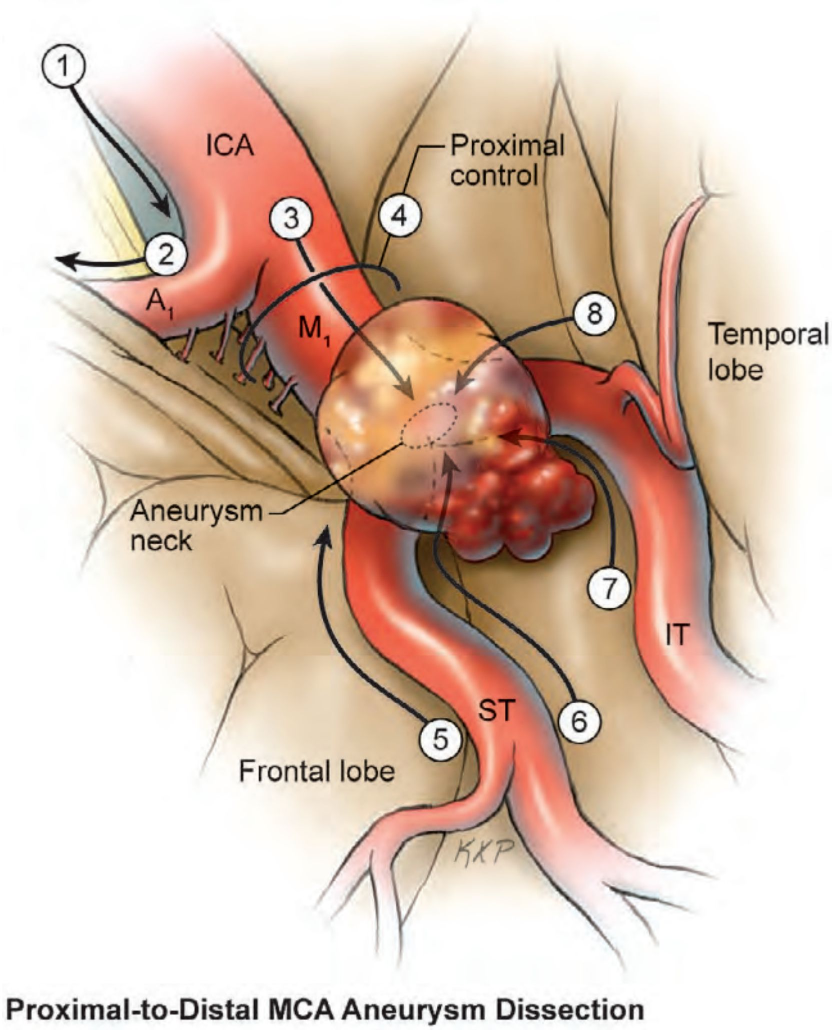



**Fig. 15.12** MCA aneurysm dissection strategy, proximal-to-distal dissection. Step 1, dissecting the supraclinoid ICA; step 2, dissecting the A1 ACA; step 3, identifying the AChA laterally and dissecting the proximal M1 segment; step 4, gaining proximal control; step 5, shifting to the distal sylvian fissure and following the superior trunk (outer surface); step 6, following the superior trunk (inner surface); step 7, following the inferior trunk (inner surface); step 8, dissecting the distal neck (blind spot).

sylvian dissection is completed, the dissection shifts to the distal sylvian fissure where the superior trunk is followed retrograde to the frontal side of the aneurysm neck (**Fig. 15.12**, steps 5 and 6), the inferior trunk is followed to the temporal side of the aneurysm neck (**Fig. 15.12**, step 7), and the blind spot at the distal neck is opened (**Fig. 15.12**, step 8).

## Clipping Technique

The wide variety in MCA aneurysm anatomy requires clipping with many techniques: simple clipping, multiple clipping, tandem clipping, angled fenestrated clipping, and clip reconstruction. Simple clipping techniques are used with small, simple, narrow neck aneurysms (**Figs. 15.13 and 15.14**). Typically the blade is perpendicular to the afferent artery and parallel to the efferent trunks. Small MCA aneurysms are often broad-based or sessile with little tissue to grab. Downward pressure against the parent artery during clip application and softening with temporary clipping may help the clip grab this aneurysm tissue.

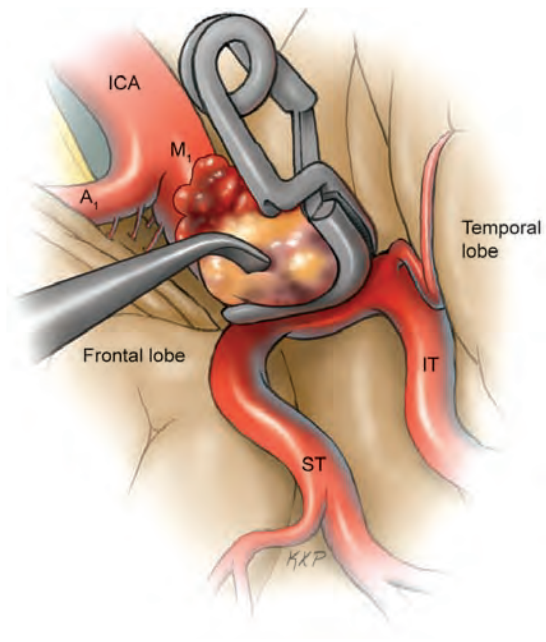



**Fig. 15.13** Simple clipping technique for MCA aneurysms with a right-angled clip.

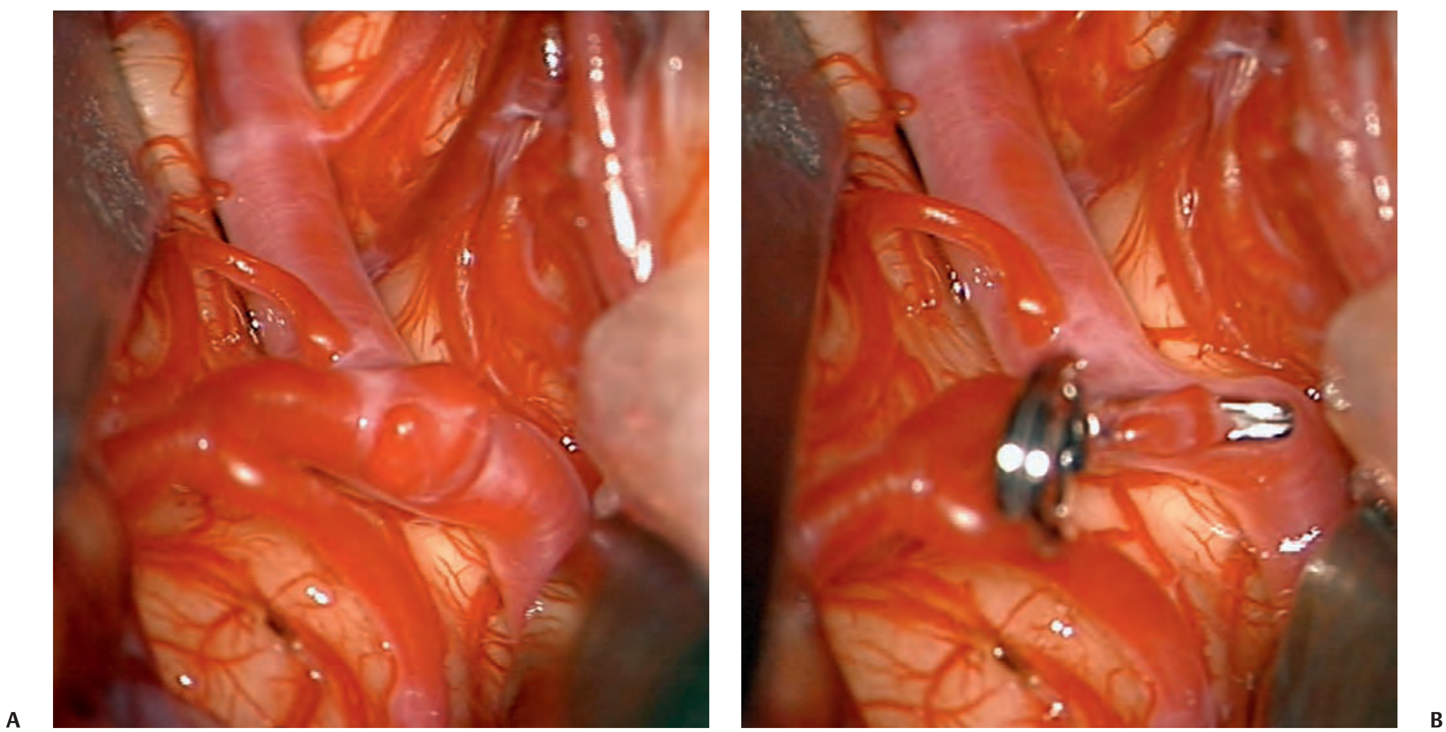
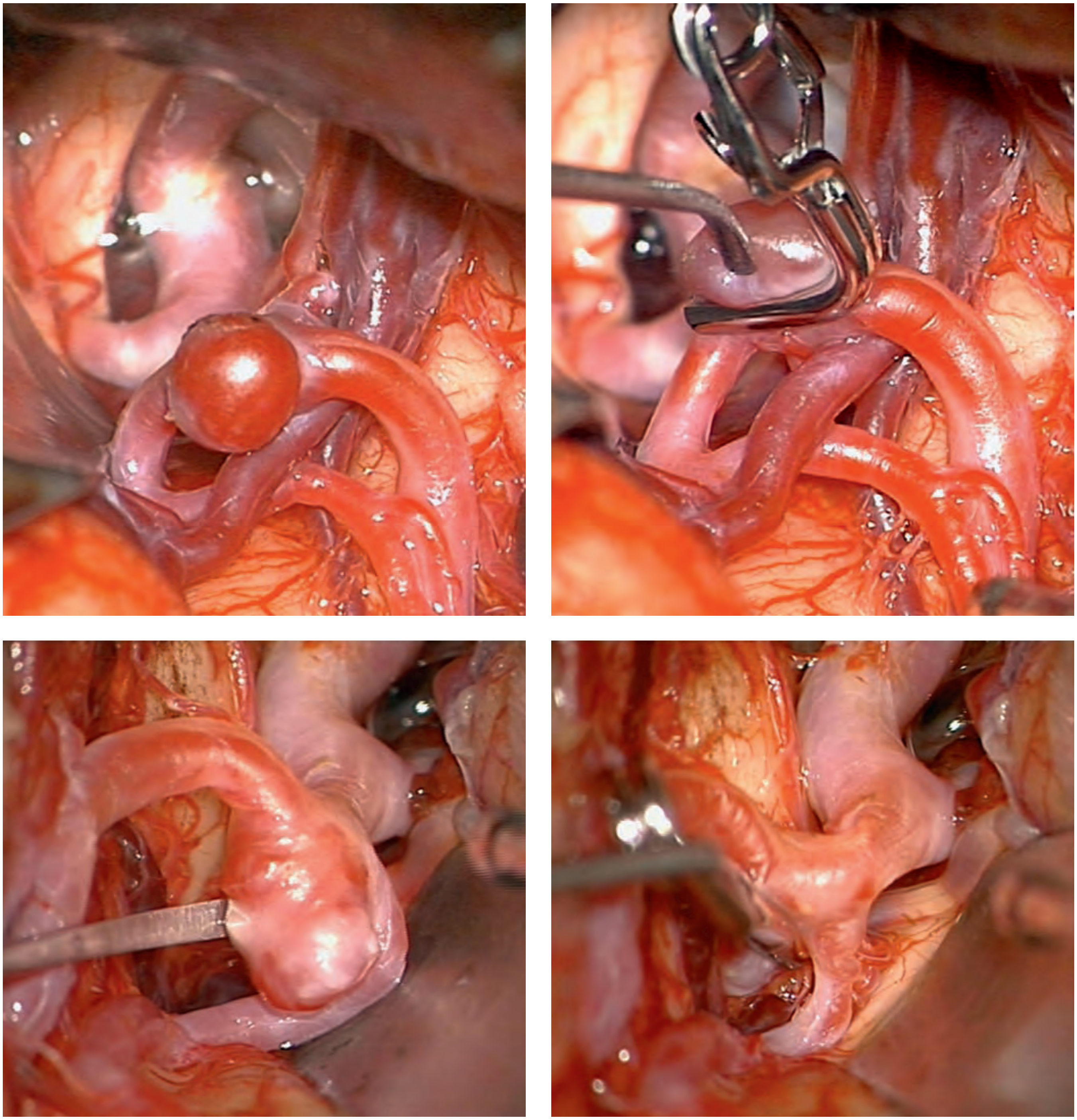
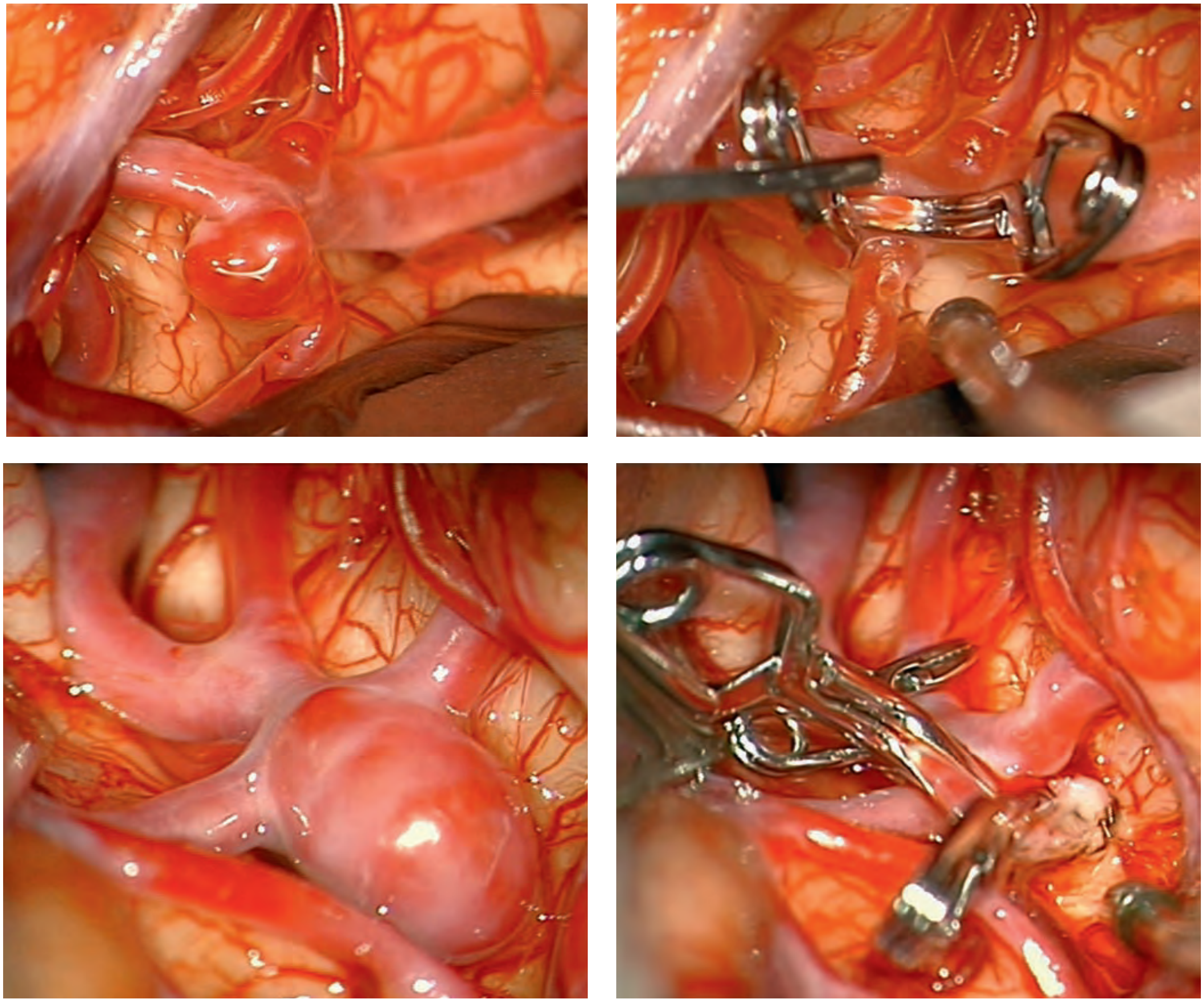



**Fig. 15.14** Examples of simple clipping of MCA aneurysms. **(A)** This sessile right MCA aneurysm at the bifurcation between the superior and inferior trunks was clipped with a slightly curved mini-clip **(B).** Sessile aneurysms have little aneurysm tissue for the blades to grab, and the blades can slide over a tense dome during clip application. These aneurysms are often clipped using a temporary clip, which softens the aneurysm and allows the blades to grab the aneurysm.



C D E F

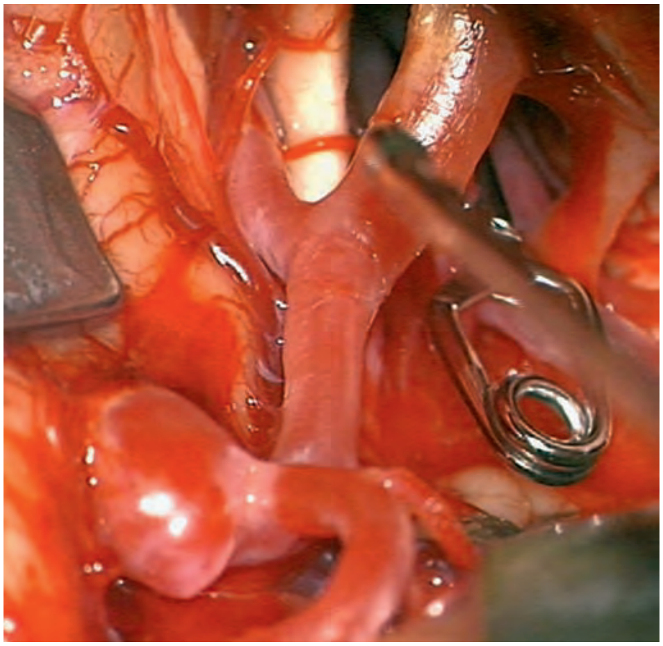
**Fig. 15.14** (*Continued*) A right-angled clip closes the neck of this right MCA aneurysm **(C),** with the blades perpendicular to the afferent M1 segment and parallel to the efferent M2 segments **(D). (E)** This left MCA aneurysm was clipped with one straight clip paralleling the superior and inferior trunks **(F).**



A B C D

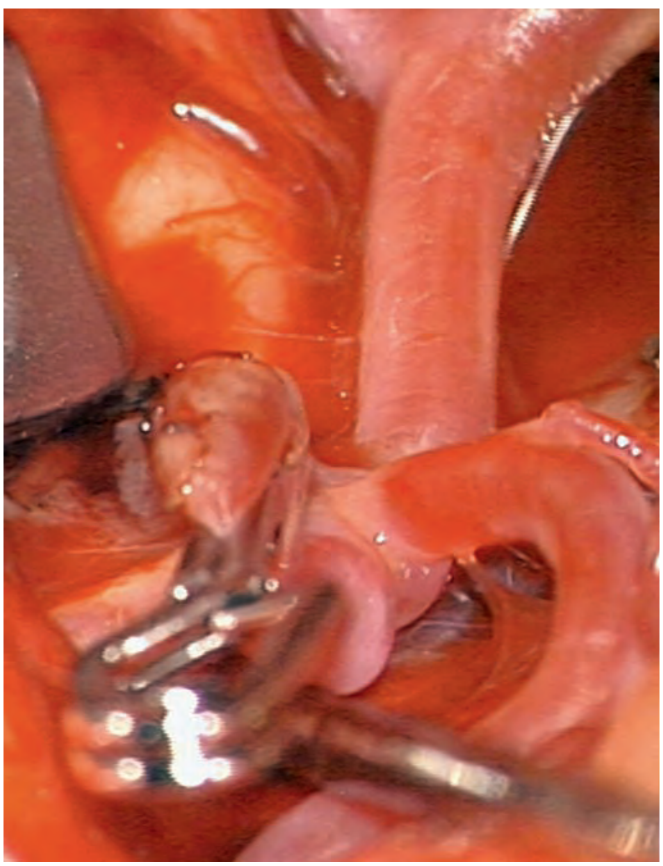
**Fig. 15.15** Examples of multiple clipping technique with intersecting clips. **(A)** Even small MCA aneurysms have broad bases that extend behind and in front of the parent artery, as with this left-sided aneurysm. **(B)** A straight clip closes the back portion of the neck, and an intersecting curved mini-clip closes the front portion of the neck. **(C)** This laterally projecting right MCA aneurysm was repaired with a straight clip angled down the back of the aneurysm **(D),** followed by an intersecting curved clip to close the remnant beneath the initial clip. A small bleb at the anterior temporal artery (ATA) origin was also clipped.

The MCA aneurysms are notorious for their broad necks, and these aneurysms require multiple clipping techniques (**Fig. 15.15**). Broad-necked aneurysms are deconstructed into portions, and an initial clip closes the deep portion at the distal neck. Additional intersecting, stacked, or overlapping clips close the remaining portions (**Fig. 15.16**). The superficial location of MCA aneurysms and a spacious sylvian fissure facilitate multiple clipping constructs. Tandem clipping is routinely used for larger aneurysms (**Figs. 15.17, 15.18, and 15.19**). The fenestrated clip blade lies on the shoulder of the deep or hidden trunk and repairs the distal neck. Closing clips over the fenestration lie on the shoulder of the superficial or superior trunk and contour the repair of the proximal neck. Atherosclerotic thickening and calcifications can be encircled with fenestrated clips and tandem clipping techniques (**Fig. 15.20**). Fenestrated clips can also construct fenestration tubes (**Fig. 15.21**).



E

**Fig. 15.15** (*Continued*) **(E)** This right MCA aneurysm had a broad base that was closed with a straight blade across the anteriorly projecting portion, parallel to the M1 segment **(F)**. **(G)** The remaining posteriorly projecting portion was closed with an overlapping fenestrated clip.



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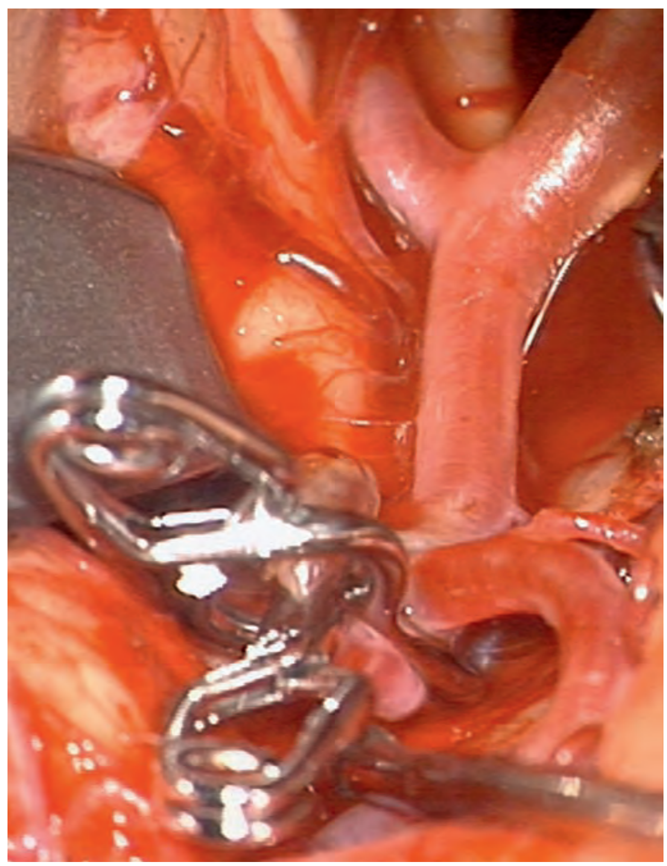
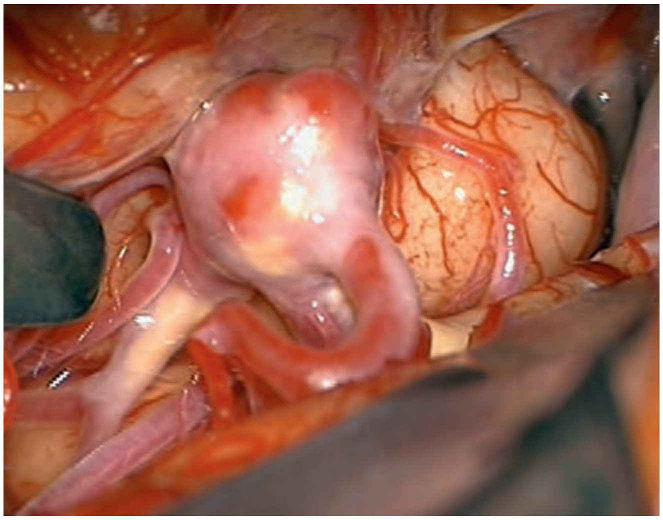


G



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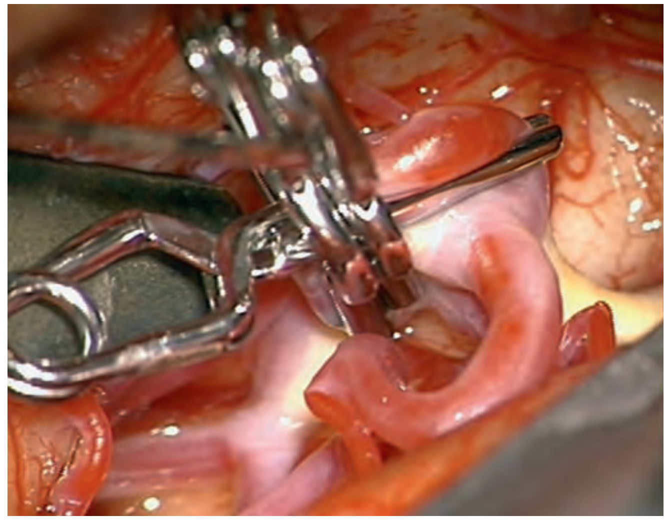

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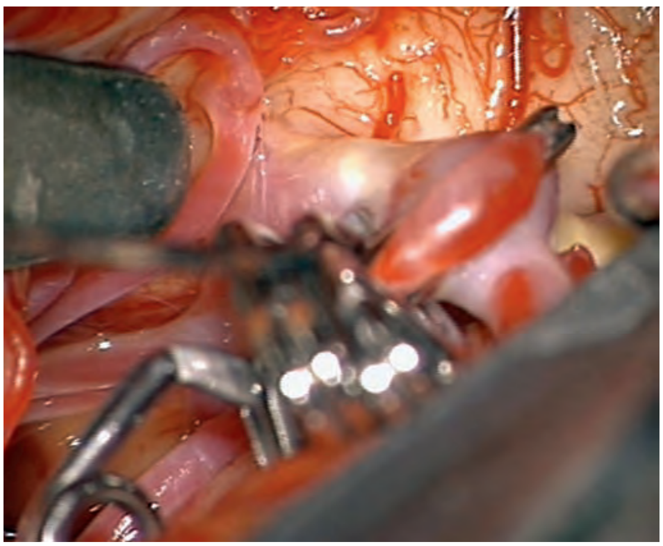

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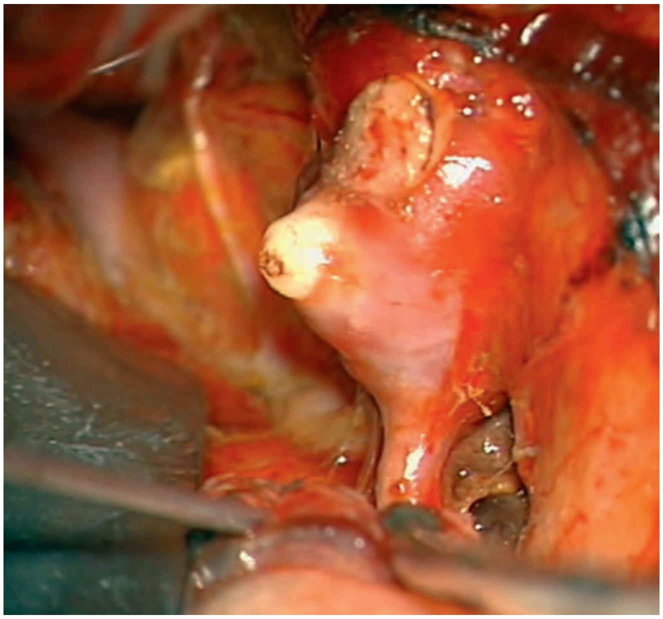
**Fig. 15.16** Overlapping fenestrated clips can reconstruct broad-based MCA aneurysms like this left-sided aneurysm. **(A)** Both superior and inferior trunks originated from the side of the aneurysm, and the proximal M1 segment was accessed above the aneurysm, between the trunks, for temporary clipping. **(B)** A straight clip perpendicular to the M1 segment closed the anterior portion of the aneurysm, and two overlapping straight fenestrated clips closed the superior portion of the aneurysm. **(C)** A view down the axis of M1 segment showed the right-angled intersection of clips.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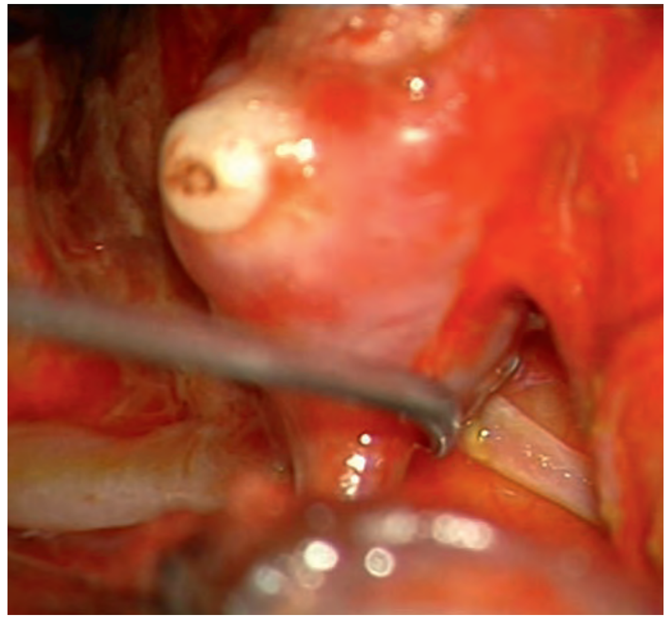
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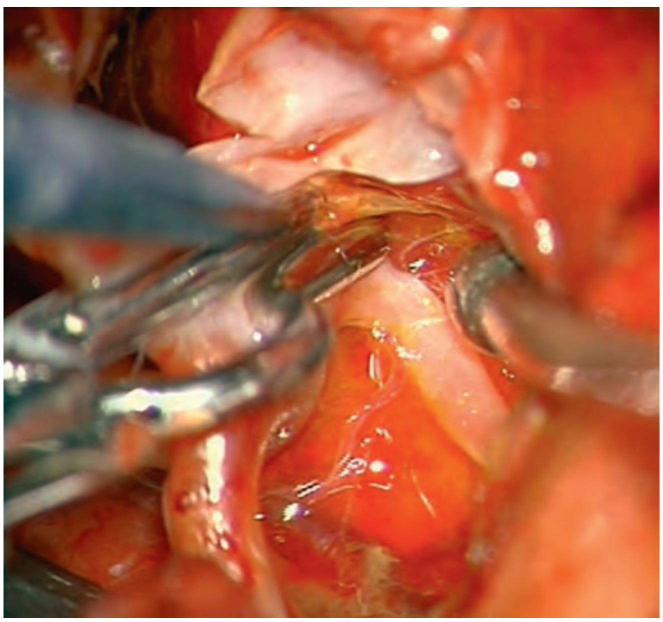
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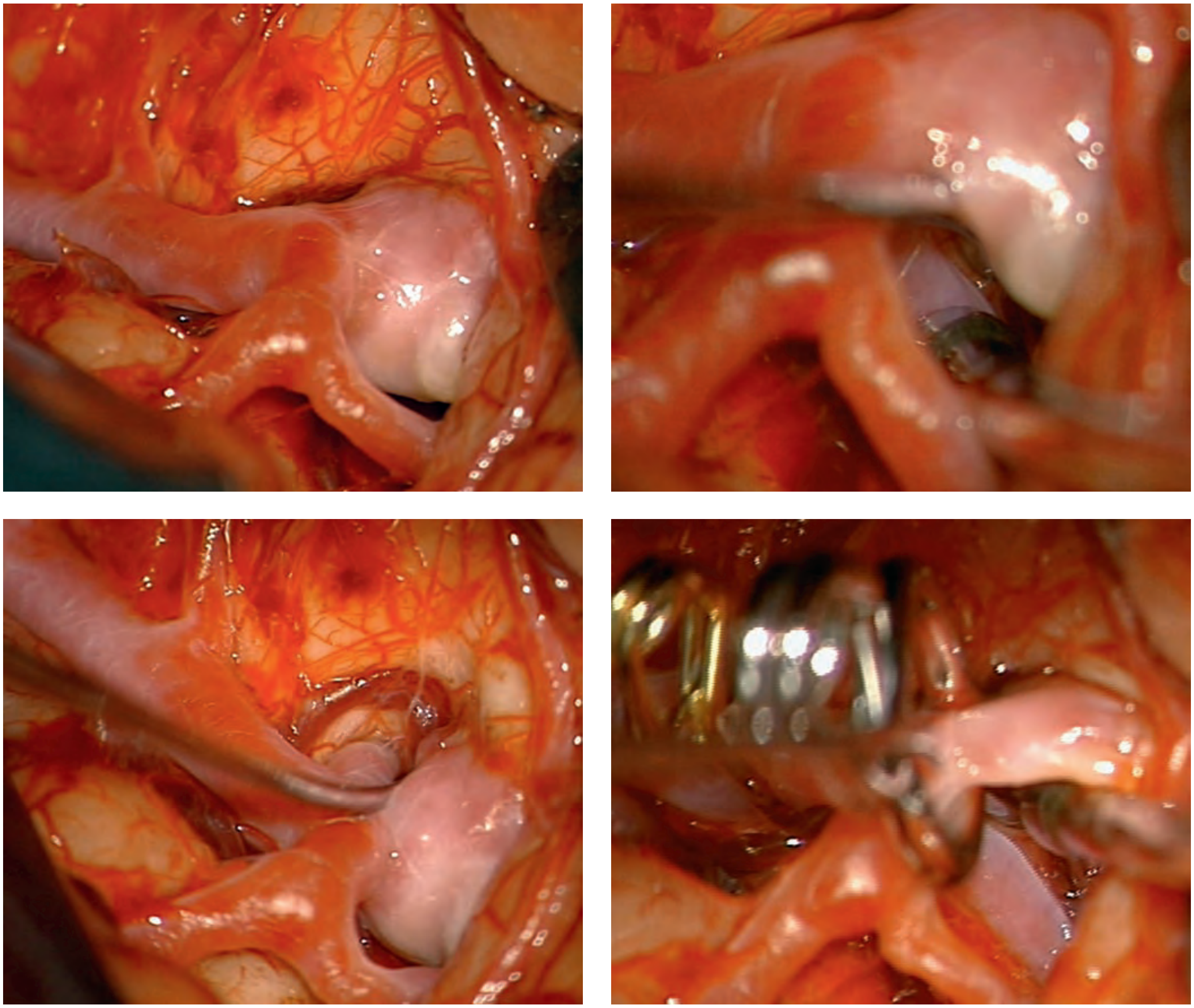
**Fig. 15.17** This 42-year-old man presented with a subarachnoid hemorrhage from a right MCA aneurysm. **(A)** The sylvian fissure was split to access the M1 segment for proximal control, and the dome adhered to the temporal lobe. **(B)** The superior trunk was followed behind the aneurysm and the inferior trunk was identified in the insular recess of the sylvian fissure, seen at the tip of the No. 6 dissector. **(C)** The aneurysm neck was closed with tandem clipping, with an overstacked straight clip leaving a generous lumen at the origin of the superior trunk. The fragile aneurysm dome was avoided during the dissection and remained embedded in the temporal lobe, but after permanent clipping, the fundus was transected to better inspect the clip placement and confirm complete aneurysm occlusion.



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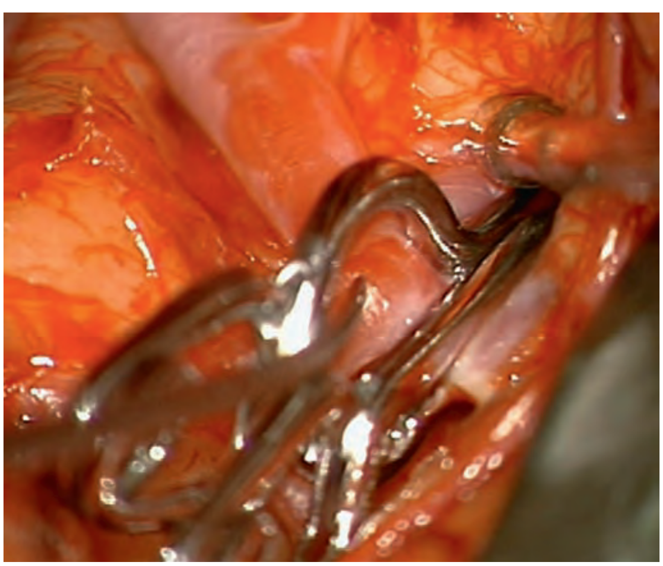

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**Fig. 15.18** This large right MCA aneurysm was incidentally diagnosed in a healthy 71-year-old woman. **(A)** The superior trunk was easily identified, but the dome projected into the temporal lobe and hid the inferior trunk. **(B)** The inner surface of the superior trunk was followed behind the aneurysm and across the neck to find the inferior trunk. **(C)** Some deflection of the aneurysm neck with a No. 6 dissector revealed the inferior trunk in front of the aneurysm. **(D)** A temporary clip on the M1 segment softened the aneurysm and facilitated placement of a straight fenestrated clip with the blades on the shoulder of the inferior trunk. **(E)** A stacked straight clip completed the tandem clipping and reconstructed the origin of the superior trunk.

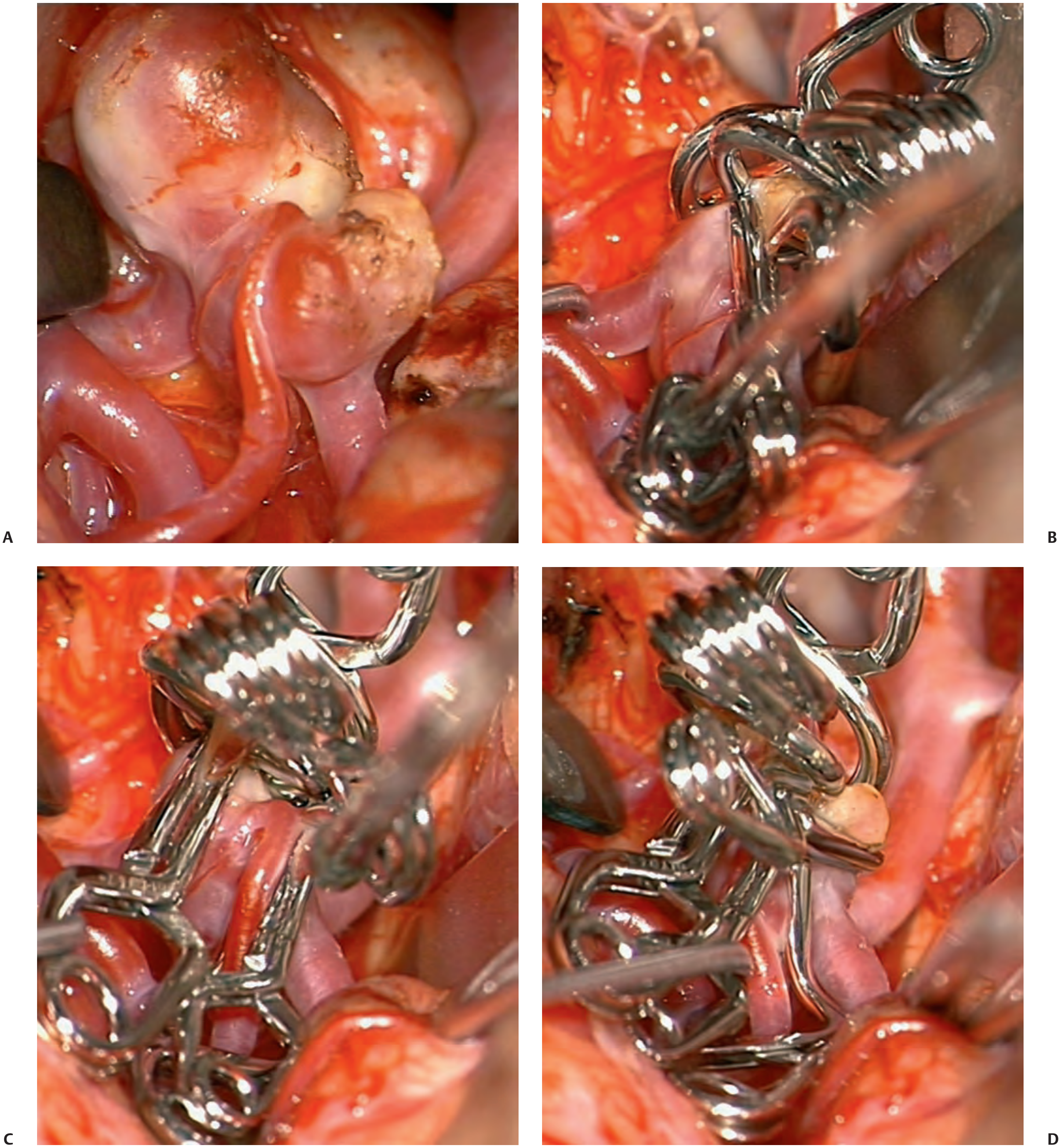
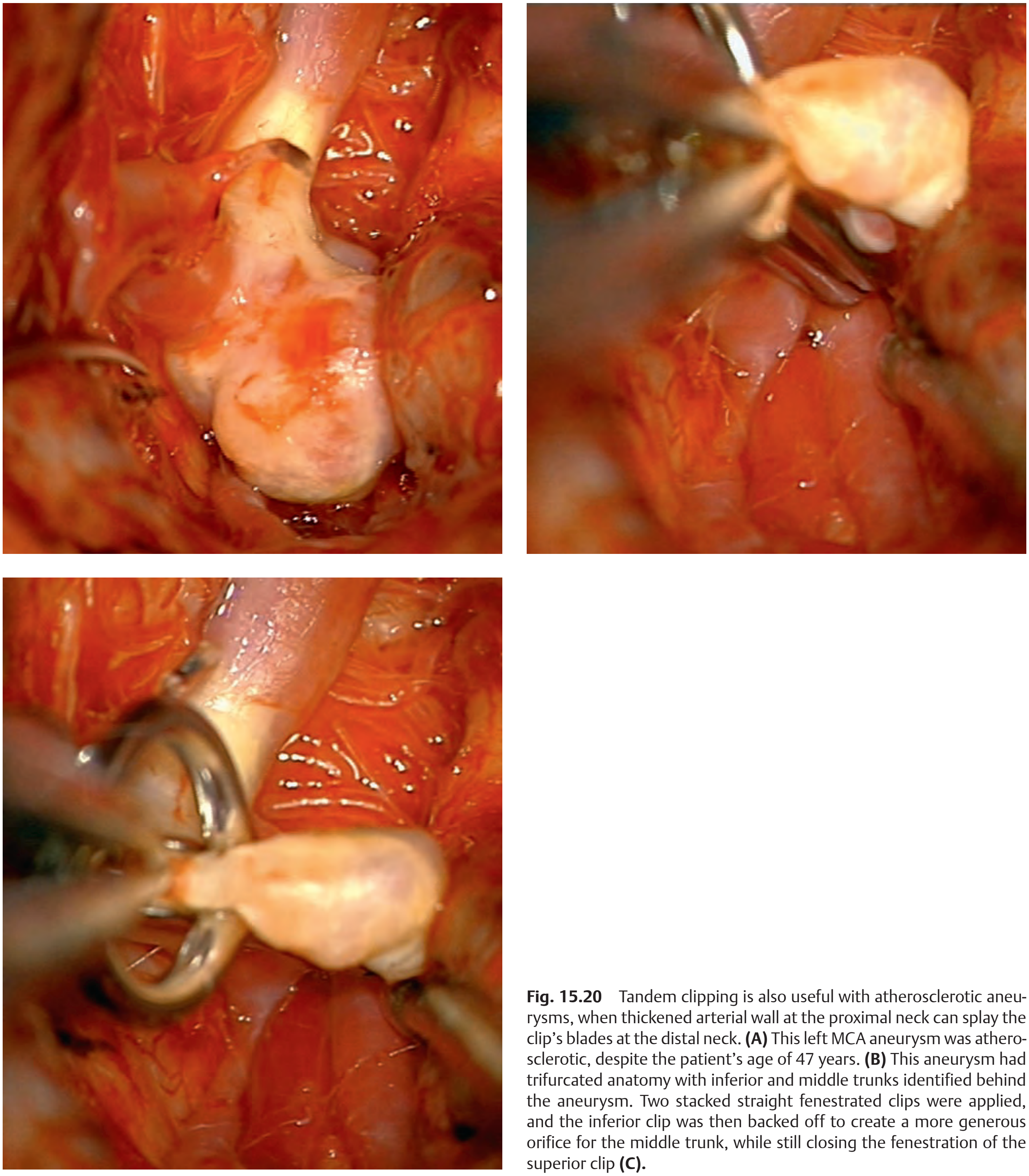
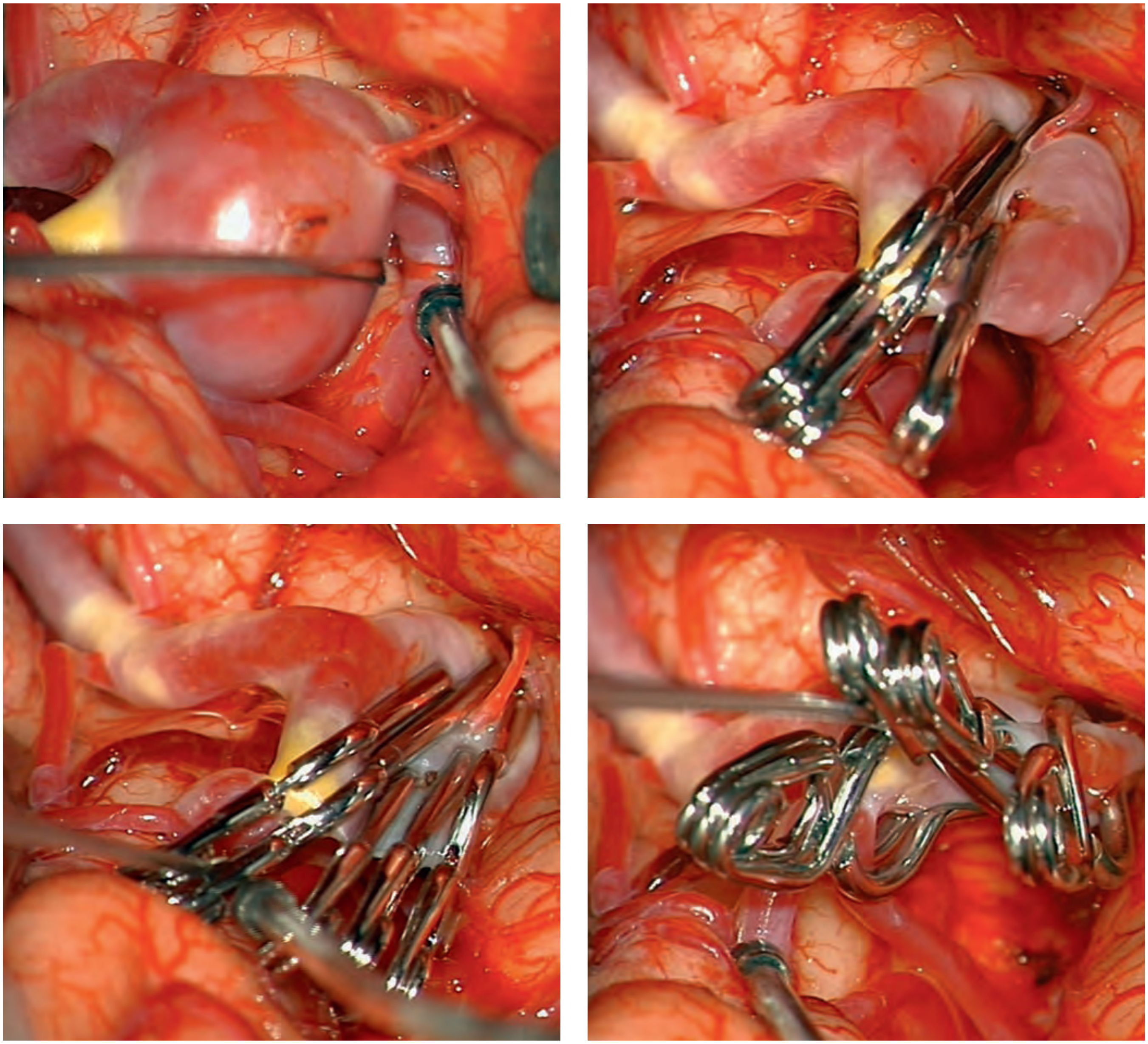


**Fig. 15.19** Complex aneurysms with multiple lobes are sometimes treated best by clipping each lobe as a separate aneurysm. **(A)** This bi-lobed left MCA aneurysm in a 61-year-old woman had large superior and inferior trunks with a small middle trunk originating between the aneurysm's two lobes. **(B)** The larger lobe was clipped with a tandem clipping technique with both over- and understacked closing clips reconstructing the inferior trunk. **(C)** The middle trunk can be seen medial to these clips. **(D)** The smaller lobe was clipped with intersecting straight and angled-fenestrated clips, with good reconstruction of the superior trunk.



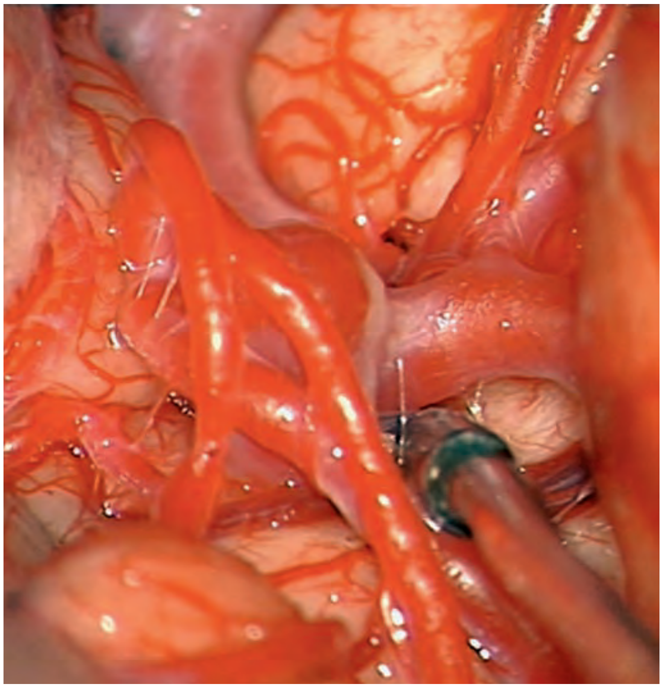
A B C

**Fig. 15.20** Tandem clipping is also useful with atherosclerotic aneurysms, when thickened arterial wall at the proximal neck can splay the clip's blades at the distal neck. **(A)** This left MCA aneurysm was atherosclerotic, despite the patient's age of 47 years. **(B)** This aneurysm had trifurcated anatomy with inferior and middle trunks identified behind the aneurysm. Two stacked straight fenestrated clips were applied, and the inferior clip was then backed off to create a more generous orifice for the middle trunk, while still closing the fenestration of the superior clip **(C).**



A B C D

**Fig. 15.21** **(A)** This large, wide-necked right MCA aneurysm in a 63-year-old woman was clipped with a retrograde fenestration tube. **(B)** This construct used two stacked straight fenestrated clips, the first one shorter than the second one to refashion a **Y**-shaped bifurcation. A straight clip closed the fenestration to reconstruct the superior trunk. **(C)** Indocyanine green (ICG) videoangiography demonstrated residual filling of the aneurysm, necessitating two additional booster clips around an artery that adhered to the dome. **(D)** After lifting the clips, the superior trunk and its branches were seen exiting the fenestration tube.



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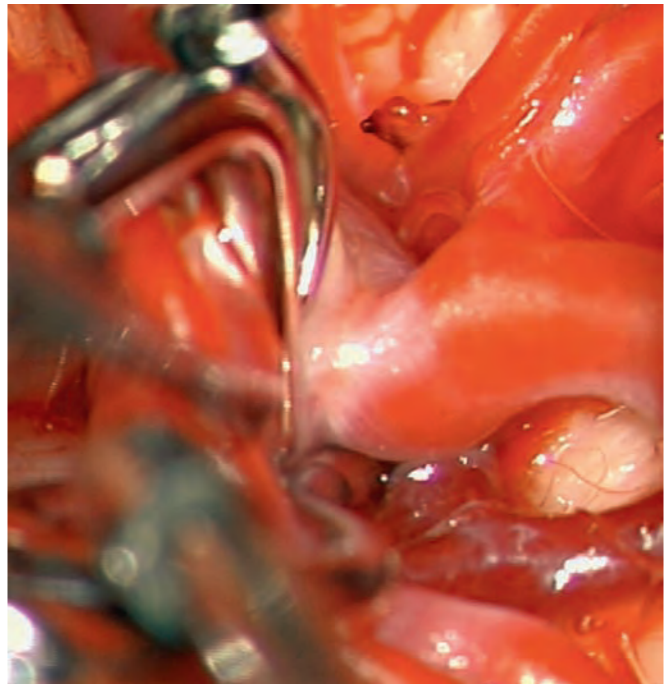

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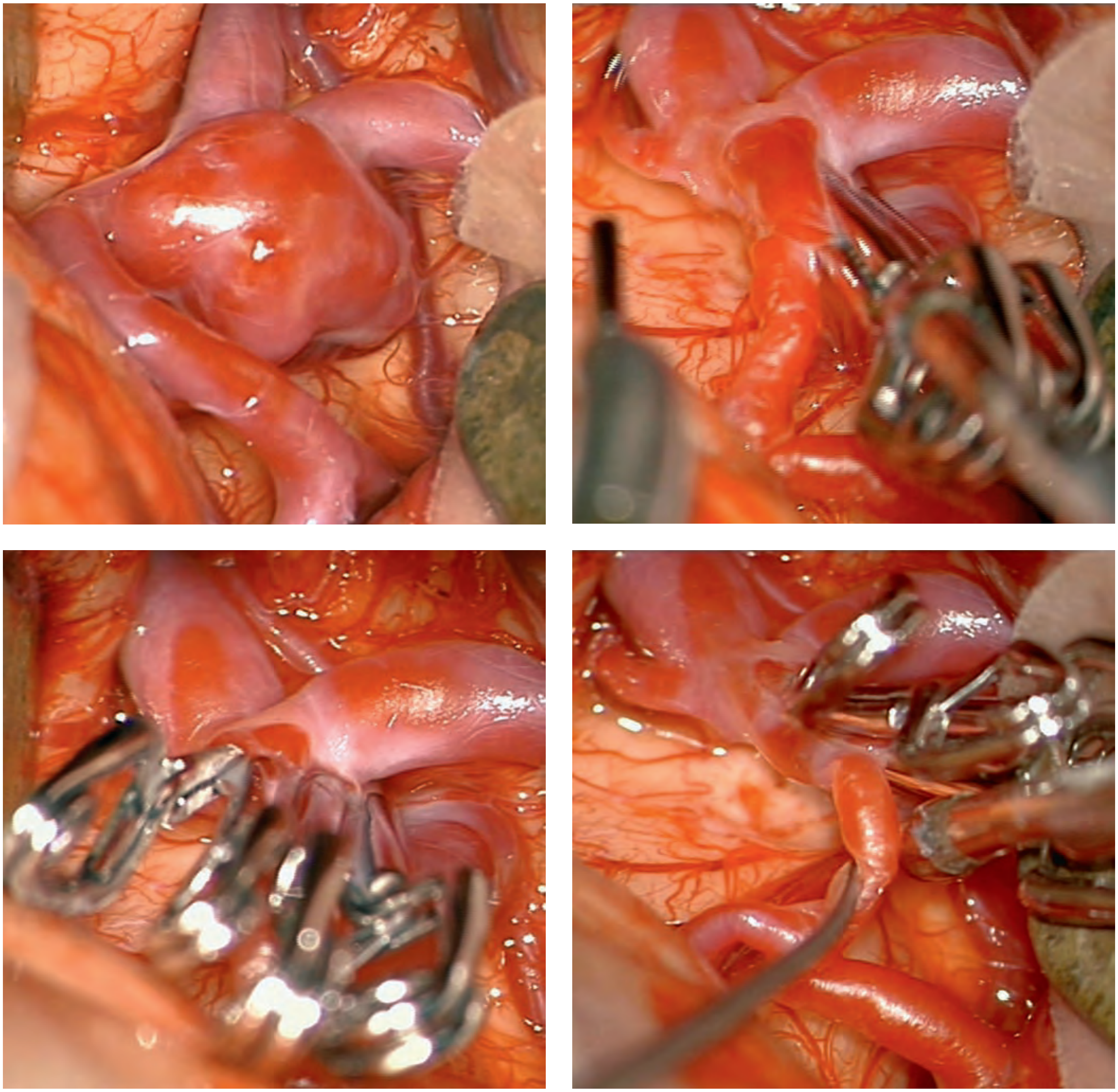
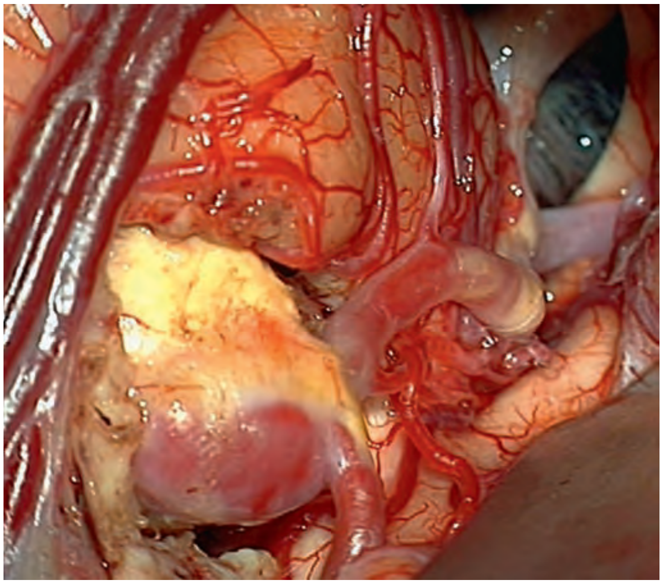
**Fig. 15.22** Efferent arteries can adhere to thin aneurysm walls to complicate the clipping. **(A)** The frontal branches were stuck to a thin dome on this right MCA aneurysm in a 52-year-old woman. **(B)** Rather than dissect these branches off the aneurysm and risk its rupture, the surgeon left them on the aneurysm and encircled them with a straight fenestrated clip. The blade of the fenestrated clip closes the deep neck posterior to the bifurcation, and intersecting right-angled and curved clips close the superficial neck. **(C)** Two branches from the frontal trunk passed through the fenestration.

The MCA branch arteries often adhere to parts of the aneurysm. The ATA frequently drapes over the dome of laterally projecting MCA aneurysms, and trunks from the MCA bifurcation adhere to the aneurysm's side walls. Opening cleavage planes and freeing these adhesions simplifies permanent clipping. These dissection steps are facilitated by temporary clipping and some aneurysm deflection, and are saved for the final dissection steps. When mobilizing an adherent branch risks rupturing the aneurysm, or when a branch is simply too adherent to be mobilized, permanent clips are applied around the branch to close the aneurysm neck and also preserve the branch artery (**Figs. 15.22 and 15.23**).



A B C D

**Fig. 15.23** **(A)** The inferior trunk of this right MCA aneurysm in a 44-year-old woman was free from the distal neck, but the superior trunk was adherent and the cleavage plane between it and proximal neck was difficult to open. **(B)** The neck was closed with a long straight clip that left a saccular remnant beneath the blades, which was closed with three understacked straight clips. **(C)** This multiple clipping technique obliterated the remnant and preserved patency of the superior trunk **(D)**.



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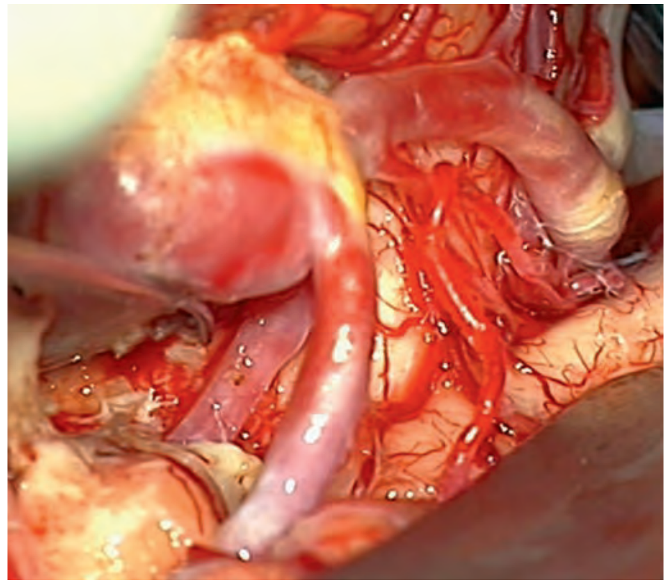

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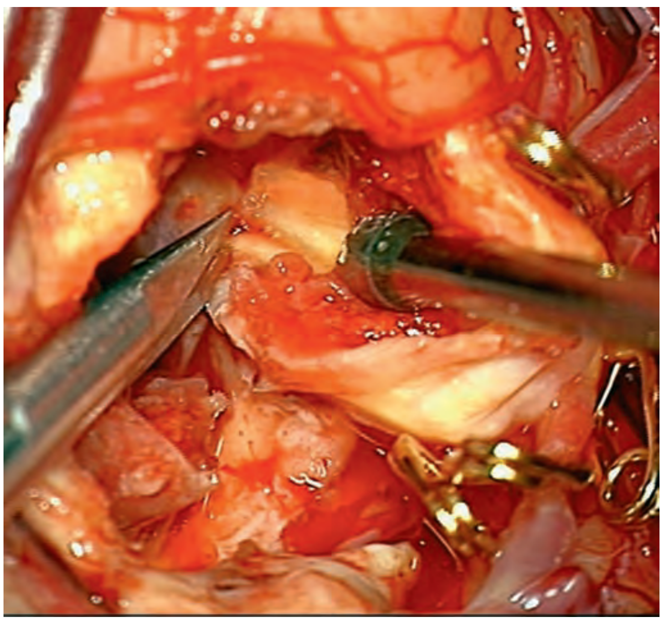

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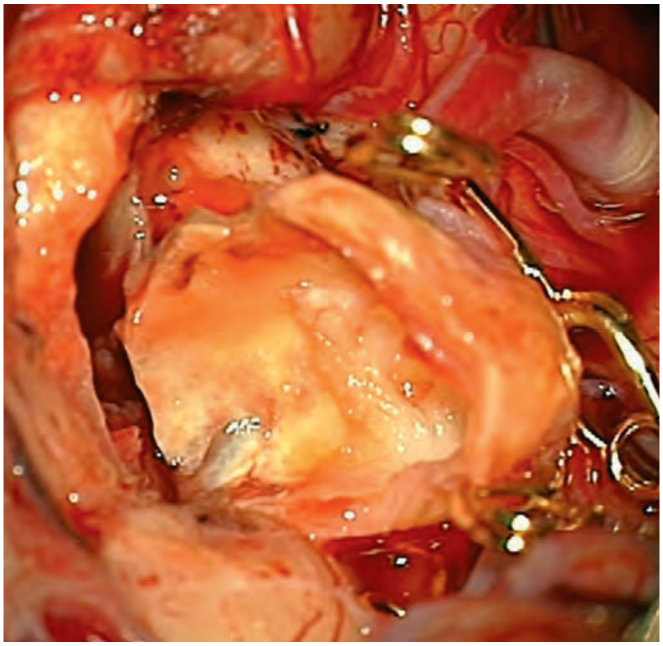
**Fig. 15.24** **(A)** This giant (4 cm diameter) thrombotic left MCA aneurysm was treated with thrombectomy and clip reconstruction. Most of the aneurysm is buried in the temporal lobe and only the calcified base is seen in the sylvian fissure. **(B)** The anatomy of the M1 afferent artery and the superior and inferior trunks was straightforward. **(C)** The aneurysm was trapped with temporary clips, opened with microscissors, and debulked with a Cavitron ultrasonic aspirator.

Thrombotic aneurysms are not uncommon at the MCA bifurcation, and can be trapped with temporary clips, opened, debulked with an ultrasonic aspirator, and reconstructed with clips. The neck of a giant thrombotic aneurysm might be simplified by completely transecting the fundus, debulking the thrombus at the neck, and reconstructing the neck with stacked clips (**Fig. 15.24**).

Proximal M1 segment aneurysms project superiorly and often require angled fenestrated clipping because the trajectory of approach is from the inferior aspect of the M1 seg-



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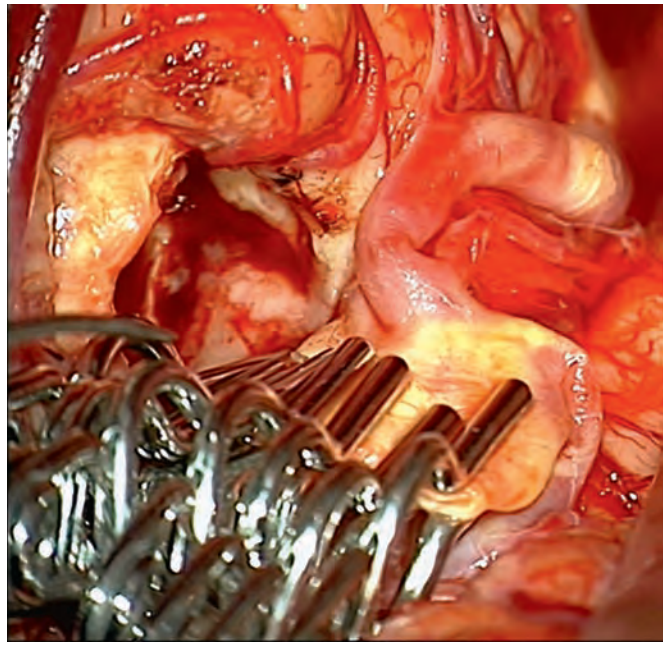

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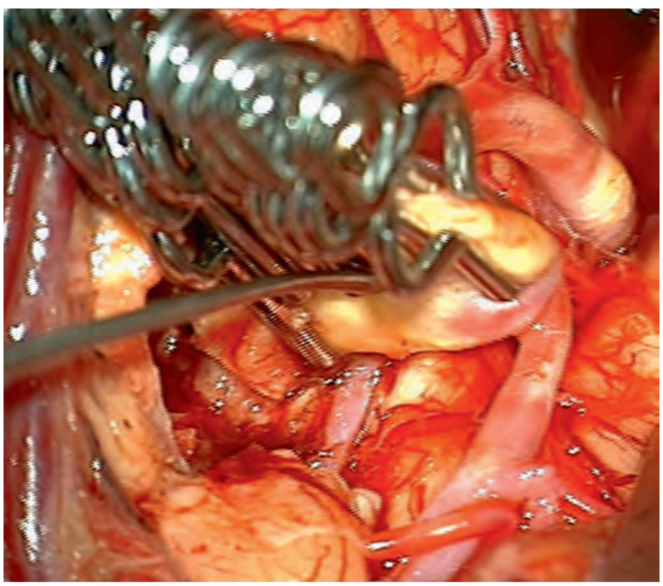
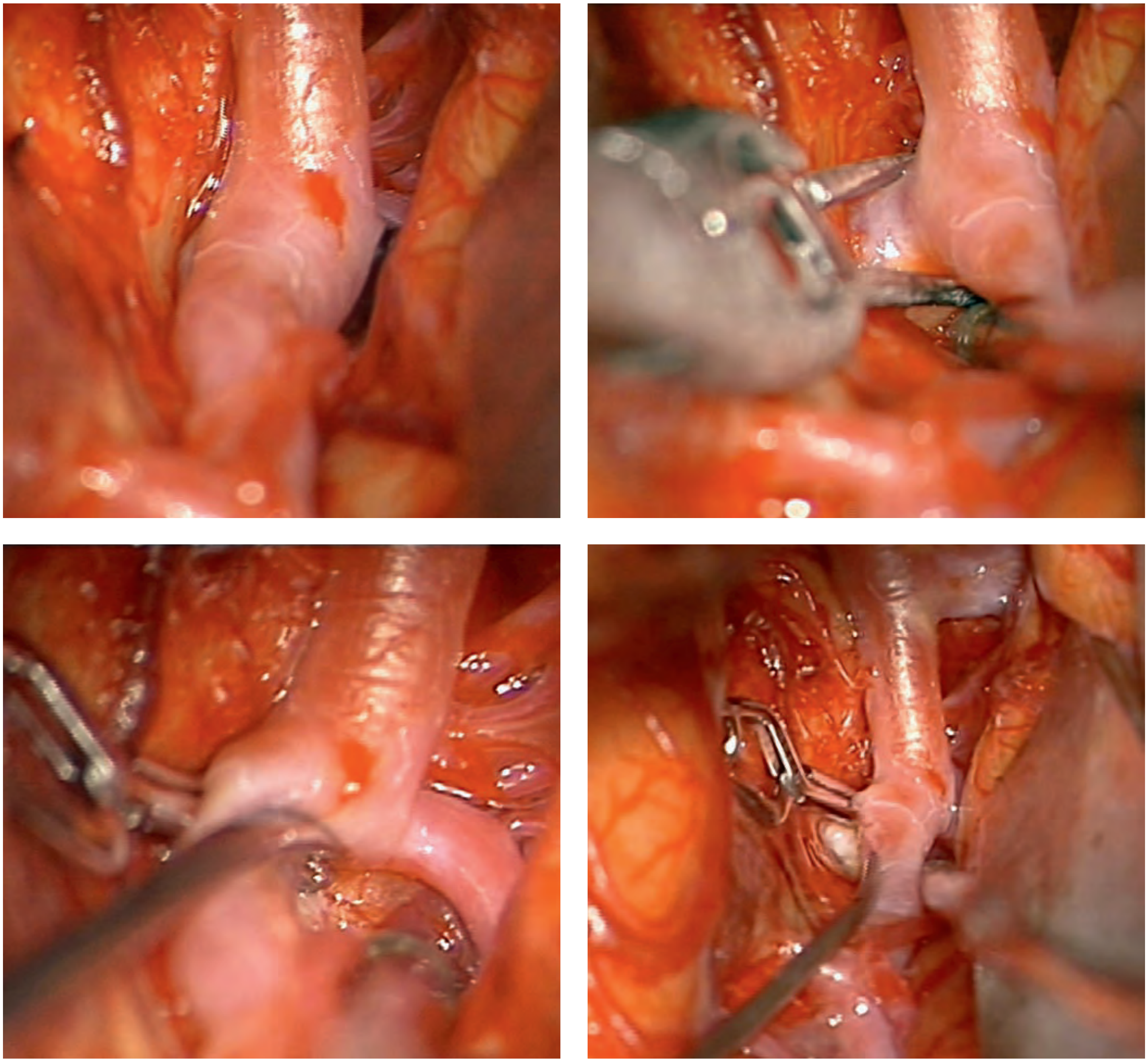


F

**Fig. 15.24** (*Continued*) The neck was completely transected to simplify the clipping, and the intraluminal thrombus was removed **(D)**. **(E)** The neck was closed with stacked straight fenestrated clips (dome fenestration tube), reconstructing the MCA bifurcation and preserving both the superior and inferior trunks **(F)**. After clip reconstruction and restoring flow in the MCA territory, additional thrombus within the aneurysm was removed to eliminate the aneurysm's mass effect.

ment (**Figs. 15.25 and 15.26**). Distal MCA aneurysms are uncommon and require distal splitting of the sylvian fissure to enter the opercular cleft. These aneurysms often have unusual anatomy that prevents direct clipping, and instead may require trapping with a superficial temporal artery-to-MCA bypass or an end-to-end reanastomosis of the parent artery (**Fig. 15.27**).

After permanent clipping, superior, middle, and inferior trunks are inspected for patency. A full view of the hidden trunk may not be prudent before clipping because the aneurysm manipulation needed for such a view might precipitate re-rupture. However, a full view of the hidden trunk after clipping is much easier because the dome can be de-tethered, mobilized, deflated, or transected. It is useful to assume that



A B C D

**Fig. 15.25** **(A)** M1 segment aneurysms often project superiorly and are not apparent after splitting the sylvian fissure, as in this 64-year-old woman with a left-sided aneurysm. **(B)** The aneurysm projected into the temporal lobe, and deflecting the distal M1 segment with a sucker revealed the aneurysm neck. **(C)** Deflecting the distal M1 segment in the opposite direction revealed the other trunk and the position of the clip's tips on the neck. **(D)** This overview demonstrated the proximal location of this aneurysm on the M1 segment, just beyond the ICA and its bifurcation.

a deep trunk has been missed until proven otherwise; this assumption prompts aggressive dissection all around the aneurysm neck, after clipping, during the inspection phase.

Middle cerebral artery aneurysms are job security for vascular neurosurgeons. Anatomic peculiarities such as broad necks, trifurcations, dysmorphic shapes, and branch arteries that are angiographically undecipherable make them difficult to manage endovascularly. However, they are surgically accessible, well visualized, and can be manipulated, making them favorable for microsurgical clipping.

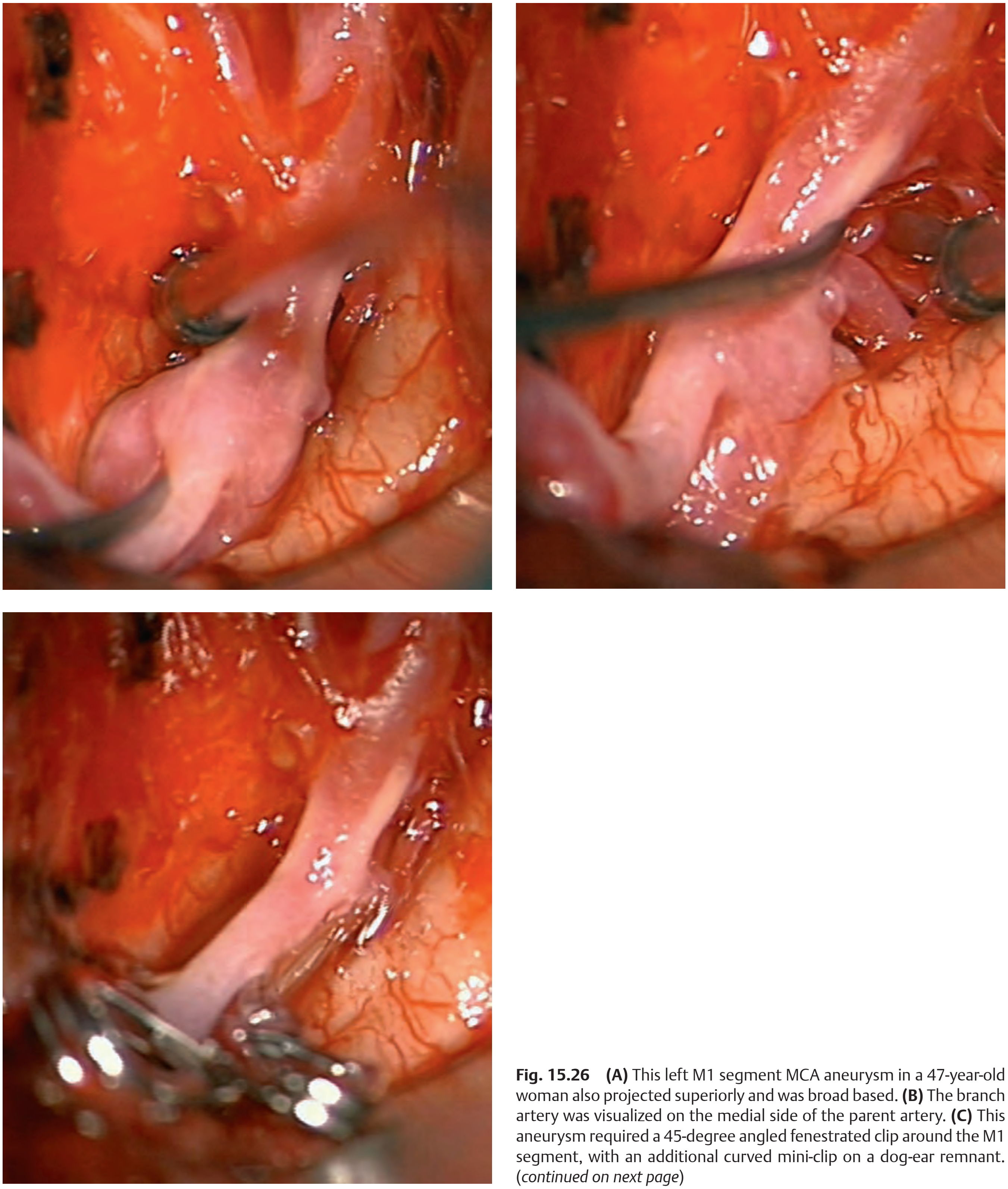


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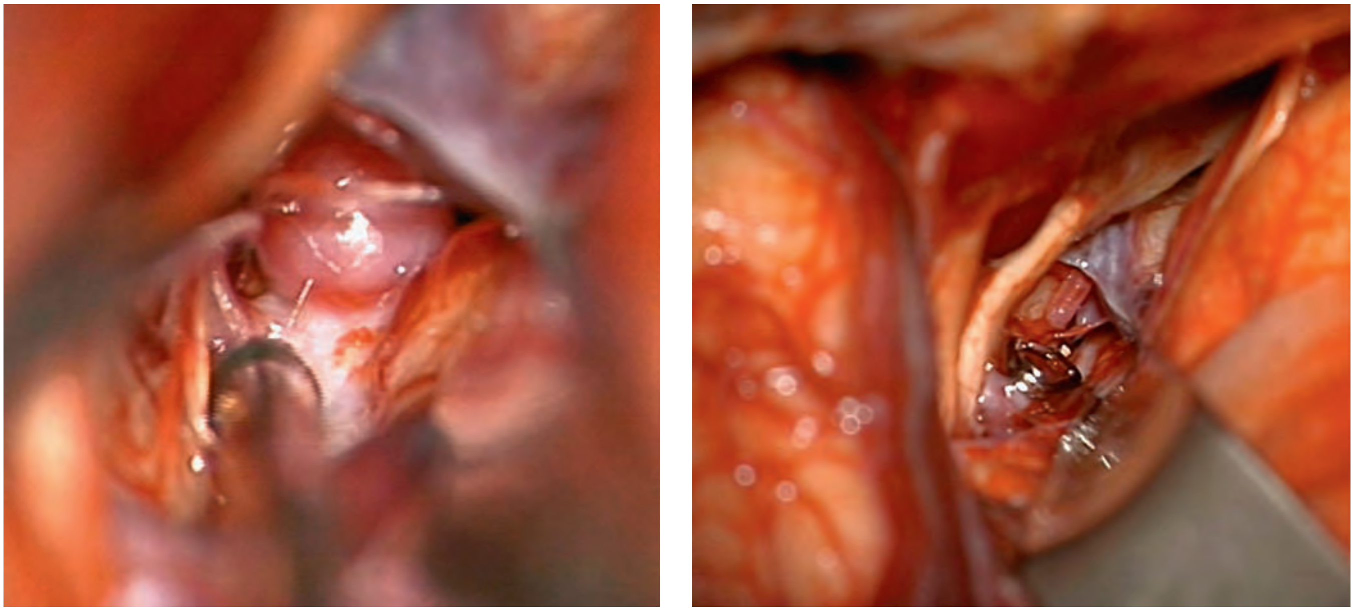
**Fig. 15.26** **(A)** This left M1 segment MCA aneurysm in a 47-year-old woman also projected superiorly and was broad based. **(B)** The branch artery was visualized on the medial side of the parent artery. **(C)** This aneurysm required a 45-degree angled fenestrated clip around the M1 segment, with an additional curved mini-clip on a dog-ear remnant. (*continued on next page*)



D E

**Fig. 15.26** (*Continued*) **(D)** The patient also had a contralateral right MCA aneurysm that was accessed by following the right A1 segment to the right M1 segment and opening the contralateral sylvian fissure. **(E)** The aneurysm was successfully clipped, sparing the patient an additional intervention. Note the clear pathway under both frontal lobes and above both optic nerves into the opposite sylvian fissure. Contralateral clipping of MCA aneurysms can be considered with small, unruptured aneurysms that project inferiorly.

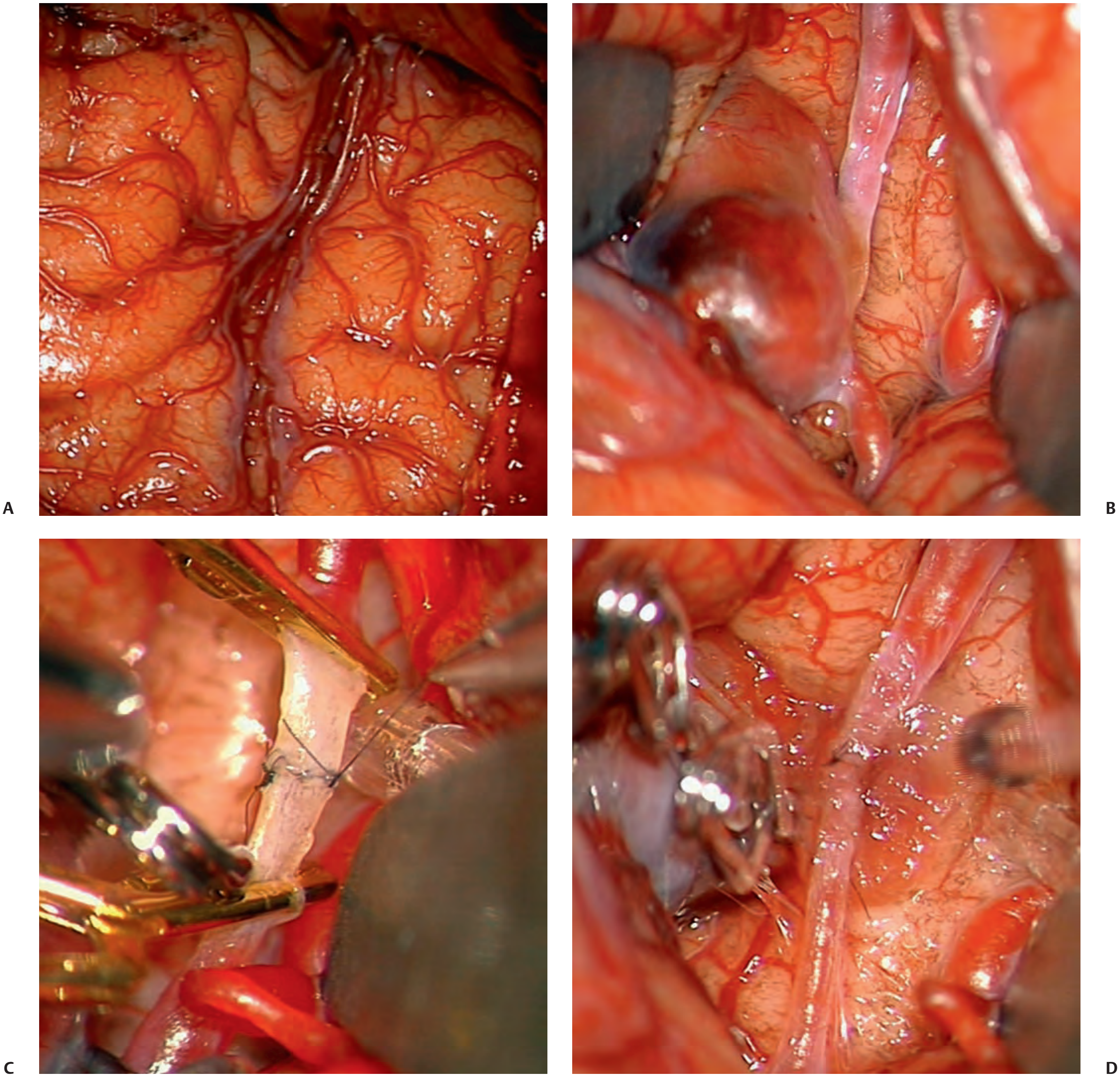


Fig. 15.27 (A) Distal MCA aneurysms are exposed in the distal sylvian fissure between the lateral frontal and temporal lobes. (B) Distal MCA aneurysms often have unusual anatomy, like this right dolichoectatic, thrombotic aneurysm in a 66-year-old man presenting with a transient ischemic attack. (C) The aneurysm was trapped between permanent aneurysm clips. Afferent and efferent arteries were transected and reanastomosed end-to-end. (D) This reconstruction excluded the aneurysm completely and restored flow in this angular artery.

# 16 Anterior Communicating Artery Aneurysms

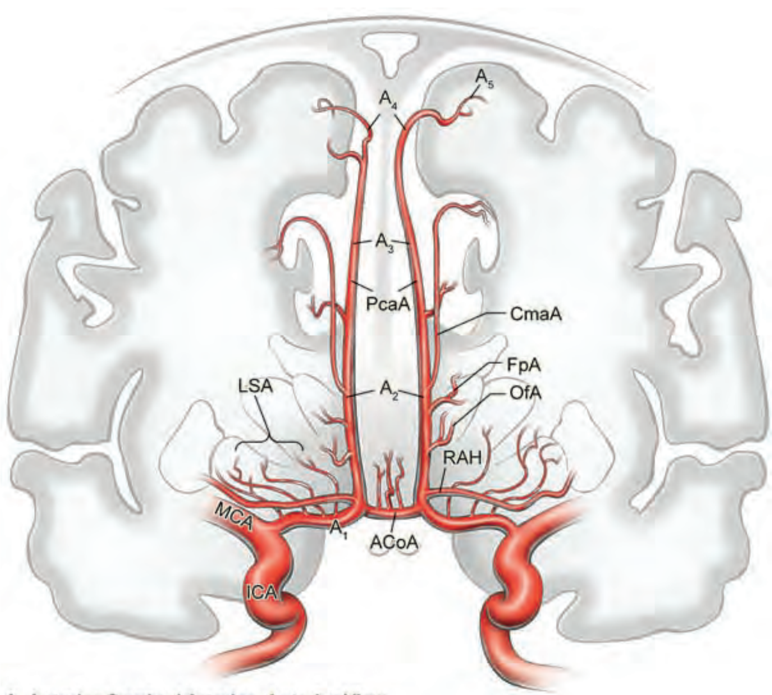
## Microsurgical Anatomy

The A1 segment begins at the terminal bifurcation of the internal carotid artery (ICA) and ends at the anterior communicating artery (ACoA) (**Fig. 16.1**). This *precommunicating segment* is also called the horizontal segment because of its flat course across the optic tract to the midline. Even though the A1 segment begins and ends at branch points, the segmental anatomy of the anterior cerebral artery (ACA) is defined by its curvature and its relationships to the brain rather than by branch anatomy. The A2 segment, or *postcommunicating segment*, begins at the ACoA and follows the rostrum of the corpus callosum. The A3 segment, or *precallosal segment*, curves around the anterior corpus callosum, following the genu until the artery assumes a posterior course. The A4 (*supracallosal*) and A5 (*postcallosal*) segments continue over the anterior and posterior halves, respectively, of the body of the corpus callosum, with the vertical plane of the coronal suture dividing them. The ACA's bifurcation into the pericallosal artery (PcaA) and the callosomarginal artery (CmaA) does not define these distal segments.

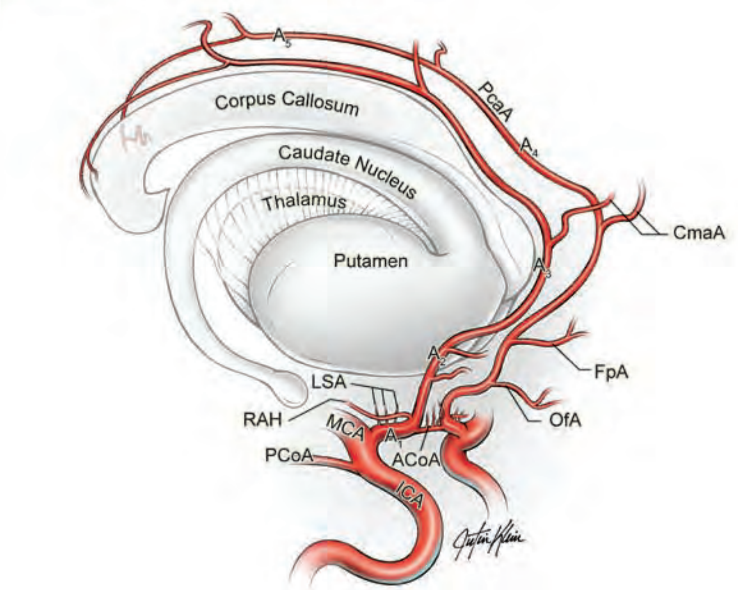
Anterior communicating artery aneurysm dissection identifies 12 arteries: ipsi- and contralateral A1 segments; ipsi- and contralateral A2 segments; the ACoA; ipsi- and contralateral recurrent arteries of Heubner; ipsi- and contralateral orbitofrontal arteries; ipsi- and contralateral frontopolar arteries; and the collection of ACoA perforators. The ipsilateral A1 segment is identified at the ICA terminus and leads medially and anteriorly over the optic tract and chiasm to the ACoA. On average, eight medial lenticulostriate arteries originate from the superior surface of the A1 segment and ascend to the anterior perforated substance, subfrontal area, hypothalamus, anterior commissure, septum pellucidum, and paraolfactory structures. A1 segments are symmetric in most people (90%), but can be asymmetric due to hypoplastic or aplastic A1 segments. Despite the suggestion by angiography, absence or true aplasia of the A1 segment is rare and a vestige can be found intraoperatively. A1 segment dominance is relevant to aneurysm formation, dome projection, side of hematoma, side of surgical approach, and proximal control. Duplicated A1 segments are rare (2% of patients).

A recurrent artery of Heubner is considered the "medial-most" medial lenticulostriate artery, defining the inner border of the collection of perforators along the A1 segment (medial lenticulostriates) and M1 segment (lateral lenticulostriates). As its name implies, a recurrent artery of Heubner travels back along the A1 segment to supply the head of the caudate nucleus, the putamen, the outer segment of the globus pallidus, and the anterior limb of the internal capsule, and its injury can produce contralateral face and arm weakness and expressive aphasia in the dominant hemisphere. A recurrent artery of Heubner originates on the lateral wall of the proximal A2 segment just distal to the ACoA, almost as lateral continuations of the ACoA. Anatomic variation can shift its origin proximal to the ACoA on the distal A1 segment, or in line with the ACoA at the A1-A2 junction, but a recurrent artery of Heubner lies within 4 mm of the ACoA in 95% of patients. Exploiting this relationship in reverse, a recurrent artery of Heubner is a reliable guide to the ACoA and is particularly useful when A1 segment arcs superiorly out of view. It drapes over the shoulder of the A1 segment at its origin and lies superior (60%) or anterior (40%) to the A1 segment as it recurs laterally. Therefore, a recurrent artery of Heubner is often seen before the A1 segment when the frontal lobe is retracted. The artery can be duplicated in 2% of patients.

The ACoA joins the A1 segments as they arrive in the interhemispheric fissure and completes the anterior circle of Willis. ACoA diameter is about half that of the A1 segments, but asymmetric A1 segments increase the ACoA diameter. For example, large-caliber ACoAs are observed with a hypoplastic or absent A1 segment because they cross-fill the nondominant side. The ACoA is always present, and can be duplicated (one third of patients), triplicated (one tenth of patients), fenestrated, or supplemented with an accessory ACoA (**Fig. 16.2**). Important perforating arteries originate from the ACoA's superior and posterior surfaces and ascend to the hypothalamus, median paraolfactory nuclei, genu of corpus callosum, columns of the fornix, septum pellucidum, and anterior perforated substance. Perforators also originate from the anterior and inferior aspects of the ACoA and descend to the dorsal optic chiasm. These perforators prevent trapping or dividing the ACoA. If the anterior circle of Willis




**A. Anterior Cerebral Arteries, Anterior View**




**B. Anterior Cerebral Arteries, Lateral View**

**Fig. 16.1** Microsurgical anatomy of the anterior cerebral artery (ACA). Anterior **(A)** and oblique **(B)** lateral views, showing the five ACA segments and 12 arteries that can enter the surgical field around an anterior communicating artery (ACoA) aneurysm. The five ACA segments are asa follows: A1, precommunicating or horizontal segment; A2, postcommunicating or infracallosal segment; A3, precallosal segment; A4, supracallosal segment; and A5, postcallosal segment. CmaA, callosomarginal artery; FpA, frontopolar artery; ICA, internal carotid artery; LSA, lenticulostriate artery; MCA, middle cerebral artery; OfA, orbitofrontal artery; PcaA, pericallosal artery; RAH, recurrent artery of Heubner.

requires interruption, it is safer to divide the A1 segment, as long as the opposite A1 segment and ACoA are sufficiently large.

Orbitofrontal and frontopolar arteries lie beyond a recurrent artery of Heubner. The orbitofrontal artery is the first cortical ACA branch, arising from the anterolateral surface of the A2 segment approximately 5 mm distal to the ACoA and coursing perpendicularly over the gyrus rectus and olfactory tract. Its course can be similar to that of a recurrent artery of Heubner, but distally it drifts away from the A1 segment, whereas a recurrent artery parallels the A1 segment. Orbitofrontal artery is larger in caliber than the recurrent artery (2 to 3 mm versus 1 mm). The orbitofrontal artery supplies the gyrus rectus, orbital gyri (anterior, posterior, medial, and lateral), and olfactory bulb and tract. The frontopolar artery is the second cortical ACA branch, originating from the A2 segment approximately 14 mm from the ACoA. Rarely, it originates from a common trunk with the orbitofrontal artery. The frontopolar artery courses anteriorly in the interhemispheric fissure and supplies the ventromedial frontal lobes.

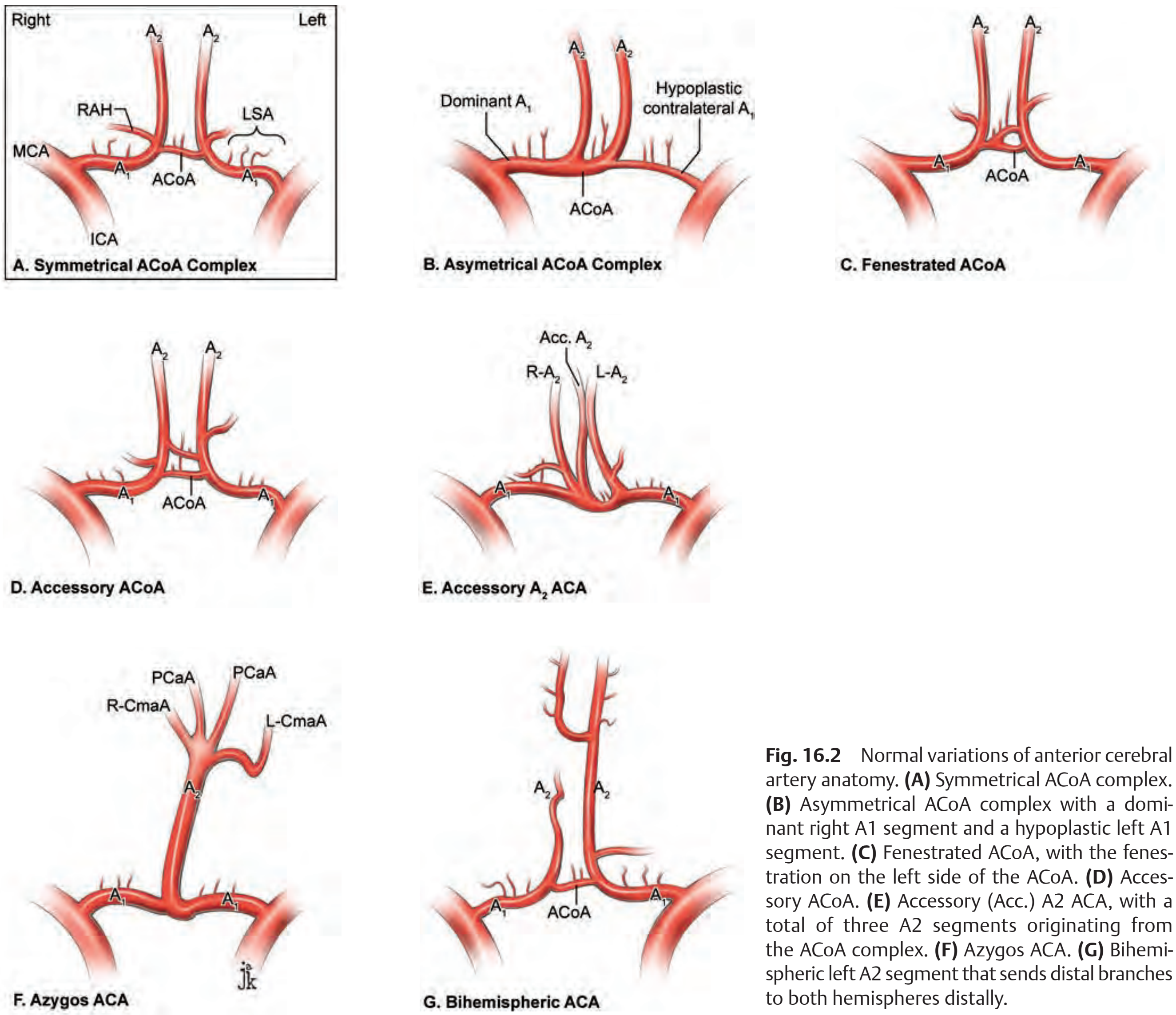



**Fig. 16.2** Normal variations of anterior cerebral artery anatomy. **(A)** Symmetrical ACoA complex. **(B)** Asymmetrical ACoA complex with a dominant right A1 segment and a hypoplastic left A1 segment. **(C)** Fenestrated ACoA, with the fenestration on the left side of the ACoA. **(D)** Accessory ACoA. **(E)** Accessory (Acc.) A2 ACA, with a total of three A2 segments originating from the ACoA complex. **(F)** Azygos ACA. **(G)** Bihemispheric left A2 segment that sends distal branches to both hemispheres distally.

Three variations in efferent A2 segments can lead to misinterpretations of aneurysm anatomy: *azygos*, *bihemispheric*, and *accessory* ACA (**Fig. 16.2**). The azygos or "unpaired" ACA is a single midline artery arising from the confluence of the A1 segments, and occurs in less than 2% of patients. Distally, the azygos ACA divides into the PcaA and CmaA with bifurcations, trifurcations, or quadrifurcations. The "bihemispheric" ACA is an A2 segment that transmits branches across the midline to both hemispheres, usually in the presence of a contralateral A2 segment that is either hypoplastic or terminates early in its course toward the genu. This anomaly is seen in as many as 12% of patients. The accessory A2 segment is a third artery originating from the ACoA in addition to ipsi- and contralateral A2 segments. The accessory ACA varies in caliber from a small remnant of the median artery of the corpus callosum (MACC), to a hyperplastic trunk resembling an azygos ACA between two smaller A2 segments. The MACC originates during embryogenesis (44 days) when elongating ACAs coalesce in the midline to form plexiform anastomoses. The MACC regresses and disappears as A2 segments mature, but remnants account for the accessory ACA.

## Aneurysm Dissection

Anterior communicating artery aneurysms can be approached from either side. The right side is chosen in patients with symmetric A1 segments, and the side of the dominant A1 segment is chosen in patients with asymmetric A1 segments. This policy avoids the speech-dominant hemisphere in patients with balanced anatomy and exploits advantages of A1 dominance: early proximal control, dome avoidance, and favorable view of the neck. Although infrequent in the general population (around 10%), A1 dominance is frequent in the aneurysm population (as high as 80%). Consequently, the side of approach was even divided in the author's ACoA aneurysm experience. With this policy, intraparenchymal hematomas associated with rupture are typically in the contralateral frontal lobe, but are contiguous with the aneurysm dome and easily evacuated after clipping. The side of approach may be influenced by the presence of other lateral aneurysms that might be treated simultaneously. A standard pterional craniotomy is sufficient for most ACoA aneurysms, but the orbitozygomatic approach increases exposure for large, giant, and complex aneurysms (16% in the author's experience).

The dissection of ACoA aneurysms proceeds in steps that identify the five major arteries of the dozen arteries around the ACoA complex, beginning with the ipsilateral A1 segment (**Fig. 16.3**, step 1), moving to the ipsilateral A2 segment (**Fig. 16.3**, step 2), and crossing the midline to the contralateral anatomy via the ACoA (**Fig. 16.3**, step 3). Proximal control of the aneurysm is completed by identifying the opposite A1 segment (**Fig. 16.3**, step 4). The contralateral A2 segment is located by entering the interhemispheric fissure above the aneurysm and distal to the dome (**Fig. 16.3**, step 5). The contralateral A2 segment runs parallel to the ipsilateral A2 segment and perpendicular to the contralateral orbitofrontal artery, which can often be seen anteriorly in the interhemispheric fissure. The contralateral A2 segment is traced proximally to the aneurysm neck (**Fig. 16.3**, step 6), and finally the ACoA perforators are dissected from the posterior neck and the aneurysm is prepared for the clip blade (**Fig. 16.3**, step 7).

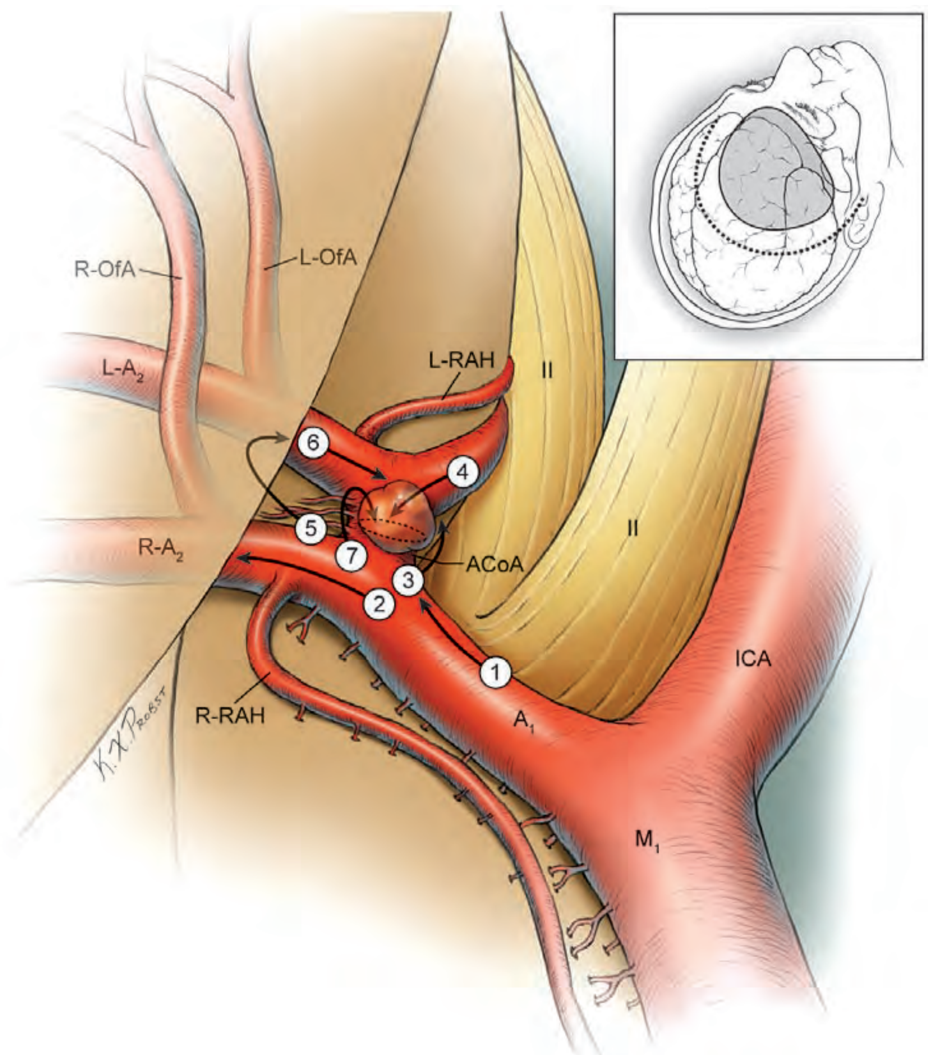



**Fig. 16.3** ACoA aneurysm dissection steps. Step 1, following the A1 segment and recurrent artery of Heubner; step 2, identifying the A2 segment; step 3, crossing the midline via the ACoA; step 4, controlling the contralateral A1 segment; step 5, entering the distal interhemispheric fissure; step 6, tracing the contralateral A2 segment proximally; and step 7, separating the perforators from the aneurysm neck.

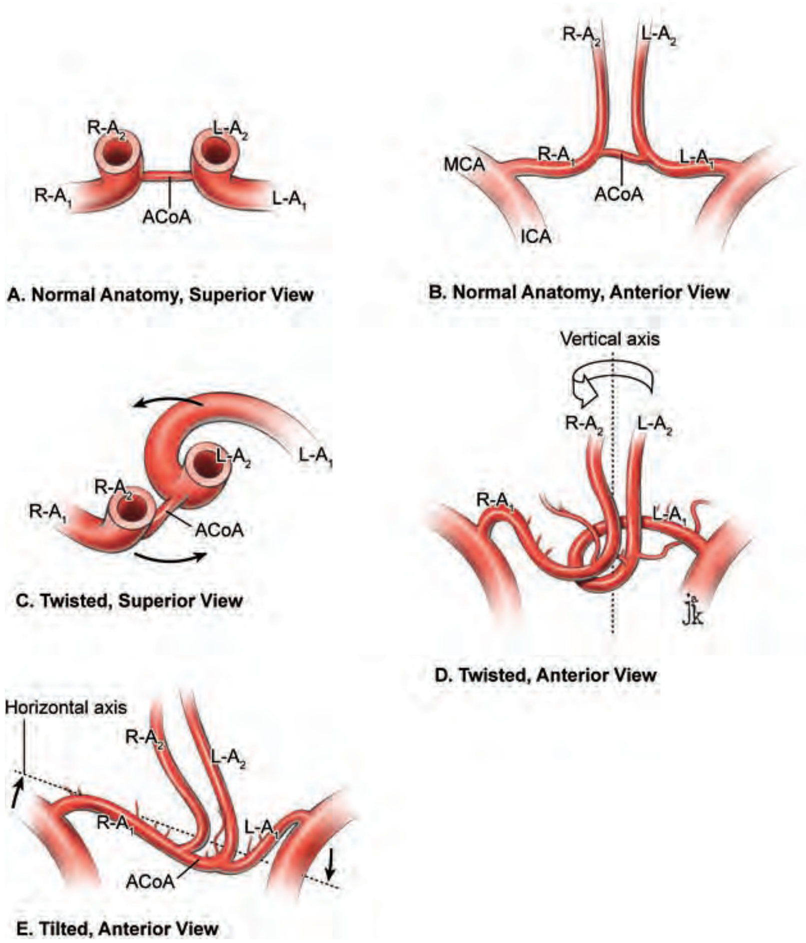



**Fig. 16.4** The ACoA complex is rotated in some patients, shifting the relationships between its major arteries. Normal orthogonal anatomy is shown in superior **(A)** and anterior **(B)** views. An ACoA complex twisted counterclockwise about its vertical axis brings the right A1 and A2 segments forward into view from a right-sided pterional approach, but the left A1 and A2 segments move backward out of view, as seen in superior **(C)** and anterior **(D)** views. **(E)** An ACoA complex tilted to the left, as shown in this anterior view, brings the left A1 and A2 segments into the view of a right pterional approach, but pulls the right A1 and A2 segments up out of view.

Opening the carotid cistern and the proximal sylvian cistern often exposes the distal ICA and the origin of the A1 segment, but a more extensive sylvian fissure split might be needed if the ICA bifurcation is high-riding or if the frontal and temporal lobes cover the ICA bifurcation. Frontal lobe retraction, with the retractor tip on the posterior portion of the medial orbital gyrus, lateral to the olfactory tract, increases visualization of the A1 segment. Retraction with an inferiorly projecting ACoA aneurysm is done lightly and with caution, because it can avulse a dome that adheres to the optic chiasm. A recurrent artery of Heubner is often seen before the A1 segment, and it is mobilized off of the optic tract and chiasm inferiorly and off of the frontal lobe superiorly. Liberating this artery circumferentially positions it prominently in the field as a landmark to the ACoA, and keeps it from being swept under the retractor blade. The inferior surface of the A1 segment is followed medially to avoid perforators on its superior surface, and frontal retraction is shifted progressively from the posterior medial orbital gyrus to the gyrus rectus.

The optic apparatus is another orienting landmark that can be followed from the ipsilateral optic nerve, across the anterior edge of the chiasm, to the opposite optic nerve and interoptic triangle, remaining beneath most aneurysms except those projecting inferiorly.

After exposing the ipsilateral A1 segment and gaining partial control of the aneurysm, the ipsilateral A2 segment is found by opening the interhemispheric fissure inferiorly where the right and left gyri rectus meet. Brain atrophy, prominent orbitofrontal arteries, or an interhemispheric hematoma facilitate opening this fissure. The ipsilateral gyrus rectus is then lifted with the retractor to view the ipsilateral A2 segment. A high-riding ACoA complex, swollen brain, or tight fissure may call for gyrus rectus resection and entrance into the interhemispheric fissure through the pia of the medial hemisphere, but subarachnoid dissection in the interhemispheric fissure is preferred over brain transgression.

The ACoA complex's classic position has no lateral rotation, with the ACoA and both A2 segments lying in a coronal plane (**Fig. 16.4A,B**); extreme rotation of the complex orients the ACoA and its A2 segments in a sagittal plane (**Fig. 16.4C,D**). This twisting of the ACoA complex about a vertical axis shifts the A2 segments and can confuse the dissection. Dominant A1 segments tend to twist the ACoA complex to

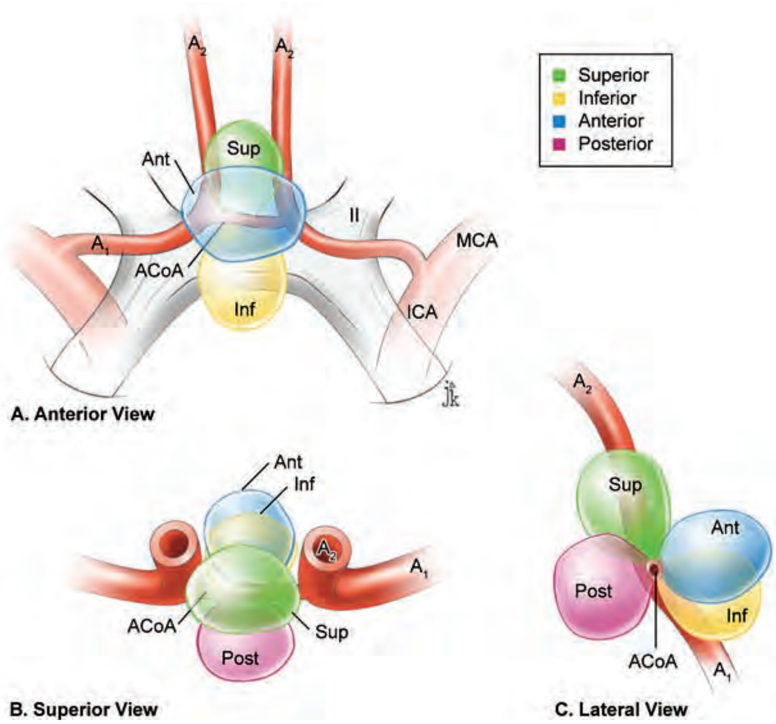



**Fig. 16.5** Dome projection of ACoA aneurysms in the anterior, posterior, superior, and inferior directions, as seen from anterior **(A),** superior **(B),** and lateral **(C)** views.

face the contralateral side in the direction of blood flow (according to Rhoton's third rule), bringing the ipsilateral A2 segment forward and making it easier to identify. However, an ACoA complex that is twisted toward the side of the approach recesses the ipsilateral A2 segment backward in the fissure and makes it harder to identify. In addition to this twisting rotation, the horizontal axis of the ACoA complex can also tilt (**Fig. 16.4E**). An ACoA complex tilted downwards on the side of approach lowers the ipsilateral A2 segment and brings it into view low in the interhemispheric fissure; an ACoA complex tilted upwards on the side of approach raises the ipsilateral A2 segment and often requires gyrus rectus resection. Tilting and twisting of the ACoA complex also affects the A1 segment. Tilt toward the opposite side elevates the ipsilateral A1 segment and the superiorly arcing trajectory makes the artery more difficult to visualize.

The dissection path across the midline to the contralateral A1 and A2 segments is influenced by aneurysm projection. ACoA aneurysms project *anteriorly*, *posteriorly*, *inferiorly*, or *superiorly* (**Fig. 16.5**). In Yasargil's experience, superior aneurysms were most common (34%), followed by anterior (23%), posterior (14%), and inferior (13%); multiple lobes or mixed projection was encountered in 16% of aneurysms. Dome projection creates a surgical blind spot that conceals a critical artery or part of the aneurysm. Inferiorly projecting aneurysms hide the contralateral A1 segment, which limits proximal control. Anteriorly projecting aneurysms hide the contralateral A1-A2 junction, which hinders dissection of the distal aneurysm neck. Superiorly projecting aneurysms hide the contralateral A2 segment. Posteriorly projecting aneurysms hide the ACoA perforators, which puts them in jeopardy during permanent clipping. The dissection strategy is determined by the dome projection and this shifting surgical blind spot. Visible arteries in open surgical corridors are dissected first, and hidden arteries in the surgical blind spot are dissected last, often with temporary clipping, aneurysm manipulation, and some de-tethering of the dome.

With *inferiorly* projecting aneurysms, the contralateral A2 segment (**Fig. 16.6**, step 4) and ACoA (**Fig. 16.6**, step 5) are exposed with a superior dissection path over the aneurysm. The dome hides the contralateral A1 segment, and these aneurysms are sometimes clipped without contralateral proximal control. Full exposure of the contralateral A1 segment might require mobilization of the aneurysm and might risk intraoperative rupture. The dome is also susceptible to avulsion with upward mobilization of the neck when developing the plane under the neck (**Fig. 16.6**, step 6). The contralateral A1 segment and A1-A2 junction are carefully inspected after permanent clipping if they were not fully exposed before permanent clipping (**Fig. 16.6**, step 7). Perforators course away from the neck and require minimal dissection.

With *anteriorly* projecting aneurysms, dissection crosses beneath the dome to control the contralateral A1 segment (**Fig. 16.7**, steps 3 and 4), and then shifts above the dome to identify the contralateral A2 segment (**Fig. 16.7**, step 5 and 6). The distal portion of the contralateral A2 segment is found high in the interhemispheric fissure, but the aneurysm

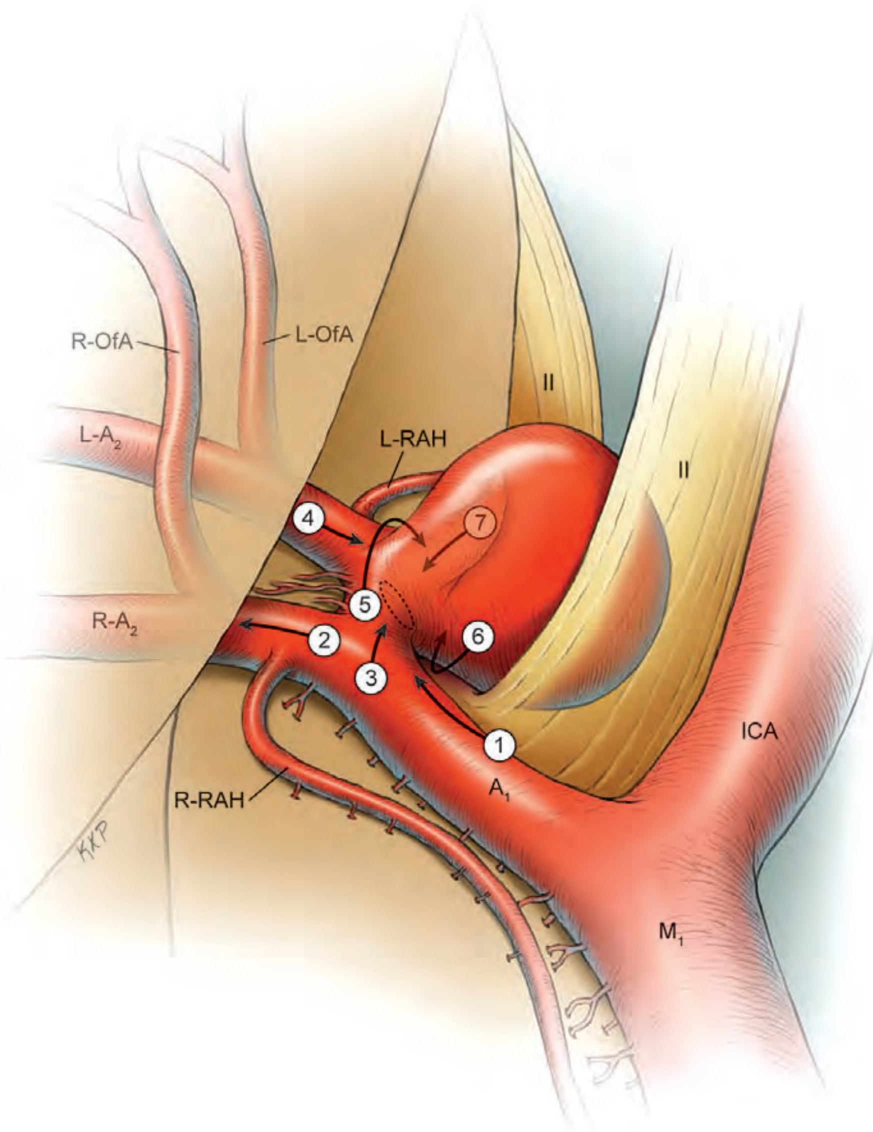



**Fig. 16.6** Dissection steps for an *inferiorly* projecting ACoA aneurysm. Step 1, following the A1 segment and recurrent artery of Heubner; step 2, identifying the A2 segment; step 3, crossing the midline via the ACoA; step 4, tracing the contralateral A2 segment proximally; step 5, separating the perforators from the aneurysm neck; step 6, developing a plane under the neck; step 7, inspecting the contralateral A1 segment, often after permanent clipping.

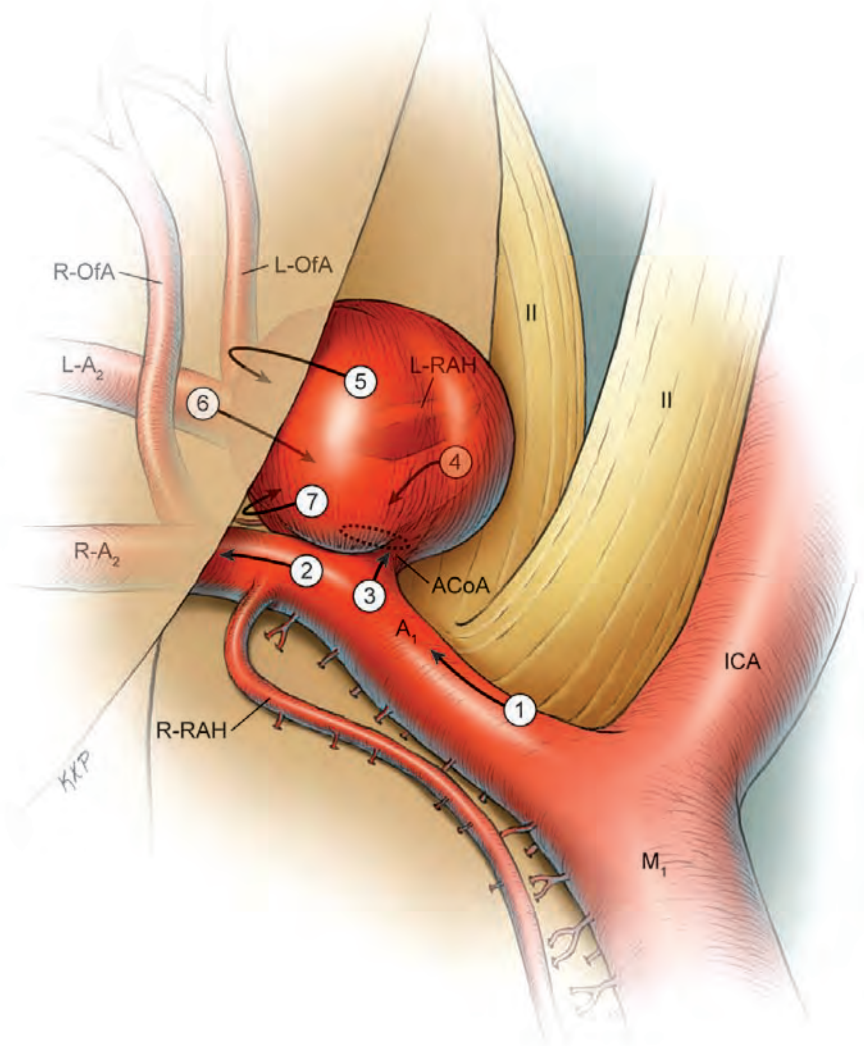



**Fig. 16.7** Dissection steps for an *anteriorly* projecting ACoA aneurysm. Step 1, following the A1 segment and recurrent artery of Heubner; step 2, identifying the A2 segment; step 3, crossing the midline via the ACoA; step 4, controlling the contralateral A1 segment; step 5, entering the distal interhemispheric fissure; step 6, tracing the contralateral A2 segment proximally; and step 7, separating the perforators from the aneurysm neck.

obscures its origin as dissection descends to the A1-A2 junction. ACoA perforators associated with anteriorly projecting aneurysms are visualized across the neck and must be cleared from the path of the superior blade (**Fig. 16.7**, step 7).

With *superiorly* projecting aneurysms, the ACoA and contralateral A1 segment are also exposed early with an inferior dissection path (**Fig. 16.8**, steps 3 and 4). The contralateral A2 segment is hidden behind the aneurysm and cannot be found simply by ascending into the interhemispheric fissure. The initial course of the contralateral A2 segment can sometimes be seen under the belly of the aneurysm, sometimes requiring upward traction on the aneurysm (**Fig. 16.8**, step 5). However, finding the contralateral A2 ACA requires dissection behind the aneurysm, deep in the interhemispheric fissure (**Fig. 16.8**, step 6). A window is opened behind the ipsilateral A2 segment, maneuvering the artery and its orbitofrontal and frontopolar branches anteriorly. Dissection remains above a recurrent artery of Heubner; the space under it, in its axilla, is narrow, and working there can avulse this delicate artery. Superior aneurysm projection provides complete proximal control for temporary clipping and aneurysm softening, which is often needed to mobilize the aneurysm during this deep dissection. The aneurysm's posterior fundus is traversed until the contralateral A2 ACA is identified. With large aneurysms, it often helps to climb higher in the interhemispheric fissure, looking for the A2 ACA as it courses beyond the dome. When the contralateral A2 ACA is found, its inner surface is traced inferiorly, opening this important cleavage plane down to the origin of the A2 ACA and distal aneurysm neck. The A2 origin and distal neck are carefully separated to prepare this spot for the tips of the permanent clip. This critical anatomy is right in the blind spot of the superiorly projecting aneurysm. Finally, the pathway for the posterior clip blade is opened along the neck above the posterior perforators, being careful not to overdissect delicate or densely adherent perforators (**Fig. 16.8**, step 7).

With *posteriorly* projecting ACoA aneurysms, all five major arteries around the ACoA complex are visible in front of the aneurysm (**Fig. 16.9**, steps 1 to 5). Perforators in front of the aneurysm are easily visualized and dissected (**Fig. 16.9**, step 6), but perforators behind the aneurysm are displaced inferiorly by the dome and hidden deep in the interhemispheric fissure. Again, the ipsilateral A2 segment is mobilized anteriorly with a recurrent artery of Heubner, and the inferior neck and perforators are dissected behind the ACoA, working over the shoulder of a recurrent artery of Heubner (**Fig. 16.9**, step 7). With the ACoA complex inter-

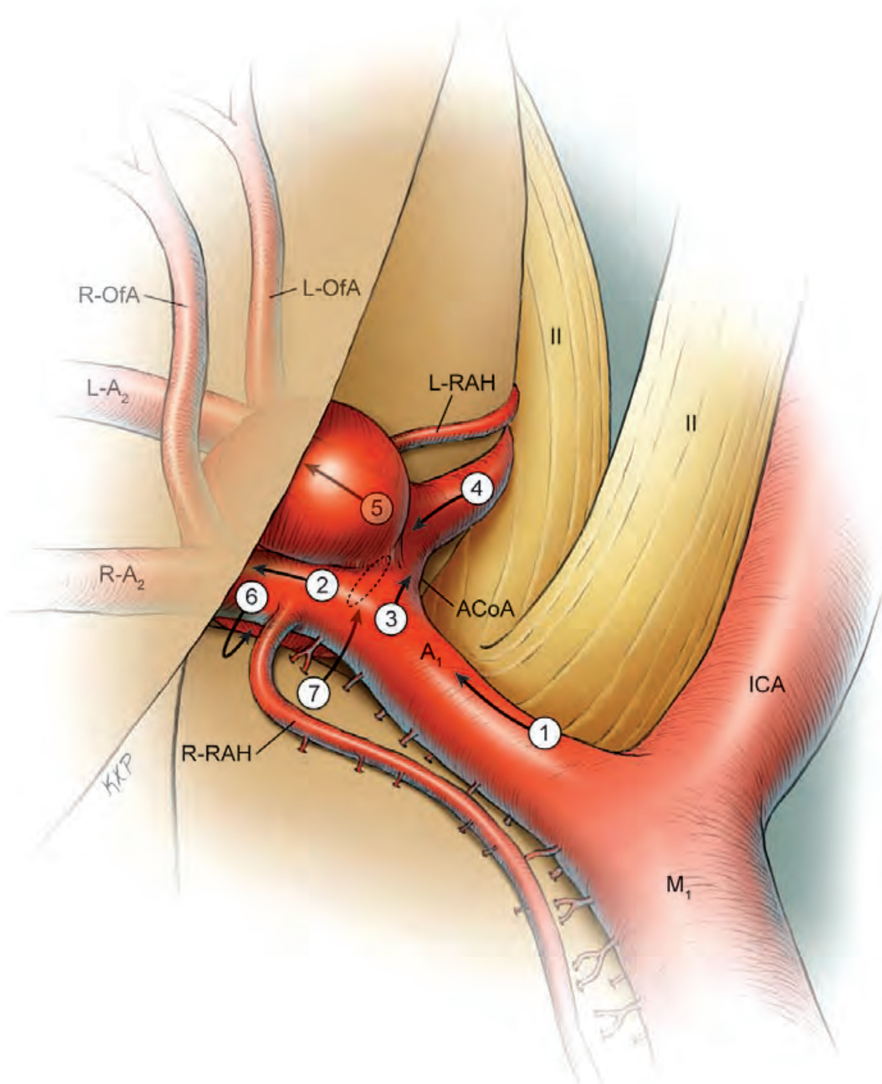



**Fig. 16.8** Dissection steps for a *superiorly* projecting ACoA aneurysm. Step 1, following the A1 segment and recurrent artery of Heubner; step 2, identifying the A2 segment; step 3, crossing the midline via the ACoA; step 4, controlling the contralateral A1 segment; step 5, tracing the contralateral A2 segment distally; step 6, entering the interhemispheric fissure behind the ipsilateral A2 segment; and step 7, separating the perforators from the aneurysm neck.

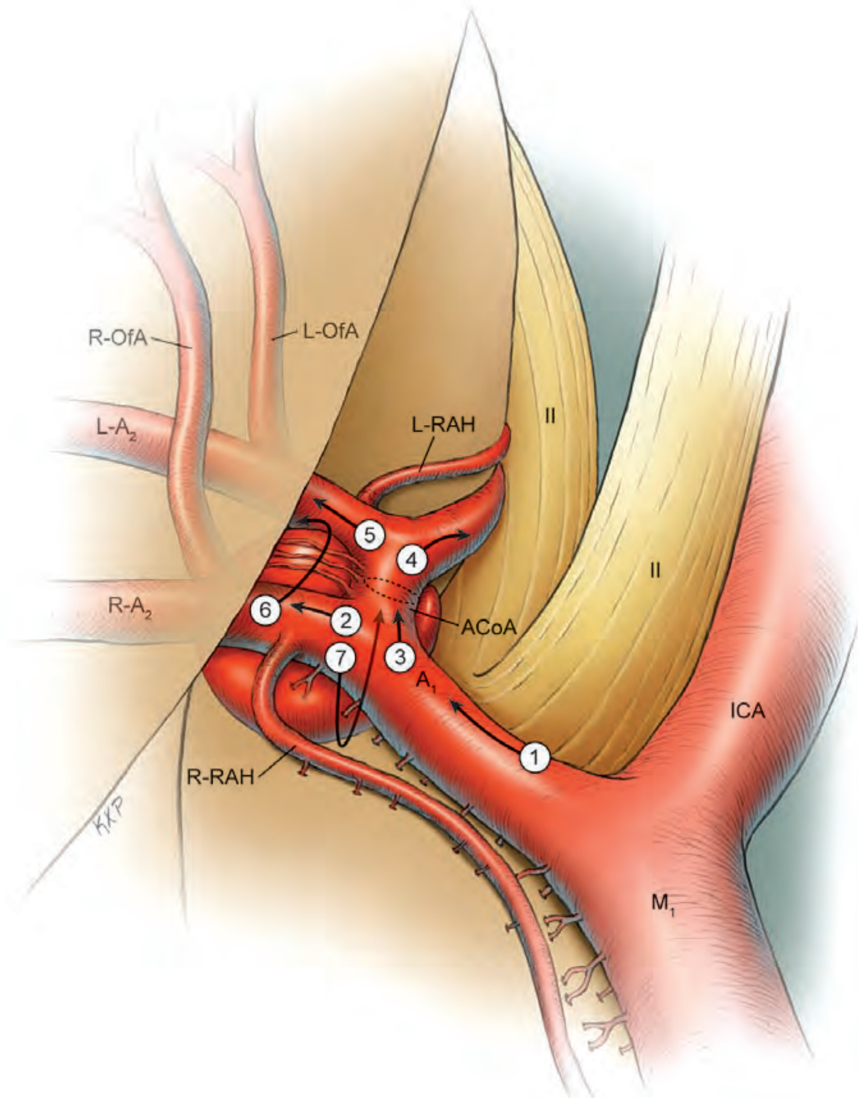
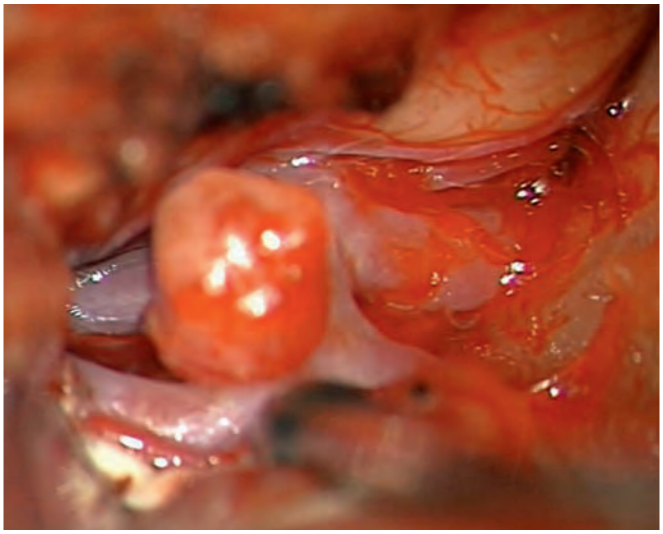



**Fig. 16.9** Dissection steps for a *posteriorly* projecting ACoA aneurysm. Step 1, following the A1 segment and recurrent artery of Heubner; step 2, identifying the A2 segment; step 3, crossing the midline via the ACoA; step 4, controlling the contralateral A1 segment; step 5, tracing the contralateral A2 segment distally; step 6, separating the perforators from the superior aneurysm neck; and step 7, entering the interhemispheric fissure behind the ipsilateral A2 segment and separating the perforators from the inferior aneurysm neck.

posed between the neurosurgeon and the aneurysm neck, the view of the neck is obscured. As with superior ACoA aneurysms, posterior ACoA aneurysms provide complete proximal control for temporary clipping, aneurysm softening, and aggressive manipulation during this dissection.

In general, most of the dissection is focused on the five major ACoA arteries: the bilateral A1 and A2 segments and the ACoA that together form the big **H**. Final dissection is focused on perforators. However, the minor arteries of the ACoA complex—the bilateral orbitofrontal and frontopolar arteries—are important because they can be misleading, appearing falsely as A2 segments. These cortical branches of the A2 segment are not true efferent trunks; they do not originate at the neck of ACoA aneurysms and should not interfere directly with the blade path across the neck. However, their anterior course often drapes these arteries across the dome of ACoA aneurysms that project superiorly or anteriorly, much like the anterior temporal artery (ATA) often drapes across the dome of middle cerebral artery (MCA) aneurysms that project inferiorly. In addition to being misinterpreted as A2 segments, draped arteries tether the dome and limit the aneurysm's mobility. Draped arteries also interfere with permanent clipping. The decision to dissect these branches off of the dome depends on the extent of adhesions, the fragility of underlying aneurysm wall, and the importance of clearing that pathway for clip blades.



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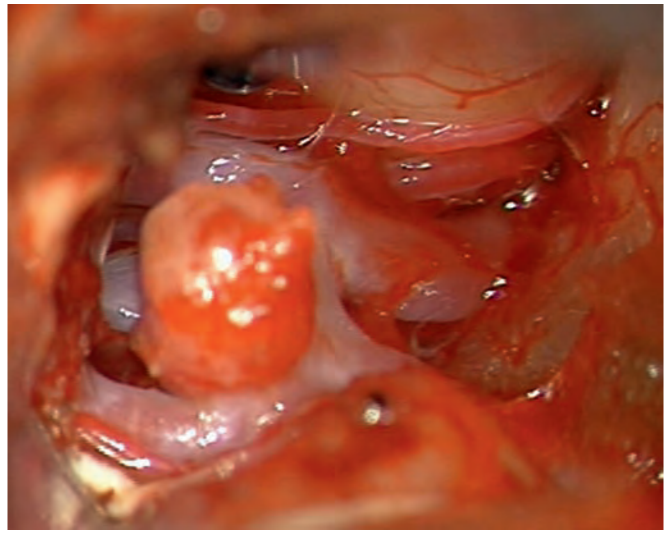

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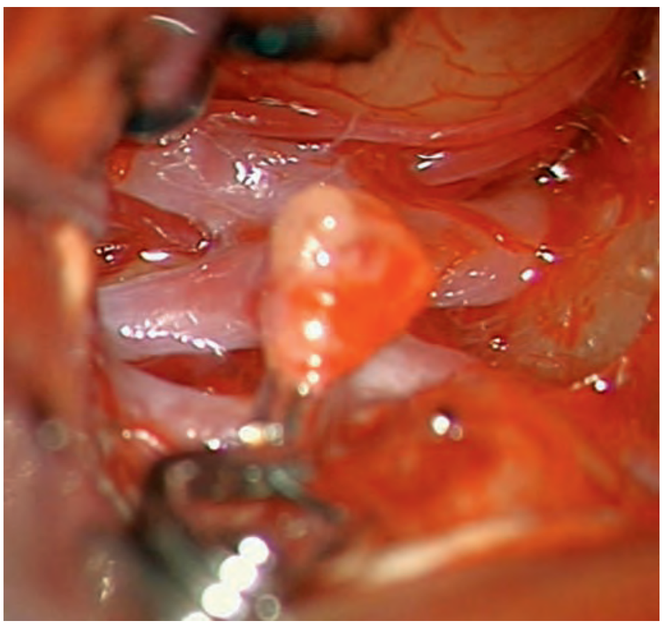
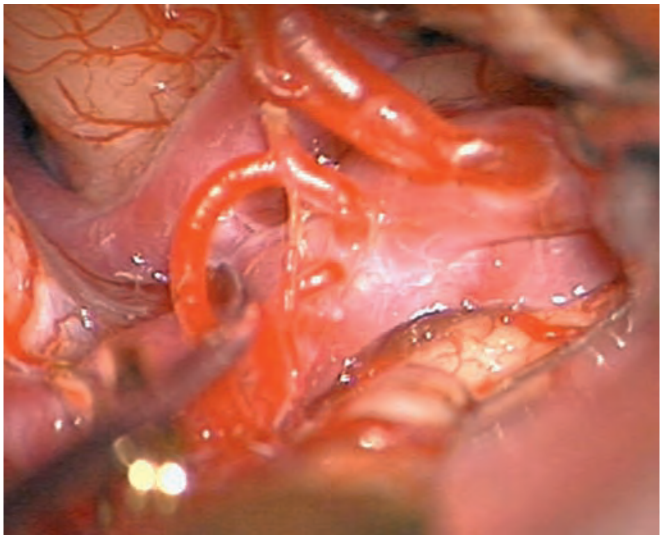


C

**Fig. 16.10** **(A)** At first glance through this right pterional exposure, this small, ruptured, anteriorly projecting ACoA aneurysm appeared to have classic anatomy, but **(B)** additional dissection revealed an accessory A2 ACA. **(C)** The neck was clipped with one straight clip.

## Clipping Technique

At the end of the final dissection, an aneurysm differentiates into a true ACoA aneurysm arising from the ACoA proper, an A1-A2 junction aneurysm, or a variant aneurysm arising from a fenestration, an accessory A2 trifurcation, or an azygos A2 segment. The bihemispheric ACA does not impact aneurysm clipping but may explain asymmetry in efferent A2 segments. The azygos ACA is not dangerous because an enlarged trunk is usually obvious. However, failure to appreciate the accessory ACA and preserve the extra A2 segment can lead to inadvertent arterial occlusion and infarction. Aneurysms associated with an accessory A2 ACA can arise in front of a trifurcated ACoA complex (**Fig. 16.10**), but more commonly they reside in one bifurcation or the other (**Fig. 16.11**). A1-A2 junction aneurysms are off the midline, and perforator dissection tends to be easier than with true ACoA aneurysms (**Fig. 16.12**).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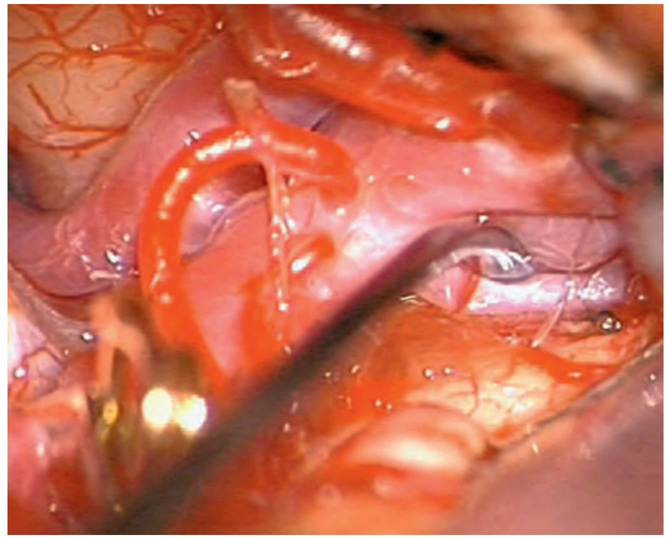
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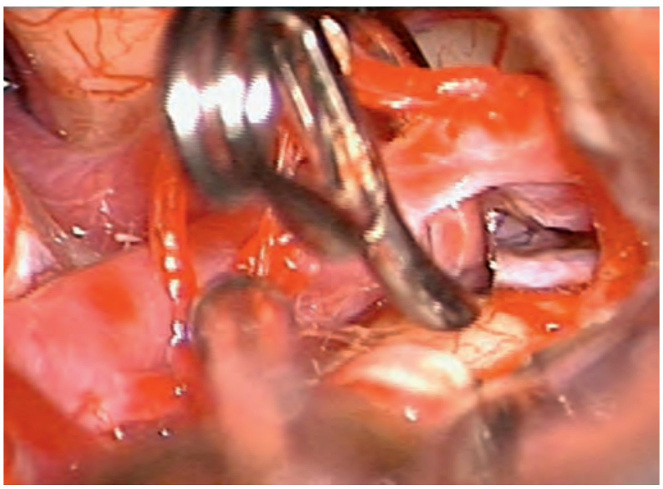
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**Fig. 16.11** **(A)** This 44-year-old woman had a left MCA aneurysm and an ACoA aneurysm and was therefore approached from the left side. The aneurysm projected posteriorly behind the ACoA complex, with the major arteries clearly in view (bilateral A1 and A2 segments, ACoA, left recurrent artery of Heubner, and left orbitofrontal artery). **(B)** Aneurysm neck dissection revealed an accessory A2 ACA coursing posteriorly in the interhemispheric fissure, with the aneurysm arising in the bifurcation between the left A2 ACA and the accessory A2 ACA. **(C)** The aneurysm was clipped with a straight fenestrated clip transmitting the left A2 ACA, recurrent artery of Heubner, and orbitofrontal artery.

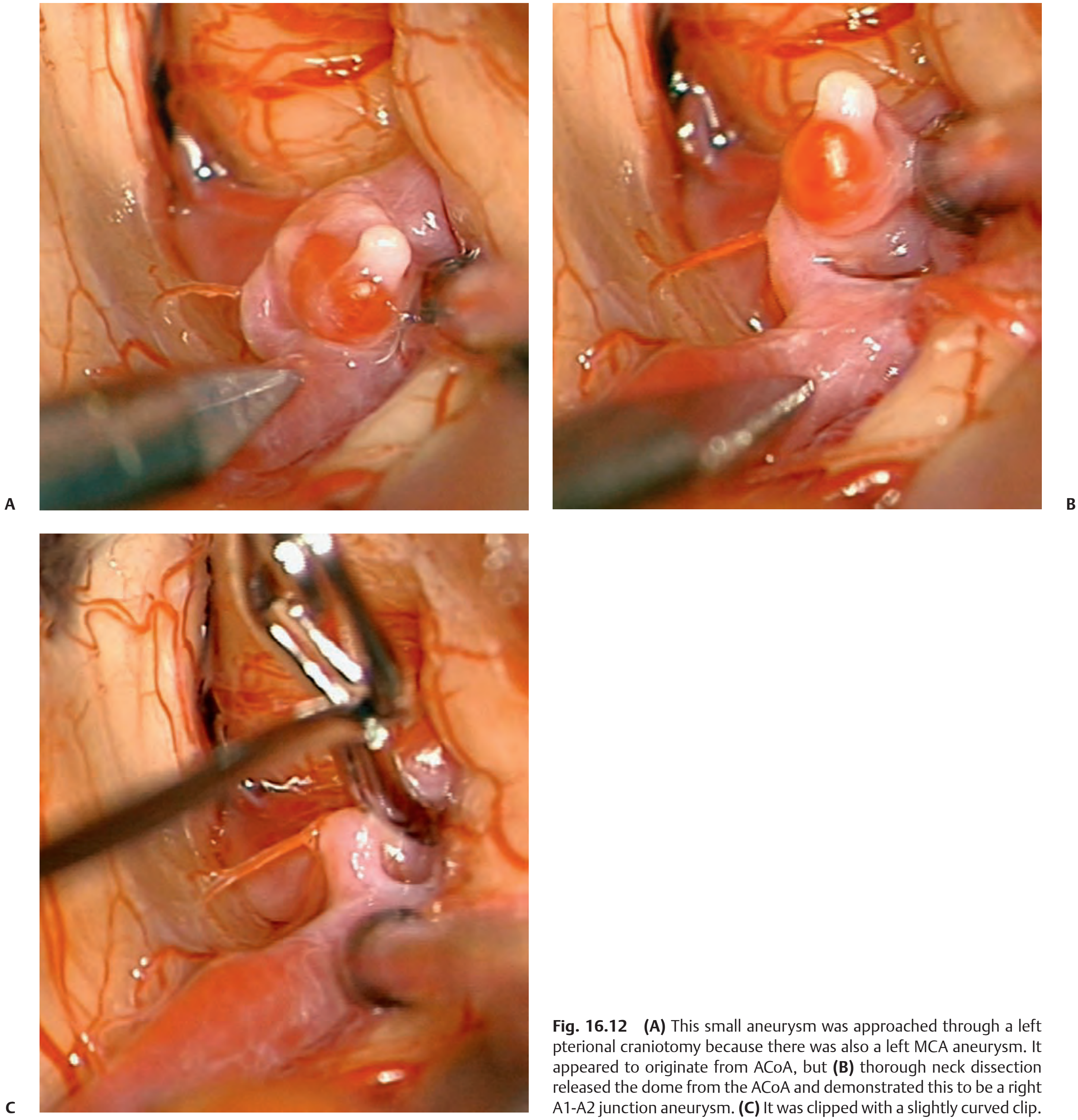


**Fig. 16.12** **(A)** This small aneurysm was approached through a left pterional craniotomy because there was also a left MCA aneurysm. It appeared to originate from ACoA, but **(B)** thorough neck dissection released the dome from the ACoA and demonstrated this to be a right A1-A2 junction aneurysm. **(C)** It was clipped with a slightly curved clip.

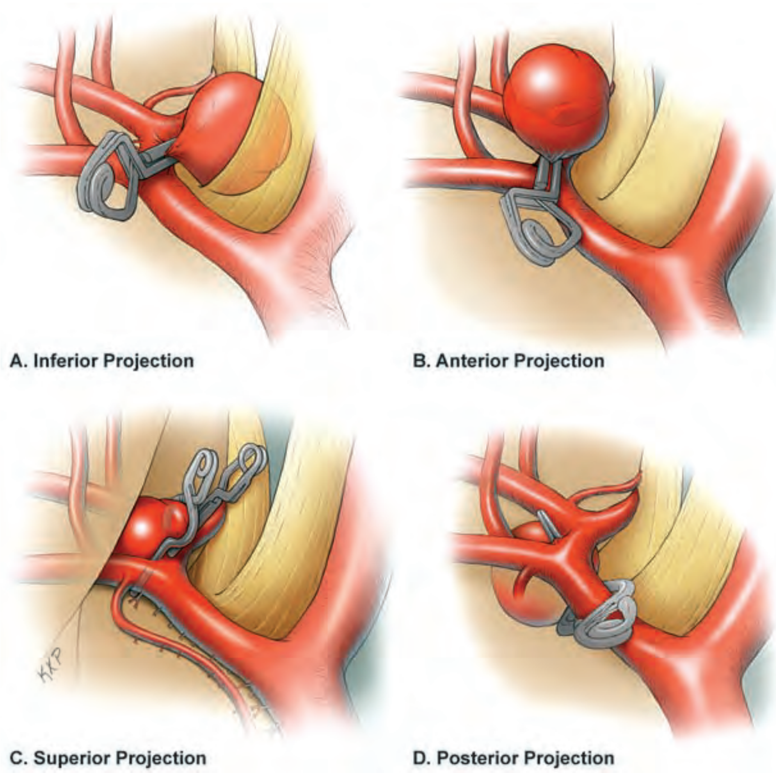
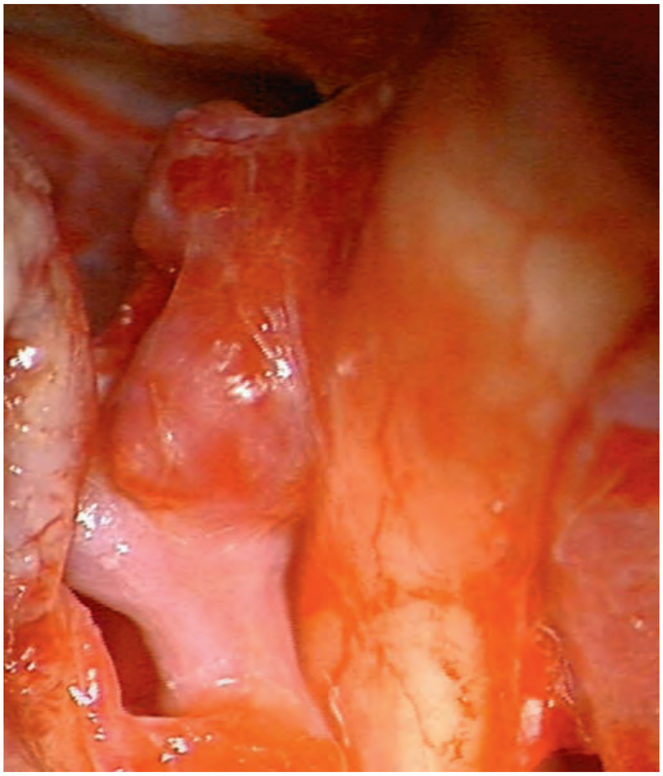



**Fig. 16.13** Clipping techniques for ACoA aneurysms projecting (**A**) inferiorly (simple clipping, straight clip), (**B**) anteriorly (simple clipping, straight clip), (**C**) superiorly (tandem clipping), and (**D**) posteriorly (simple clipping, angled fenestrated clip).

Dome projection influences the clipping technique (**Fig. 16.13**). Inferiorly and anteriorly projecting aneurysms are usually clipped simply with straight clips. The operative view is along the neck, with afferent and efferent branches away from the pathway of the clip blades. Inferiorly projecting aneurysms hide the contralateral A1 segment in the blind spot, and its exposure may require too much manipulation of a fragile, adherent aneurysm dome (**Figs. 16.14, 16.15, and 16.16**). Therefore, complete proximal control may not be available. However, the neck of an inferiorly projecting aneurysm is usually well visualized and an intraoperative rupture can be controlled by simply clipping the aneurysm. The clip's tips are inspected safely after permanent clipping; they must not pass beyond the neck and compromise the contralateral A1 afferent artery.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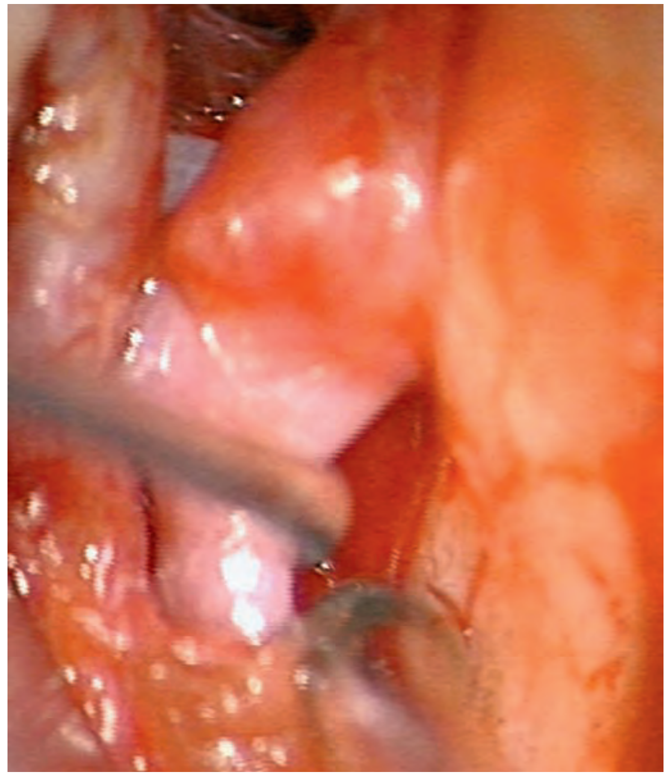
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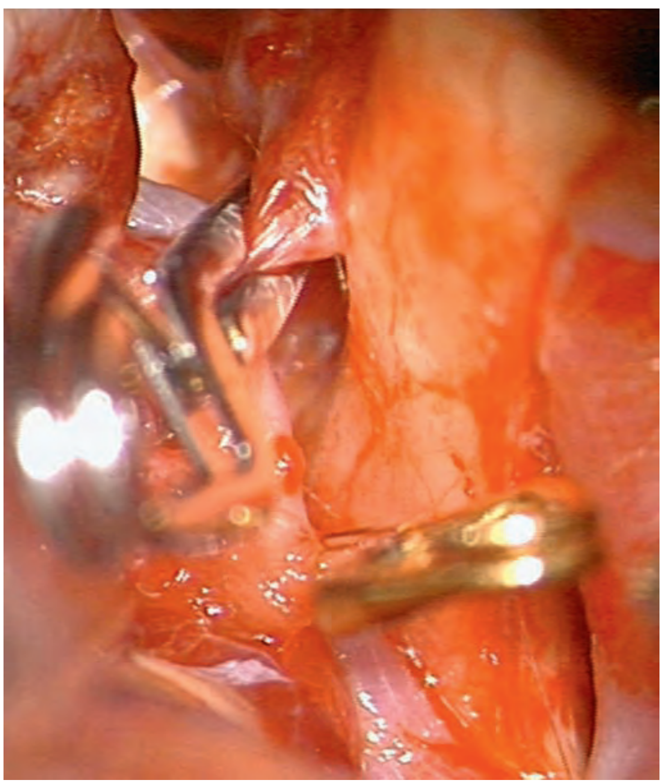
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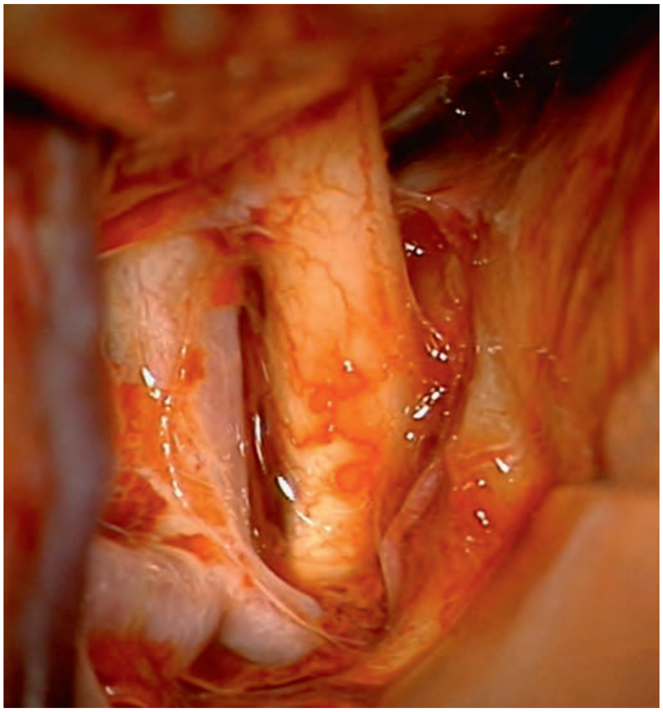
**Fig. 16.14** **(A)** Inferiorly projecting ACoA aneurysms adhere to the optic chiasm and optic nerves. The dome hides the contralateral A1 segment, as in this 51-year-old woman with subarachnoid hemorrhage. **(B)** The dissection crossed the inferior neck above the optic chiasm. The contralateral A1 could not be visualized without mobilizing the aneurysm, and the rupture site at the dome is susceptible to rerupture with even slight manipulation. **(C)** This aneurysm, and inferiorly projecting aneurysms generally, can be clipped with incomplete proximal control (ipsilateral A1 segment only). The contralateral A1 segment was carefully inspected after permanent clipping. Intraoperative rupture can be controlled by simply clipping the aneurysm neck, which is in full view.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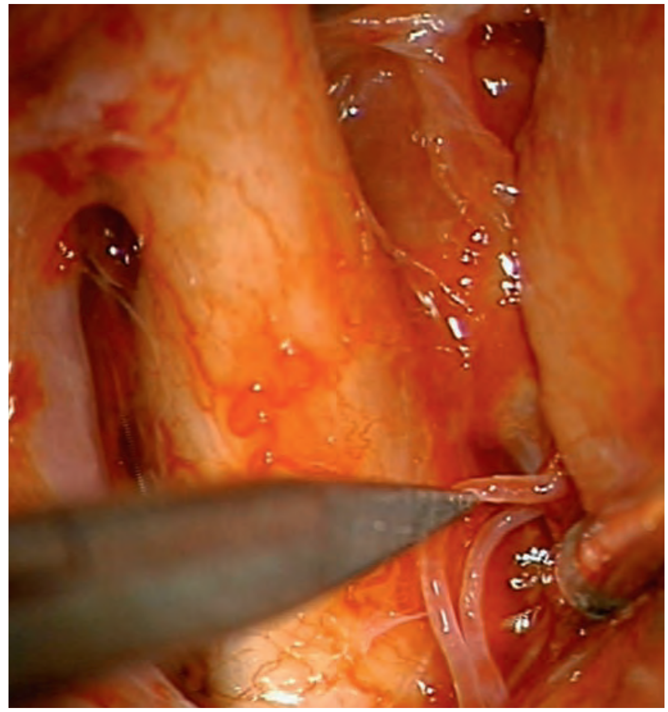
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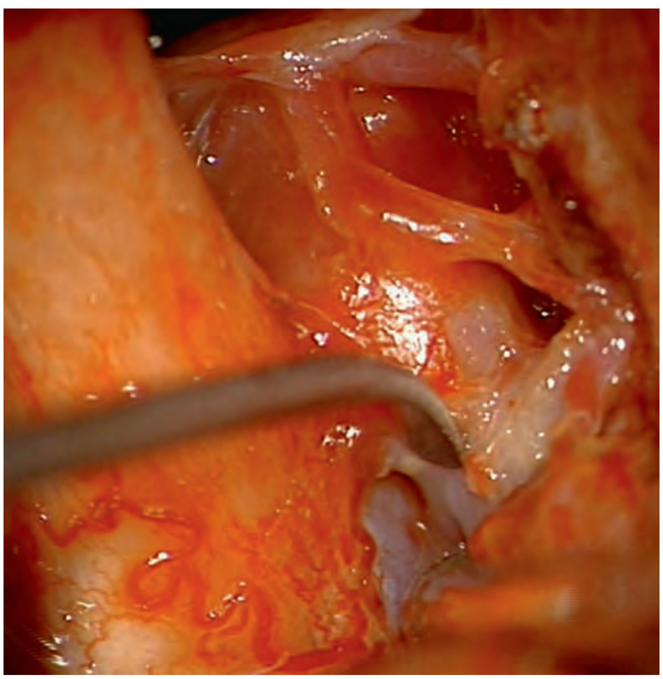
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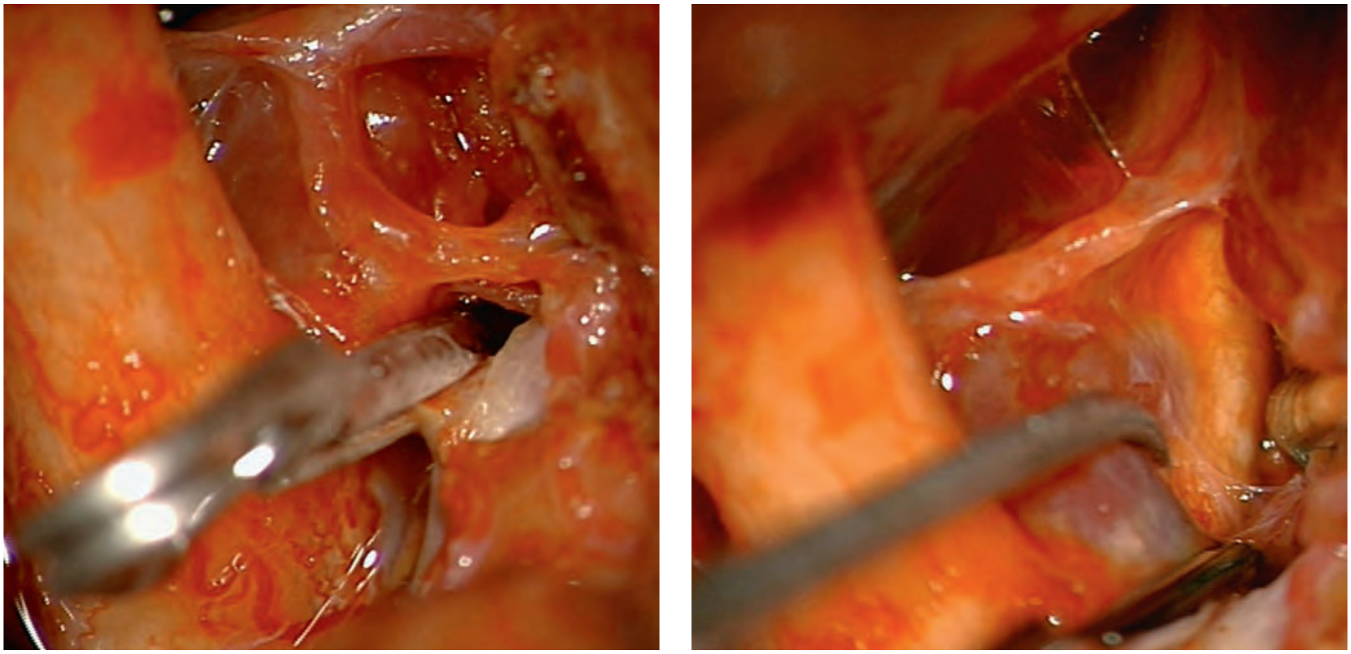
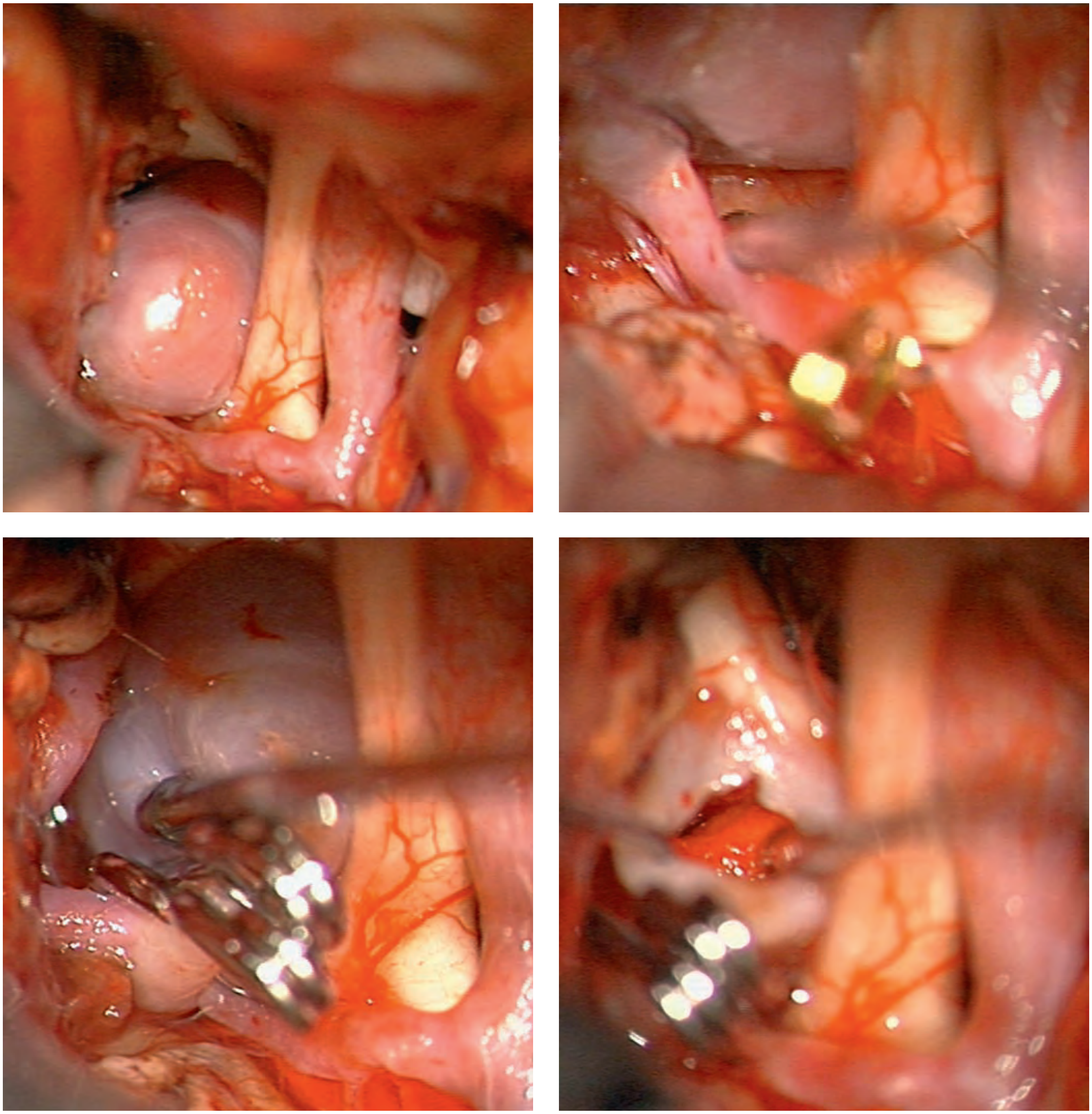
**Fig. 16.15** **(A)** This inferiorly projecting ACoA aneurysm in a 49-year-old man extended into the interoptic triangle. The left A1 ACA was dominant and a left pterional craniotomy was used. **(B)** A duplicated recurrent artery of Heubner was visible before the distal A1 segment and was followed to ACoA. **(C)** The plane between the inferior aneurysm neck and lamina terminalis was opened for a good view across the neck. The orbitofrontal artery was draped across the aneurysm fundus, but did not obstruct clip placement. (*continued on next page*)



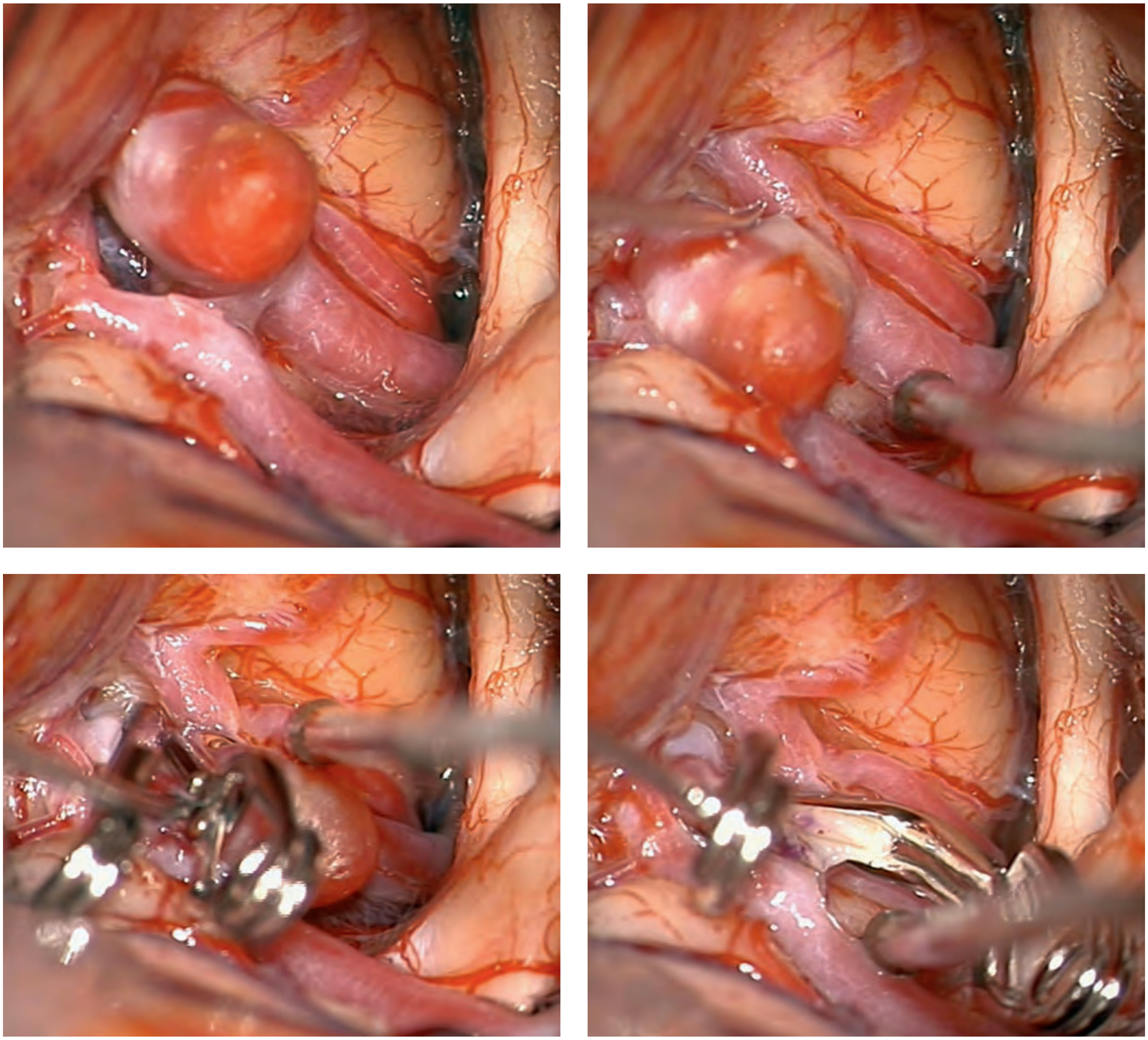
D E

**Fig. 16.15** (*Continued*) **(D)** The aneurysm was clipped with a straight clip. **(E)** The dome projected through the interoptic triangle and under the contralateral optic nerve, and was punctured to decompress this nerve.



A B C D

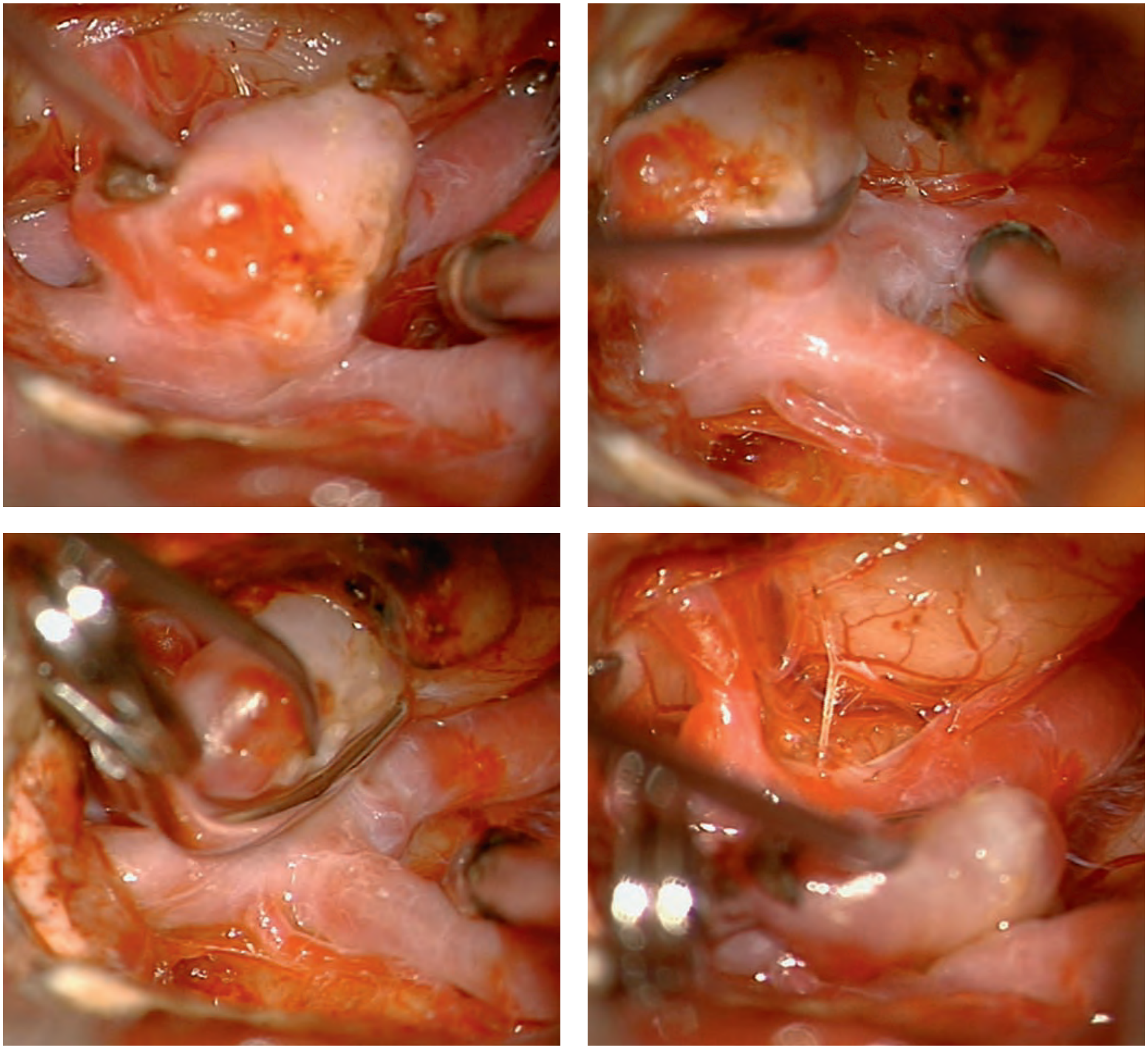
**Fig. 16.16** **(A)** This 51-year-old woman presented with a progressive bitemporal hemianopsia from an inferiorly projecting giant ACoA aneurysm and chiasmal compression. **(B)** The aneurysm softened with a temporary clip and the neck was visualized with dissection across the chiasm. **(C)** Tandem clipping was used to close the neck, with a straight fenestrated clip and a stacked straight clip. **(D)** The aneurysm was opened and the intraluminal thrombus was removed to decompress the optic apparatus. he patient's visual field deficit improved at late follow-up.



A B C D

**Fig. 16.17 (A)** Anteriorly projecting ACoA aneurysms hide the contralateral left A1-A2 junction, but all the other major arteries around the ACoA complex are visualized with slight retraction on the gyrus rectus. **(B)** Small aneurysms like this one can be displaced posteriorly to see the contralateral A1-A2 junction, as well as the contralateral recurrent artery of Heubner and orbitofrontal artery. **(C)** Clipping required a straight clip across the superior portion of the aneurysm and **(D)** an intersecting angled clip across the inferior portion of the aneurysm.

With anteriorly projecting aneurysms, the clip's tips must not pass beyond the neck and compromise the origin of contralateral A2 ACA in the blind spot (**Figs. 16.17 and 16.18**). Large and giant aneurysms may require tandem clipping or fenestration tubes (**Fig. 16.19**). With superiorly projecting aneurysms, the ipsilateral A2 segment can interfere with the clip trajectory. A straight clip can be maneuvered around the ipsilateral A2 segment in the fore field with smaller aneurysms and simple anatomy (**Fig. 16.20**). An anteroposterior clip trajectory, with the clip facing the front of the aneurysm, avoids the ipsilateral A2 segment. The initial clip obliterates all the aneurysm behind the A2 segments, and additional un-



A B C D

**Fig. 16.18** **(A)** This anteriorly projecting ACoA aneurysm hid the contralateral left A1-A2 junction, but **(B)** upward traction on the aneurysm revealed the distal neck. **(C)** The neck was clipped simply with a curved clip. **(D)** Inspection of the contralateral anatomy demonstrated contralateral A1 and A2 segments, an recurrent artery of Heubner, and an orbitofrontal artery.

derstacked clips obliterate any remaining aneurysm in front of the A2 segments. Wide-necked and dolichoectatic aneurysms do not permit this anterior clip trajectory because clipping often kinks the efferent arteries. Straight fenestrated clips may be more favorable, with the fenestration encircling the ipsilateral A2 ACA and the blade paralleling the ACoA (**Fig. 16.21**). Fenestrated clips are also indicated when the cleavage plane between the ipsilateral A2 segment and the proximal neck cannot be opened to pass a blade. Stacked fenestrated clips build an antegrade fenestration tube that effectively reconstructs the proximal neck without overdissecting this plane, which can be adherent to thinned aneurysm wall.

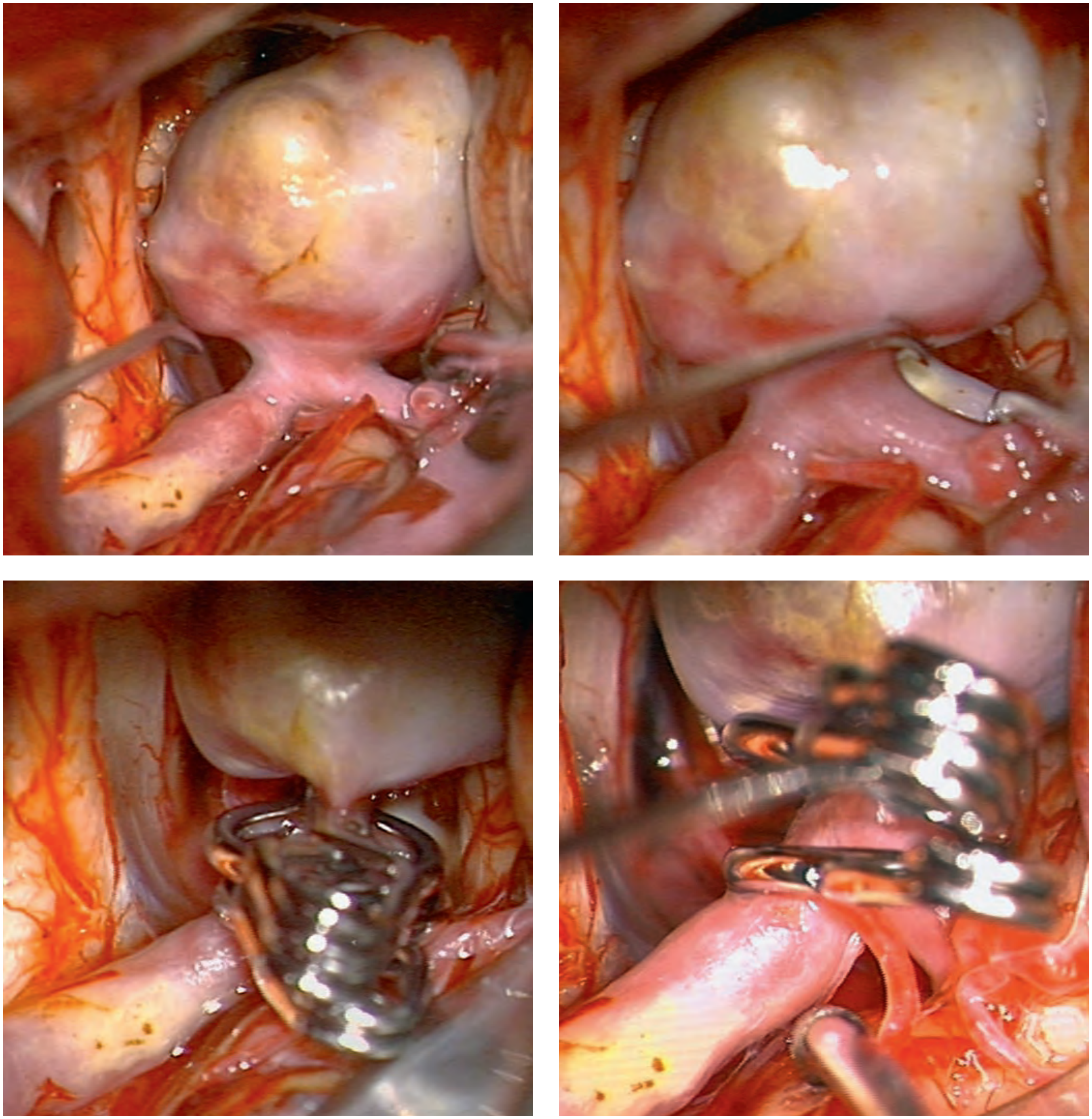
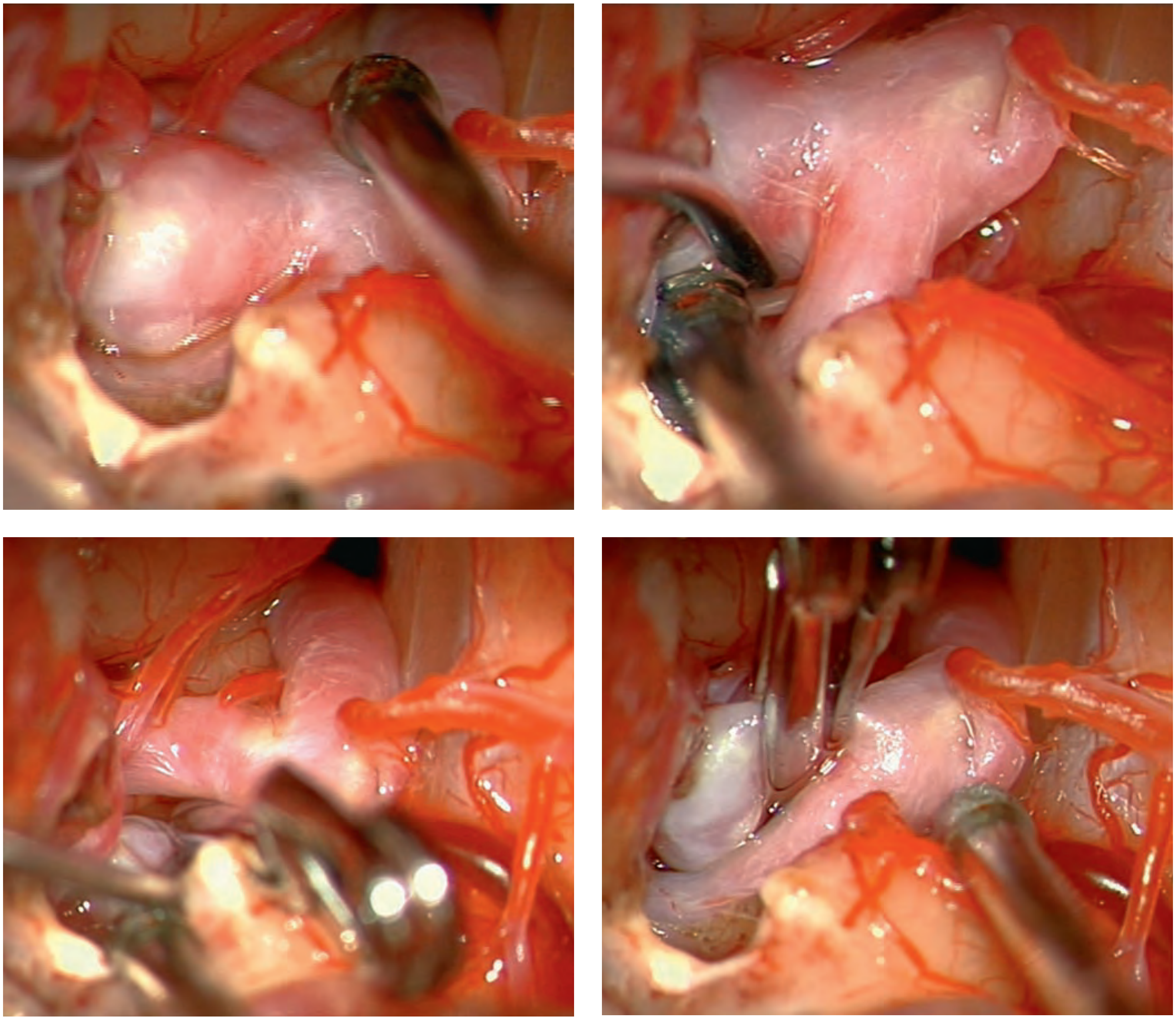
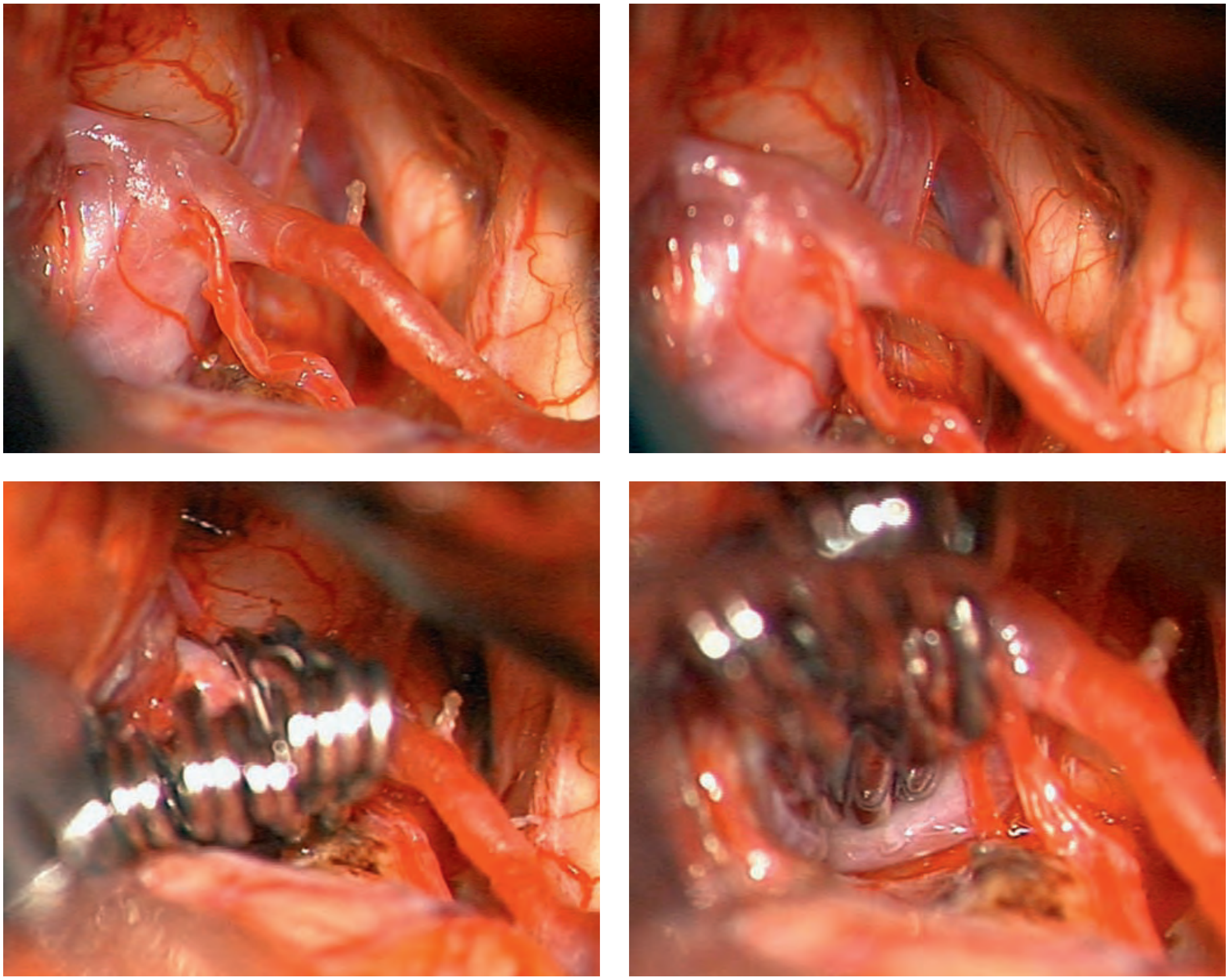



**Fig. 16.19** **(A)** This giant ACoA aneurysm was exposed through a left pterional craniotomy to treat a large middle cerebral artery aneurysm simultaneously. **(B)** Anterior projection of the aneurysm enabled easy visualization of the contralateral A2 ACA. **(C)** A retrograde fenestration tube built around the left A1-A2 junction was required to preserve flow in the A2 ACA and close the aneurysm neck. **(D)** This right-angle confluence of the A1 and A2 ACAs was reconstructed within the fenestration tube, with transmission of the recurrent artery of Heubner.



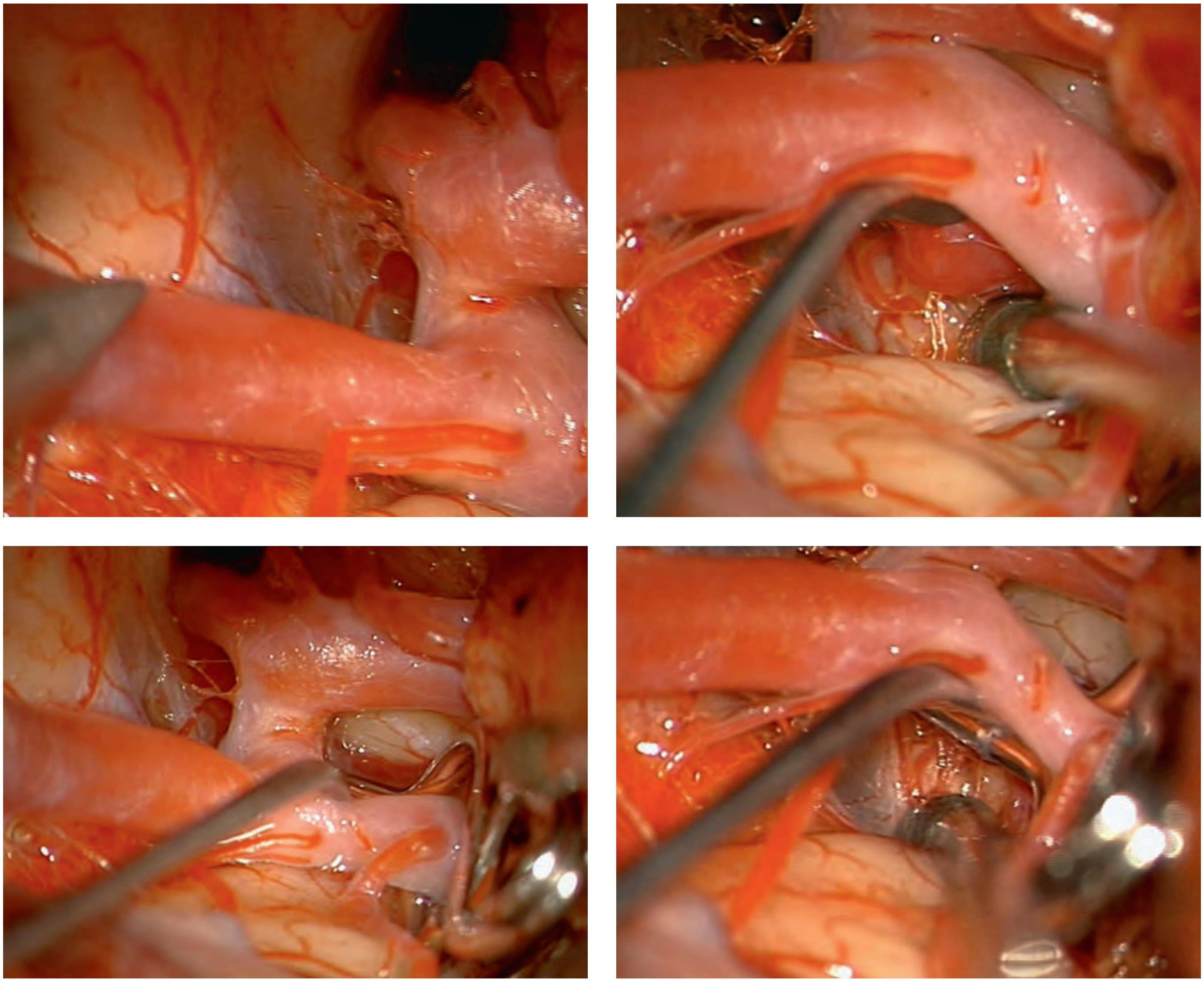
A B C D

**Fig. 16.20** ACoA aneurysms are generally approached from the side of A1 dominance, but left-sided approaches can be avoided with unruptured aneurysms that project superiorly. **(A)** This 64-year-old woman had a small, superiorly projecting ACoA aneurysm fed mainly from the left A1 ACA, which was easily exposed from the right for proximal control. Some gyrus rectus was resected to visualize the right A2 segment. **(B)** Dissection behind the aneurysm revealed a large ACoA perforator (at the tip of a No. 6 dissector). Note the hypoplastic right A1 segment. **(C)** The cleavage plane between the contralateral A2 ACA and the distal neck opened easily to pass the clip blade. **(D)** A small dog-ear remnant was closed with an understacked mini-clip.



A B C D

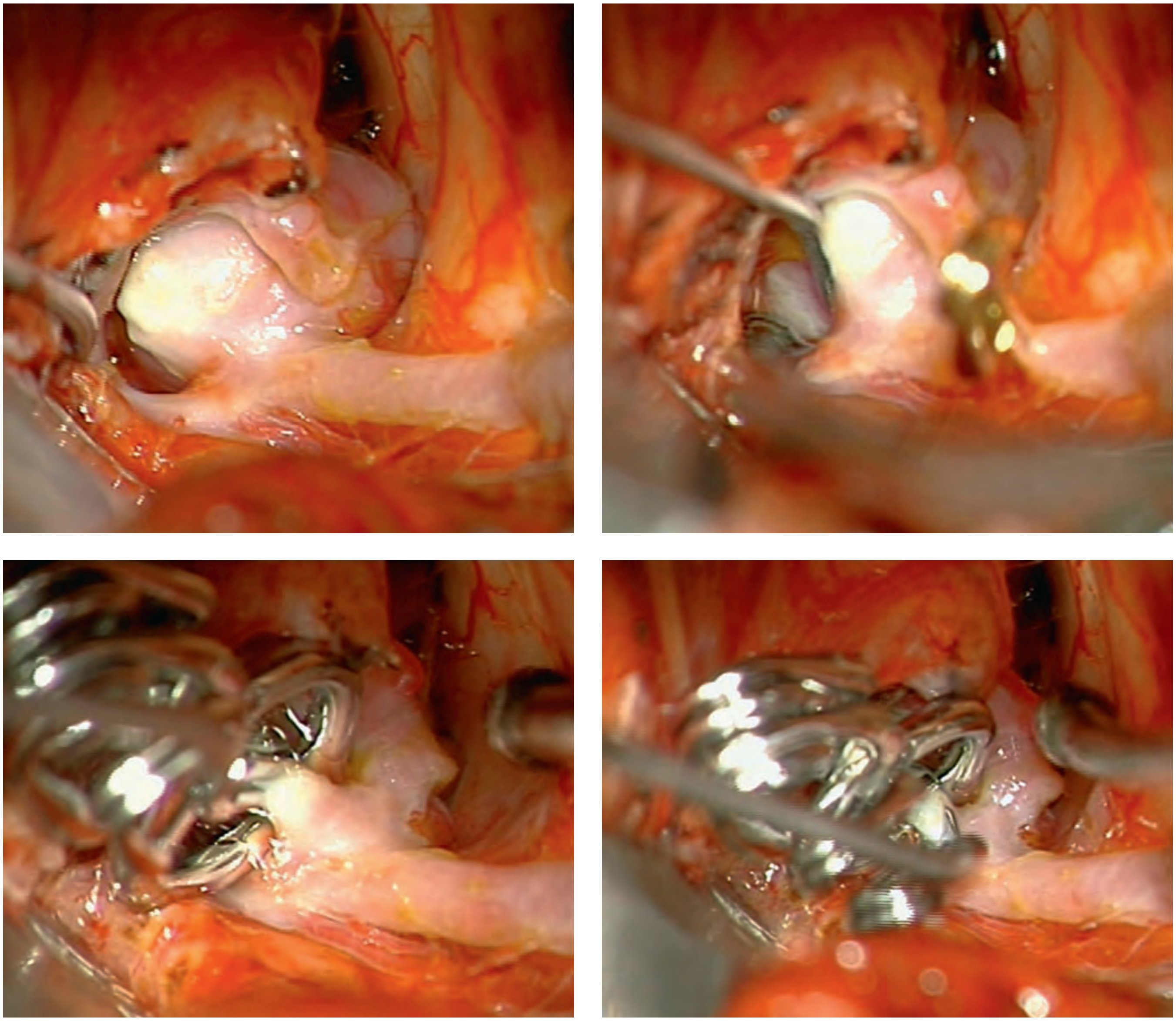
**Fig. 16.21** Twisting or rotation of the ACoA complex hid the contralateral anatomy in this 44-year-old woman, which was approached through a right pterional craniotomy. **(A)** The aneurysm's broad base separated the right A1 and A2 ACA, and the recurrent artery of Heubner originated from this segment. **(B)** Rotation of the ACoA complex from right to left pulled the contralateral A1 ACA posteriorly, and the contralateral A2 ACA was hidden behind the aneurysm. **(C)** After softening the aneurysm with temporary occlusion and mobilizing it posteriorly to find the left A2 ACA, the neck was closed with an antegrade fenestration tube: two stacked straight fenestrated clips around the right A1-A2 junction and the recurrent artery of Heubner, followed by two straight clips beyond the fenestration, behind the right A2 ACA. **(D)** The contralateral A2 ACA was deep in the interhemispheric fissure, seen at the tips of the fenestrated clip blades. The ACoA perforators coursed beneath the clip blades.



A B C D

**Fig. 16.22** This patient presented with blurred vision in her left eye from a tuberculum sella meningioma, and an incidental ACoA aneurysm was also diagnosed. **(A)** A left pterional craniotomy exposed both lesions, and the ACoA complex hid the posteriorly projecting aneurysm. **(B)** Posterior dissection exposed the aneurysm, working over the shoulder of the recurrent artery of Heubner and behind the ipsilateral A2 ACA. **(C)** The aneurysm was clipped with a 45-degree angled fenestrated clip transmitting the A2 segment and the orbitofrontal artery. **(D)** Both blades were inspected to be certain that the ACoA perforators were excluded from the clip. The meningioma was then removed completely.

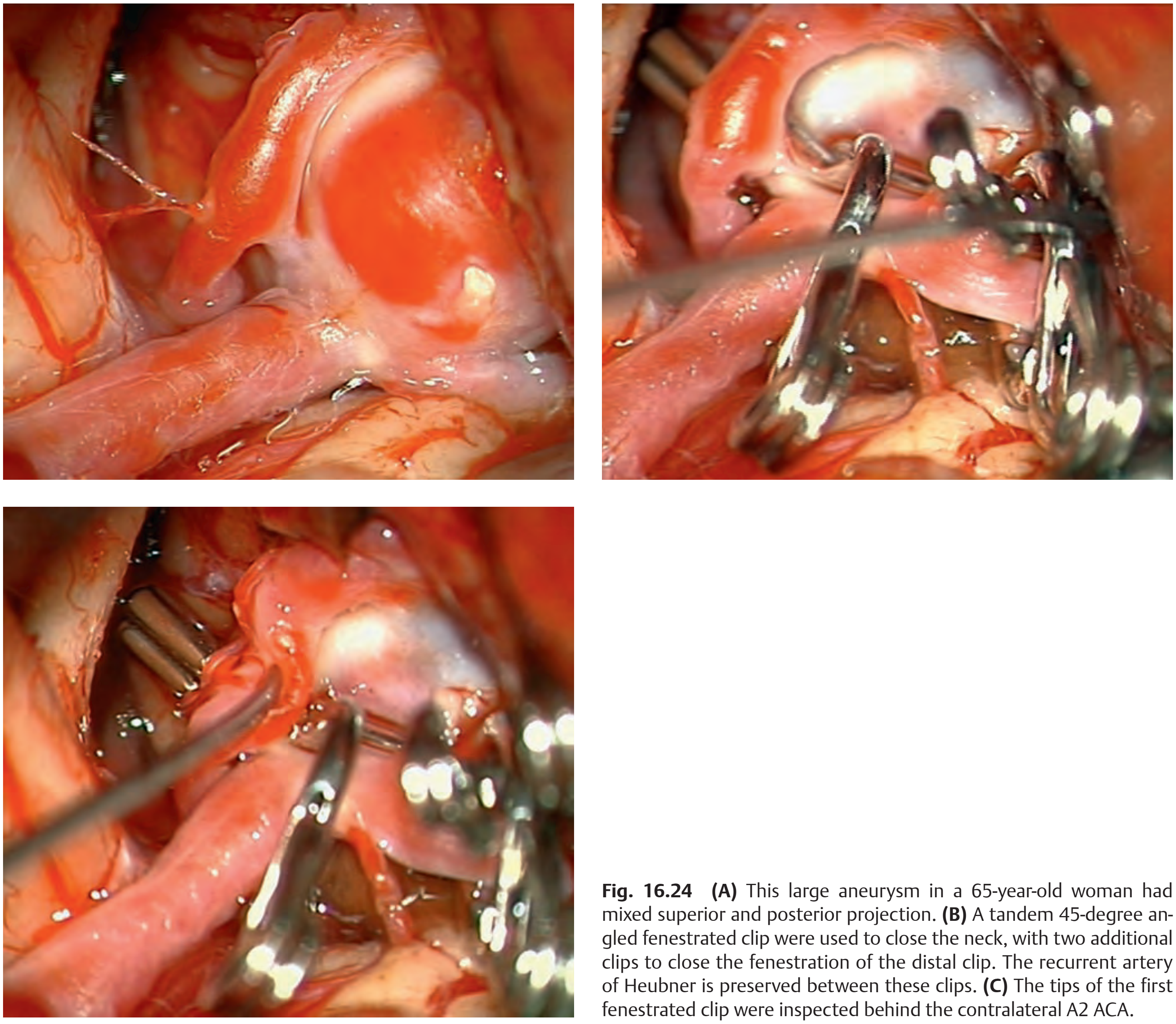
Posteriorly projecting aneurysms are challenging to clip. Eleven of the 12 arteries around the ACoA complex are visible in front of the aneurysm, but the dome projects away from the neurosurgeon and displaces perforators deep in the interhemispheric fissure. The aneurysm's axis is parallel to the line of sight and the neck is behind the ACoA. This aneurysm geometry and an interposed ACoA complex often require the use of angled fenestrated clips, which are less maneuverable than straight fenestrated clips. These clips might encircle the ipsilateral A1 segment, ipsilateral A2 segment, and/or the ACoA itself, and the view of the perforators is limited (**Figs. 16.11 and 16.22**). These concerns are exacerbated by perforators that adhere to the aneurysm.



A B C D

**Fig. 16.23** **(A)** This ACoA aneurysm projected posteriorly, but the ACoA complex was rotated 90 degrees from left to right, orienting the dome laterally into the left frontal lobe. A right pterional approach was used; the right A1 ACA was dominant and the left A1 ACA was atretic. Twisting of the ACoA complex moved the ipsilateral A2 ACA back in the interhemispheric fissure, behind the aneurysm, and shifted the contralateral A2 ACA anteriorly, all the way around to the right side of the interhemispheric fissure. **(B)** The posterior neck was dissected with a temporary clip to soften the aneurysm. **(C)** The neck was closed with tandem clipping: a straight fenestrated clip with the blades between the A2 segments, with an overstacked straight clip. **(D)** A dog-ear remnant in the fenestrated was closed with a curved mini clip.

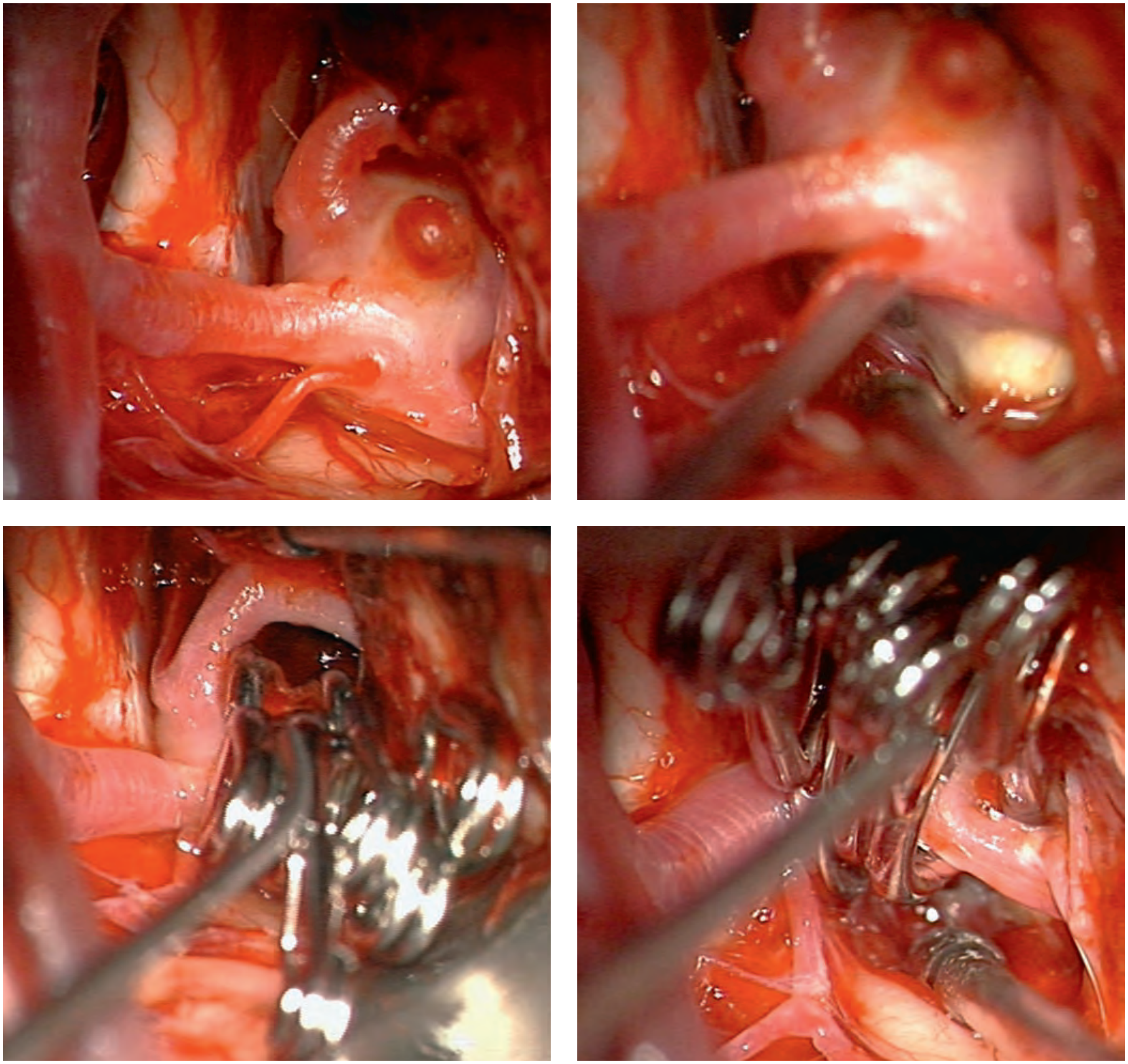
Twisted ACoA complexes can be confusing (**Figs. 16.21** and **16.23**), and misinterpreted anatomy can lead to clipping errors. Large and giant aneurysms with mixed dome projection in multiple directions require careful analysis to avoid leaving residual aneurysm. These technical challenges are addressed with temporary clipping, forceful handling of the aneurysm, and sophisticated clipping techniques, like tandem clipping (**Fig. 16.23**), angled fenestrated clipping (**Fig. 16.24**), and fenestration tubes (**Fig. 16.25**).



A B C

**Fig. 16.24** **(A)** This large aneurysm in a 65-year-old woman had mixed superior and posterior projection. **(B)** A tandem 45-degree angled fenestrated clip were used to close the neck, with two additional clips to close the fenestration of the distal clip. The recurrent artery of Heubner is preserved between these clips. **(C)** The tips of the first fenestrated clip were inspected behind the contralateral A2 ACA.

Anterior communicating artery aneurysms are variable, complex, and frequently ruptured. Endovascular techniques, such as stent-assisted coiling or flow diversion, that might be well suited for complex aneurysms in other locations are often ill suited for complex aneurysms at the ACoA complex. Furthermore, these devices require the use of antiplatelet agents that would be ill advised in the setting of an acute aneurysm rupture. Therefore, expertise with microsurgical clipping of ACoA aneurysms is needed.



A B C D

**Fig. 16.25** **(A)** This 51-year-old woman presented with a subarachnoid hemorrhage from a large ACoA aneurysm with mixed superior and posterior projection. The aneurysm was fed by a dominant left A1 ACA, and was approached through a left pterional craniotomy. The ACoA complex was rotated 90 degrees, with the right A2 segment twisted forward and the left A2 segment twisted backward. **(B)** The posterior portion of aneurysm and the ACoA perforators were seen behind the ipsilateral A2 segment, working over the recurrent artery of Heubner. **(C,D)** The aneurysm was clipped with an antegrade fenestration tube: three stacked straight fenestrated clips around the ipsilateral A2 ACA and a straight clip to close the proximal neck in the fenestration.

# 17 Ophthalmic Artery Aneurysms

## Microsurgical Anatomy

### Arterial Anatomy

Ophthalmic artery (OphA) aneurysms originate from the *ophthalmic segment* of the internal carotid artery (ICA). Simple classifications such as Rhoton's describe only four ICA segments: cervical (C1), petrous (C2), cavernous (C3), and supraclinoid (C4). A contemporary classification by van Loveren and colleagues defines seven segments using the surrounding anatomy and compartments through which the ICA travels, numbered in the direction of antegrade blood flow (**Fig. 17.1**): *cervical* (C1), *petrous* (C2), *lacerum* (C3), *cavernous* (C4), *clinoidal* (C5), *ophthalmic* (C6), and *communicating* (C7). The cervical segment begins at the ICA's origin at the carotid bifurcation and extends to the skull base. The petrous segment begins at the ICA's entrance into the carotid canal and terminates at its exit from the carotid canal. The lacerum segment runs over, not through, the foramen lacerum for a short distance and ends at the petrolingual ligament. The cavernous segment extends through the cavernous sinus, beginning as it enters at the lateral dural ring and ending as it exits at the proximal dural ring. The clinoidal segment abuts the anterior clinoid process (ACP), extending between the proximal and distal dural rings. The ICA then enters the subarachnoid space and the ophthalmic segment courses from the distal dural ring to the posterior communicating artery (PCoA). The communicating segment runs from the PCoA to the ICA terminus. The clinoidal and ophthalmic segments together are referred to as the paraclinoid ICA because of their intimacy with the ACP.

Dolenc defined four right-angle bends along the intracranial ICA. The *posterior loop* is a turn in the petrous segment as it changes from a vertical, ascending course to a horizontal, medial course. The *lateral loop* is the second turn, located along the cavernous segment as it returns to a vertical, ascending course. The *medial loop* is next, also located along the cavernous segment, changing course from ascending to horizontal and anterior. The medial loop is only slightly more medial than the lateral loop, as seen in the frontal view. The *anterior loop*, also known as the *carotid siphon*, contains the distal cavernous segment, the entire clinoidal segment, and the proximal ophthalmic segment, as well as the proximal and distal dural rings.

Extradural ICA branches are few. The petrous segment gives rise to the caroticotympanic artery and the vidian artery of the pterygoid canal. The cavernous segment gives rise at the medial loop to the meningohypophyseal trunk, which trifurcates into the inferior hypophyseal artery, dorsal meningeal artery, and tentorial artery of Bernasconi and Cassinari. The inferolateral trunk and McConnell's capsular artery arise more distally on the cavernous segment. None of these extradural arteries is relevant to intradural aneurysms; they are seen with other pathologies such as dural arteriovenous fistulas and meningiomas.

Only two named arteries branch from the 1.5-cm length of the ophthalmic segment: the OphA and the superior hypophyseal artery. The OphA originates from the superior surface of the ICA just beyond the distal dural ring. It turns anteriorly under the optic nerve to enter the optic canal and follows the nerve to the orbit (**Fig. 17.2A**). In 8% of patients, the OphA originates from other spots including the cavernous ICA (**Fig. 17.2B**), the clinoidal ICA (**Fig. 17.2C**), and the middle meningeal artery. The superior hypophyseal artery (SHA) originates from the medial surface of the ICA, also beyond the distal dural ring, but the ring's downward slant along its posterior course positions the SHA origin posterior to the OphA origin (**Fig. 17.2**). The SHA is approximately 90 degrees medial to the OphA, as seen on the ICA cross section in the frontal view. The SHA courses medially to the sella to supply the pituitary stalk, pituitary gland, optic nerve, chiasm, and floor of the third ventricle. The caliber of the SHA is smaller than that of the OphA, and is even smaller when the SHA is a group of small perforators rather than a single artery.

### Aneurysm Anatomy

Paraclinoid aneurysms are categorized as *ophthalmic*, *superior hypophyseal*, or *variant* aneurysms (**Fig. 17.3**). OphA aneurysms arise from the superior (dorsal) surface of the ICA in clear relation to the OphA and distal to its origin. The aneurysm lies at the end of the siphon's curve and projects superiorly in the direction of blood flow around the bend. The dome impacts the lateral half of the optic nerve because the nerve angles medially along its course to the chiasm and the ICA curves laterally along its supraclinoid course.

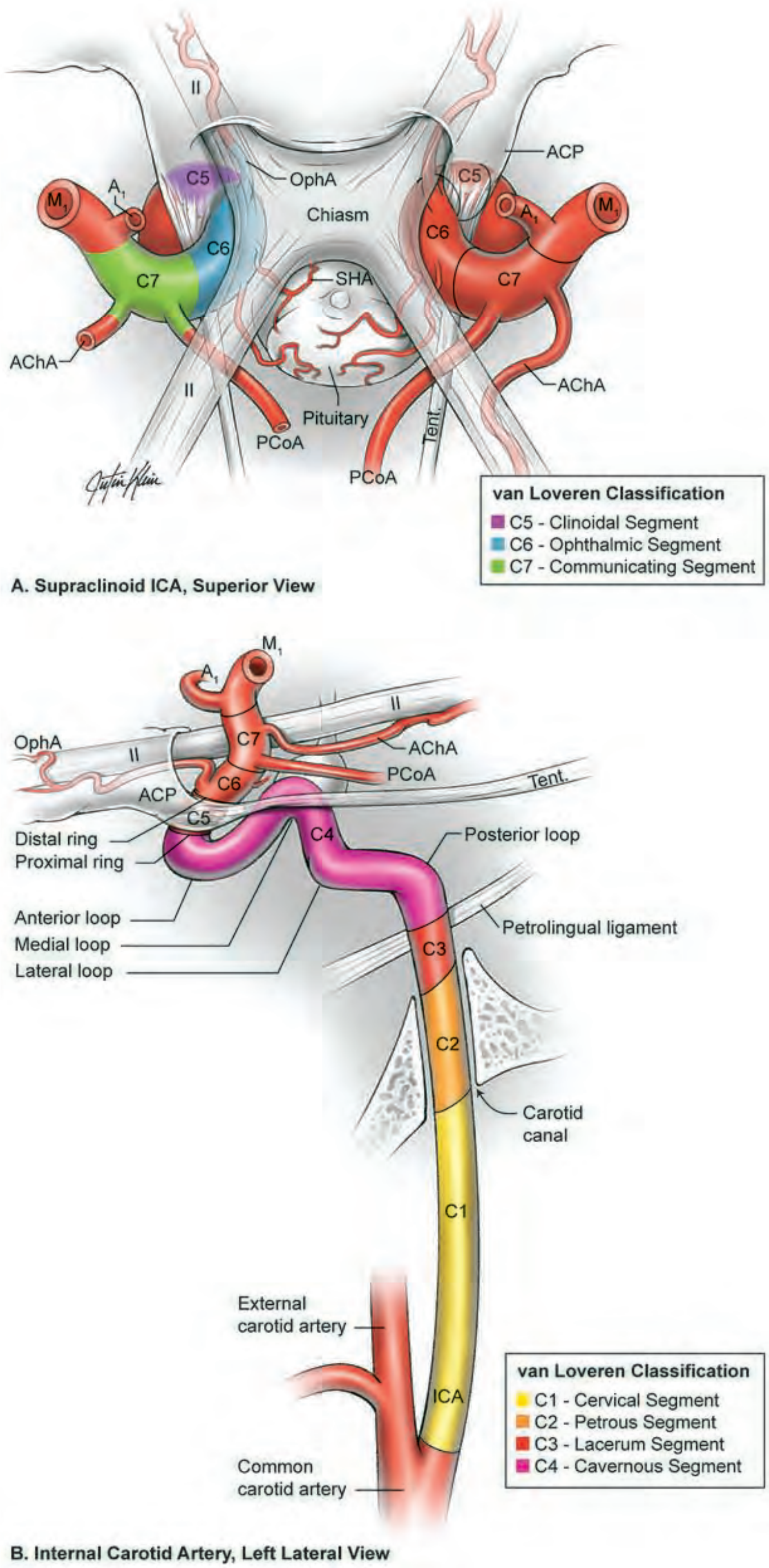



**Fig. 17.1** Microsurgical anatomy of the internal carotid artery and ophthalmic artery. Superior **(A)** and left lateral **(B)** view of the internal carotid artery (ICA) showing its segmental anatomy: C1, cervical segment; C2, petrous segment; C3, lacerum segment; C4, cavernous segment; C5, clinoidal segment; C6, ophthalmic segment; and C7, communicating segment. Dolenc's loops of cavernous ICA are also shown: anterior loop, medial loop, lateral loop, and posterior loop. AChA, anterior choroidal artery; ACP, anterior clinoid process; OphA, ophthalmic artery; PCoA, posterior communicating artery; SHA, superior hypophyseal artery; Tent, tentorium.

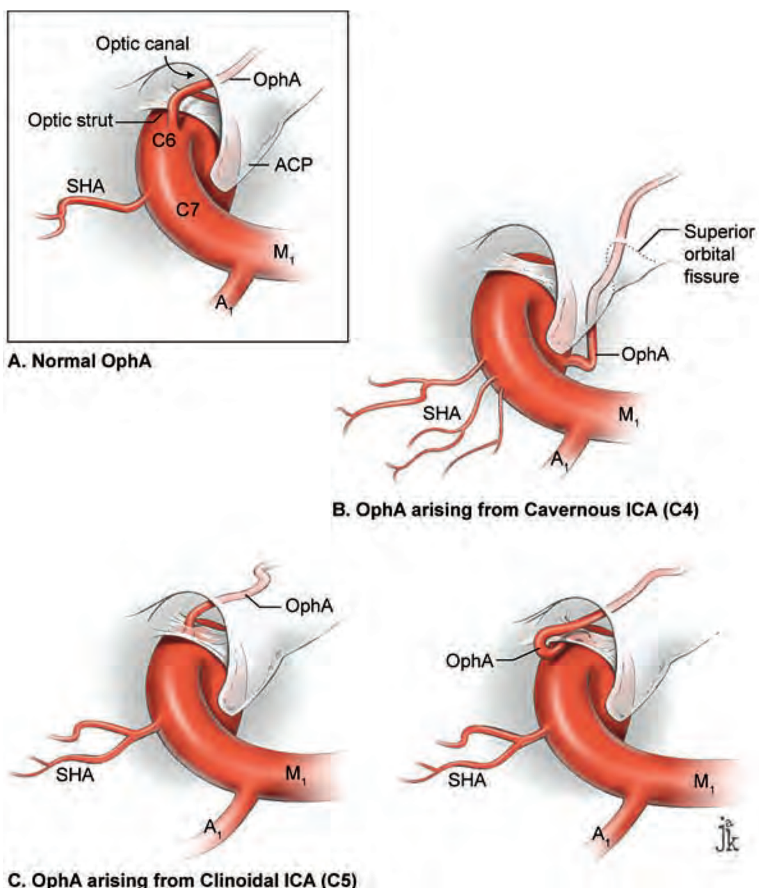
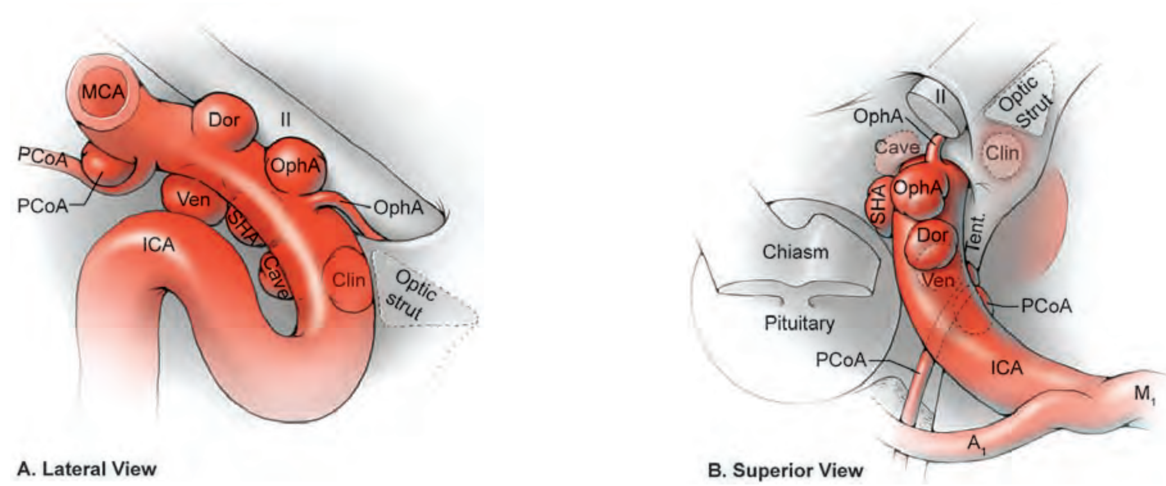



**Fig. 17.2** **(A)** The OphA originates from the ophthalmic segment of the ICA (C6) on its superior surface, courses under the optic nerve, and enters the optic canal (superior view, right ICA). The OphA can originate from the cavernous segment (C4) **(B)** or from the clinoidal segment (C5) **(C)** of ICA. The SHA originates from the medial surface of the ICA, also beyond the distal dural ring, but posterior to OphA origin and approximately 90 degrees more medial.

The optic nerve is typically displaced superiorly and medially, with its superolateral aspect pressed against the falciform ligament and accounting for the inferomedial (lower nasal) quandrantanopsia detected in many patients. Contact between a large aneurysm dome and the optic nerve can be appreciated angiographically as "notching" the aneurysm and "closing" the carotid siphon (the curve tightens as the efferent ophthalmic segment is pushed down toward the afferent cavernous segment, as seen on lateral angiography). The origin of the OphA varies medially to laterally along the superior surface of the ICA and changes the relationship between the dome and the nerve. The OphA with a superomedial origin produces a medially projecting aneurysm that impacts the medial half of the optic nerve and tilts it laterally. Other superiorly projecting OphA aneurysms impact the middle of the nerve and drape it over the dome. The interval between the superior surface of the ICA and the inferior surface of the optic nerve also varies; wide intervals spare the nerve and tight intervals worsen its impingement.

Superior hypophyseal artery aneurysms arise from the inferomedial surface of the ICA in clear relation to the SHA and with no relation to the OphA (**Fig. 17.3**). Like OphA aneurysms, SHA aneurysms lie at the end of the carotid siphon, but their formation relates to the lateral curvature of the supraclinoid ICA. These aneurysms project medially toward the sella in the direction of blood flow around this bend. They are distal to the distal dural ring and sit on the diaphragma sella, but larger ones can burrow beneath the diaphragma or forward into the carotid cave, which is an outpouching of subarachnoid space into the medial clinoidal space where the distal dural ring is thinned or depressed along its medial aspect at the end of the carotid sulcus of the sphenoid bone. SHA aneurysms impact the optic nerve when they are large, and parasellar projection elevates the optic chiasm to produce bitemporal hemianopsia like a pituitary tumor. Growth in this direction "opens" the carotid siphon (the siphon's curve widens as the efferent ophthalmic segment is lifted away from the afferent cavernous segment, as seen on lateral angiography).

Variant aneurysms include *dorsal carotid* aneurysms, *carotid cave* aneurysms, *clinoidal segment* aneurysms, and *ventral carotid* aneurysms (**Fig. 17.3**). Dorsal carotid aneurysms are located on the superior wall of ophthalmic segment several millimeters distal to the ophthalmic artery origin and have no relationship to the ophthalmic artery or any other branch. They are small, blister-shaped, and caused by hemodynamic stress or arterial dissection. Carotid cave aneurysms are located in the cave where the distal dural



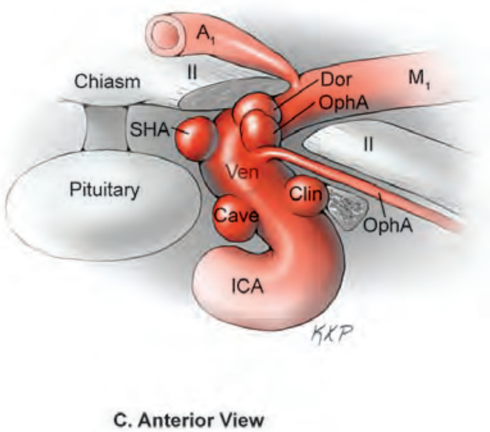



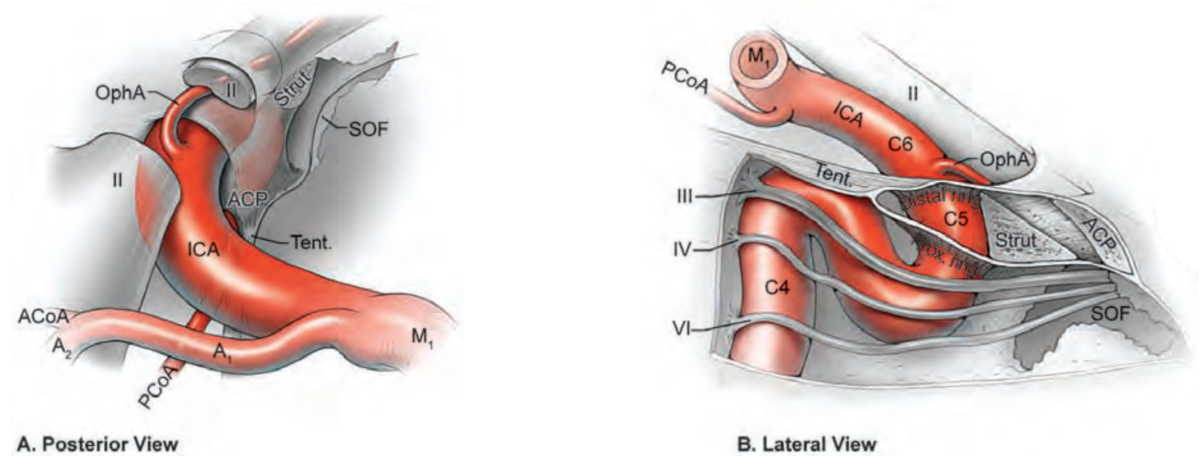

**Fig. 17.3** The OphA, SHA, and variant aneurysms in the paraclinoid region, as viewed from lateral **(A),** superior **(B),** and anterior **(C)** perspectives. Variant aneurysms include dorsal carotid aneurysms (Dor), carotid cave aneurysms (Cave), clinoidal segment aneurysms (Clin), and ventral carotid aneurysms (Ven).

ring thins and invaginates proximally. The aneurysm lies in the subarachnoid space, originates from the medial carotid wall at the end of the carotid sulcus, and has no relationship to other branch arteries. When the ICA is viewed in cross section, the cave aneurysm has a latitude similar to that of the SHA aneurysm but is more proximal. Clinoidal segment aneurysms originate even further proximally, between the dural rings. They originate below the plane of the ACP's superior surface and proximal to the ophthalmic artery, as seen on lateral angiography. One variant originates from the lateral wall of the clinoidal segment, projects superolaterally, erodes into the ACP and optic strut, and is often associated with an early ophthalmic artery arising from the clinoidal segment (anterolateral variant). The other variant originates from the medial wall of the clinoidal segment, projects superomedially, and remains outside the subarachnoid space when small (medial variant). The medial variant aneurysm arises from an extradural spot just proximal to the carotid cave, and is differentiated from cave aneurysms by its more superior projection. Ventral carotid wall aneurysms originate from the inferior surface of the ophthalmic segment, distal to the distal dural ring. This aneurysm resembles the PCoA aneurysm, but arises proximal, not distal, to the PCoA and has no relationship to a branch artery at this point of origin.

## Anterior Clinoid Process Anatomy

The term *clinoid* was derived from the Greek word *klineios,* which means "resembling a bed post." The ACP is a small triangle of bone with a 1-cm base and a 1-cm height (**Fig. 17.4A**). It projects posteriorly as the medial continuation of the sphenoid ridge (or lesser wing of the sphenoid bone). It attaches medially to the roof of the optic canal (or anterior root of the lesser sphenoid wing), and is buttressed below by the *optic strut* (or posterior root of the lesser sphenoid wing). The base of the ACP forms the lateral wall of the optic canal and the superior wall of the superior orbital fissure. The medial aspect of the ACP abuts and is indented by the clinoidal segment of the ICA. The ACP has dense cortical bone along these surfaces and cancellous bone at its core.

The optic strut occupies a critical position at the intersection of the optic canal, superior orbital fissure, and orbital apex, and it separates the optic nerve, anterior cavernous sinus, and carotid siphon (**Fig. 17.4B**). The strut originates



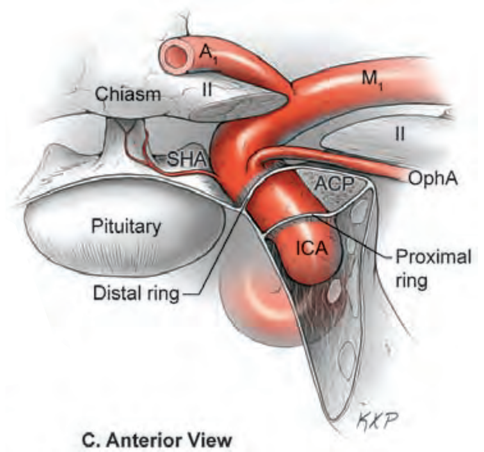




**Fig. 17.4** Microsurgical anatomy of the anterior clinoid process, as viewed from superior (with a section of the optic nerve removed to show the course of OphA) **(A),** lateral (after an anterior clinoidectomy to show the dural rings as continuations of the dura covering the ACP) **(B),** and anterior perspectives (with optic strut removed to show its relationship to the carotid siphon and ACP) **(C).** ACoA, anterior communicating artery.

from the body of the sphenoid and runs superolaterally to the inferomedial aspect of the ACP. The sphenoid sinus can occasionally extend into the optic strut through the opticocarotid recess and reach the ACP, with ramifications for wound closure after clinoidectomy. The superomedial surface of the optic strut forms the floor of the optic canal, and the inferolateral surface forms the roof of the superior orbital fissure. The strut's posterior face is the wall against which the anterior loop of the cavernous ICA turns.

Dura lining the anterior cranial fossa floor, anterior temporal fossa, and sphenoid ridge converge at the ACP. The falciform ligament is the dural edge that runs from the posterior tip of the ACP to the planum sphenoidale, crossing the roof of the optic canal. Dural reflections beneath the falciform ligament fold into the optic canal to form the optic sheath. The ACP is the site of attachment of the anteromedial tentorium and interclinoidal dural fold, two borders of the oculomotor triangle through which CN3 travels before entering its dural sheath en route to the cavernous sinus.

Dura arising from the superomedial aspect of the ACP continues medially in an oblique plane that intersects with the ICA to form the *distal dural ring* (**Fig. 17.4C**). Dura arising from the inferomedial aspect of the ACP continues medially in a flat axial plane that intersects with the ICA to form the *proximal dural ring*. The superior dural plane slants downward in the anterior-posterior axis and slants inward in the lateral-medial axis. This layer lies beneath the dura covering the superior aspect of the ACP, and is visible only after reflecting this superficial dura, removing the bone of the medial ACP, and opening the optic sheath. The superior dural plane's slant intersects with both the ICA and the optic nerve, making it the origin of the distal dural ring and the dura lining the optic canal floor. This dura is thick laterally but thins medially as it courses to the diaphragma sellae and into the carotid cave. The distal dural ring is not a natural anatomic structure; it is a surgical artifact created by a circumferential incision around the ICA as it penetrates this dural divide.

The inferior plane is a thin, translucent layer of dura that forms the roof of the cavernous sinus, through which venous blood can be seen. It is called the *carotid-oculomotor membrane* because it courses from the oculomotor nerve laterally to the ICA medially. Unlike the superior plane that originates from the superomedial edge of the ACP, the inferior dural plane originates from the lateral wall of the cavernous sinus, lines the inferior surface of the ACP, and continues medially past the ACP's inferomedial edge. Its intersection with the ICA is not as sharp as the superior plane, resulting in a funnel-shaped extension of the cavernous sinus that collars the clinoidal segment. This carotid collar contains venous channels that communicate with the cavernous sinus and can appear as a venous plexus extending as far as the distal dural ring. Like the distal dural ring, the proximal ring is not a natural anatomic structure but a surgical artifact created by a circumferential dural incision around the ICA. Such an incision would open the cavernous sinus and induce brisk venous bleeding. The carotid-oculomotor membrane and dura lining the superior aspect of the ACP fuse into a single layer at the posterior tip of the ACP and the apex of the oculomotor triangle.

Thus, the dural rings define important anatomic landmarks. The proximal dural ring marks the termination of the cavernous segment of the ICA and the beginning of the clinoidal segment. The distal dural ring marks the termination of the clinoidal segment and the beginning of its ophthalmic segment. The distal ring is also the barrier between the extra- and intradural compartments, or the beginning of the subarachnoid course of the ICA. An important triangle in the dissection of OphA aneurysms is the *clinoidal triangle*, which is the space between the optic and oculomotor nerves, with the optic strut at its apex, the dural rings in its midportion, and the roof of the cavernous sinus posteriorly.

# Aneurysm Dissection Strategy

## Modifications in Approach

The standard pterional approach is modified slightly with OphA aneurysms. Head extension that normally allows gravity to retract the frontal lobe also steepens the view into the clinoidal triangle. Therefore, the head is positioned with less extension than with other aneurysms, with the anterior cranial fossa floor oriented vertically. The head is rotated laterally an additional 10 to 20 degrees to improve the lateral view under the optic nerve into the clinoidal triangle.

Normally, the pterion is thinned to an egg-shell layer over the orbital roof and lateral wall that preserves the integrity of the orbit. With an anterior clinoidectomy, the posterior orbit is opened around the base of the ACP by up-fracturing the roof at the lateral extent of the superior orbital fissure. Periorbita is stripped from the inside of the orbit and preserved to contain periorbital fat. The superior orbital fissure is widened by rongeuring the lateral plate of bone at the front of the temporal fossa that also forms the intracranial portion of the lateral orbital wall. The dural fold within the superior orbital fissure running between the anterior temporal dura and the periorbita mobilizes laterally, and the posterior orbital roof and the medial end of the sphenoid ridge can be encircled. Rongeuring this bone begins the process of detaching the ACP from its lateral attachment. An anterior clinoidectomy can be completed extradurally by continuing this resection (Dolenc approach), but the intradural resection is preferred because it visualizes the aneurysm and enables immediate clipping if the aneurysm ruptures prematurely.

The cervical ICA is routinely prepared and draped whenever the ACP is going to be removed. The decision to open the neck is individualized, and is rare with small, unruptured aneurysms. Neck exposure should be anticipated with ruptured aneurysms and large or giant aneurysms that might require softening or suction decompression. The clinoidal segment offers some proximal control in the cranial field, but the bony canal of the carotid sulcus prevents the tips of a temporary clip from advancing completely across the ICA, and occlusion of aneurysm inflow may be incomplete.

Intraoperative angiography is more useful with ophthalmic artery aneurysms than with any other aneurysm because of difficulties in visualizing the aneurysm neck, dissecting around the cavernous sinus, and working beneath the optic nerve. Preparations for intraoperative angiography are made at the start of the procedure by preparing the groin or by inserting a sheath in the femoral artery.

## Removing the Anterior Clinoid Process

Superficial dura on the ACP is incised in an arc that extends from the tip of the ACP posteriorly to the sphenoid ridge laterally, deep to the temporal veins bridging to the sphenoparietal sinus (**Fig. 17.5A**, step 1). This dural incision extends posteriorly into the oculomotor triangle and down to the oculomotor sheath to completely uncover the posterior tip of ACP. The ACP adheres to the carotid-oculomotor membrane and to superficial clinoidal dura as they converge posteriorly, and attachments of the tentorium and interclinoidal dural fold can cover bony irregularities that fixate the ACP. For example, the middle clinoid process is a small prominence at the medial end of the carotid sulcus that can bridge upwards with the tip of the ACP to form an osseus ring (caroticoclinoidal foramen). An osseus bridge can also form between the anterior and posterior clinoid processes.

A second dural incision is made from the middle of the first cut, arcing medially across the roof of the optic canal onto the planum sphenoidale to the medial aspect of the falciform ligament. This second incision extends above the rongeured base of the ACP to connect the intradural resection with the extradural resection. Two dural flaps are elevated with round knives, the first one folding posteriorly to protect the optic nerve and aneurysm dome, and the second one folding laterally to expose the ACP's lateral margin.

The optic canal is unroofed with a high-speed drill and a round diamond-tipped drill bit (2 mm diameter) (**Fig. 17.5B**, step 2). Early decompression of optic nerve not only relieves pressure and distortion from the aneurysm, but also improves the nerve's tolerance to clinoidal dissection later.

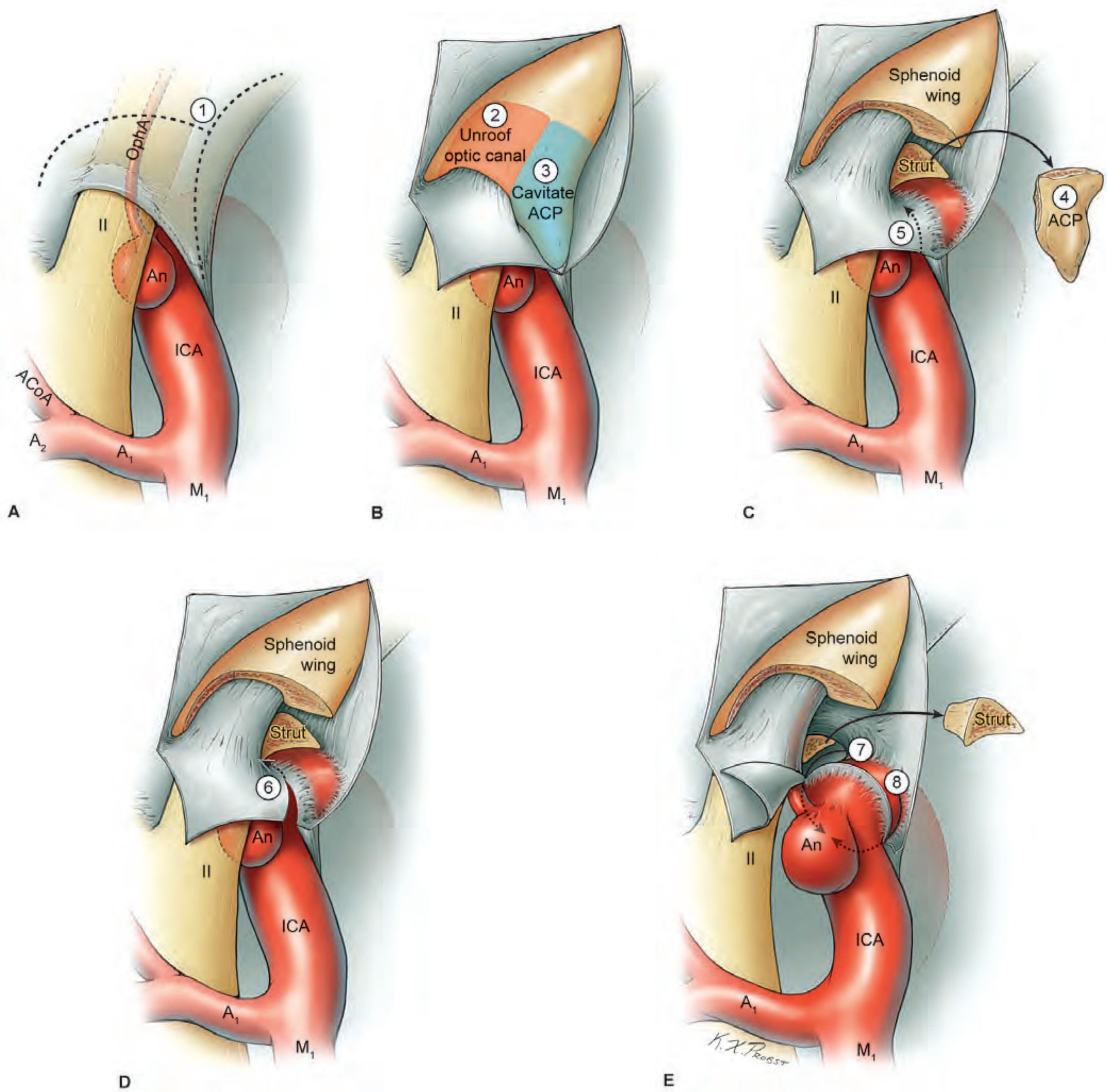



**Fig. 17.5** Dissection strategy for anterior clinoidectomy. **(A)** Step 1, incising the dura on the ACP and the flapping dura to protect the optic nerve and the aneurysm. **(B)** Step 2, unroofing the optic canal; step 3, cavitating the ACP. **(C)** Step 4, removing the ACP; step 5, opening the optic sheath. **(D)** Step 6, incising the distal dural ring superiorly. **(E)** Step 7, incising the distal dural ring medially; step 8, incising the distal dural ring laterally and inferiorly.

Bone forming the optic roof is thinned with the drill, dissected from the optic sheath with a round knife, and upfractured away from the optic nerve. Copious irrigation with cold saline and frequent pauses help dissipate the heat from the drill. The optic canal is unroofed to the medial wall and then 1 cm anteriorly.

The ACP's cancellous core is drilled away and its cortical margins are thinned (**Fig. 17.5C**, step 3). This cavitating technique methodically reduces the ACP, detaches it medially from the roof and lateral wall of optic canal, and detaches it inferiorly from the optic strut. The optic sheath is dissected off the floor of the optic canal to define these bony medial attachments. The ACP is fractured up from inferior attachments to the optic strut and begins to mobilize within the dural envelope of the clinoidal triangle. Circumferential dissection around the ACP's cortical margins loosens adhesions to the carotid-oculomotor membrane inferiorly, the sphenoidal dura laterally, the tentorial dura posteriorly, and the optic sheath medially. After this dural grip is released, the ACP is removed with minimal force directed away from the aneurysm (**Fig. 17.5C**, step 4).

Final removal of the ACP often elicits cavernous sinus bleeding through the carotid-oculomotor membrane, which is easily controlled with Surgicel Nu-Knit (Ethicon, Somerville, NJ) packing. In cases where extensive ring dissection is anticipated, 5 to 10 cc of fibrin glue (Tiseel; Baxter Healthcare Corp., Deerfield, IL) is injected into the cavernous sinus through this bleeding point in the membrane. Having adopted this maneuver only recently, it is clear that venous bleeding is the major deterrent to thorough ring dissection and that fibrin glue injections dramatically decrease venous bleeding.

## Distal Dural Ring Dissection

The cut initiating the dural ring incision begins in the dura lateral to the mouth of the optic sheath and converges on the lateral border of the sheath (**Fig. 17.5C**, step 5). More anterior cuts lead to the optic strut (**Fig. 17.5D**, step 6). The optic strut is positioned at the apex of the clinoidal triangle where the line of dura of the distal ring crosses the curve of the carotid artery around the siphon. This bone fills the space in front of the clinoidal segment of the ICA and below the dural ring. Therefore, strut resection creates a space that transforms the ring from a bony lining to a free-floating tissue layer. The transosseous pathway with the drill becomes the incision pathway for the microscissors' inferior blade as it cuts across the ring. Bony reduction of the strut allows the dural ring to mobilize anteriorly, opening an incision pathway for the microscissors' superior blade on the subarachnoid side of the ring. Dural snips alternate with additional drilling as dissection proceeds medially. The optic strut is progressively drilled away until the dissection drops medially around the clinoidal ICA into the carotid sulcus. A 1-mm-diameter round diamond-tipped bit enables accurate drilling in this tight wedge of space. The operating table is rotated for a more lateral view under the optic nerve.

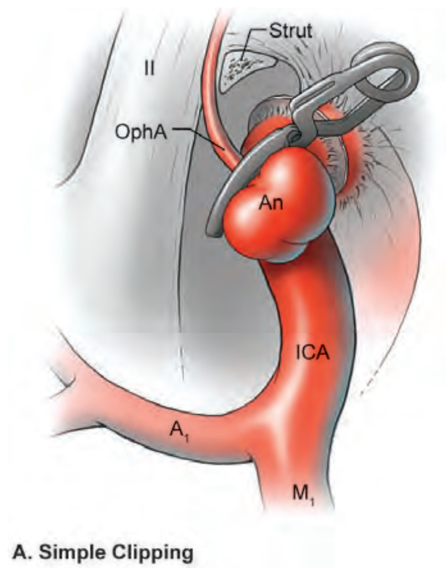
The distal dural ring crosses the ICA anterior to the origin of the OphA and cuts around the ring lead into the axilla of the OphA (**Fig. 17.5E**, step 7). This artery is elevated off the dura of the ring and canal floor before it is cut because it can adhere to or fuse with this dura. There is a thin ridge of bone where the posterior face of the optic strut and the floor of the optic canal merge, and this ridge can be followed on the proximal side of the ring across the ICA. After incising under the ophthalmic artery, the ring's medial-inferior-posterior course can be hidden by the OphA and the ICA. The dissection pathway should remain in the axilla of the OphA and follow the clinoidal ICA to the bony carotid sulcus, defining the ring along its proximal side. A dissection pathway over the shoulder of the OphA can disrupt perforators to the undersurface of the optic nerve and is avoided. With transaxillary dissection, the clinoidal ICA bears the brunt of any surgical manipulation rather than the optic nerve. A vanishing medial view of the dural ring and venous bleeding are offset by a thinner ring that is easier to cut. These last medial cuts that complete the dissection of the upper half of the ring are critically important because they de-tether the ICA and open a blade path with SHA aneurysms.

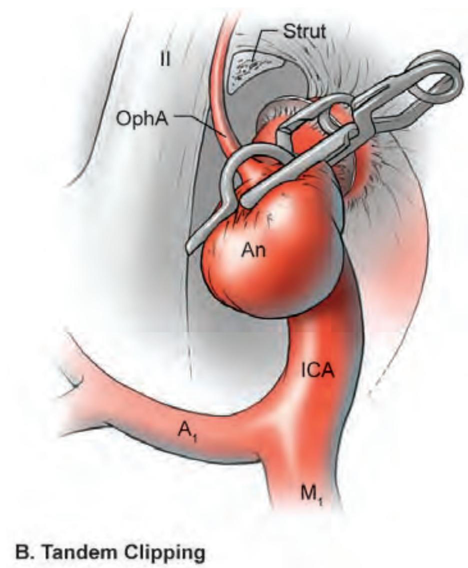
The dissection returns to the dural ring laterally to incise the lower half of the ring (**Fig. 17.5E**, step 8). Initial cuts in this direction are easy to see, but inferior and medial cuts adjacent to the cavernous and intercavernous sinuses can cause venous bleeding. It is difficult for the inferomedial dissection to join previous superomedial cuts, but a completely circumferential incision is not needed with most OphA aneurysms.

## Aneurysm Dissection

Most paraclinoid aneurysms differentiate into OphA and SHA aneurysms; variant aneurysms are relatively uncommon. Both the OphA and the SHA require anterior clinoidectomy and distal ring dissection, but the extent of ring dissection is tailored. Ophthalmic artery aneurysms typically require an incision around the upper half of distal dural ring, whereas SHA aneurysms require an incision that is nearly circumferential. OphA aneurysms have their neck on the superior carotid wall, have superior dome projections, and have simple permanent clippings that allow for more limited ring dissection. SHA aneurysms have inferomedial dome projection, have their neck on the ICA's blind side, and have fenestrated clippings encircling the ICA that demand thorough ring dissection.

Complex dissection of the dural ring contrasts with relatively straightforward dissection of the neck. Proximally, the OphA origin is defined and separated from the neck. It is not uncommon for the OphA to arise from the aneurysm base rather than from the ICA. Manipulation is poorly tolerated by the optic nerve, particularly when already deflected, stretched, or attenuated by large aneurysms. Manipulation is well tolerated by the ICA, and gentle pressure downward and slightly laterally moves the artery after ring dissection to see into the medial corners of the dissection. Temporary clipping of the cervical ICA softens the aneurysm and permits more forceful manipulation. An aneurysm that remains tense after proximal occlusion of the cervical ICA may have collateral supply from the OphA and the PCoA that may require additional temporary clips. Distally, the SHA and other medial perforators are adjacent to the neck and must be dissected away to preserve blood supply to the optic nerve.



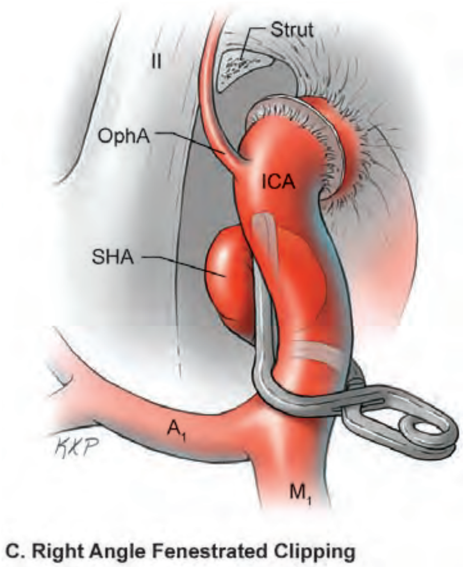
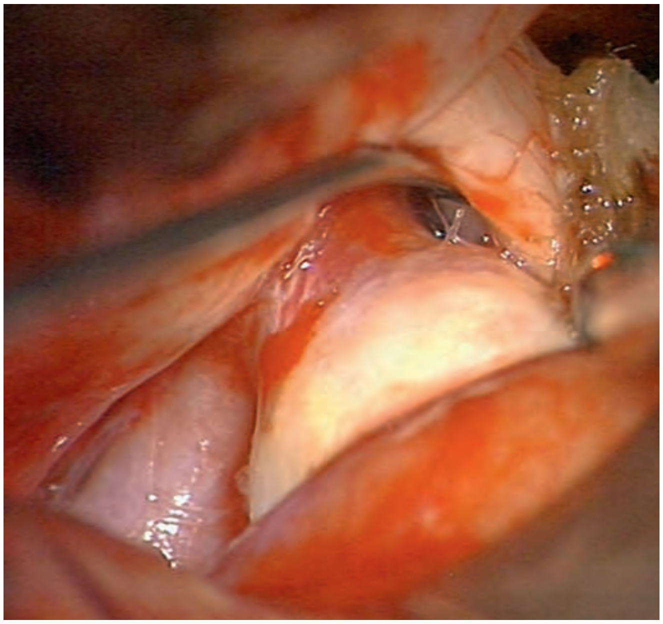




**Fig. 17.6** Clipping techniques for OphA aneurysms. **(A)** Simple side-curved clip for a small, narrow-necked OphA aneurysm. **(B)** Tandem clipping technique for a large OphA aneurysm, with the fenestration encircling the OphA origin and a stacked straight clip closing the fenestration. **(C)** SHA aneurysms typically require an angled fenestrated clip because the aneurysm projects away from the neurosurgeon. An, aneurysm.

## Clipping Technique

A simple straight or curved clip may be sufficient for small OphA aneurysms (**Fig. 17.6A**). A side-angled clip is optimal for OphA aneurysms because its blades parallel the ophthalmic segment of the ICA, and its side angle deviates the clip appliers laterally away from the optic nerve. Side-curved clips have a similar favorable geometry (**Figs. 17.7 and 17.8**). Broad-based OphA aneurysms clipped with one simple clip can leave residual aneurysm medially beneath its tips that may be difficult to see. A second clip will address this remnant. The first clip is applied with a steeper pitch to grab the medial neck, and the second clip is under-stacked at the lateral neck. Alternatively, a medial remnant can be clipped with an overlapping straight fenestrated clip, with its fenestration encircling the blades of the initial clip (**Figs. 17.9 and 17.10**).

In contrast to OphA aneurysms, SHA aneurysms typically require angled fenestrated clips (**Figs. 17.6C and 17.11**). These aneurysms project away from the neurosurgeon with their neck on the blind side of the ICA, making it difficult to visualize both blades in one view. Clip application relies on full visualization, toe to heel, of one of the blades and subsequent inspection of the other blade with a different viewing angle, often after clip application. The clip tips meet medially at the proximal neck adjacent to the distal dural ring. The tips must advance past the ring to obliterate the neck. With an inadequately dissected distal dural ring, the clip tips will be blocked by the ring and might not advance beyond the proximal neck. Clip tips advanced over an inadequately dissected ring will be splayed by the ring itself, and the aneurysm will refill.



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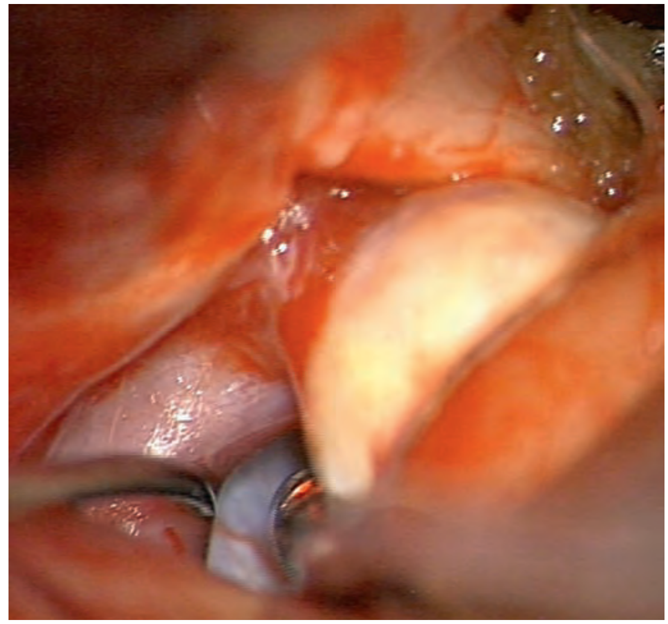

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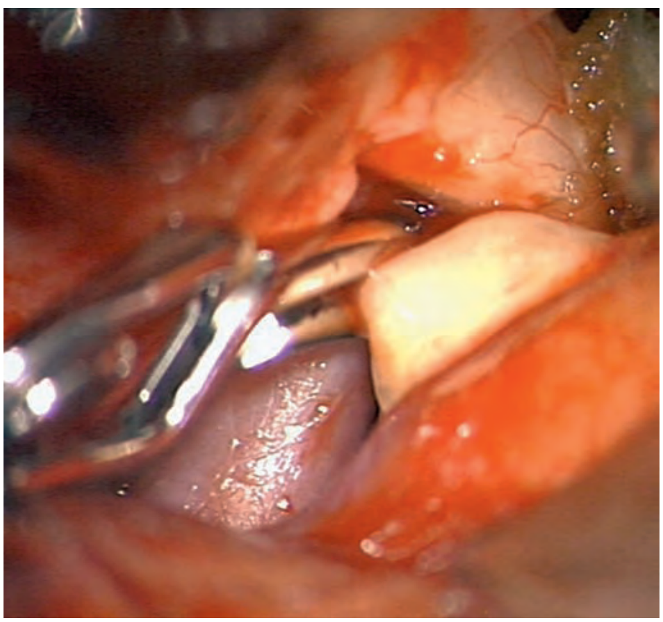
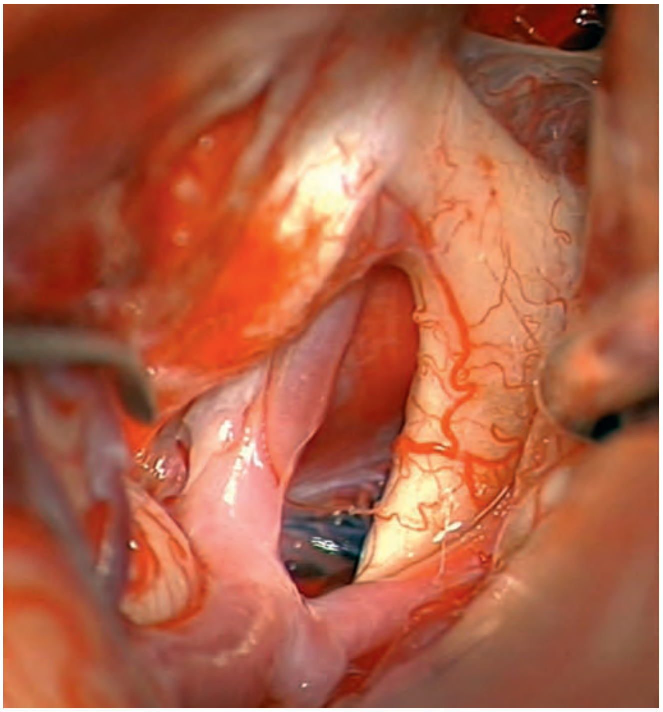


C

**Fig. 17.7** **(A)** This left OphA aneurysm was located more posteriorly on the superior ICA surface than most OphA aneurysms, and projected lateral to the optic nerve. Therefore, anterior clinoidectomy was not required, and an incision in the falciform ligament exposed the proximal neck. **(B)** The distal neck was easily exposed. **(C)** The neck was closed with a one side-curved clip, despite the atherosclerotic changes.



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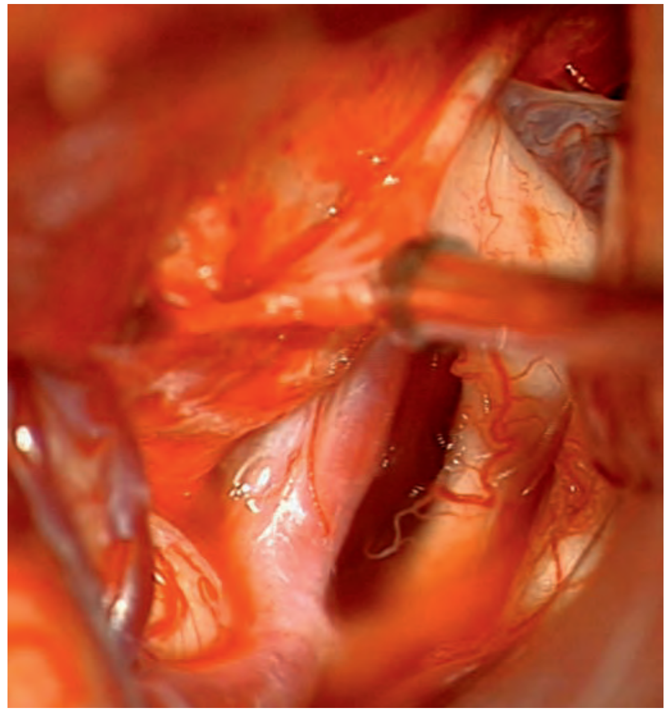

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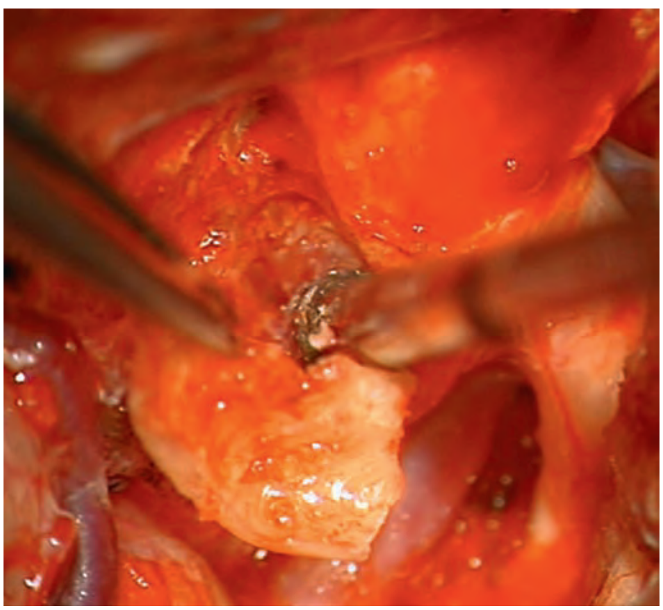
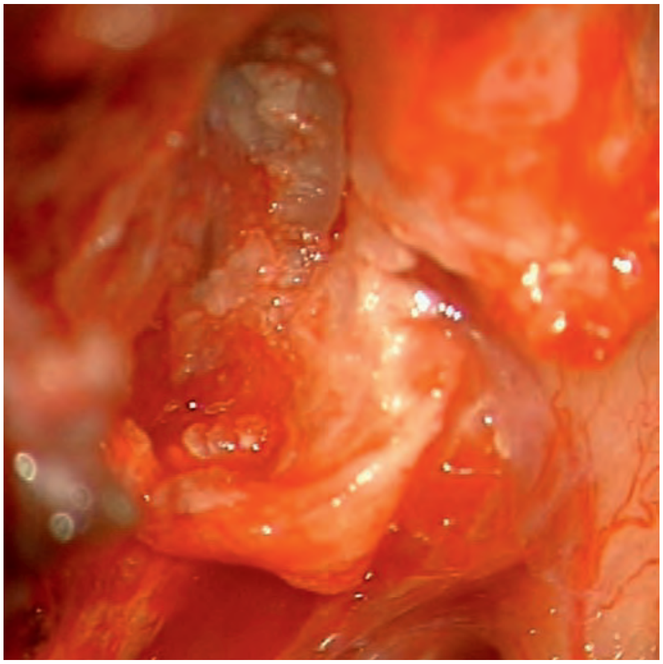


C

**Fig. 17.8** **(A)** This left OphA aneurysm was covered by the ACP and barely visible under the falciform ligament. **(B)** The ACP was exposed with a dural incision and **(C)** removed. (*continued on next page*)



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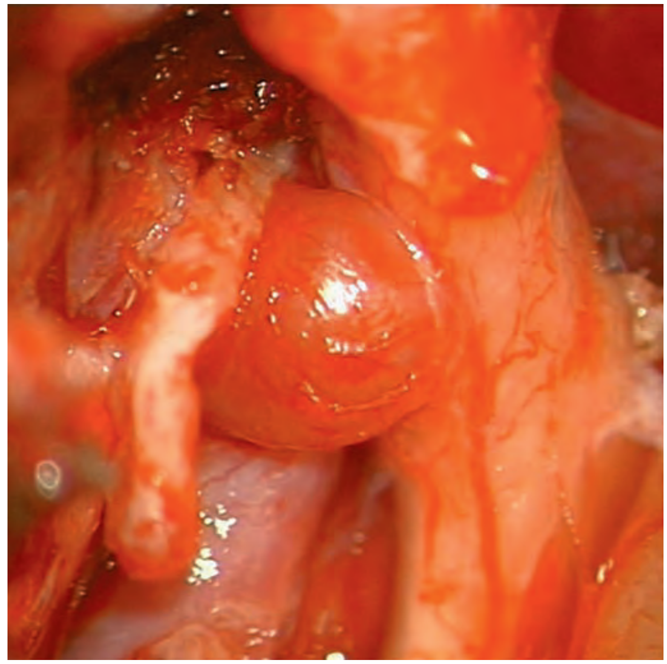

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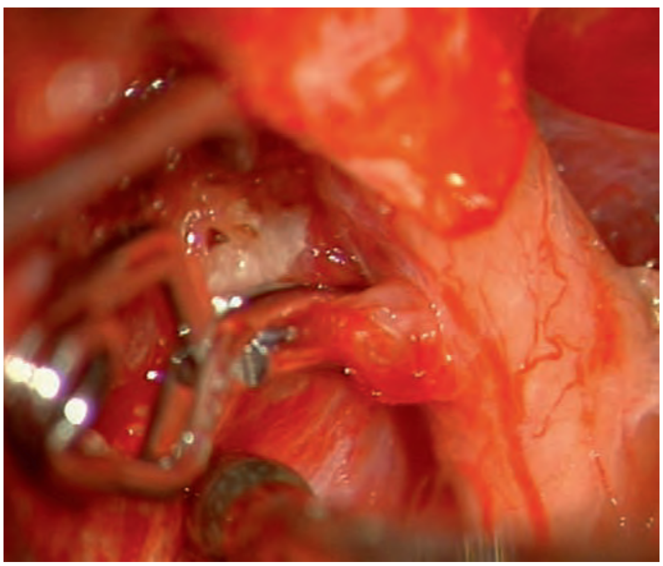
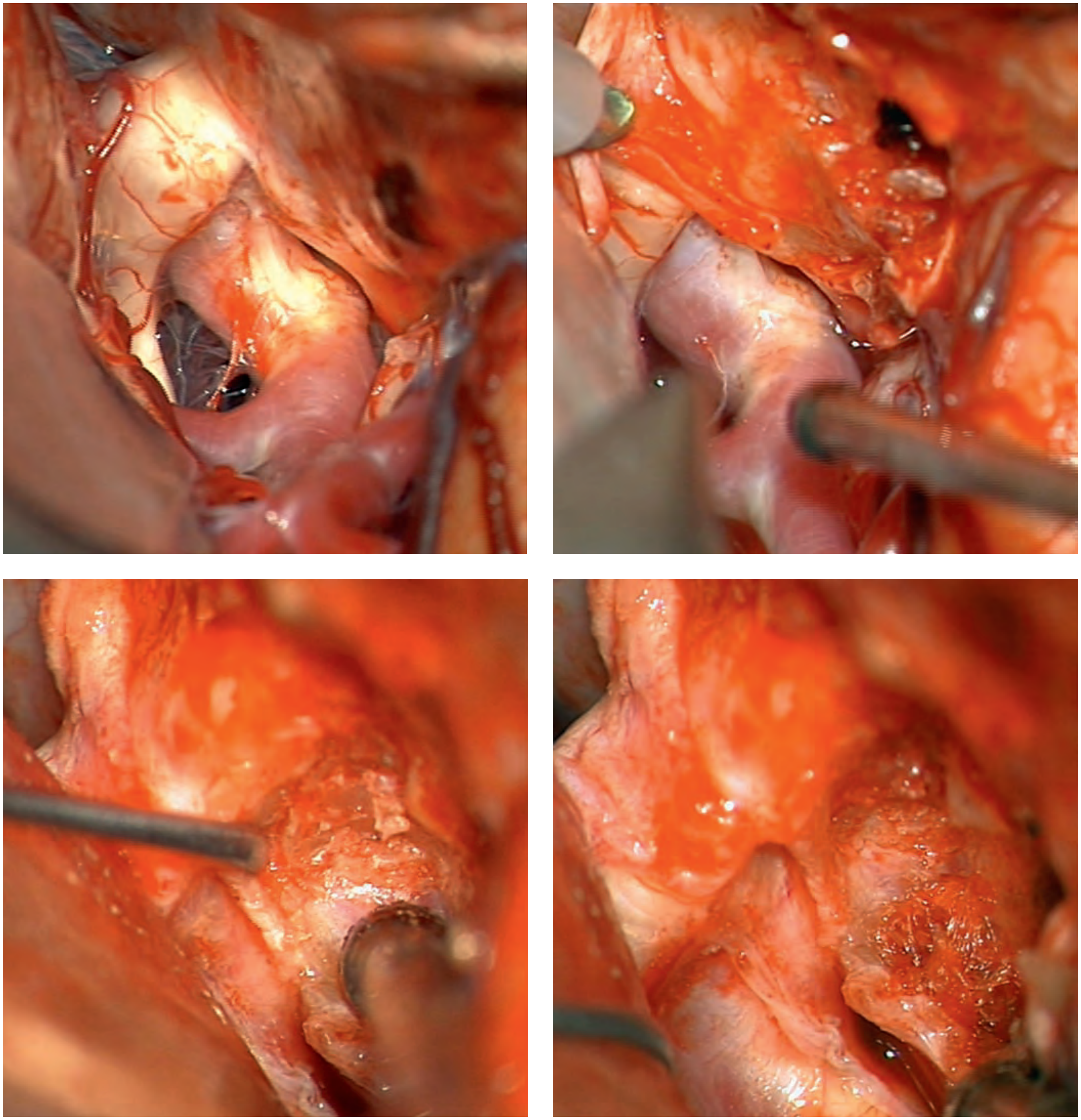


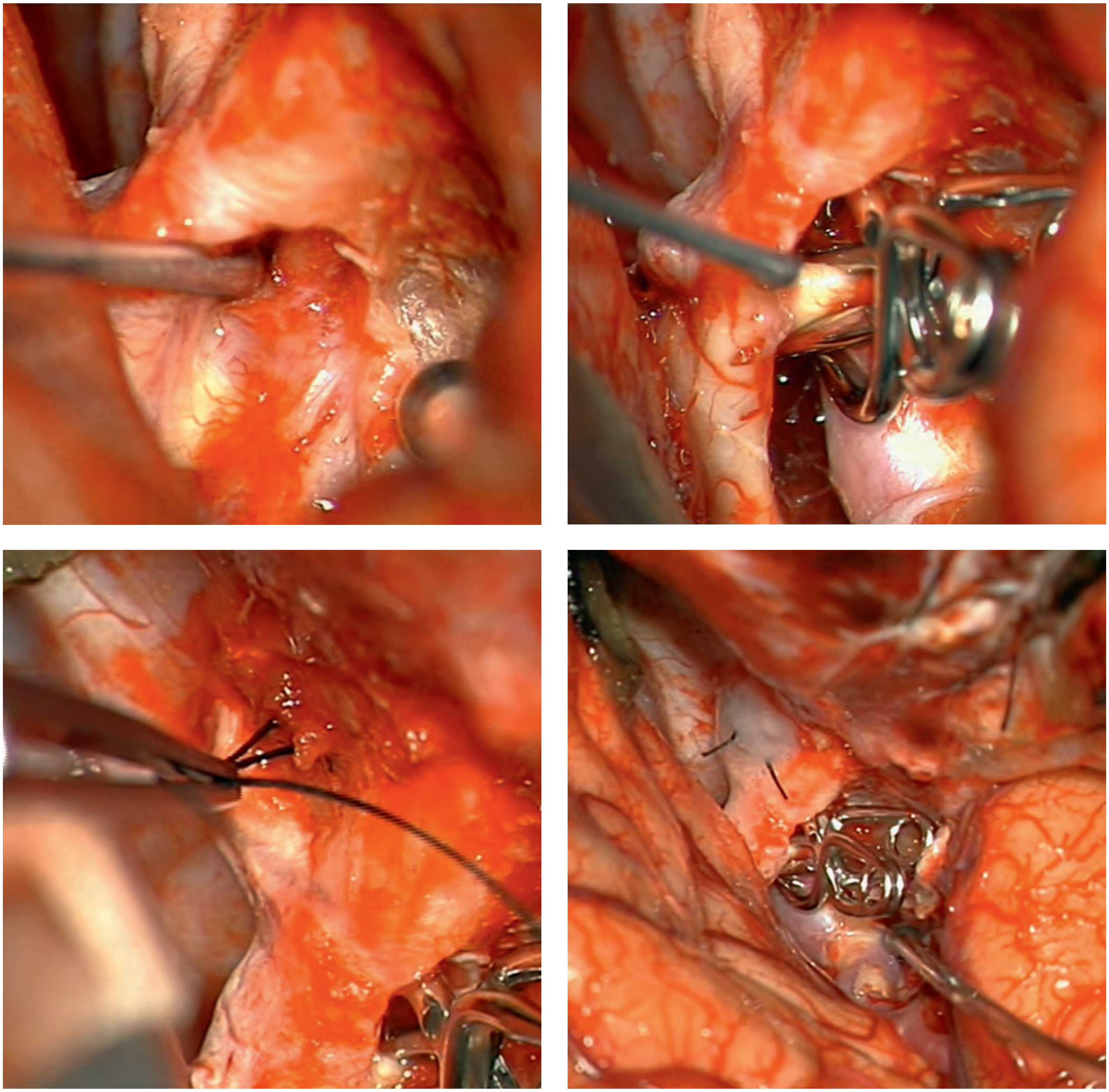
F

**Fig. 17.8** (*Continued*) **(D)** The optic strut was visualized in front of the aneurysm and drilled down to expose the distal dural ring. **(E)** After incising the distal dural ring medially under the OphA, the aneurysm was fully exposed. **(F)** A side-curved clip was used to clip the aneurysm, with the blades paralleling the ICA.



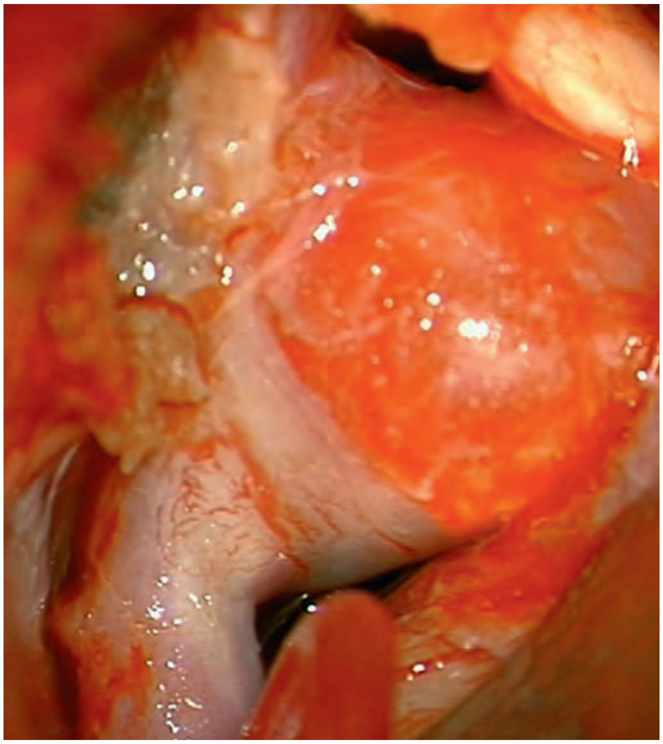
A B C D

**Fig. 17.9** **(A)** The right OphA aneurysm in this 61-year-old woman was directly under the optic nerve, which was bowed upwards over the dome. **(B)** The dura over the ACP was incised and a dural flap was raised medially to protect the optic nerve. **(C)** The ACP was cavitated and removed, exposing the optic sheath, optic strut, and clinoidal ICA. **(D)** Drilling down the optic strut exposed the distal dural ring, which was incised medially under the OphA. (*continued on next page*)



E F G H

**Fig. 17.9** (*Continued*) **(E)** The OphA and proximal aneurysm neck were visualized after dissecting the distal dural ring, with a No. 6 dissector probing the spot for the proximal clip blade. **(F)** The aneurysm was clipped with a straight clip, and an overlapping fenestrated clip was applied to close a medial remnant. **(G)** The ethmoid sinus was entered when unroofing the medial optic canal, and was packed with temporalis muscle during the closure. Using the yo-yo technique, the muscle plug was pulled back into the subarachnoid space until it was snug in the bony defect. **(H)** The muscle plug was secured with fibrin glue, and the suture tied around the muscle was cut.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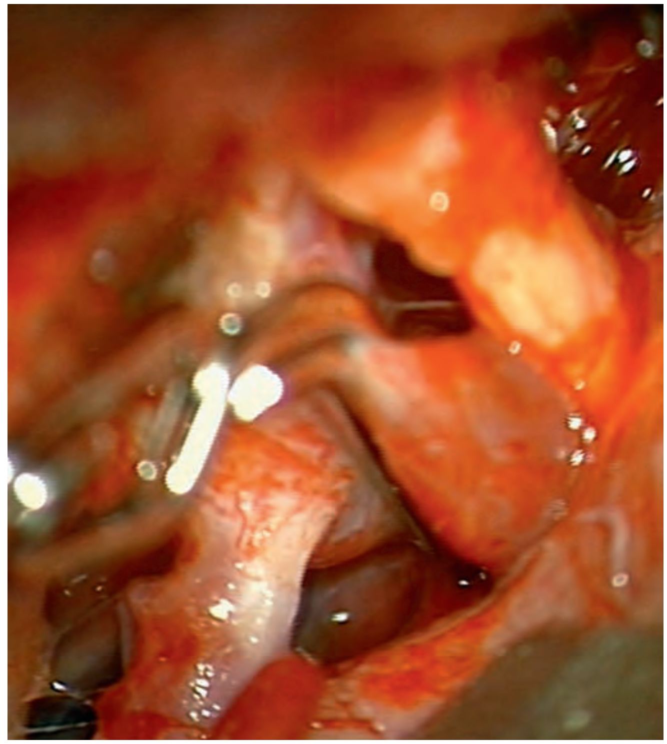
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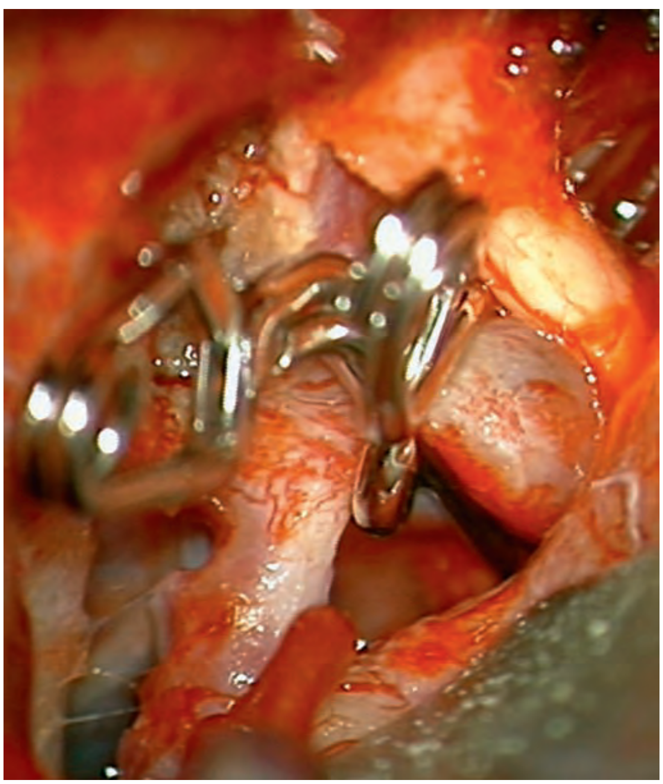
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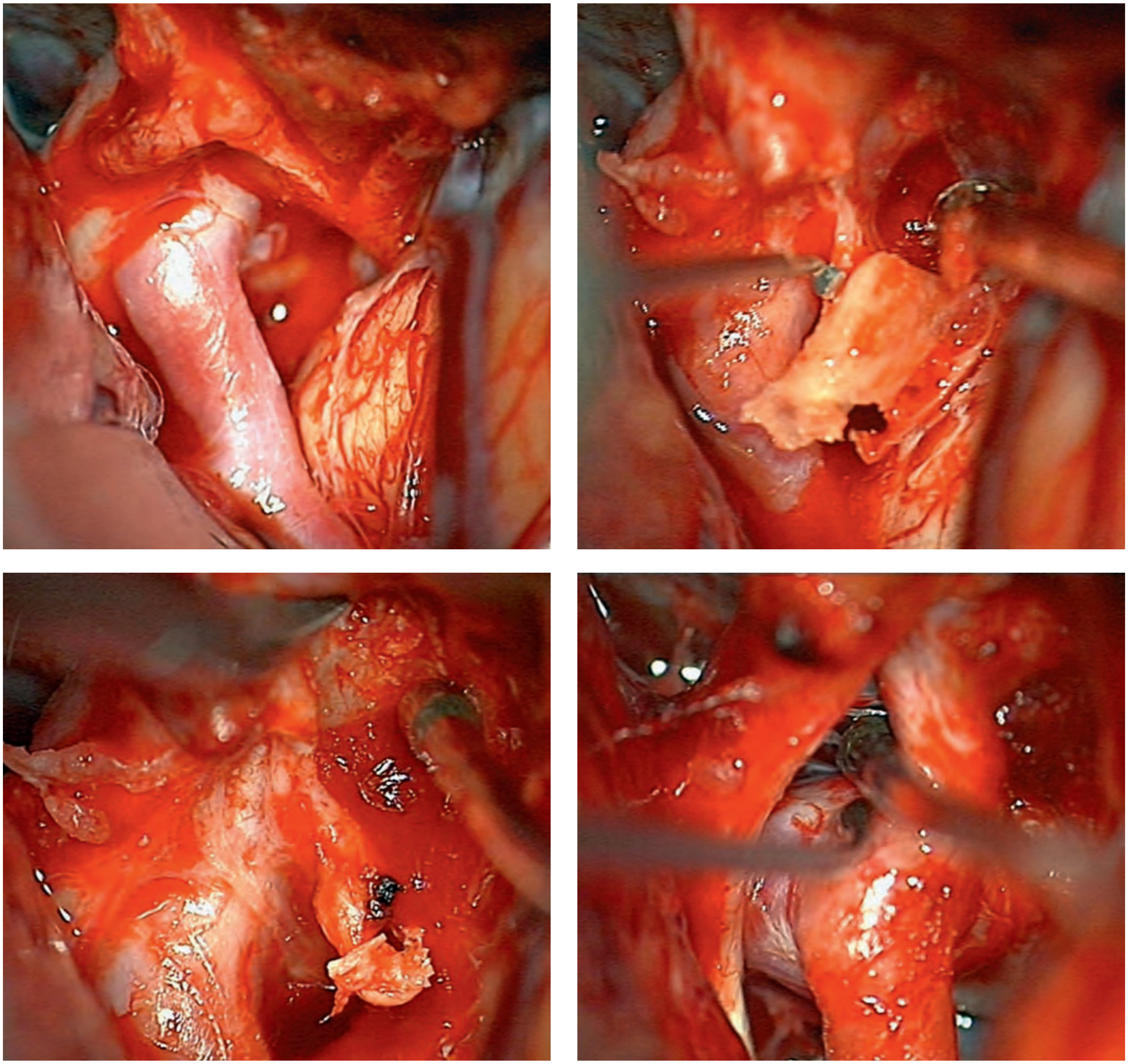
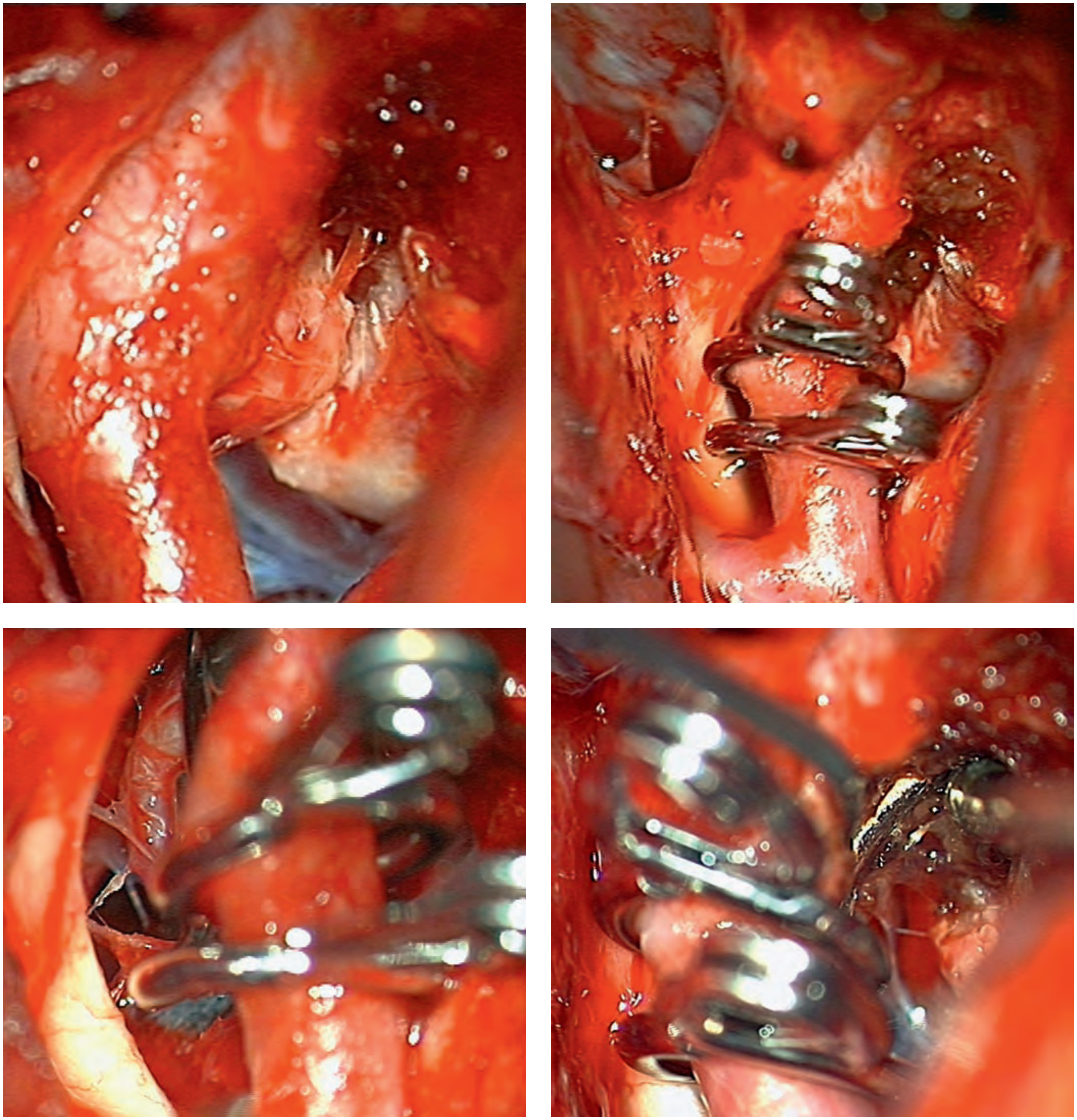
**Fig. 17.10** **(A)** This left OphA aneurysm in a 21-year-old woman was exposed with an anterior clinoidectomy and the distal dural ring dissection. **(B)** Its broad base did not close completely after applying a side-angled clip, with residual neck seen medially at its base below the clip's tips. **(C)** An overlapping fenestrated clip was applied to close the portion of the neck.



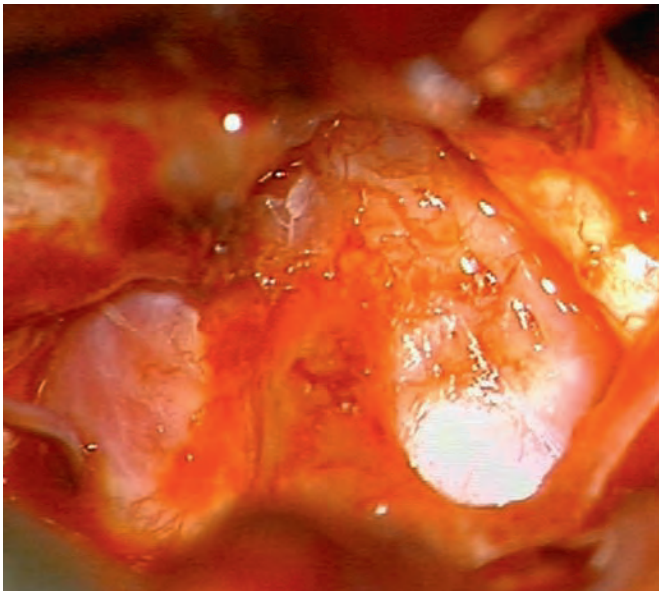
A B C D

**Fig. 17.11** This 59-year-old woman presented with progressive vision loss in her right eye from a large superior hypophyseal artery aneurysm. **(A)** The clinoidal dura was incised. **(B)** The ACP was removed. **(C)** The distal dural ring was incised under the optic nerve. **(D)** After incising the upper half of the distal dural ring, the ICA and aneurysm were mobilized down away from the optic nerve.



E F G H

**Fig. 17.11** (*Continued*) **(E)** After incising the lower half of the distal dural ring and separating the aneurysm from the posterior clinoid process, the underside of the aneurysm neck could be seen. **(F)** The aneurysm was clipped with tandem right-angled fenestrated clips. **(G)** The tip of the distal clip overlaps the heel of the proximal clip to ensure that the aneurysm does not fill between the clips. Inspection of the superior and **(H)** inferior sides of the neck is necessary to confirm good clip placement, because complete visualization is not always possible during application of angled fenestrated clips.



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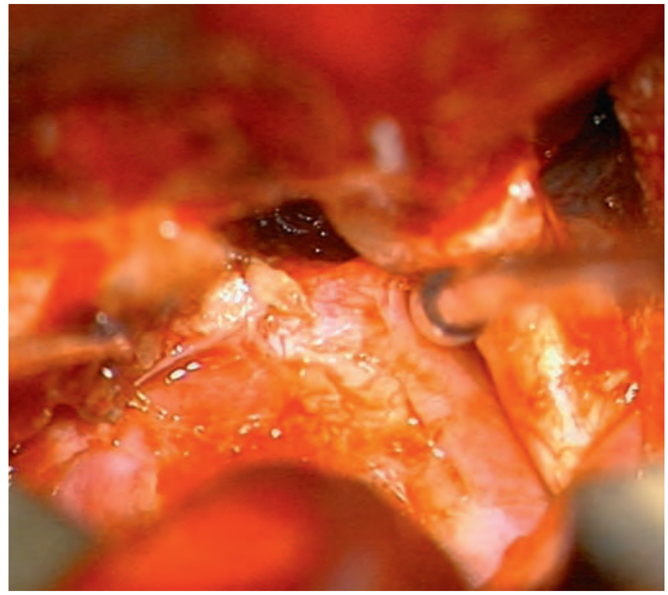

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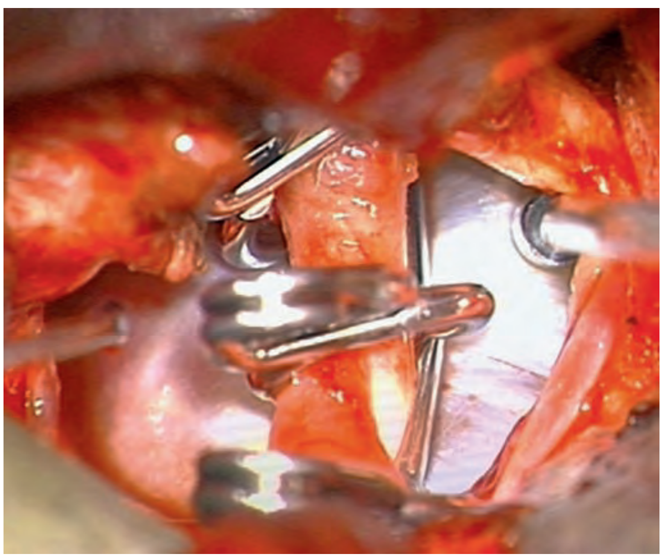
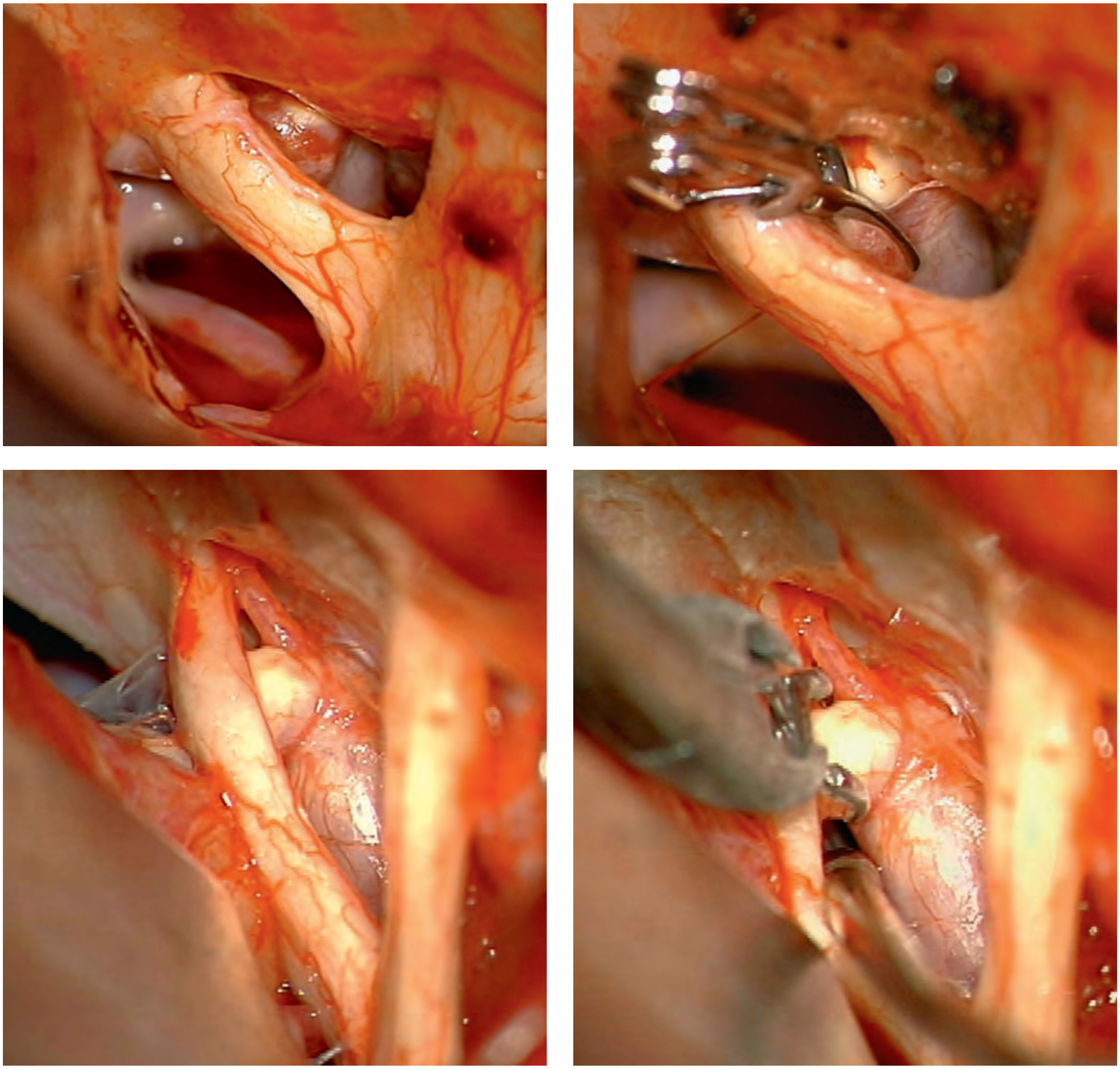


C

**Fig. 17.12 (A)** This 49-year-old woman presented with a subarachnoid hemorrhage from this giant left SHA aneurysm. The distal ICA originated from the lateral wall of the aneurysm. **(B)** After an anterior clinoidectomy and distal dural ring dissection, the proximal ICA was identified. **(C)** The tandem right-angle fenestrated clipping technique was used with three clips, applied in a proximal to distal direction, with temporary occlusion of the cervical ICA.

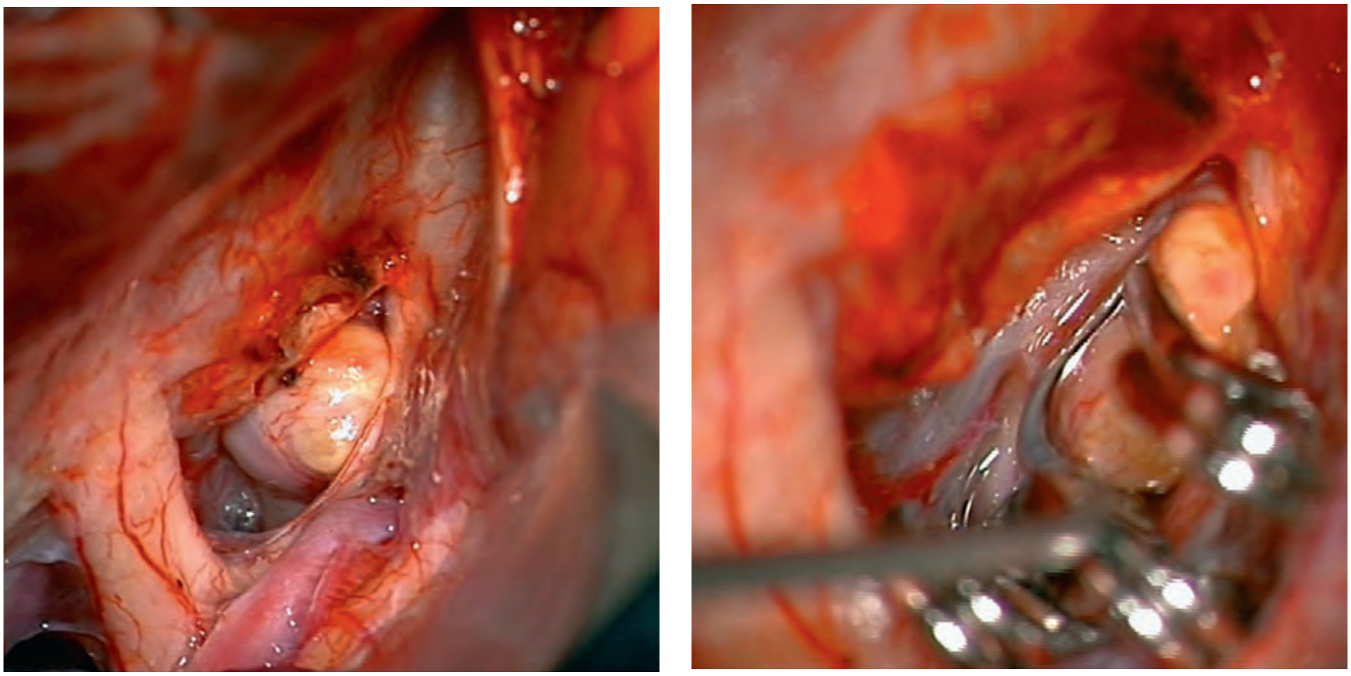
A single angled fenestrated clip may not be enough, especially with a large SHA aneurysm or a carotid artery with increased curvature. These aneurysms require tandem angled fenestrated clipping (**Fig. 17.12**). The first clip is a short angled fenestrated clip applied at the proximal neck, and subsequent clips are applied proceeding from the proximal to distal neck. The ICA is mobilized from side to side to check for proper clip placement. Persistent aneurysm filling after permanent clipping is most commonly explained by problems at the tip of the initial clip. Tandem clips are applied toe to heel, with subsequent tips passing under or over the heel of prior clips to overlap the blades. Angled fenestrated clips with shorter blade lengths are more maneuverable than longer blade lengths. The final clip at the distal neck can often be maneuvered under the ICA and around the branches, and may not need to be a fenestrated clip. Fenestrated clips that encircle the ICA usually have large fenestrations and right angles, but other angles, curves, and blade deviations allow for unique contouring. Counterclipping techniques with angled fenestrated clips facing tip to tip or crossing heel to heel can be used, particularly when applied as booster clips across overlapping clips with aneurysms that continue to fill.



A B C D

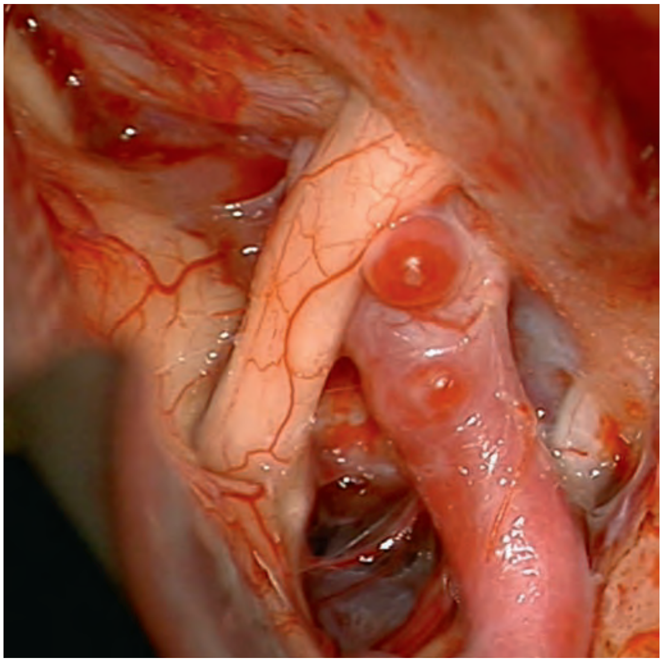
**Fig. 17.13** Examples of contralateral clipping of OphA aneurysms. **(A)** This medially projecting left OphA aneurysm was approached from the right side and visualized under the left optic nerve, through the interoptic triangle. **(B)** The aneurysm was clipped with two stacked curved clips, without an anterior clinoidectomy. **(C)** This woman presented with a ruptured right PCoA aneurysm, and this incidental OphA aneurysm was exposed in the interoptic triangle. **(D)** It was clipped at the same time. (*continued on next page*)

Some OphA and SHA aneurysms can be clipped more simply from the contralateral side (**Fig. 17.13**). Indications for contralateral clipping include the following: small aneurysms, medial projection, multiple aneurysms with a single contralateral OphA aneurysm, and prior surgery with clips or scar tissue on the ipsilateral side. The *interoptic triangle* offers good exposure of the medial wall of the ophthalmic segment of the ICA. Contralateral clipping obviates the need for clinoidectomy, but the contralateral ICA in the neck is not as accessible for proximal control. Therefore, contralateral clipping is reserved for highly selected aneurysms that are unruptured and have a simple anatomy.



E F

**Fig. 17.13** (*Continued*) **(E)** This large right OphA aneurysm projected medially and was approached through a left pterional craniotomy. **(F)** Working through the interoptic triangle and drilling some of the planum sphenoidale exposed the aneurysm. Two curved clips and a straight booster clip were applied to the aneurysm neck.



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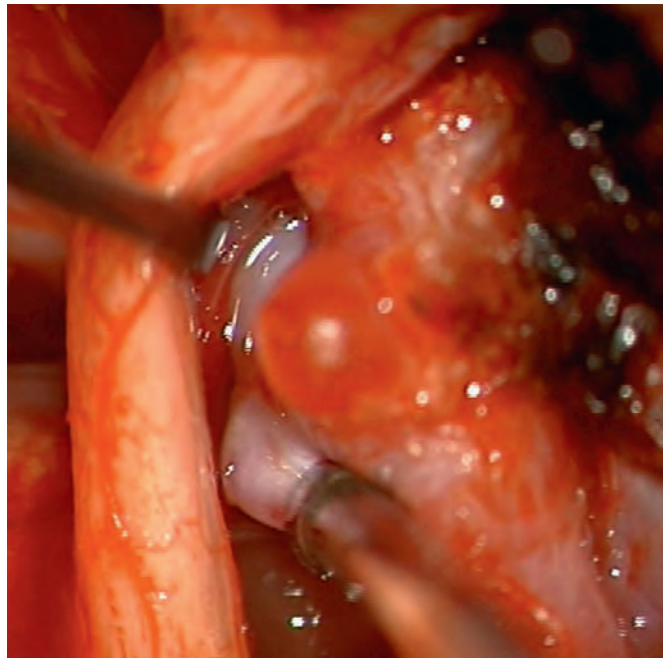

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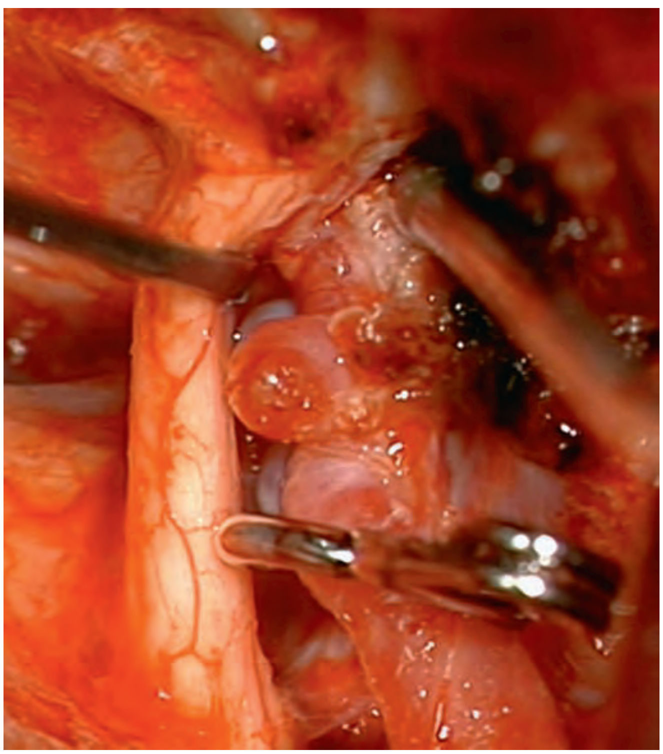

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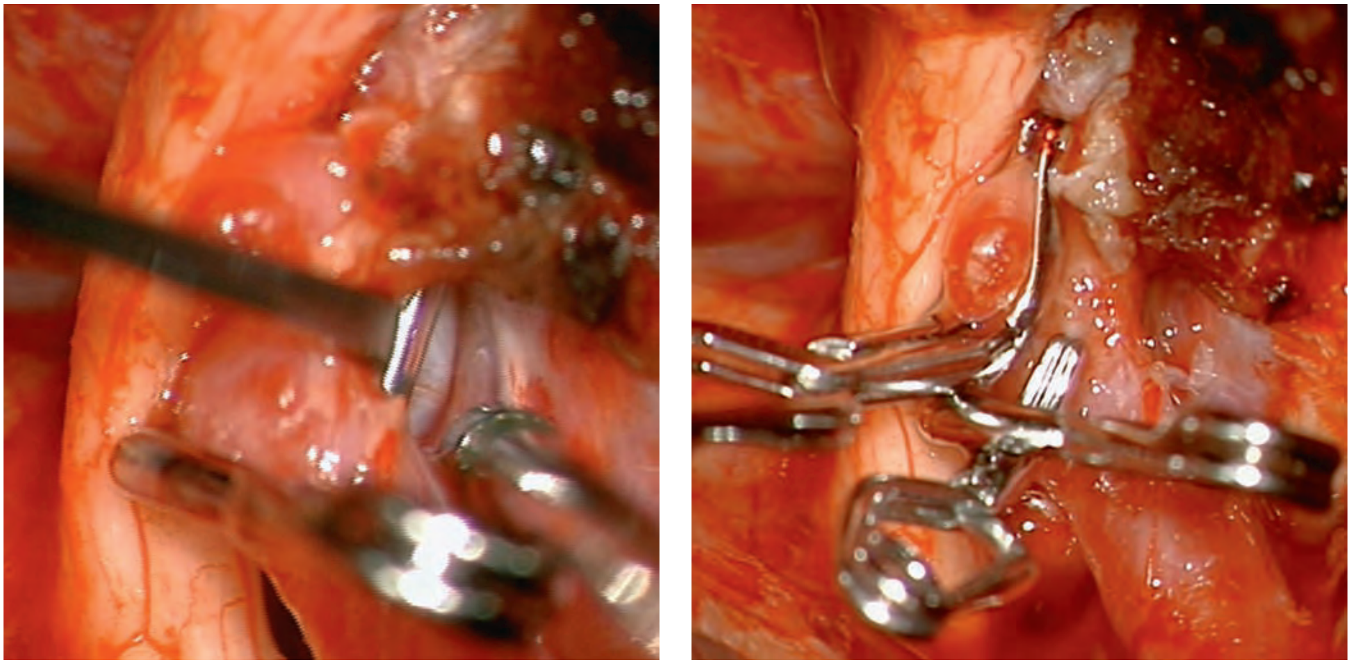
**Fig. 17.14** This 37-year-old patient had two dorsal carotid aneurysms and a SHA aneurysm on the right side, in association with a contralateral ICA aneurysm that ruptured 6 months earlier. **(A)** The two small dorsal carotid aneurysms were seen on the superolateral aspect of the ICA, distal to and not associated with the OphA. **(B)** Exposure of the SHA under the optic nerve required an anterior clinoidectomy and distal dural ring dissection. **(C)** The SHA aneurysm was clipped first, using a right-angled fenestrated clip. (*continued on next page*)

Dorsal carotid and anterolateral clinoidal segment aneurysms are clipped like OphA aneurysms (**Fig. 17.14**); carotid cave, medial clinoidal segment aneurysms, and ventral carotid aneurysms are clipped like SHA aneurysms (**Figs. 17.15 and 17.16**). Clipped aneurysms that distort the optic nerve should be punctured, deflated, or debulked to relieve pressure on the nerve.



D E

**Fig. 17.14** (*Continued*) **(D)** The inferior blade was inspected before clipping the two dorsal carotid aneurysms. **(E)** The proximal one was clipped with a right-angled clip, and the distal one required clip application within the fenestration of the initial clip.

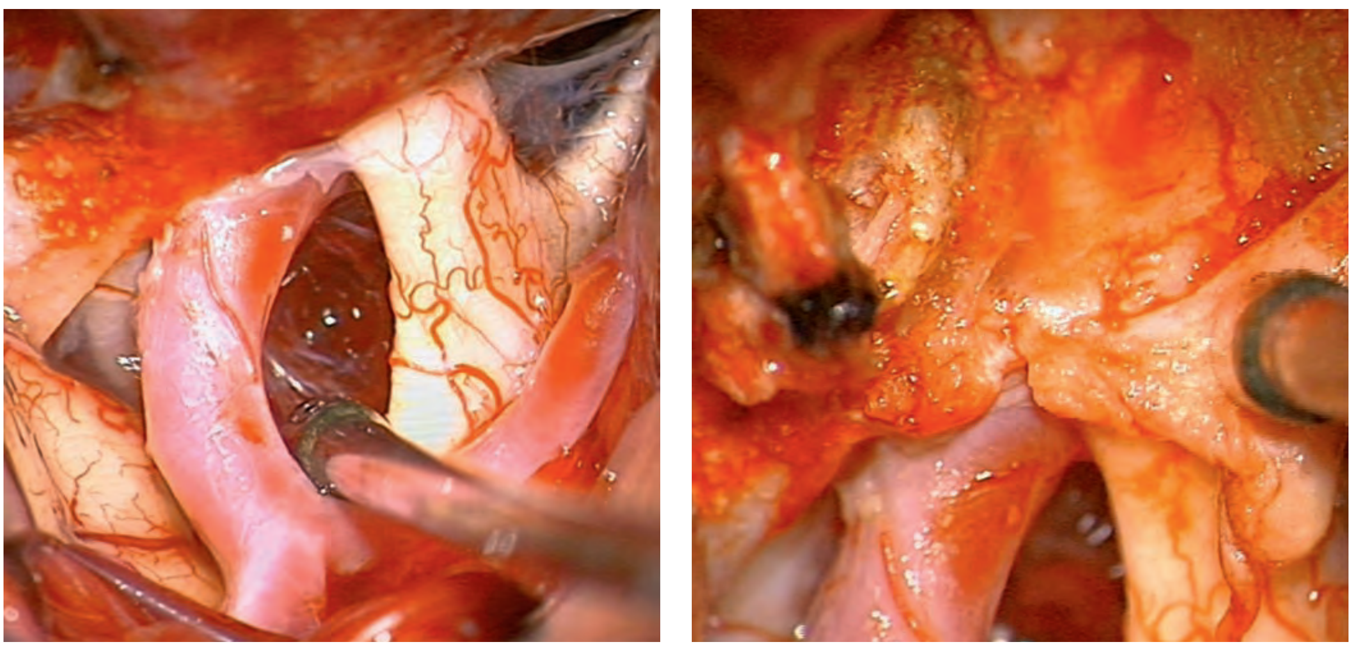


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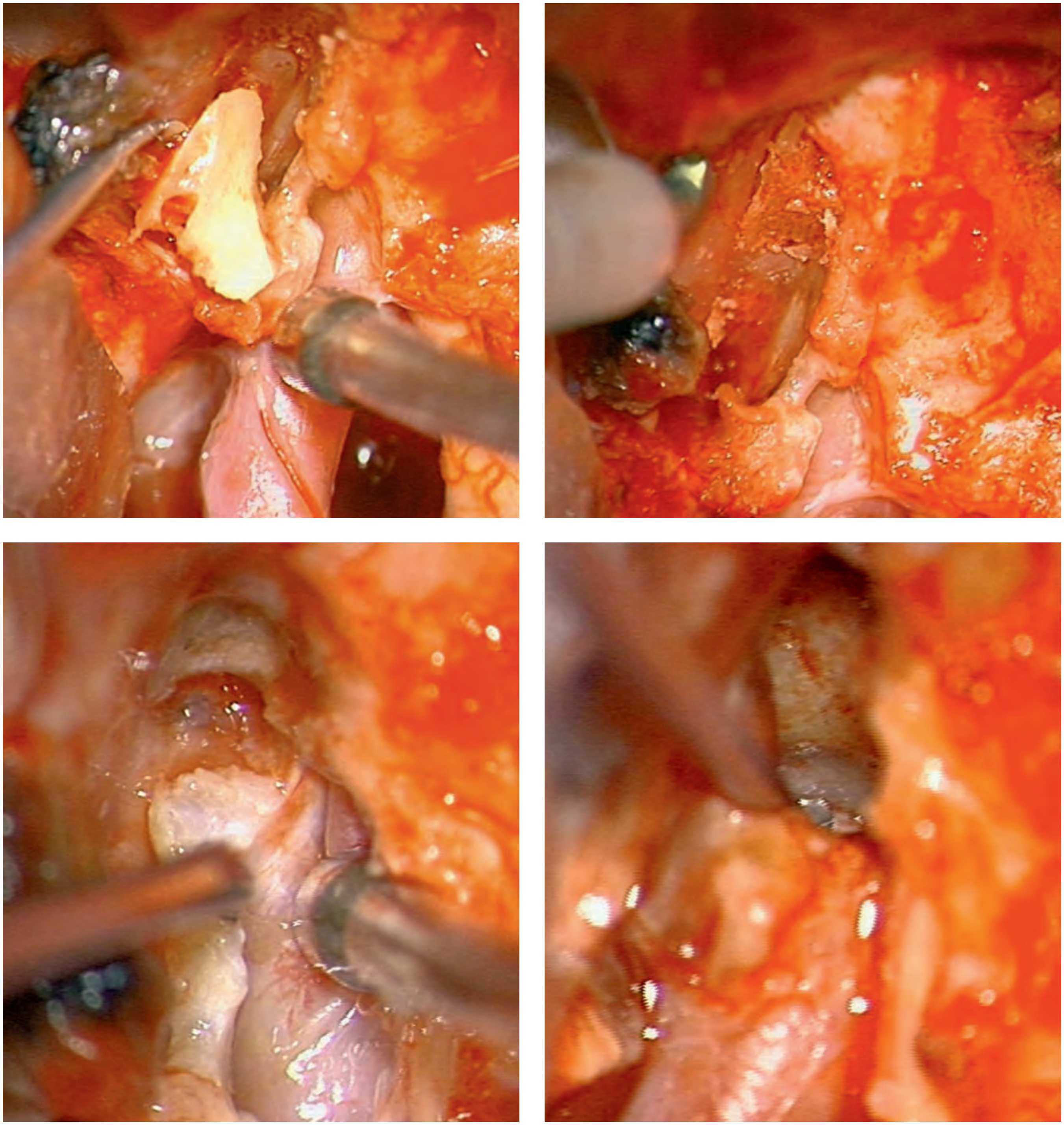
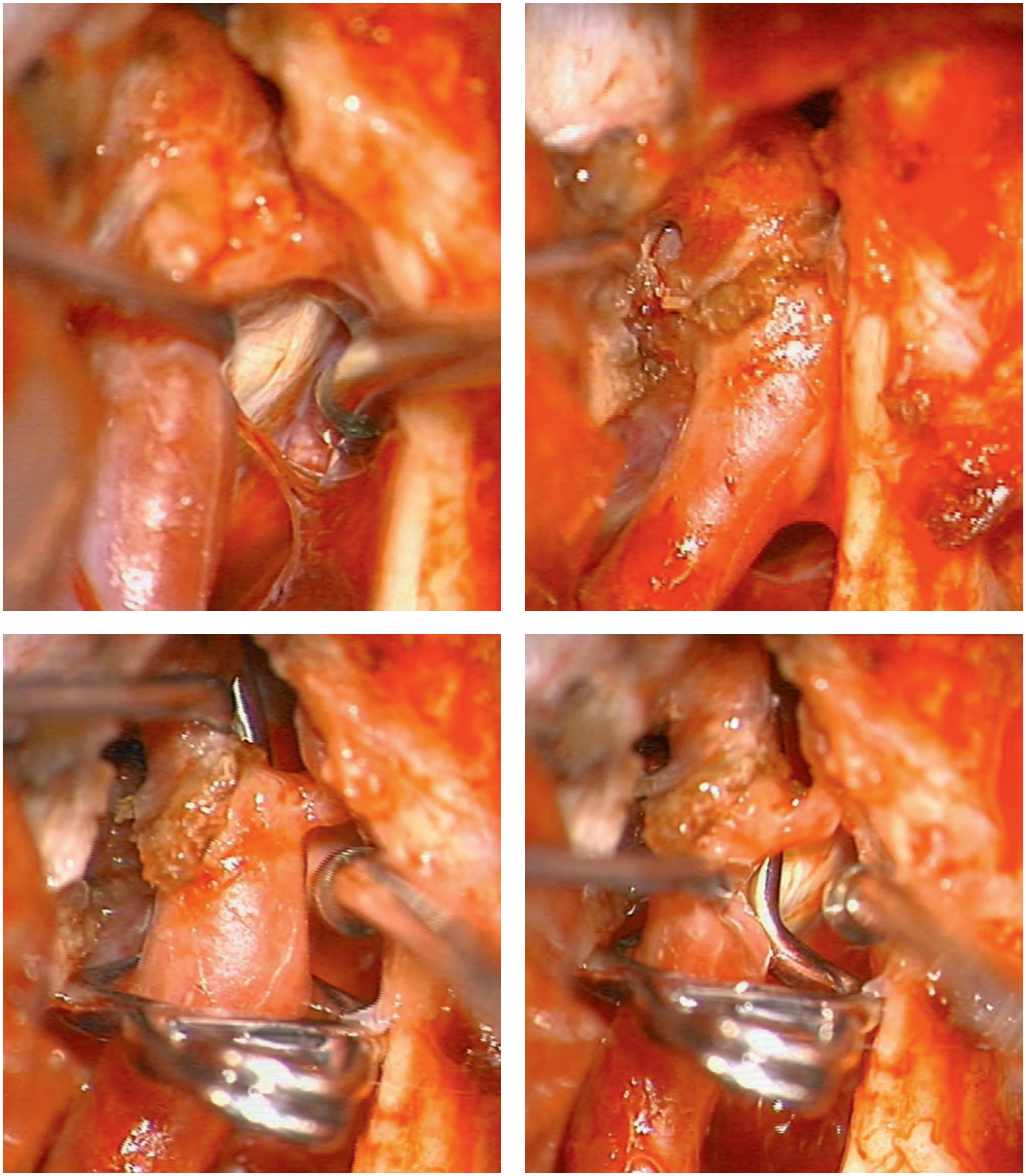
**Fig. 17.15** Carotid cave aneurysms are more proximally located than superior hypophyseal artery aneurysms, but have a similar inferomedial projection. **(A)** This left carotid cave aneurysm was not apparent initially in this 52-year-old woman. **(B)** After the surgeon flapped the clinoidal dura posteriorly, the optic canal was unroofed early during the anterior clinoidectomy to decompress the nerve and increase its tolerance to any subsequent manipulation.



C D E F

**Fig. 17.15** (*Continued*) **(C)** The ACP was removed, **(D)** the optic strut was drilled away, and **(E)** the distal dural ring was cut under OphA. **(F)** Once the medial portion of the distal dural ring was cut, the clinoidal segment of the proximal ICA mobilized out of the carotid sulcus of the sphenoid bone to open the pathway for the medial clip blade. (*continued on next page*)



G H I J

**Fig. 17.15** (*Continued*) **(G)** The SHA was seen along the medial aspect of the ICA, distal to the cave aneurysm. **(H)** Dissection continued along the inferior half of the distal dural ring under the ICA to expose the distal aneurysm neck. **(I)** The aneurysm was clipped with a slightly curved, right-angled fenestrated clip, with the tip across the proximal neck and **(J)** the heel across the distal neck. This upper clip blade slid in medial to the OphA, seen coursing up to the optic canal. Visualizing the medial anatomy requires some mobilization of the ICA, rather than deflecting the optic nerve.

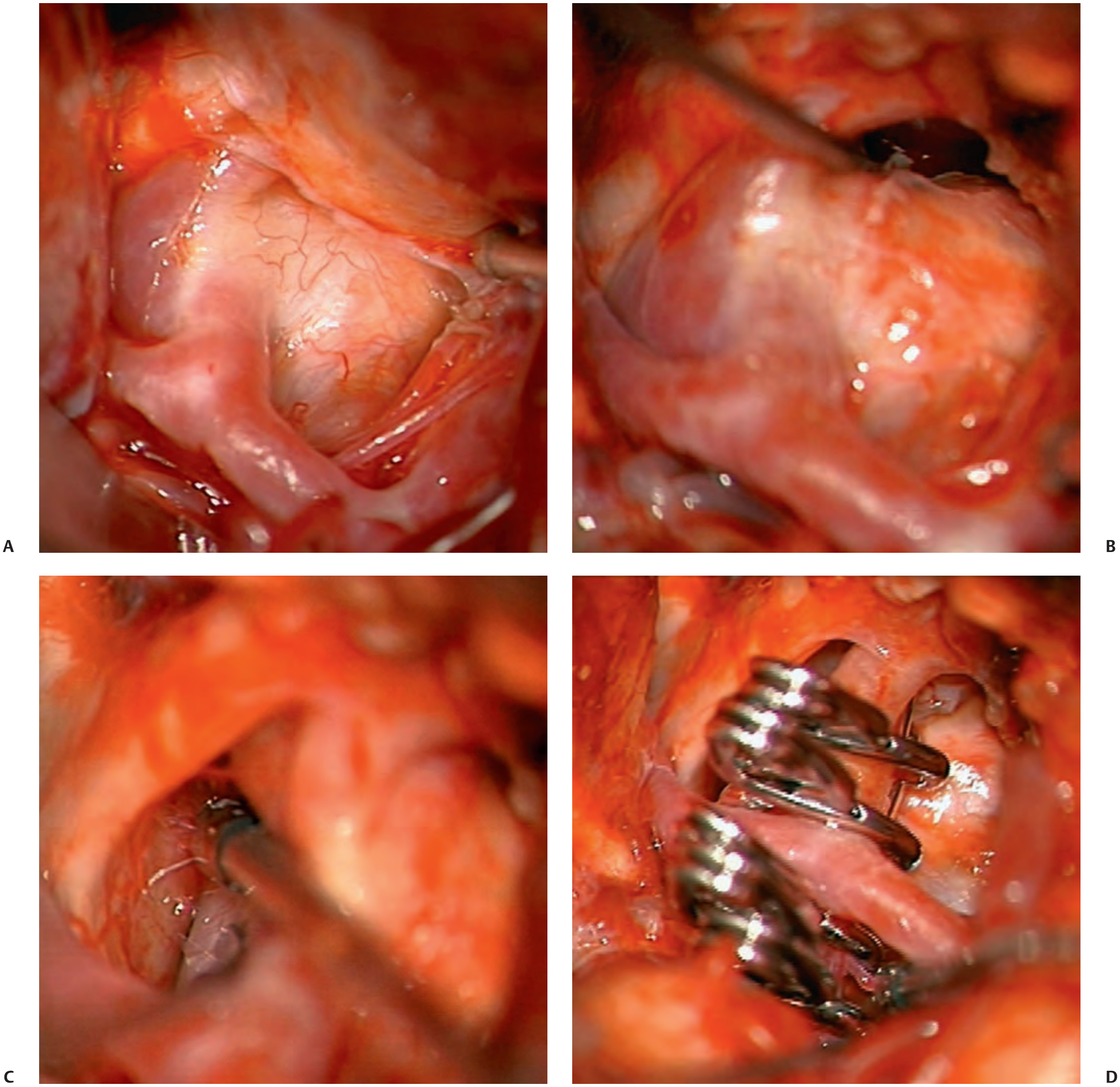


**Fig. 17.16** This 50-year-old woman had a right-sided, giant ventral carotid aneurysm. **(A)** The aneurysm originated distal to the OphA on the inferomedial carotid wall. **(B)** An anterior clinoidectomy and distal dural ring dissection exposed the proximal neck. **(C)** Temporary occlusion of the cervical ICA softened the aneurysm, allowing it to mobilize off the optic chiasm. **(D)** The aneurysm was clipped with tandem right-angle fenestrated clips. The distal two clips were applied above the ICA bifurcation, through the supracarotid triangle, and the fenestrations transmitted the AChA and its branches, seen at the tip of the sucker.

## Complications

### Cerebrospinal Fluid Rhinorrhea

Cerebrospinal fluid (CSF) rhinorrhea can occur when frontal or ethmoidal sinuses are opened with the craniotomy or drilling of the pterion. Dural incisions required for clinoidectomy prevent a competent dural closure, and sinuses must be covered with vascularized pericranium. CSF rhinorrhea can also occur when the optic strut is pneumatized with a finger-like projection from the sphenoid sinus (opticocarotid recess) that is opened during strut removal. This anatomy, occurring in 4 to 13% of patients, results in a communication between the subarachnoid space and the sphenoid sinus that can be repaired with the “yo-yo” technique.

After aneurysm clipping, a generous strip of temporalis muscle is harvested that is thicker than the opening in the strut and three times the length of the strut (usually >2 cm). A 4–0 nylon suture is placed through the muscle at its midpoint and tied. The ends of the suture are passed around the muscle circumferentially and tied again to create a “waist” in the muscle. The muscle is passed through the opening in the strut completely into the sphenoid sinus, with the ends of suture trailing in the subarachnoid space. They are used to retract muscle from the sphenoid sinus back into the optic strut, which folds the muscle in half and packs it tightly inside the strut. The muscle is retracted until the lasso of suture emerges into the subarachnoid space, where it mushrooms over the strut to form a plug. Appropriately sized muscle will also mushroom in the sphenoid sinus over the other end of the strut. Suture is trimmed and the repair is covered with fibrin glue (**Fig. 17.8**). No lumbar drain is needed. The yo-yo technique, named because sutured muscle resembles a yo-yo in both form and motion, reverses the usual direction of muscle packing, pulling the muscle from the sphenoid sinus into the optic strut. Pulling a plug into the funnel-shaped anatomy is more effective mechanically than pushing a plug out of a funnel. Application of this technique does not require preoperative preparations, only the intraoperative recognition of a pneumatized strut. Adequate removal of the optic strut and thorough dissection of the distal dural ring is critical to clipping OphA aneurysms and should not be compromised by concern for postoperative CSF rhinorrhea.

### Blindness

New monocular blindness is one of the neurosurgeon’s worst complications and the patient’s most distressing deficits. Patients react strongly to this problem, even though they can see with the other eye. Therefore, delicate dissection around the optic nerve cannot be overemphasized. Vision loss may be due to heat from drilling around the optic canal, manipulation of the optic nerve during aneurysm dissection, or compromise of the perforators to the optic nerve. The OphA is usually intact in patients with this complication. The optic canal and strut must be drilled with generous cold irrigation and frequent pauses. The touch with the drill should be light. The optic canal should be unroofed early and widely. Bone around the optic canal should be thinned and fractured away from the nerve. Dissection should depress the carotid artery rather than lift the optic nerve. Perforators to the optic nerve from the SHA and directly from the ICA are fragile and must be handled delicately. Intraoperative visual evoked responses might provide feedback for the neurosurgeon during the dissection, but this technique has not been reliable. Therefore, we operate on these aneurysms blinded to the patient’s possible blindness. If a patient wakes up with new monocular blindness, little can be done to recover vision. We are left with a “no touch” policy toward the optic nerve, and strive to maintain this policy as best as possible.

# 18 Pericallosal Artery Aneurysms

## ■ Microsurgical Anatomy

The anterior cerebral artery (ACA) distal to the anterior communicating artery (ACoA) is divided into four segments (**Fig. 18.1**). The A2 segment, also called the *postcommunicating* or *infracallosal segment*, begins at the ACoA and follows the rostrum of the corpus callosum; the A3 segment, or *precallosal segment*, curves around the genu until the artery assumes a posterior course; the A4 segment (*supracallosal*) and A5 segment (*postcallosal*) continue over the anterior and posterior halves, respectively, of the body of the corpus callosum, the division between them being the vertical plane of the coronal suture. The ACA's ascending segment consists of A2 and A3, and its horizontal segment consists of A4 and A5. The bifurcation into the pericallosal and callosomarginal arteries does not define these distal segments. Its location varies from just distal to the ACoA to the genu, and is most often in the A3 segment. The callosomarginal artery (CmaA) may be absent in 20% of patients.

The pericallosal artery (PcaA) lies on top of the corpus callosum, whereas the callosomarginal artery courses in or near the cingulate sulcus, one gyrus above the corpus callosum and parallel to the PcaA. The PcaA and CmaA are the two largest distal ACA branches, and their calibers are inversely related. The PcaA is usually bigger than the CmaA. All of the PcaA runs below the free margin of the falx, whereas only the anterior portion of the CmaA does.

Eight cortical branches are typically observed: orbitofrontal, frontopolar, internal frontal (anterior, middle, and posterior), paracentral, and parietal (superior and inferior) arteries (**Fig. 18.1**). The orbitofrontal and frontopolar arteries originate from the A2 segment and are more relevant to ACoA aneurysms, where they can drape the aneurysm dome and appear as false trunks. The anterior internal frontal artery (AIFA), the middle internal frontal artery (MIFA), and the callosomarginal arteries originate from the A3 segment; the paracentral artery originates from the A4 segment; and the superior and inferior parietal arteries originate from the A5 segment. The posterior internal frontal artery (PIFA) can arise from the A3 or A4 segments. The branching pattern of the distal ACA is highly variable, and these branches provide little anatomic guidance during the fissure dissec-

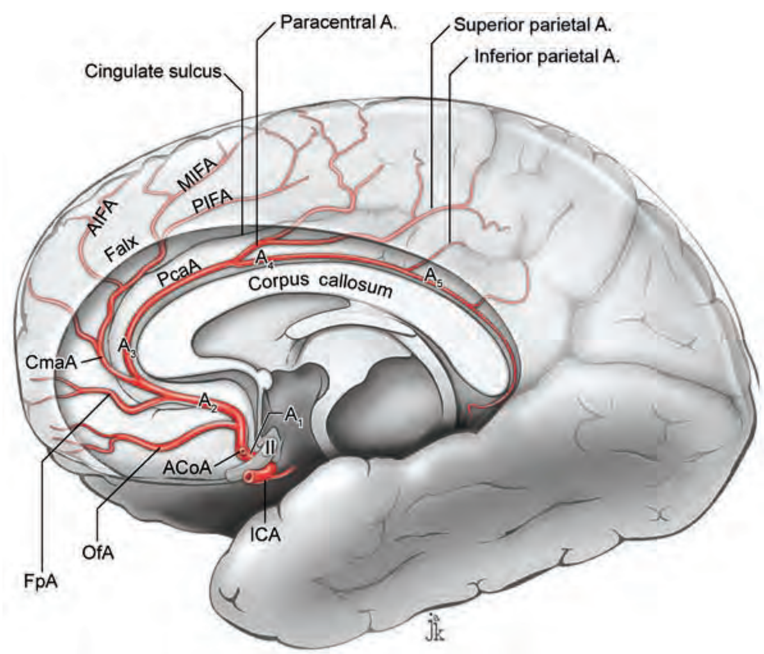



**Fig. 18.1** Microsurgical anatomy of the anterior cerebral artery, ACA, pericallosal artery (PcaA), and callosomarginal artery (CmaA) (lateral view). The ACA is divided into five segments: A1, precommunicating or horizontal segment; A2, postcommunicating or infracallosal segment; A3, precallosal segment; A4, supracallosal segment; and A5, postcallosal segment. ACA, PcaA, and CmaA have eight major cortical branches: orbitofrontal, frontopolar, internal frontal (anterior, middle, and posterior), paracentral, and parietal (superior and inferior) arteries. ACoA, anterior communicating artery; AIFA, anterior internal frontal artery; FpA, frontopolar artery; ICA, internal carotid artery; MIFA, middle internal frontal artery; OfA, orbitofrontal artery; PIFA, posterior internal frontal artery.

tion. These cortical branches extend over the convexity to supply the superomedial surfaces of the hemisphere, anastomosing laterally with the middle cerebral arteries and posteriorly with the posterior cerebral arteries in watershed areas. Anomalies of the distal ACA include triplication of the A2 segments (accessory A2 segment), an unpaired A2 segment (azygos ACA), and a bihemispheric ACA (an ACA that supplies both hemispheres).

## Aneurysm Dissection Strategy

The anterior interhemispheric fissure is opened widely with PcaA aneurysms, separating the medial frontal lobes along the corridor down to the aneurysm. Bifrontal craniotomy, dural opening in a flap based along the superior sagittal sinus (SSS), and dural reflection to the opposite side with taut tacking sutures access a subdural plane down the falx from the SSS to the inferior sagittal sinus (ISS), obstructed only by some arachnoid granulations and adhesions that are easily released (**Fig. 18.2**, step 1). Bridging veins and veins that fuse with the parasagittal dura before reaching the midline can be more problematic. Fused or intradural veins can be preserved by splitting the dural flap and creating a dural sleeve over the vein; bridging veins can be preserved by maximizing working spaces between them.

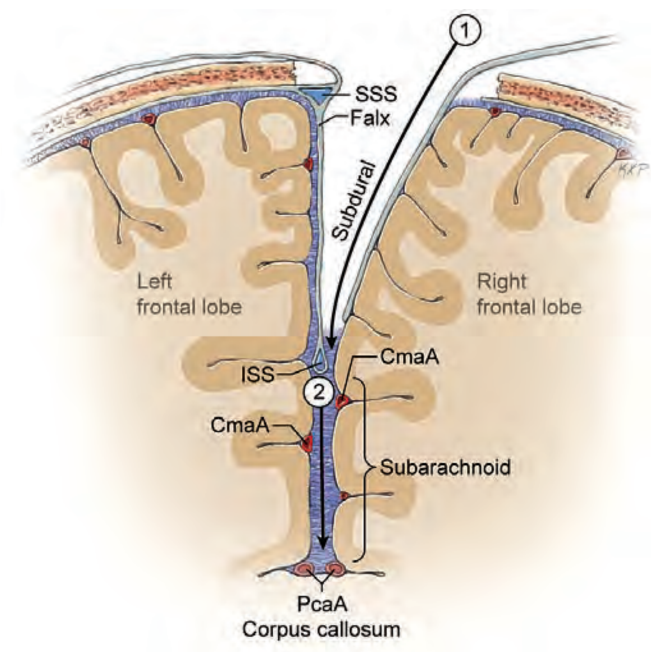


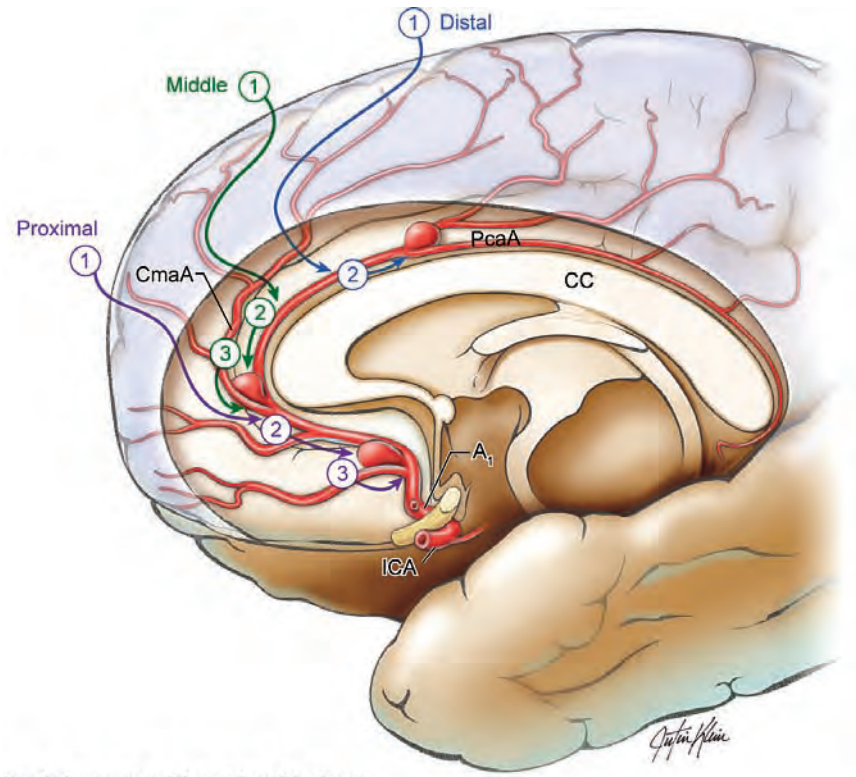

**Fig. 18.2** Opening the anterior interhemispheric fissure involves subdural dissection between the falx and the medial right frontal lobe (step 1), and subarachnoid dissection between the medial frontal lobes through the corpus callosum cistern (step 2). Arterial branches are followed in this subarachnoid plane to deepen the dissection down to the corpus callosum and the paired PcaAs. ISS, inferior sagittal sinus; SSS, superior sagittal sinus.

Subdural dissection transitions to subarachnoid dissection beneath the free edge of the falx at the roof of the posterior corpus callosum cistern (**Fig. 18.2**, step 2). This cistern is entered in the midline, looking for one of the ascending branches from the CmaA. The cortical surfaces of the medial frontal lobes can be tightly opposed and adherent, and the technique for opening the interhemispheric fissure is the same as for splitting the sylvian fissure. A peripheral artery is followed deeper and deeper to larger trunks using a combination of sharp and spreading dissection (**Fig. 18.3**, step 1). However, the corpus callosal cistern does not widen as the dissection deepens, as the sylvian cisterns do with sylvian fissure splitting. In addition, the caliber of the ACA branches does not enlarge the way that MCA branches enlarge to separate the sylvian surfaces of the frontal and temporal lobes. Subarachnoid hemorrhage, interhemispheric hematoma, and secondary brain swelling can make brain tissue friable, making this separation of frontal lobes without pial transgression challenging. The PcaA can hide beneath the inferior edge of the cingulate gyrus, but the white color of the corpus callosum signals the arrival at the pericallosal's depth. The laterality of the PcaA and the CmaA can be unclear when they are encountered unpaired, but each artery sends branches to only one hemisphere, and the direction of these branches indicates the side with which that artery is associated.

The PcaA is followed anteriorly to open the interhemispheric fissure from "inside-out" (**Fig. 18.3**, step 2). The fissure is opened from the depth of the PcaA up to the depth of the CmaA and up further to the falx's free edge. Dissection progressing from distal to proximal is rarely dangerous with unruptured PcaA aneurysms, but can be with ruptured aneurysms. Therefore, once the dissection plane between the frontal lobes is established posteriorly, dissection shifts anteriorly for proximal control.

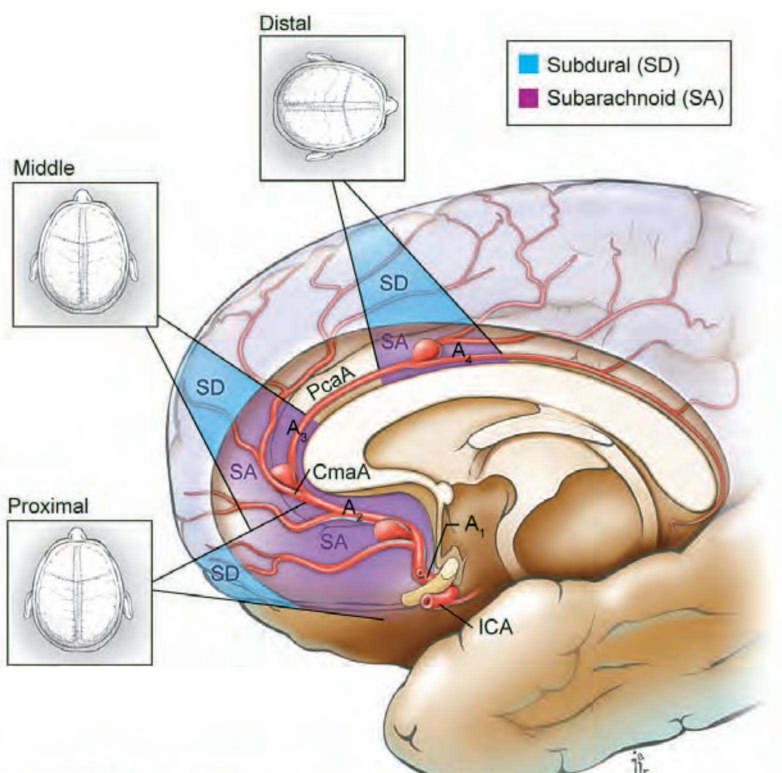
Low-lying or proximal PcaA aneurysms on the A2 segment have poorly accessible proximal control and require a dissecting trajectory almost along the floor of the anterior cranial fossa (**Fig. 18.3**). Falx is thinned here and provides minimal separation of the frontal lobes, shortening the subdural and lengthening the subarachnoid dissection distances to the A2 segment (**Fig. 18.4**). This infracallosal segment often courses anteriorly as it follows the rostrum superiorly, which deepens the point of proximal control past the aneurysm itself. Therefore, the dissection must drop low enough to avoid the dome, which often projects anterosuperiorly into this dissection path. This approach along the axis of the A2 segment causes the infracallosal segment to vanish in the field.

High-riding or middle PcaA aneurysms on the A3 segment at the genu have proximal control that is more accessible, as do distal PcaA aneurysms on the supra- and postcallosal (A4 and A5) segments. Some distal PcaA aneurysms are amenable




**PcaA Aneurysm Dissection Strategy**

**Fig. 18.3** Dissection steps for pericallosal artery aneurysms. Step 1, following the peripheral arteries deeper and deeper to split the anterior interhemispheric fissure. Step 2, widening the fissure split by following the PcaA along the corpus callosum (CC). Step 3, shifting the dissection to the aneurysm's proximal side. Low-lying or proximal PcaA aneurysms require a dissection trajectory almost along the floor of the anterior cranial fossa (purple arrows). High-riding or middle PcaA aneurysms have more accessible proximal control (green arrows). The dissection of distal PcaA aneurysms is already proximal and requires posterior dissection along the ACA to reach the aneurysm (no step 3) (blue arrows).




**Subdural and Subarachnoid Dissections**

**Fig. 18.4** The low dissection trajectory for proximal and middle PcaA aneurysms requires the neutral head position. Distal PcaA aneurysms are amenable to the lateral head position and gravity retraction of the dependent hemisphere. The falx is thin anteriorly and widens posteriorly, lengthening the subdural (SD) and shortening the subarachnoid (SA) dissection distances to the corpus callosum.

to the lateral head position and gravity retraction of the dependent hemisphere (**Fig. 18.4**). A wide posterior falx separates the frontal lobes, lengthening the subdural and shortening the subarachnoid dissection distances to the A3 or A4 segment. The more posterior craniotomy brings bridging veins along the SSS into the fore field, and instruments must be navigated through a working corridor between these veins. In addition, distal aneurysms require angling back to reach beyond the craniotomy's posterior edge. As the falx widens posteriorly, it can sometimes be a point of adhesion on the aneurysm dome or a cause of dissecting aneurysm formation when trauma shears the artery against falx's free edge. When the ACA segments are paired, the afferent artery is traced to the aneurysm to be sure that the correct artery, not the uninvolved contralateral artery, is prepared for proximal control.

Pericallosal artery aneurysms occur at the bifurcation of the ACA into the PcaA and the CmaA, but their proximity to the contralateral bifurcation involves six major arteries in the dissection. Distal to proximal dissection follows the natural convergence of the PcaA and the CmaA to the aneurysm neck. Proximal to distal dissection follows the course of the ACA around the corpus callosum. PcaA aneurysms are dangerous because their domes tend to project toward the neurosurgeon along the trajectory of the approach, and the dissection tends to drift posteriorly where the interhemispheric fissure opens easier. Dome avoidance and proximal dissection requires deliberately shifting of the dissection forward (**Fig. 18.3**, step 3). Clot associated with rupture is a common feature with PcaA aneurysms, and its removal helps open the interhemispheric fissure, but working through clot also draws the dissection posteriorly. Clot evacuation before permanent clipping should be limited because it can precipitate rupture.

Once the dissection shifts proximal to the aneurysm, the afferent artery should be prepared for proximal control (**Fig. 18.5**, step 4). The uninvolved contralateral artery is usually adjacent to the afferent artery. It is identified to confirm that the correct artery has been prepared for proximal control (**Fig. 18.5**, step 5).

The PcaA, CmaA, and early secondary branches can generate a complex of adherent arteries that can be difficult to decipher and mobilize off the aneurysm. Uninvolved contralateral arteries frequently adhere to the aneurysm because the corpus callosum cistern is narrow. These contralateral branches drape over or under the dome to create false trunks that must be differentiated from true efferent arteries. Ideally, uninvolved branch arteries are traced retrograde and cleared from the aneurysm to simplify the clipping (**Fig. 18.5**, step 6). Next, superficial efferent arteries, usually the ipsilateral CmaA, are traced retrograde to the aneurysm neck (**Fig. 18.5**, step 7). Deeper arteries, usually the uninvolved PcaA and the efferent PcaA, are dissected in a similar manner from distal to proximal (**Fig. 18.5**, steps 8 and 9). Their dissection often requires some aneurysm manipulation and is therefore performed last. Once the six major arteries are defined, the final dissection steps open the cleavage planes between the aneurysm neck, the CmaA, and the PcaA to allow passage of the clip blades. This dissection is frequently done with temporary clipping of the proximal ACA, which softens the aneurysm and enables more aggressive aneurysm manipulation. Thin aneurysm walls and dense adhesions may require leaving some of these attachments alone and using fenestrated clipping techniques that transmit adherent arteries.

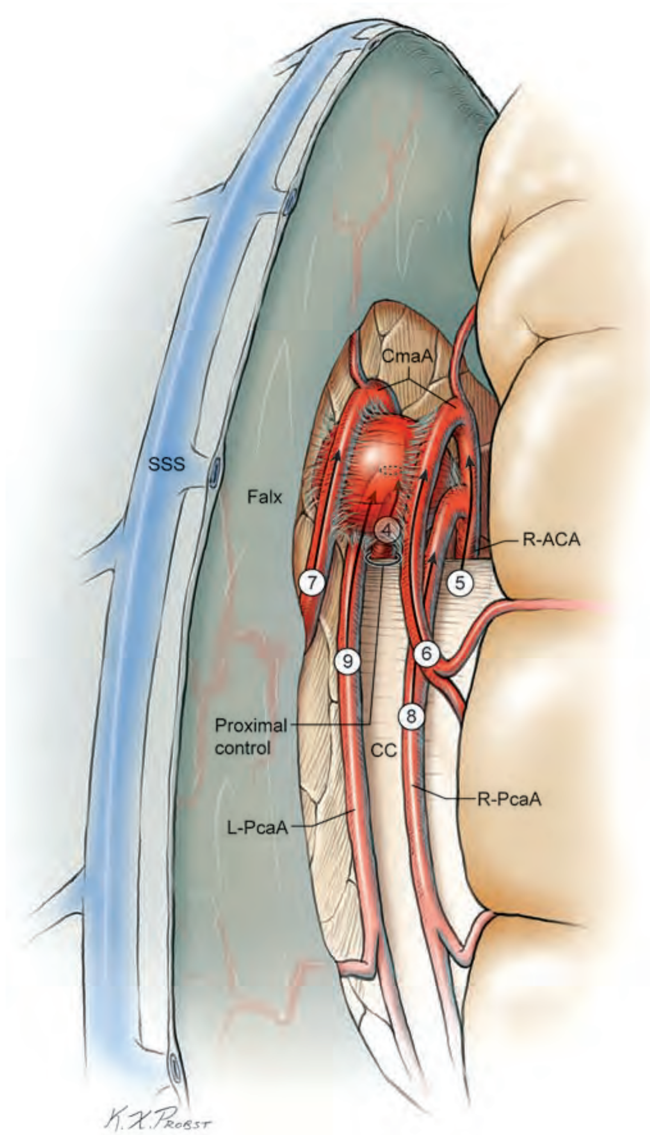
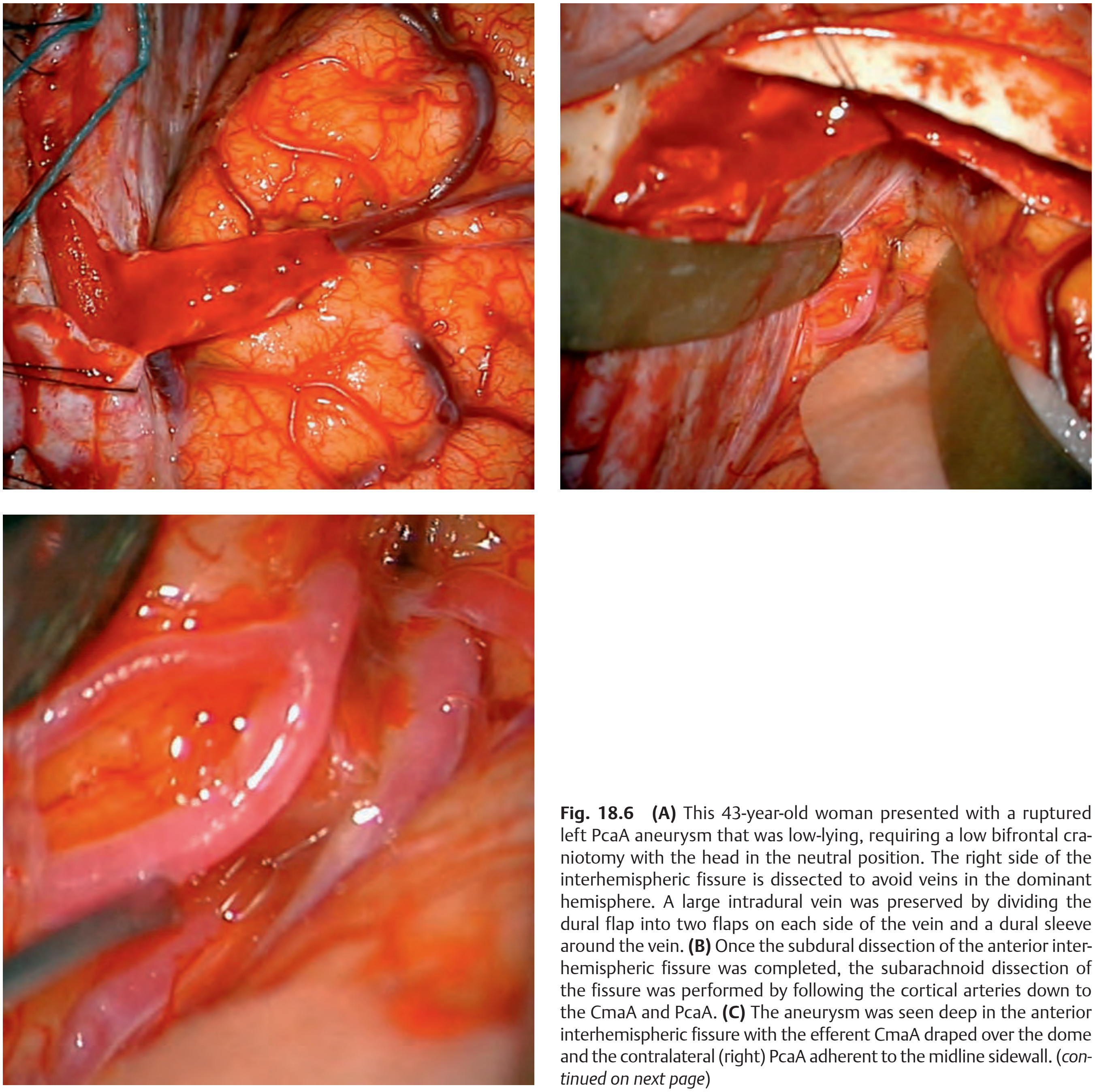
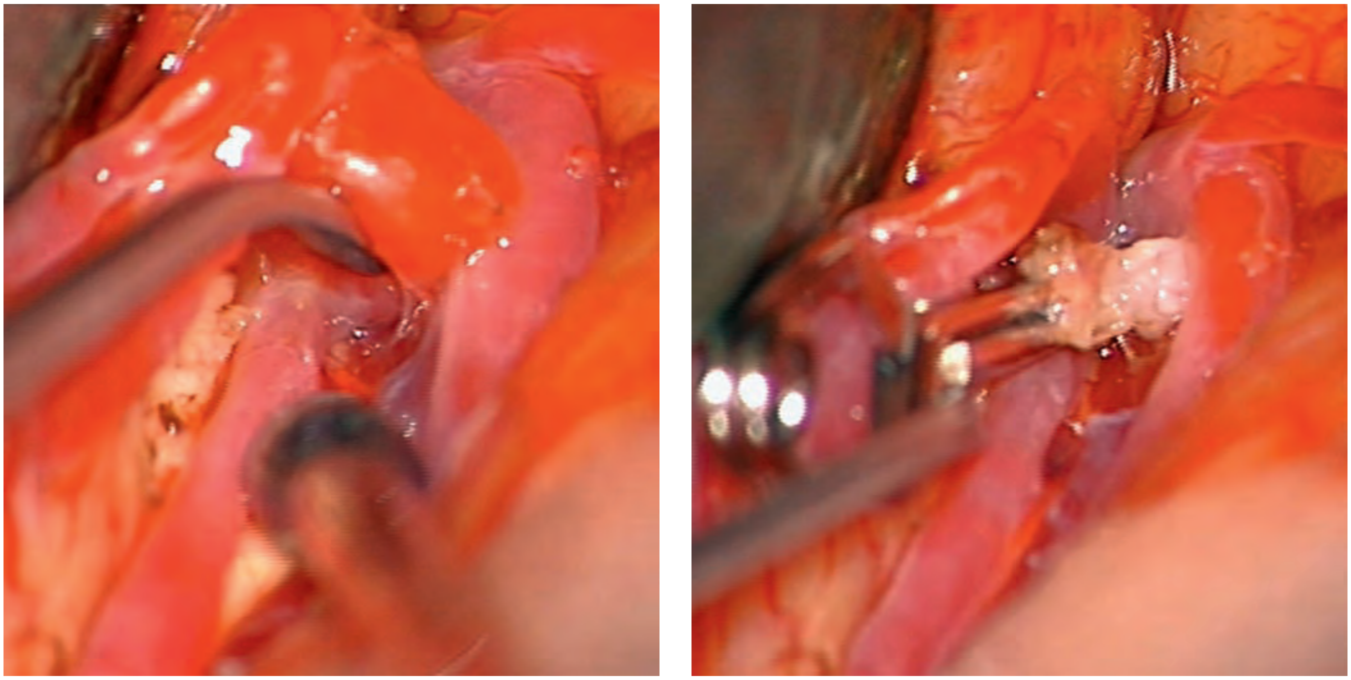



**Fig. 18.5** Dissection steps for pericallosal artery aneurysms. Step 4, preparing the afferent artery for proximal control. Step 5, identifying the contralateral ACA. Step 6, identifying and mobilizing the contralateral CmaA. Step 7, identifying and mobilizing the efferent CmaA. Step 8, identifying the contralateral PcaA. Step 9, identifying the efferent PcaA. Once the six major arteries are clarified, cleavage planes on both sides of the aneurysm neck are opened for clipping.



A B C

**Fig. 18.6 (A)** This 43-year-old woman presented with a ruptured left PcaA aneurysm that was low-lying, requiring a low bifrontal craniotomy with the head in the neutral position. The right side of the interhemispheric fissure is dissected to avoid veins in the dominant hemisphere. A large intradural vein was preserved by dividing the dural flap into two flaps on each side of the vein and a dural sleeve around the vein. **(B)** Once the subdural dissection of the anterior interhemispheric fissure was completed, the subarachnoid dissection of the fissure was performed by following the cortical arteries down to the CmaA and PcaA. **(C)** The aneurysm was seen deep in the anterior interhemispheric fissure with the efferent CmaA draped over the dome and the contralateral (right) PcaA adherent to the midline sidewall. (*continued on next page*)



D E

**Fig. 18.6** (*Continued*) **(D)** After securing proximal control, the aneurysm was mobilized to open the plane between the efferent PcaA and the distal neck. **(E)** The aneurysm was clipped with one straight clip.

## Clipping Technique

The view of PcaA aneurysms along their axis, into the convergence of the PcaA and the CmaA, often permits clipping with a single clip (**Fig. 18.6**) or with multiple stacked clips (**Fig. 18.7**). Draped arteries stuck to the aneurysm wall may need to be fenestrated (**Fig. 18.8A**). An incompletely opened cleavage plane between the aneurysm neck and an efferent artery may also require fenestrated clips that encircle the stuck artery (**Fig. 18.8B**). Some of these aneurysms have thin walls, and vigorous attempts to mobilize adherent arteries can cause intraoperative rupture. Immobile arteries can be left on the aneurysm and clips applied around them (**Fig. 18.9**). Indocyanine green (ICG) videoangiography and Doppler flow measurements help confirm patency after permanent clipping.

Temporary clipping of ruptured PcaA aneurysms during final dissection and permanent clipping softens the aneurysm, facilitates dissection, and protects against rerupture. The application of a temporary clip to a proximal ACA that

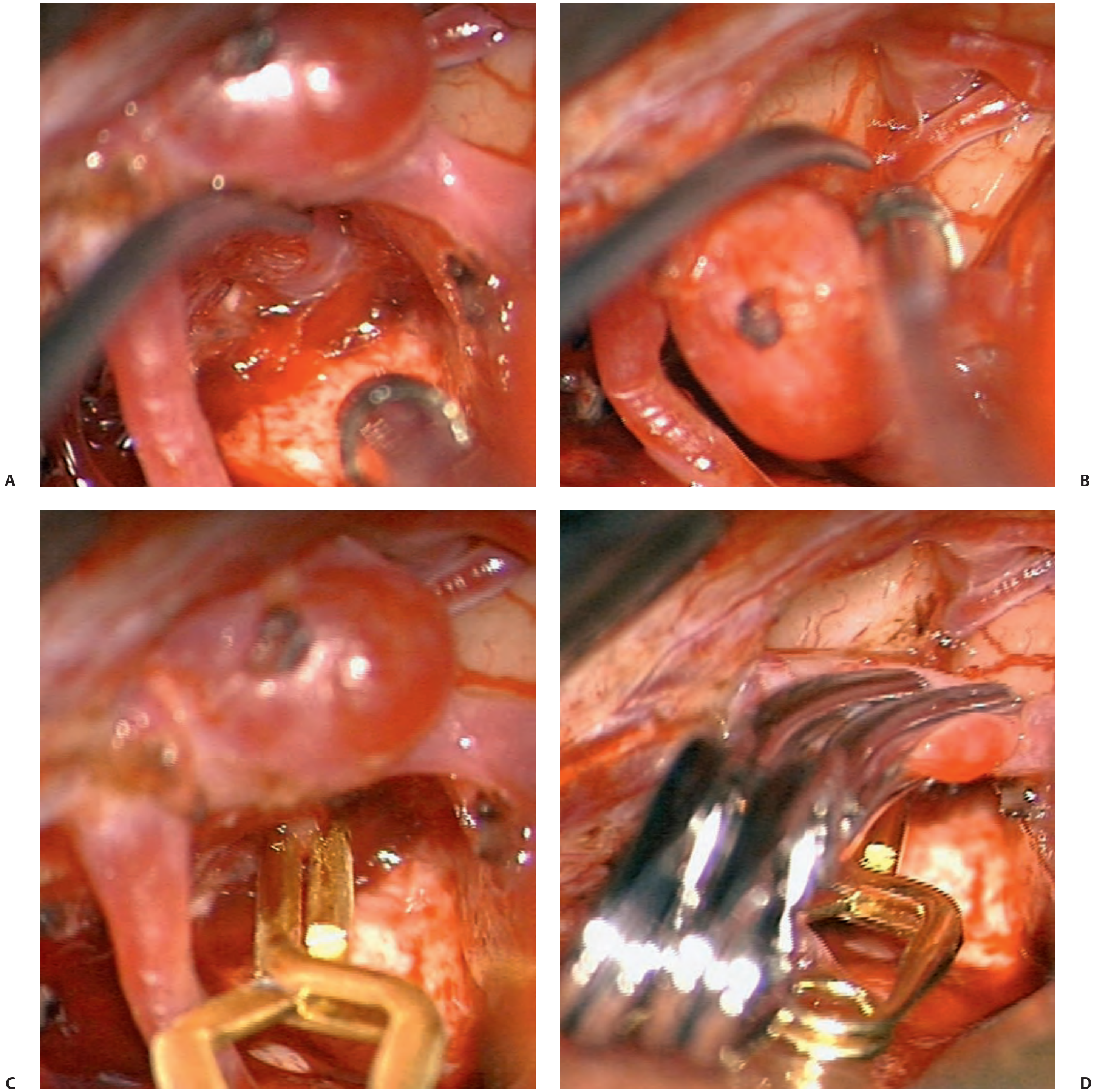


**Fig. 18.7** **(A)** This 48-year-old man presented with a subarachnoid hemorrhage (SAH) from this right PcaA aneurysm. The afferent right ACA was identified underneath the aneurysm, between the PcaA and the CmaA, demonstrating that with the curve of the artery around the genu of the corpus callosum, proximal control is not always found anterior to the aneurysm. **(B)** The left ACA was identified anterior to the aneurysm. **(C)** A temporary clip was applied on the right ACA beneath the aneurysm, and **(D)** the aneurysm was clipped with two curved clips.

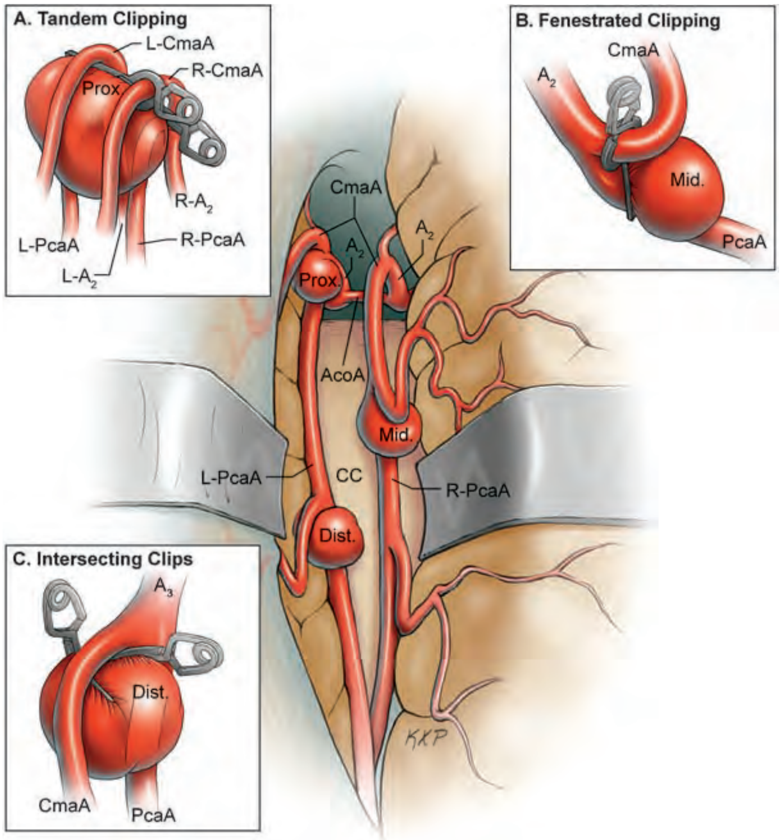
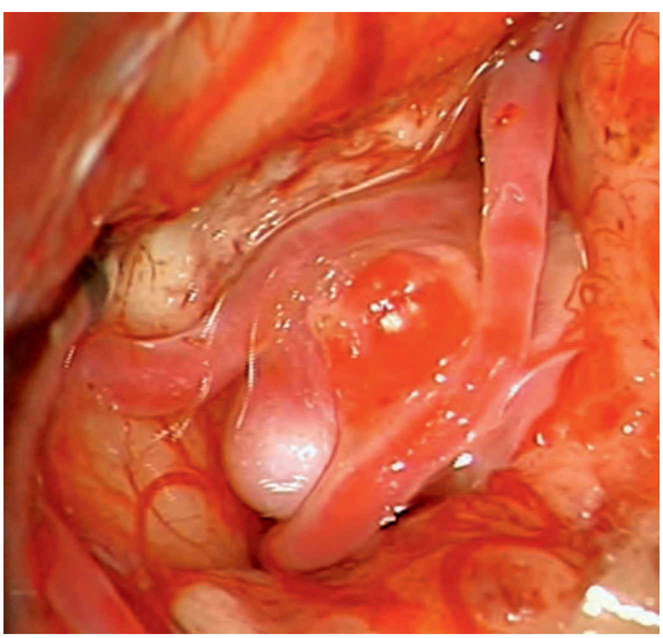



**Fig. 18.8** Clipping techniques for PcaA aneurysms. **(A)** Tandem clipping around the draped arteries adhering to the wall of a proximal aneurysm (Prox.). **(B)** Fenestrated clipping of a middle PcaA aneurysm (Mid.) around an incompletely opened cleavage plane between the aneurysm neck and an efferent artery, with the fenestration encircling the stuck artery. **(C)** Distal PcaA aneurysms (Dist.) require intersecting curved or angled clips, or fenestrated clips, around the origins of efferent arteries.



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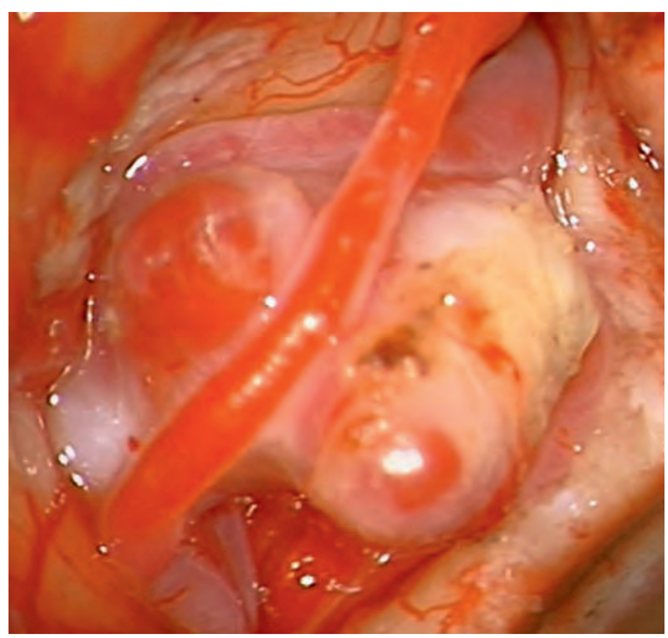
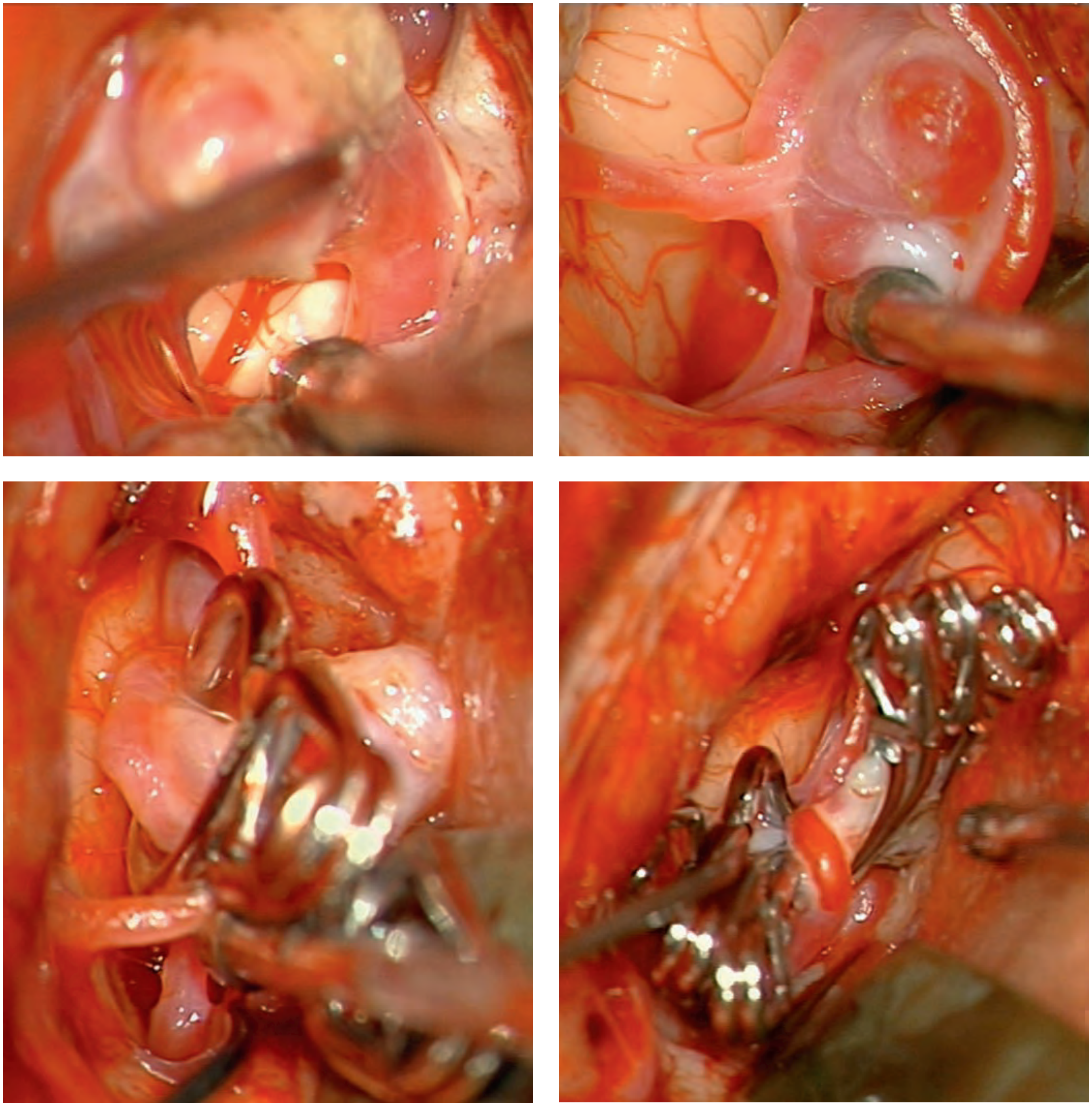


B

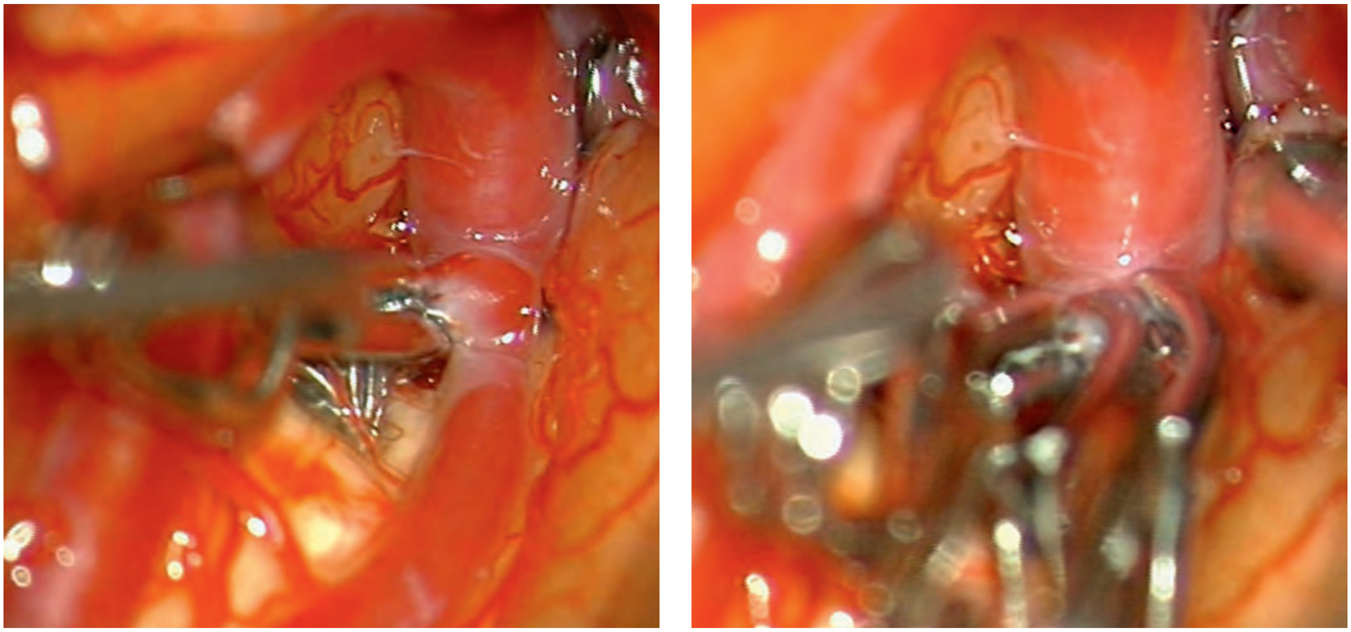
**Fig. 18.9** **(A)** This 52-year-old woman had a left PcaA aneurysm associated with a left OphA aneurysm that was coiled previously. The left CmaA was adherent to the side of the aneurysm and the right PcaA was draped over the dome. **(B)** The aneurysm had a portion that projected rightward into the frontal lobe.



C D

E F

**Fig. 18.9** (*Continued*) **(C)** under which the left PcaA was identified. **(D)** Neither the left CmaA nor the right PcaA could be mobilized off the dome. **(E)** Therefore, the portion of the aneurysm to the left of the draped PcaA was clipped with tandem clips, and **(F)** the portion of the aneurysm to the right of the draped PcaA was clipped with three stacked curved clips. The left PcaA was preserved beneath the tips of the curved clips, and indocyanine green (ICG) videoangiography confirmed flow in the draped, adherent arteries.



A B

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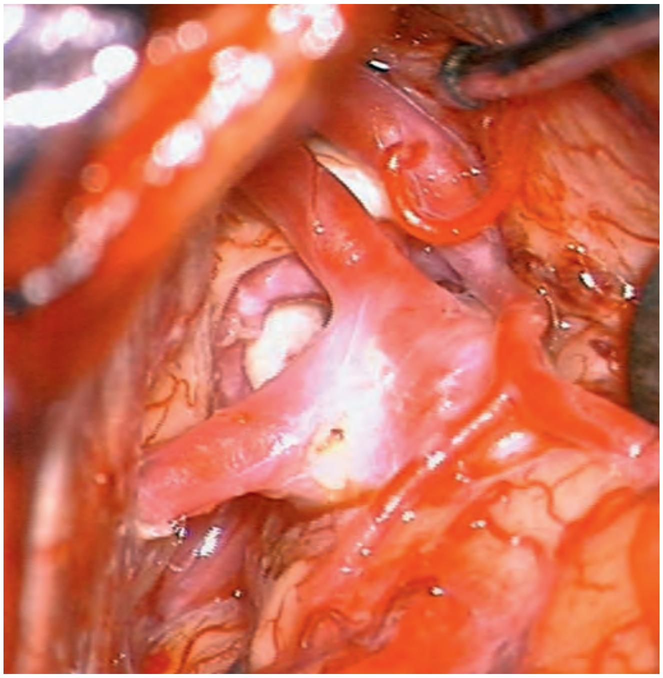
**Fig. 18.10** This left PcaA aneurysm in this 43-year-old man ruptured and was treated endovascularly. His 2-year follow-up angiogram showed coil compaction and recurrence. **(A)** Through a bifrontal craniotomy and the anterior interhemispheric approach, the aneurysm was exposed in the bifurcation between the PcaA and the CmaA, with the CmaA being the larger branch. The aneurysm projected to the left, and most of the neck was clipped with a curved clip that crossed a strand of coil in the neck. **(B)** The dog-ear remnant was closed with two curved mini-clips. **(C)** An overview down the anterior interhemispheric fissure showed that PcaA aneurysms, even those on the left side, can be accessed from the right side of the midline to avoid veins and retraction on the dominant hemisphere.

curves under the genu of the corpus callosum, away from the neurosurgeon, can be difficult. It is easier to take this precaution before rather than after intraoperative rerupture. The afferent ACA may be accessed underneath the aneurysm, between the PcaA and the CmaA, rather than anterior to the aneurysm, due to the artery's curve around the genu of the corpus callosum (**Fig. 18.7**). Previously coiled aneurysms and a large aneurysm with unusual branches may require sophisticated clipping techniques using stacked clips, tandem clipping, or fenestration tubes (**Figs. 18.9, 18.10, 18.11, and 18.12**). An azygos ACA can bifurcate, trifurcate, or quadrifurcate at the base of an associated aneurysm, and each branch is reconstructed and preserved with the repair (**Fig. 18.12**).



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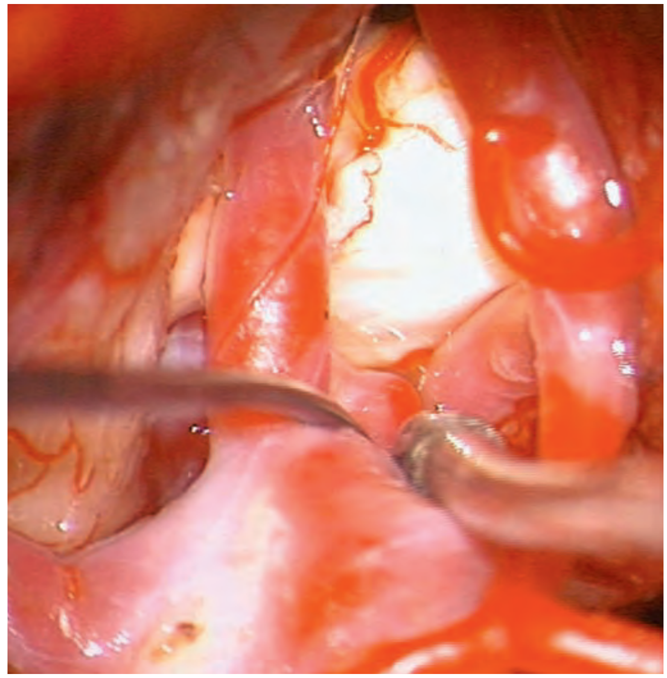

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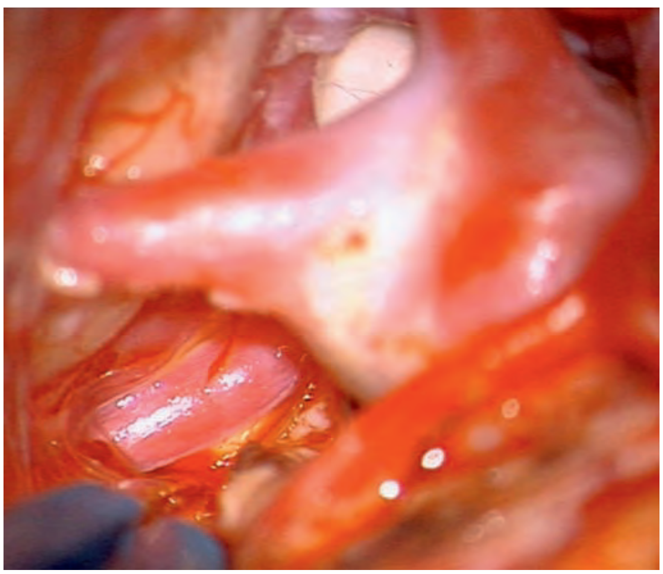
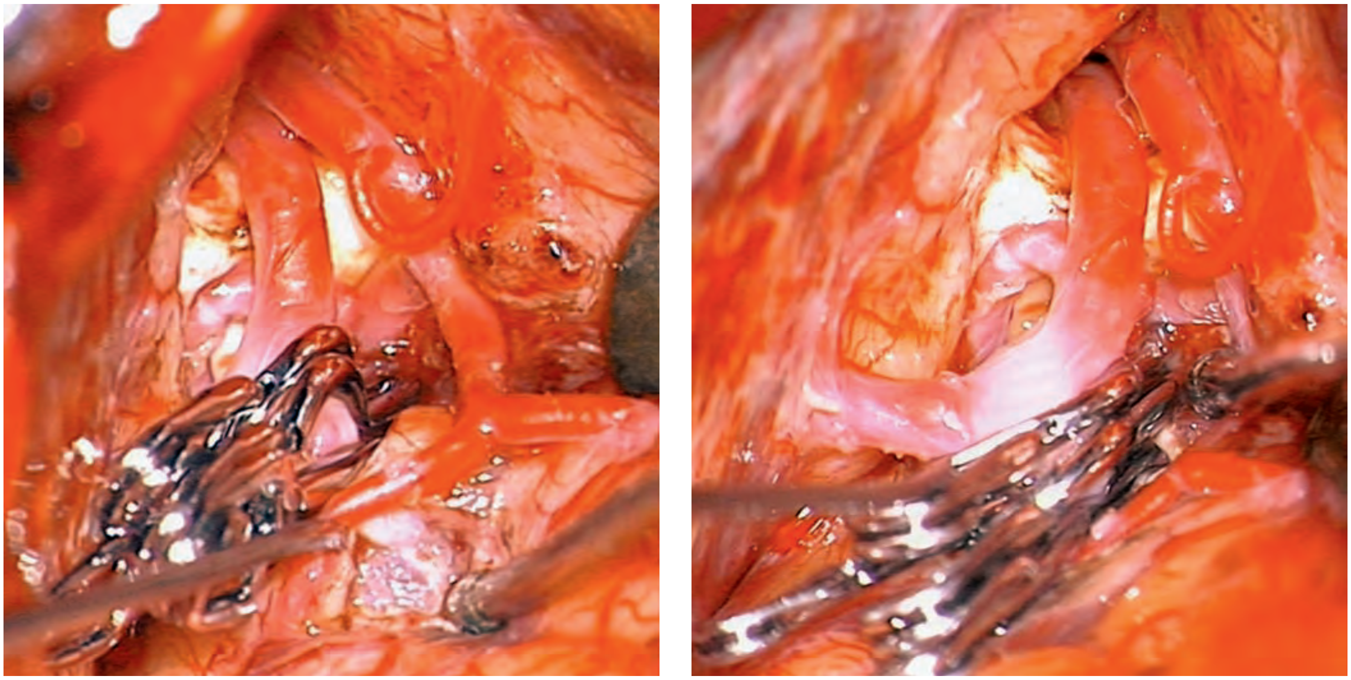


C

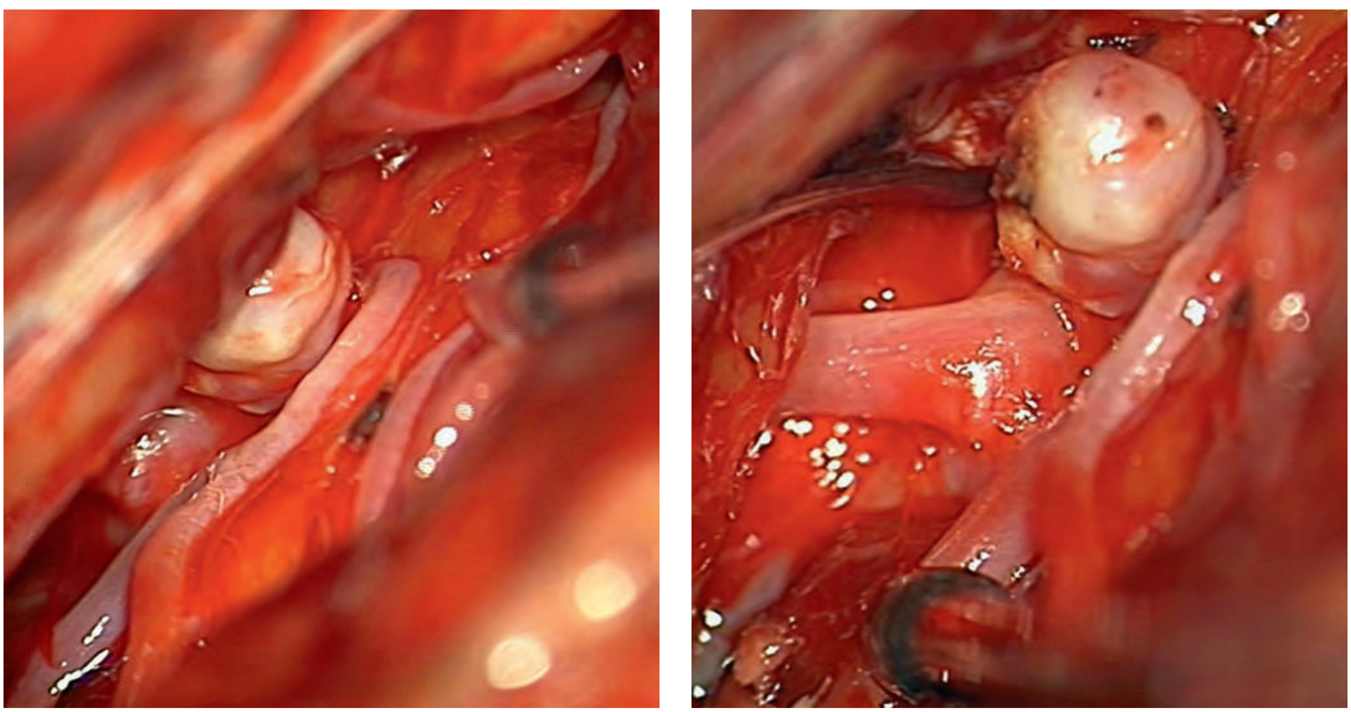
**Fig. 18.11** **(A)** This large left PcaA aneurysm in a 62-year-old man had a broad base and unusual branching of the PcaA. Both ACAs and both CmaAs were easily identified in the anterior interhemispheric fissure. **(B)** With some manipulation of the aneurysm to the left, the contralateral PcaA was visualized, and the efferent PcaA was seen originating from the bottom of the aneurysm. **(C)** This left PcaA coursed behind the aneurysm and was followed distally along corpus callosum. (*continued on next page*)



D

E

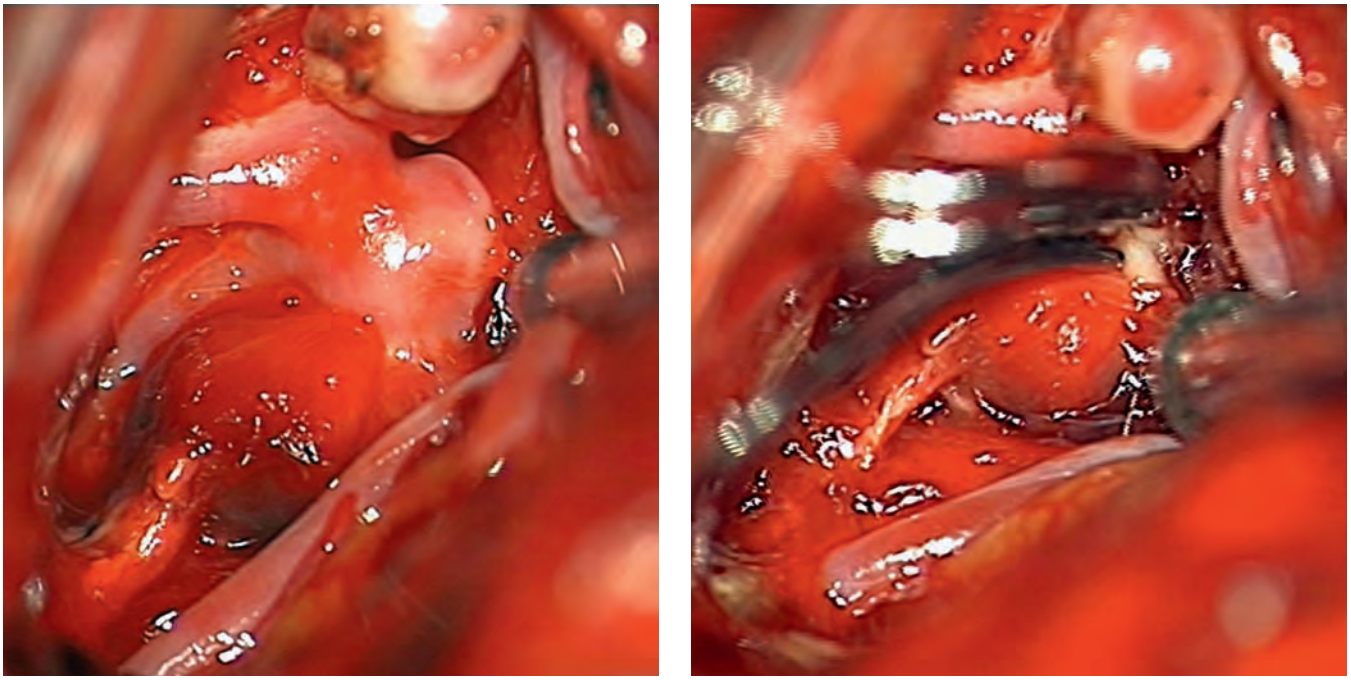
**Fig. 18.11** (*Continued*) **(D)** The neck was reconstructed with a retrograde fenestration tube, with two stacked straight fenestrated clips around the origin of the left CmaA and a stacked straight clip closing the fenestration. **(E)** The tips of the clips carefully avoided the contralateral PcaA.



A

B

**Fig. 18.12** **(A)** This 73-year-old man presenting with an SAH had an azygos ACA that ended in a trifurcation into the left PcaA, left CmaA, and a right ACA trunk. Two distinct aneurysms were seen in this trifurcation. An early view in the anterior interhemispheric fissure revealed the anterior aneurysm and the right ACA, which then divided into the right PcaA and CmaA. **(B)** The anterior aneurysm has been mobilized and the left CmaA is seen.

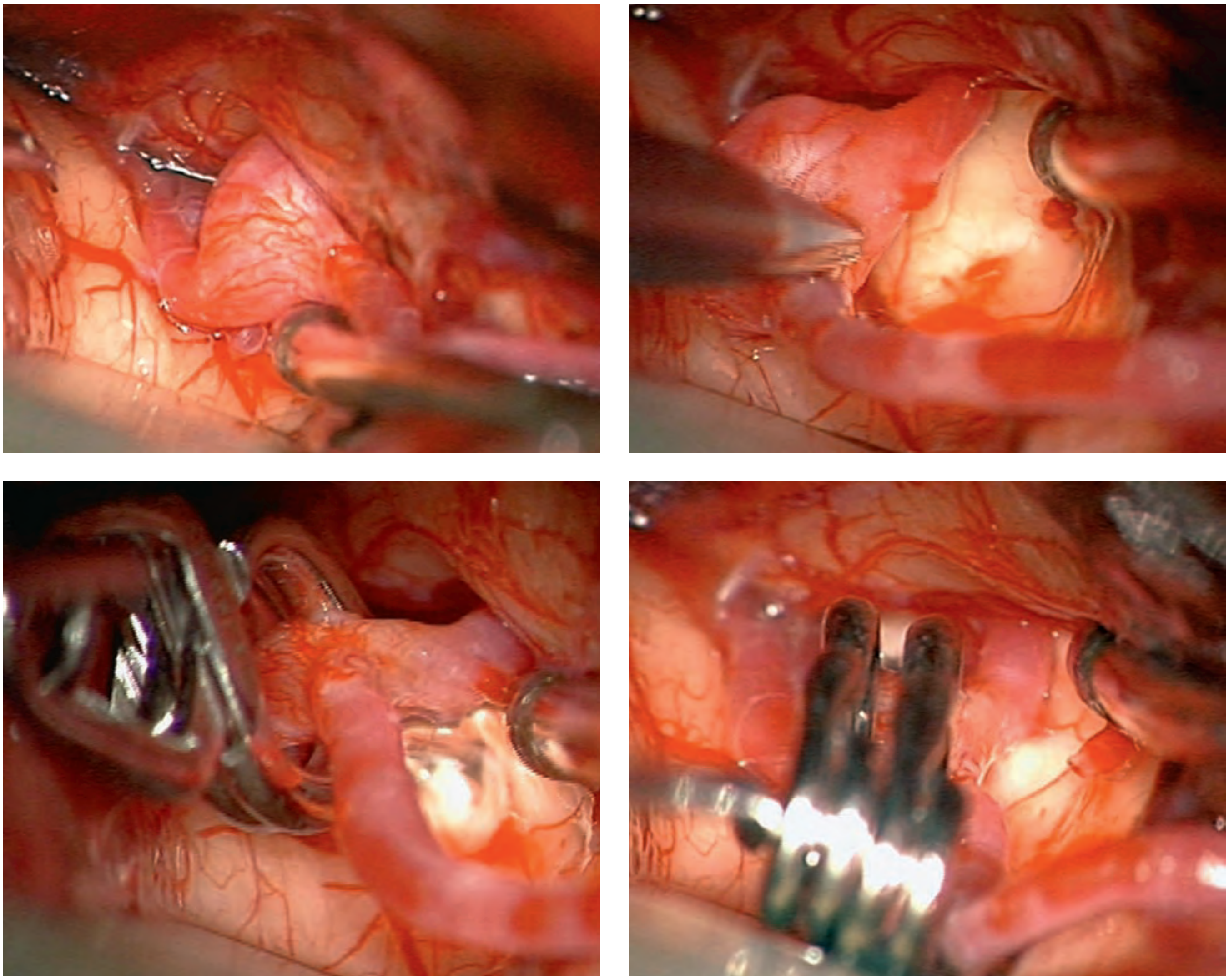


C

D

E

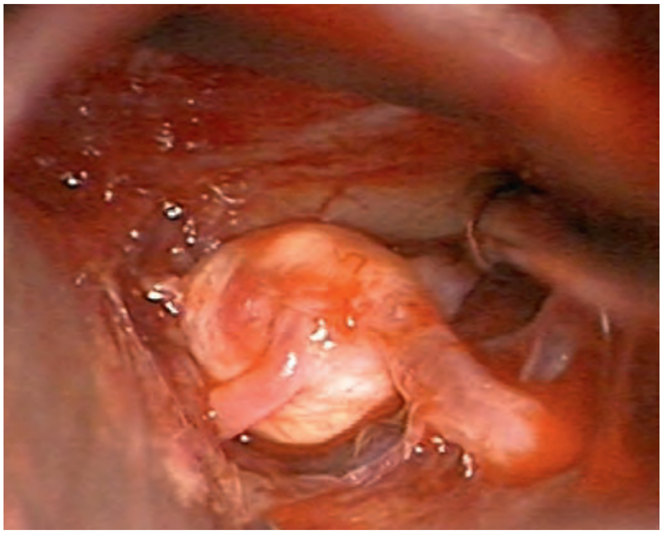
**Fig. 18.12** (*Continued*) **(C)** The posterior aneurysm projected to the right and originated between the left CmaA and PcaA. **(D)** This posterior aneurysm appeared to be the ruptured aneurysm and was clipped first with a straight clip. **(E)** The anterior aneurysm was clipped with a curved clip. The single azygos ACA was visualized coursing in front of the aneurysm complex, along the genu of the corpus callosum.



A B C D

**Fig. 18.13** This right distal PcaA aneurysm in a 48-year-old woman was far enough posterior to turn the head laterally to the right and use gravity retraction open the interhemispheric fissure. **(A)** The surgical trajectory angled back under some large bridging veins, and the ACA was followed posteriorly to the aneurysm base and the right CmaA. **(B)** The right PcaA was identified on the opposite side of the aneurysm base. **(C)** The aneurysm was clipped with two stacked fenestrated clips transmitting the right CmaA through the fenestration. **(D)** This surgical perspective provided a good view of the inflow and outflow arteries, but the aneurysm projects away from the neurosurgeon and is more difficult to visualize.

Distal PcaA aneurysms are viewed from a different perspective than proximal PcaA aneurysms. The aneurysm axis, dome, and the convergence of the PcaA and the CmaA all project away from the neurosurgeon and require clipping with fenestrated clips (**Figs. 18.6C and 18.13**) or intersecting curved clips (**Fig. 18.14**). Head trauma can cause shearing of the distal PcaA against the free edge of the falx and arterial injury, resulting in pseudoaneurysm formation. These pseudoaneurysms are approached like distal saccular aneurysms (**Fig. 18.15**).



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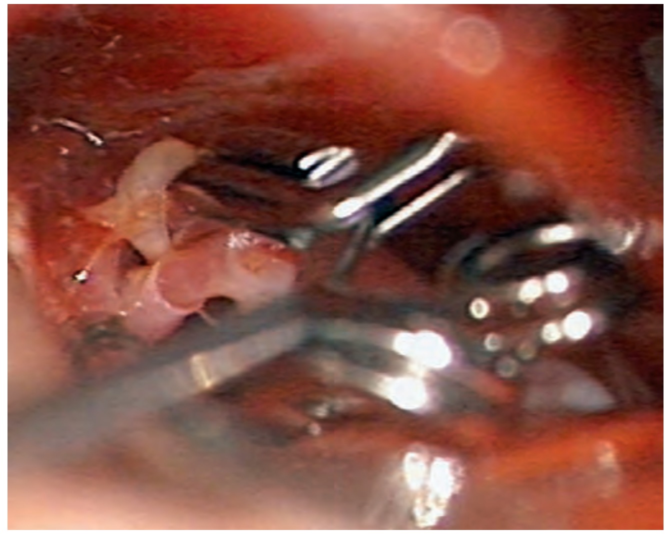

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**Fig. 18.14** An alternative to fenestrated clips for distal PcaA aneurysms is intersecting curved clips. **(A)** This left distal PcaA aneurysm was far enough posterior to turn the head laterally to the right and use gravity retraction open the interhemispheric fissure. **(B)** The superior neck of the aneurysm was clipped with a down-curved clip, and **(C)** the inferior neck was clipped with an up-curved clip. The clip blades must intersect to completely close the neck.

The interhemispheric fissure is a good location for in situ bypasses. The ACAs run parallel to each other and can be anastomosed side to side to revascularize the distal territories (A3-A3 in situ bypass). An efferent artery that is compromised by the aneurysm clipping or deliberately occluded can be mobilized and reimplanted on a contralateral artery (e.g., left-to-right PcaA reimplantation) or on an ipsilateral artery (e.g., PcaA-CmaA reimplantation, **Fig. 18.16**). Other bypass options in the interhemispheric fissure include aneurysm excision with reanastomosis of the parent artery, and reconstruction that uses a radial artery interposition graft. The interhemispheric fissure is a deep corridor, but gravity retraction opens the corridor to facilitate the anastomosis. Traditional extracranial-intracranial bypasses are not as favorable at this location. The superficial temporal artery does not reach down into the interhemispheric fissure; vein grafts from the cervical carotid artery or the trunk of the temporal artery are long, prone to delayed occlusion, and mismatched in size with the recipient artery.

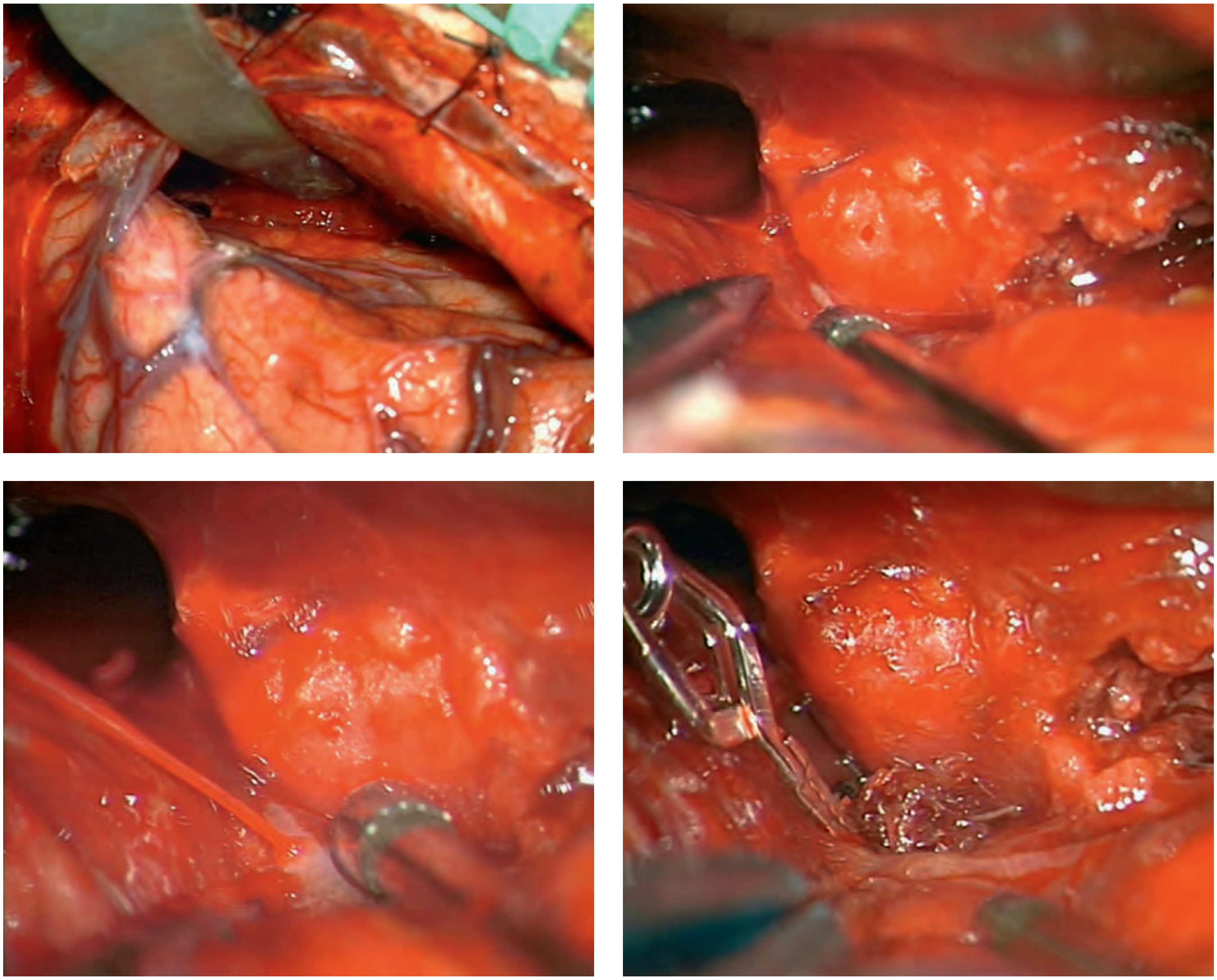

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**Fig. 18.15** The distal PcaA territory is a site of pseudoaneurysm formation, albeit rare, where the PcaA can shear against the free edge of the falx. **(A)** A right distal PcaA aneurysm was diagnosed in an elderly woman after a fall and head trauma. The aneurysm was exposed through an anterior interhemispheric approach with the head turned to the right. **(B)** A large clot was found at the location of the aneurysm. **(C)** Dissection along the base of the clot revealed this to be a pseudoaneurysm. Bleeding from the arterial tear was controlled with a temporary clip, and **(D)** the tear was closed with the tips of a straight clip.

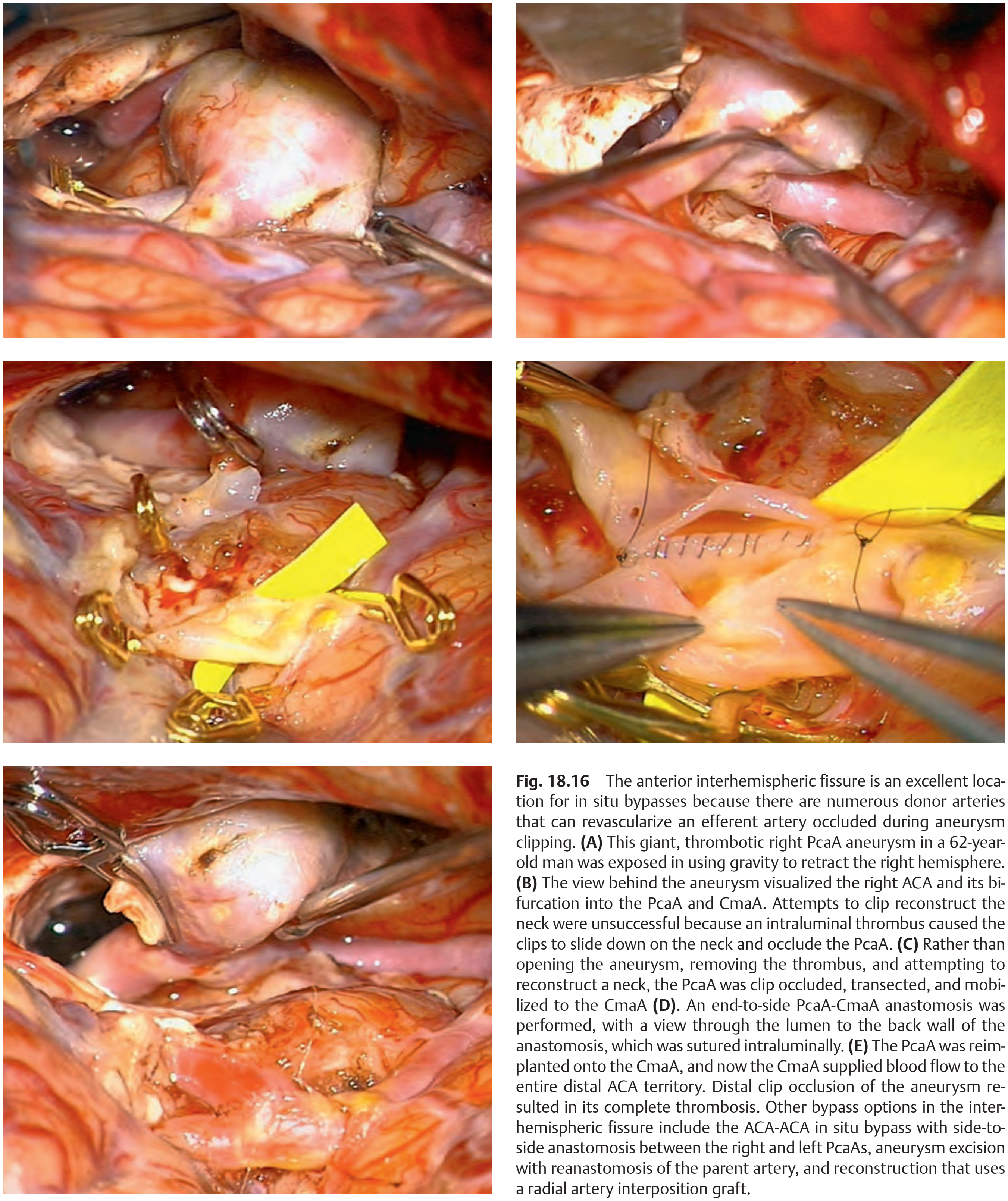

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**Fig. 18.16** The anterior interhemispheric fissure is an excellent location for in situ bypasses because there are numerous donor arteries that can revascularize an efferent artery occluded during aneurysm clipping. **(A)** This giant, thrombotic right PcaA aneurysm in a 62-year-old man was exposed in using gravity to retract the right hemisphere. **(B)** The view behind the aneurysm visualized the right ACA and its bifurcation into the PcaA and CmaA. Attempts to clip reconstruct the neck were unsuccessful because an intraluminal thrombus caused the clips to slide down on the neck and occlude the PcaA. **(C)** Rather than opening the aneurysm, removing the thrombus, and attempting to reconstruct a neck, the PcaA was clip occluded, transected, and mobilized to the CmaA **(D)**. An end-to-side PcaA-CmaA anastomosis was performed, with a view through the lumen to the back wall of the anastomosis, which was sutured intraluminally. **(E)** The PcaA was reimplanted onto the CmaA, and now the CmaA supplied blood flow to the entire distal ACA territory. Distal clip occlusion of the aneurysm resulted in its complete thrombosis. Other bypass options in the interhemispheric fissure include the ACA-ACA in situ bypass with side-to-side anastomosis between the right and left PcaAs, aneurysm excision with reanastomosis of the parent artery, and reconstruction that uses a radial artery interposition graft.

# 19 Basilar Artery Bifurcation Aneurysms

## Microsurgical Anatomy

The basilar artery terminates in a quadrifurcation from which two posterior cerebral arteries (PCAs) and two superior cerebellar arteries (SCAs) originate (**Fig. 19.1**). The P1 segment of the PCA begins at the basilar bifurcation and ends at the junction with the posterior communicating artery (PCoA). This *precommunicating segment* is typically larger in caliber than the PCoA, but may be smaller in patients with fetal anatomy. The P2 segment or *postcommunicating segment* begins at the junction with the PCoA and ends lateral to the posterior margin of the midbrain. It is sometimes divided into anterior and posterior halves. The P2A segment or *crural segment* courses around the cerebral peduncle to its lateral edge through the crural cistern, and the P2P segment or *ambient segment* courses around the lateral midbrain through the ambient cistern. The P3 segment or *quadrigeminal segment* begins lateral to the posterior margin of the midbrain, climbs over the free edge of the tentorium, courses through the quadrigeminal cistern, and ends at the anterior limit of the calcarine fissure. The PCA typically branches along this segment into its major terminal arteries: the calcarine and parieto-occipital arteries. The P4 segment or *calcarine segment* begins at the anterior limit of the calcarine fissure and ends at the cortical surface of the occipital lobe.

The nomenclature of numbered arterial segments ends in the supratentorial compartment, but the infratentorial arteries also have well-defined segmental anatomy. The SCA is divided into four segments: *anterior pontomesencephalic*, *lateral pontomesencephalic*, *cerebellomesencephalic*, and *cortical*. The anterior pontomesencephalic segment begins at the SCA origin, courses underneath the CN3, and ends at the anterolateral brainstem, medial to the tentorial edge. The lateral pontomesencephalic segment begins at the anterolateral brainstem, dips caudally to the trigeminal root, and terminates at the entrance to the cerebellomesencephalic fissure. The cerebellomesencephalic segment courses posteriorly within this fissure, following the trochlear nerve and superior cerebellar peduncle. The cortical segment begins as distal branches exit the cerebellomesencephalic fissure and supply the cerebellum's tentorial surface. Variations in SCA anatomy include a common origin with the PCA or an origin from the P1 segment. Dissection of basilar bifurcation aneurysms does not depend on the distal anatomy of the PCA and SCA, only the P1 segments bilaterally, anterior pontomesencephalic SCA segments bilaterally, basilar trunk, and thalamoperforating arteries.

The *posterior thalamoperforators* arise from the P1 segments, with the majority arising from the middle third as individual branches or branching trunks that can be bilateral and symmetric, bilateral and asymmetric, or unilateral with bilateral territory (*artery of Percheron*) (**Fig. 19.2**). The posterior thalamoperforators supply the anterior and part of the posterior thalamus, hypothalamus, subthalamus, medial midbrain, substantia nigra, red nucleus, oculomotor and trochlear nuclei, oculomotor nerve, reticular formation, and posterior internal capsule. Thalamoperforator compromise can cause somatesthetic disturbances, weakness, memory deficits, autonomic imbalance, diplopia, alterations of consciousness, and endocrine disturbances.

The peduncular and thalamogeniculate perforators arise from the P2 segments and also ascend superiorly. The long and short circumflex perforators originate from the P1 and P2 segments but they course parallel and medial to the PCA rather than ascending. The medial posterior choroidal artery originates from the P1 segment, and its course resembles that of the circumflex arteries, traveling through crural, ambient, and quadrigeminal cisterns, coursing over the superior colliculus and pineal gland to reach the choroid plexus in the roof of the third ventricle and the floor of the lateral ventricles.

In contrast to the posterior thalamoperforators, the anterior thalamoperforators arise from the PCoA along its superior and lateral surfaces. These "premamillary" arteries course superiorly to the floor of the third ventricle in front of the mamillary bodies and supply the posterior hypothalamus, anterior thalamus, posterior limb of internal capsule, and subthalamus. The PCoA itself can have normal anatomy and complete the posterior half of the circle of Willis. The PCoA has a reciprocal relationship with the P1 segment; diminutive or absent PCoAs are associated with large P1 segments, whereas fetal PCoAs are associated with hypoplastic P1 segments (**Fig. 19.2**).

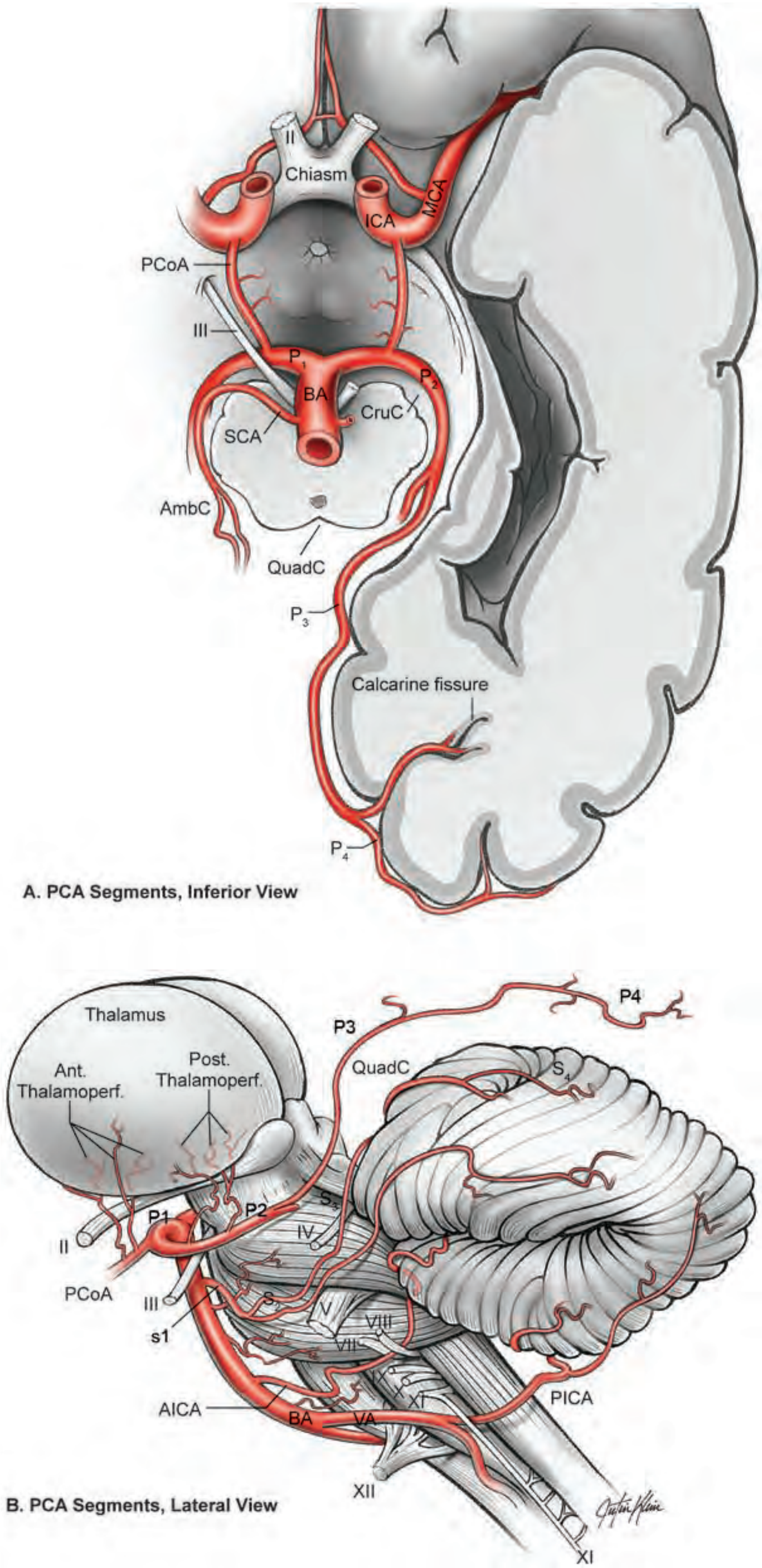
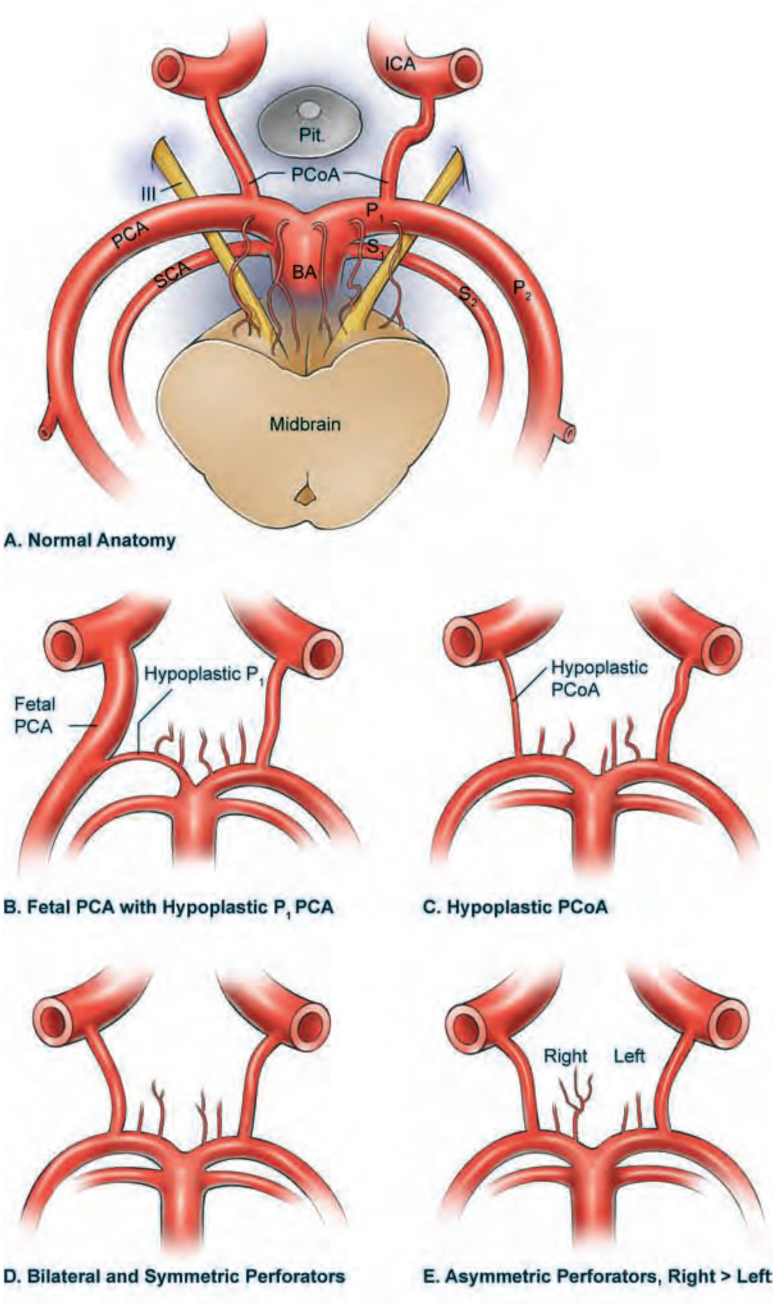



**Fig. 19.1** Microsurgical anatomy of the basilar artery (BA) apex and posterior cerebral artery (PCA). Inferior **(A)** and lateral **(B)** views of the basilar quadrifurcation and the PCA segments: P1, precommunicating segment; P2, postcommunicating segment (P2A, crural segment, and P2P, ambient segment); P3, quadrigeminal segment; and P4, calcarine segment. The superior cerebellar artery (SCA) also divides into four segments: s1, anterior pontomesencephalic segment; s2, lateral pontomesencephalic segment; s3, cerebellomesencephalic segment; and s4, cortical segment. AICA, anterior inferior cerebellar artery; AmbC, ambient cistern; CruC, crural cistern; ICA, internal carotid artery; MCA, middle cerebral artery; PCoA, posterior communicating artery; PICA, posterior inferior cerebellar artery; QuadC, quadrigeminal cistern; VA, vertebral artery.



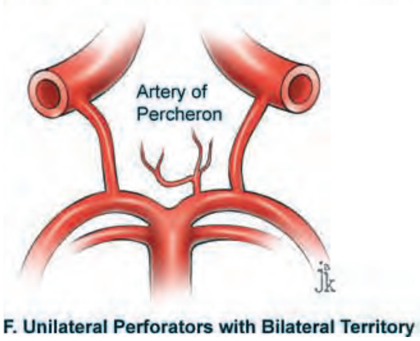




**Fig. 19.2** **(A)** Classic anatomy with large, symmetrical PCoAs completing the posterior circle of Willis. The PCoA has a reciprocal relationship with the P1 segment: **(B)** a fetal PCA is associated with a hypoplastic P1 segment, and **(C)** a diminutive or hypoplastic PCoA is associated with a large P1 segment. **(D)** Posterior thalamoperforators arise from the P1 segments, with the majority arising from the middle third as individual branches or branching trunks that can be bilateral and symmetric, **(E)** bilateral and asymmetric, or **(F)** unilateral with bilateral territory (artery of Percheron). Pit., pituitary.

## Aneurysm Dissection Strategy

Basilar bifurcation aneurysms are approached from the right side to avoid the dominant hemisphere, unless the aneurysm anatomy favors a left-sided approach, left oculomotor palsy already exists, right hemiparesis already exists, or additional left-sided aneurysms will also be clipped. The orbitozygomatic approach is used routinely, and microdissection begins with a wide splitting of the sylvian fissure to expose the middle cerebral artery (MCA) bifurcation and the M1 segment. The lamina terminalis is fenestrated early to relax the brain.

The view of the basilar apex from a transsylvian perspective is blocked by the optic nerve and the supraclinoid internal carotid artery (ICA). Three anatomic triangles provide a view through or around these obstacles: the optic-carotid triangle, the carotid-oculomotor triangle, and the supracarotid triangle (**Fig. 19.3**). The *optic-carotid triangle* is bordered medially by the optic nerve, laterally by the supraclinoid ICA, and posteriorly by the A1 segment. It provides a medial-superior view of the pituitary stalk, mamillary bodies, interpeduncular fossa, and high-riding aneurysms. This triangle is small and confining, with limited maneuverability. The *supracarotid triangle* lies above the ICA bifurcation, bordered by the A1 segment medially, the M1 segment laterally, and the basomedial frontal lobe superiorly. This triangle provides a view of the basilar apex when the supraclinoid ICA is short, atherosclerotic, or difficult to retract medially, but it is obstructed by passing perforators from the ICA bifurcation that supply the anterior perforated substance, caudate nucleus, putamen, globus pallidus, superior half of the internal capsule, and anterior thalamus. The *carotid-oculomotor triangle* is bordered by the ICA medially, the oculomotor nerve laterally, and the uncus posteriorly. It is the largest of the three triangles and can be widened by retracting the ICA medially, working lateral to the oculomotor nerve, and mobilizing the temporal lobe posteriorly. This triangle provides the best panorama of the basilar apex.

The anterior temporal lobe covers the operative corridor through the carotid-oculomotor triangle, and 2 to 3 cm of the temporal lobe retraction posteriorly uncovers it. The temporal lobe retracts naturally in a posterolateral direction if it is

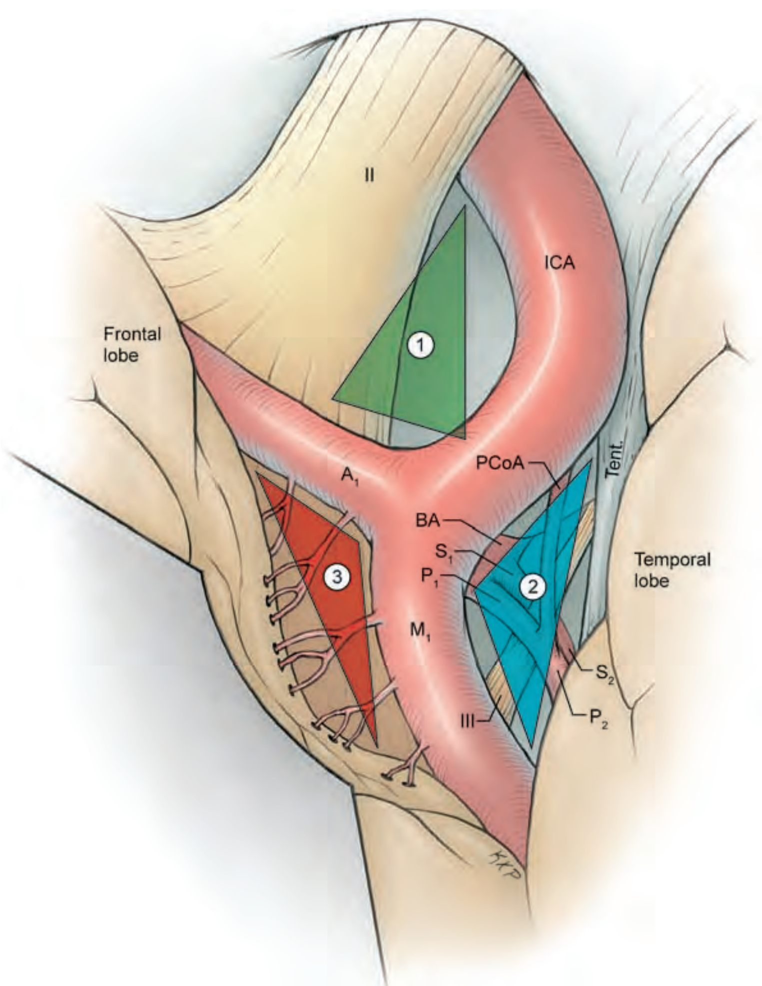



**Fig. 19.3** Anatomic triangles providing access to the basilar bifurcation: 1, optic-carotid triangle; 2, carotid-oculomotor triangle; and 3, supracarotid triangle. The carotid-oculomotor triangle is the one used most commonly for basilar bifurcation aneurysms. Tent., tentorium.

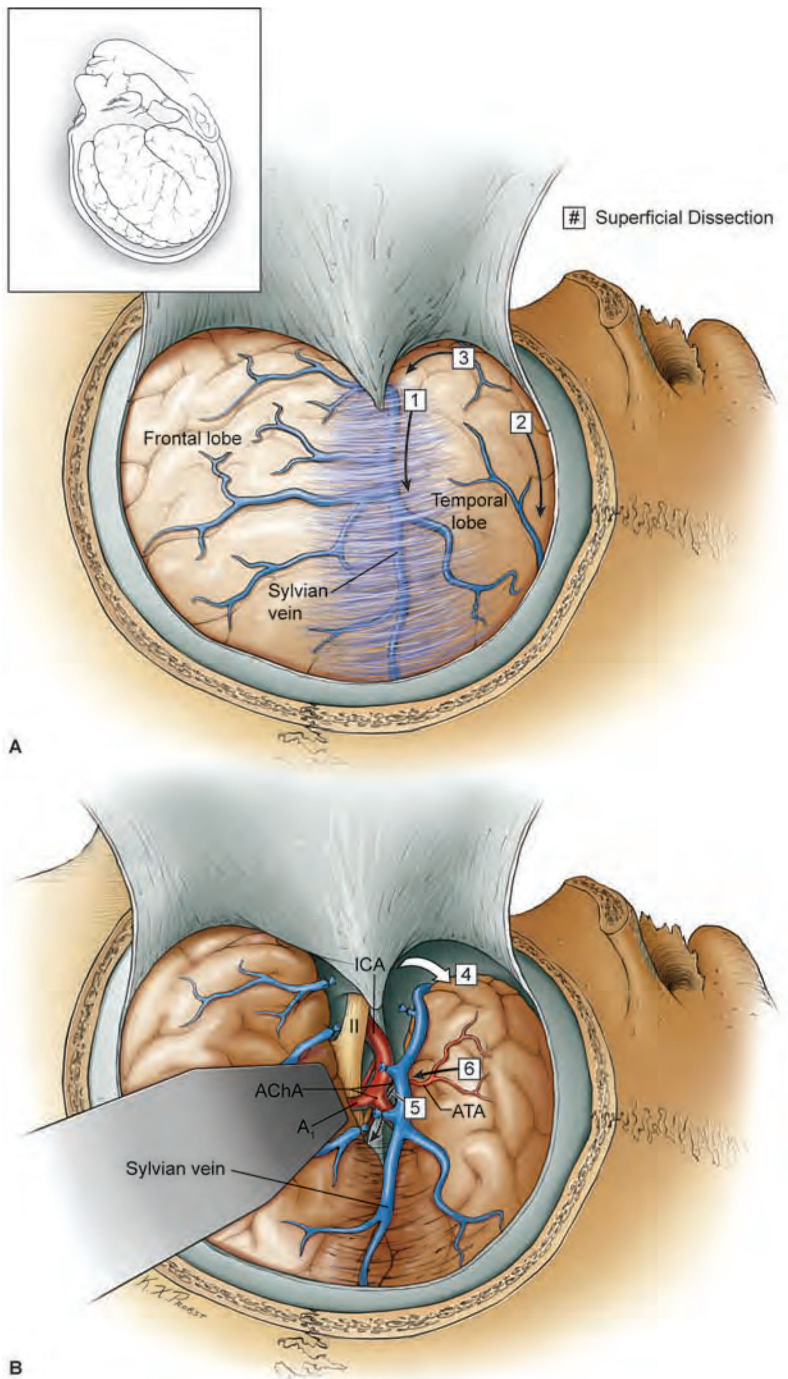



**Fig. 19.4** Superficial dissection strategy for basilar bifurcation aneurysms. Detaching and mobilizing the anterior temporal lobe opens the operative corridor through the carotid-oculomotor triangle. **(A)** Splitting the sylvian fissure separates the frontal and temporal lobes (step 1); cutting arachnoid adhesions and granulations along the middle fossa floor frees the inferior temporal lobe (step 2); and dividing the temporopolar vein untethers the anterior temporal lobe (step 3). **(B)** The temporal lobe now mobilizes posterolaterally, opening the pretemporal corridor (step 4). Dissection along the cisternal segment of the anterior choroidal artery (AChA) releases the medial temporal lobe (step 5). Dissection along the anterior temporal artery (ATA) allows more posterior mobilization of the temporal lobe (step 6).

detached on all sides (**Fig. 19.4**). The superior temporal lobe is separated from the frontal lobe by splitting the sylvian fissure (**Fig. 19.4**, step 1); the inferior temporal lobe is freed from the middle fossa floor by cutting the arachnoid adhesions, dividing any bridging veins, and cauterizing the arachnoid granulations (**Fig. 19.4**, step 2); and the anterior temporal lobe is untethered by sacrificing the vein to the sphenoparietal sinus (**Fig. 19.4**, step 3). Systematic release of these attachments allows the temporal lobe to retract posterolaterally (**Fig. 19.4**, step 4). The inferior edge of the craniotomy will not impede lateral retraction if it has been properly drilled down to the middle fossa floor. The remaining attachments along the medial temporal lobe are released by dissecting the anterior choroidal artery (AChA) along its cisternal segment (**Fig. 19.4**, step 5). After originating from the ICA, the AChA courses along the medial uncus, follows the

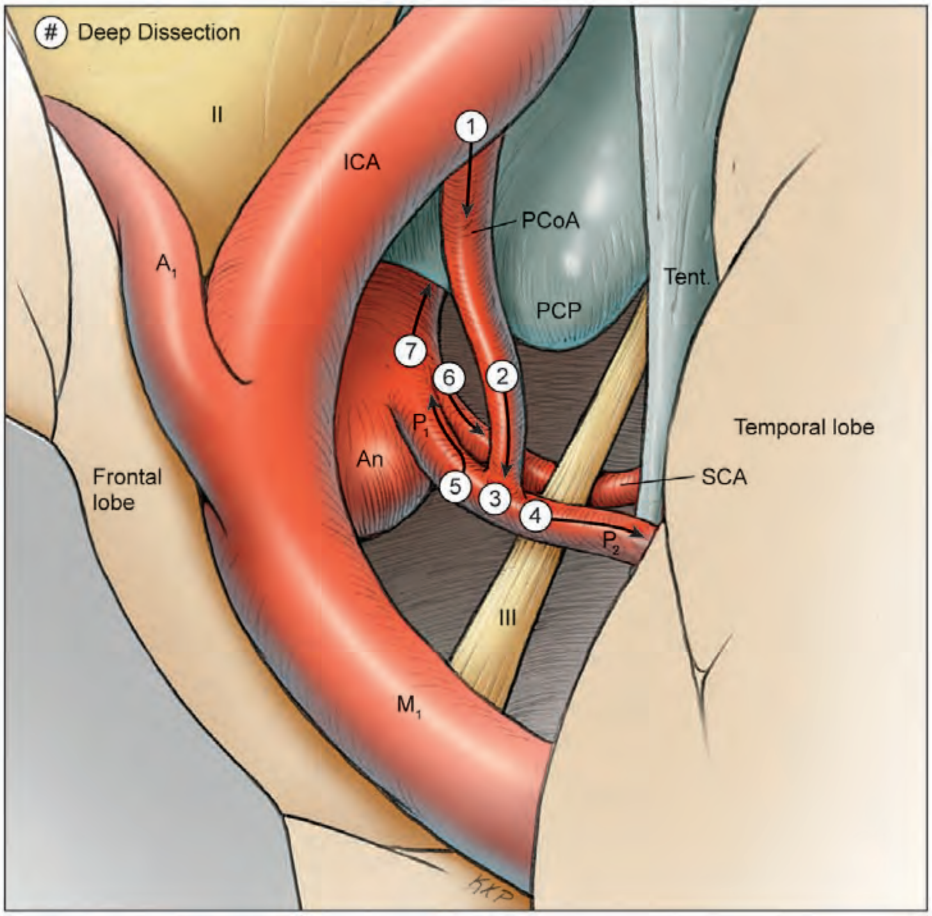



**Fig. 19.5** Deep dissection strategy for basilar bifurcation aneurysms. Step 1, identifying the PCoA as it originates from the ICA; steps 2 and 3, following the PCoA to the P1-P2 junction; step 4, dissecting the P2 segment laterally over the oculomotor nerve to the tentorial edge; step 5, dissecting the inferior surface of the P1 segment medially through Liliequist's membrane; step 6, identifying the SCA; and step 7, securing proximal control on the basilar trunk. An, aneurysm.

optic tract to the lateral aspect of the cerebral peduncle, and enters the crural cistern. AChA dissection, therefore, opens the tentorial incisura and crural cistern, identifies the P2 segment, liberates the oculomotor nerve, exposes the cerebral peduncle, and, in the process, releases the medial temporal lobe. A temporal lobe retractor positioned with its tip on the uncus and its blade against the lateral temporal lobe widens the carotid-oculomotor triangle posteriorly and opens a pretemporal corridor through the middle cranial fossa.

Temporal lobe retraction can avulse the anterior temporal artery (ATA) from the M1 segment. Dissection along the ATA relieves retraction tension on this artery and allows more posterior mobilization of the temporal lobe (**Fig. 19.4**, step 6). Occasionally it may require sacrifice. The ATA supplies a silent territory in the nondominant hemisphere and can be occluded without sequelae, whereas an avulsed ATA can injure the M1 segment and cause ischemic complications.

Dissection down to the carotid-oculomotor triangle begins by identifying the PCoA as it originates from the ICA (**Fig. 19.5**, step 1) and following it to the P1-P2 junction (**Fig. 19.5**, step 2 and 3). The P2 segment is dissected laterally over the oculomotor nerve out to the tentorial edge to open the posterior portion of the triangle (**Fig. 19.5**, step 4). When anatomic landmarks are buried in clot from the aneurysm rupture, the same steps are taken and the clot is carefully evacuated to excavate these guiding arteries.

After one has identified the posterolateral borders of the carotid-oculomotor triangle, the P1 segment is followed proximally to Liliequist's membrane, and the interpeduncular cistern is opened (**Fig. 19.5**, step 5). This dense arachnoid sheet extends from the dorsum sellae to the mamillary bodies and between the oculomotor nerves, separating chiasmatic and interpeduncular cisterns. Liliequist's membrane is opened with an incision behind the posterior clinoid process and medial to the oculomotor nerve, extending posteriorly to the undersurface of the P1 segment, where it pierces the membrane. This incision avoids anteriorly projecting aneurysms that might be encountered with a more medial incision. It also leads to the undersurface of the P1 segment, which is the safe surface to follow medially to the SCA and the basilar trunk because it avoids the thalamoperforators and the aneurysm neck on the upper surface. The SCA lies below the oculomotor nerve and is crossed carefully with the incision in Liliequist's membrane (**Fig. 19.5**, step 6).

A short segment of the basilar trunk is secured for proximal control (**Fig. 19.5**, step 7). Numerous perforators originate from the distal basilar artery, but proximal dissection leads to a perforator-free zone below the SCA origins. Subarachnoid hemorrhage (SAH) may bury arteries in clot, and the arteries are excavated along their course proximal to the aneurysm to avoid the dome. Anteriorly projecting aneurysms may require a deeply descending route to the proximal basilar artery to avoid the dome. Proximal control enables dissection to return to the P1 segment, and its superior surface is traced proximally to the aneurysm neck (**Fig. 19.6**, step 8). The PCoA and its anterior thalamoperforators sweep superiorly to open the medial corridor. A small PCoA that tethers the P1 segment or compromises the view can be cauterized and divided if its anterior thalamoperforators can be preserved; the PCoA cannot be sacrificed with fetal anatomy or when permanent clipping is expected to compromise antegrade flow in the P1 segment. When the aneurysm neck is found, dissection shifts across the basilar apex to the contralateral SCA and PCA (**Fig. 19.6**, steps 9 and 10), saving perforator dissection for last. The contralateral SCA lies in the line of sight through the carotid-oculomotor triangle, and the contralateral oculomotor nerve is an orienting landmark that differentiates the SCA (below the nerve) from the PCA (above the nerve). Identification of the five major arteries (the basilar trunk, the bilateral PCAs, and the bilateral SCAs) gives the neurosurgeon vascular control, anatomic orientation, and clearance to dissect the aneurysm neck and thalamoperforators. The pathway across the anterior neck is easily visualized in the operative corridor (**Fig. 19.6**, step 11). The pathway across the posterior neck is not easily visualized and is saved for the final step, often with temporary clipping and mobilization of the aneurysm (**Fig. 19.6**, step 12).

The contralateral P1 segment, the distal aneurysm neck, and the deep thalamoperforators are difficult to dissect because space in the interpeduncular cistern and exposure at the depth of the surgical corridor are so limited. Aneurysm projection conceals this anatomy further, depending on

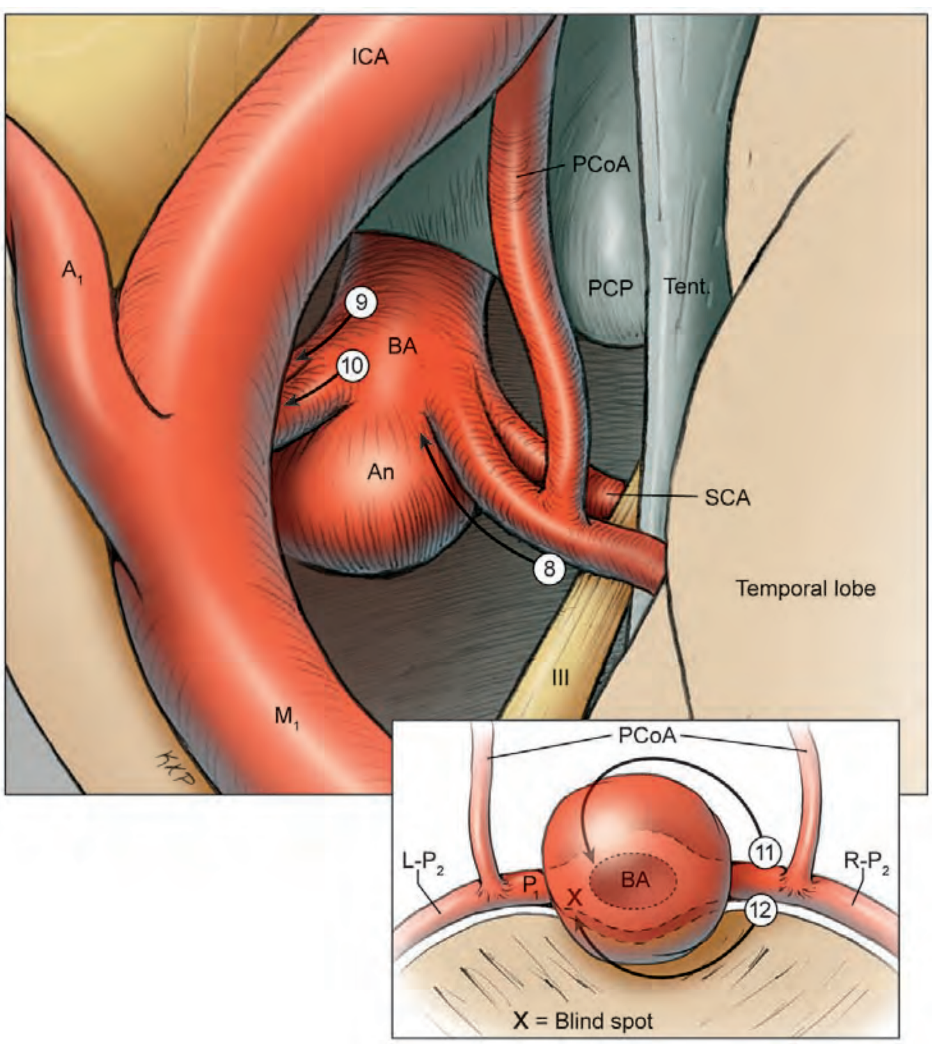



**Fig. 19.6** Deep dissection strategy for basilar bifurcation aneurysms. Step 8, dissecting the ipsilateral P1 segment along its superior surface proximally to the aneurysm neck; step 9, shifting across the basilar apex to identify the contralateral SCA; step 10, identifying the contralateral PCA and distal aneurysm neck; step 11, clearing a pathway across the aneurysm neck for the anterior clip blade; step 12, dissecting perforators across the posterior aneurysm neck for the posterior clip blade. Visualization of perforators in the blind spot (X) often requires temporary clipping and aneurysm mobilization. PCP, posterior clinoid process.

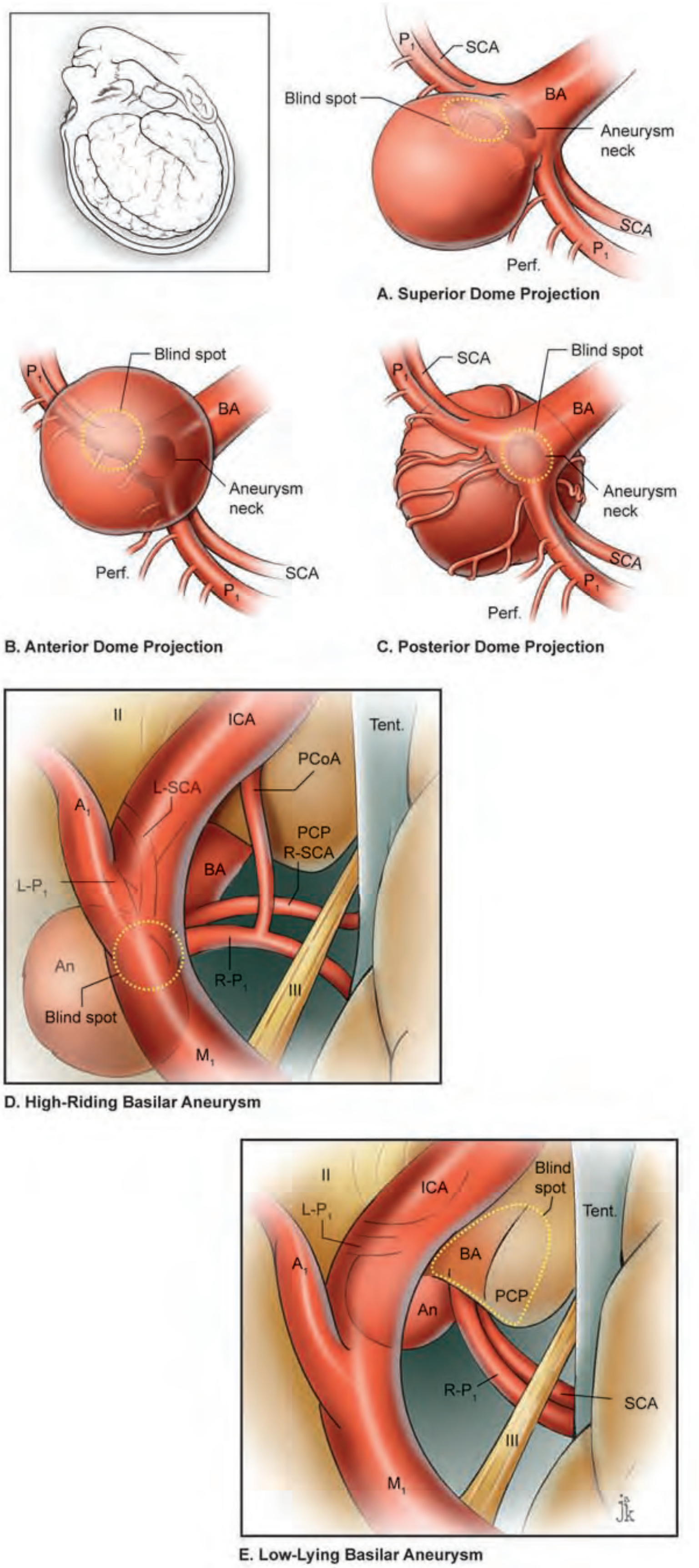



**Fig. 19.7** Variations in dome projection with basilar bifurcation aneurysms. **(A)** A superiorly projecting aneurysm creates a blind spot that hides the thalamoperforators (Perf.) behind the distal neck. **(B)** An anteriorly projecting aneurysm creates a blind spot that hides the contralateral PCA and SCA. **(C)** A posteriorly projecting aneurysm creates a blind spot that hides the thalamoperforators originating from the posterior base of the aneurysm. **(D)** High-riding basilar bifurcation aneurysms ascend out of the carotid-oculomotor window, and the ICA can create an additional blind spot. **(E)** Low-riding basilar bifurcation aneurysms descend out of the carotid-oculomotor window and are obstructed by the posterior clinoid process.

projection superiorly, anteriorly, or posteriorly. *Superior dome projection* is most common, and these aneurysms hide deep perforators behind the distal neck (**Fig. 19.7A**). The contralateral PCA and SCA are usually seen well with an anterior view facing the quadrifurcation. *Anterior dome projection* is least common, and these aneurysms hide the contralateral PCA and SCA (**Fig. 19.7B**). The neck is usually seen by working above and behind the aneurysm from the ipsi- to contralateral PCA. The thalamoperforators course away from the dome and are easier to dissect than with other basilar bifurcation aneurysms. *Posterior dome projection* hides the thalamoperforators, displacing them posteriorly and plastering them to the back wall, making this aneurysm the most difficult (**Fig. 19.7C**). The quadrifurcation is in full view, but the neck lies behind it and out of view. Many aneurysms have a dome projection that is *mixed*, like the large aneurysm that points superiorly but also has a posterior "rump" that can displace thalamoperforators. Final dissection hones in on the blind spots unique to each aneurysm.

Basilar bifurcation aneurysms tend not to have the twists and tilts that complicate other midline aneurysms such as the ACoA aneurysms. Even with asymmetrical basilar apex anatomy, the single afferent artery seems to orient these aneurysms squarely. However, their vertical position relative to the posterior clinoid process varies. Although 90% of basilar bifurcations lie within 1 cm of the dorsum sellae, this bifurcation can range from mamillary bodies rostrally to 1 cm below the pontomesencephalic junction caudally. *High-riding basilar bifurcation aneurysms* migrate out of the carotid-oculomotor window (**Fig. 19.7D**), and a steeper upward viewing angle is required, with more mobilization of the ICA or shifting into the optic-carotid window. With high-riding basilar aneurysms, the ICA can create a blind spot in addition to the one created by the aneurysm itself. High-riding basilar aneurysms have one anatomic advantage: their thalamoperforators course more inferiorly away from the dome and are easier to dissect away from the neck.

*Low-riding basilar bifurcation aneurysms* descend out of the carotid-oculomotor window and are obstructed by the posterior clinoid process (**Fig. 19.7E**). The posterior clinoid process occupies the anterior portion of the carotid-oculomotor triangle, filling the space lateral to the ICA, posterior to the tentorial edge, and medial to the oculomotor nerve. These aneurysms are dangerous because their low position can eliminate proximal control. A posterior clinoidectomy can access the proximal basilar trunk and regain control. A posterior clinoidectomy is simpler than an anterior clinoidectomy because it does not directly involve a major artery such as the ICA or a dural ring dissection. The ICA is medial to the posterior clinoid process (PCP) and can be retracted out of the way; the oculomotor nerve is lateral to the PCP and also can be retracted out of the way. Venous bleeding occurs with a posterior clinoidectomy because its dura converges with the posteromedial corner of the cavernous sinus, but can be controlled with injection of fibrin glue into the cavernous sinus through a site within the oculomotor triangle. The dura overlying the PCP is incised and a round, 2-mm-diameter diamond drill bit is used to reduce and remove this bone. Drilling progresses until the aneurysm is exposed, medially along the dorsum sellae, inferiorly into the clivus, or laterally under the CN3. Additional anatomy can be visualized by mobilizing the basilar artery posteriorly into the line of sight in the carotid-oculomotor triangle. Thalamoperforators associated with low-lying aneurysms course superiorly and intersect the path of the clip blades. Aneurysms with a particularly low position and lateral deviation can be accessed by cutting the tentorium behind the dural sheath of the trochlear nerve. The trochlear nerve is identified by pulling the tentorium inferolaterally and inspecting the arachnoid of the ambient cistern.

Perforator dissection begins ipsilaterally where arteries are visible without aneurysm manipulation. Hidden perforators on the contralateral side usually require temporary clipping, aneurysm softening, and some manipulation of the aneurysm. The temporary clip is applied lateral to the oculomotor nerve to keep the clip outside of the carotid-oculomotor triangle and away from the dissection. An aneurysm that remains tense after temporary clipping might require temporary clips on the PCoAs. Perforators are dissected away from the neck, deflecting the aneurysm rather than the perforators. They are mobilized off the aneurysm only enough to pass the blade of the clip rather than along their entire length. A clear line of dissection is developed from ipsi- to contralateral P1 origin. The first few millimeters of contralateral P1 PCA harbor the perforators that hide out of view, and perforators must be assumed present until proven otherwise. Contralateral PCA origin also determines the slope of the clip application. Therefore, a view into this tiny blind spot is critical.

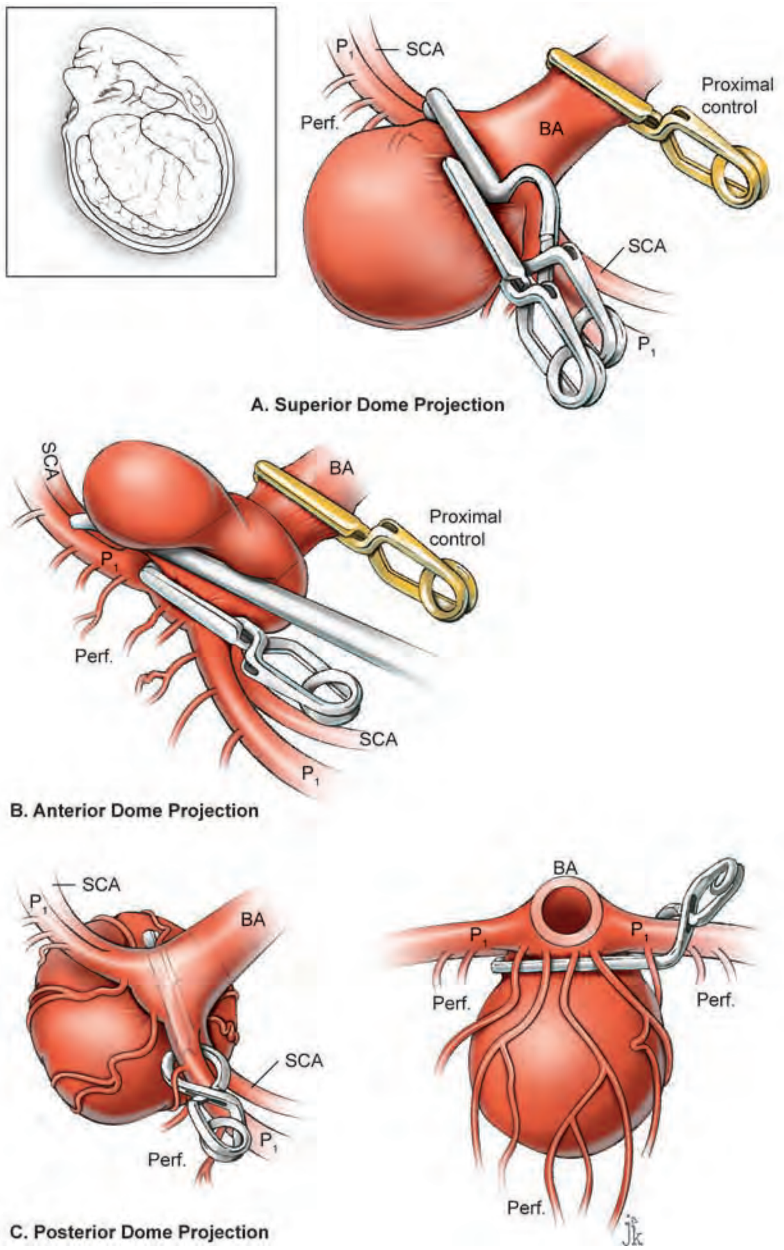



**Fig. 19.8** Clipping techniques for basilar bifurcation aneurysms. **(A)** Superiorly projecting aneurysms are clipped with an anterolateral clip trajectory, with narrow necks accommodating simple straight clips and wide necks requiring tandem clipping. **(B)** Anteriorly projecting aneurysms are clipped with a lateral clip trajectory, with the superior blade guiding the clip application. **(C)** Posteriorly projecting aneurysms are often clipped with fenestrated clips, navigating the blades around and under the ipsilateral PCA, SCA, and the collection of perforators (viewed from the anterolateral and inferior perspectives).

## Clipping Technique

As with perforator dissection, permanent clipping is facilitated by temporary clipping and aneurysm softening. Reperfusion after final dissection and before permanent clipping extends the next ischemic period. Both sides of the neck and the pathway for both clip blades are brought into one panoramic view. The shoulder of the contralateral P1 segment is the target for the clip's tips and sets the angle of clip application, but sometimes it is visible only after applying, partially releasing the clip, and squeezing the neck. In these cases, the clip performs some dissection and adjustments are made in the midst of clip application. The SCA can be mistaken for the PCA, which results in a clip that is too low on the quadrifurcation; the contralateral oculomotor nerve identifies an artery as the PCA or SCA. The cleavage plane between the contralateral P1 segment and the distal neck is thoroughly opened to seat the clip's tip on the shoulder of the P1 segment. Complete release of the clip may ovalize and elongate the distal neck beyond the tips. The tangential view along the clip blades is unavoidable at the depths of the basilar apex and may compromise the view along one side of the distal neck.

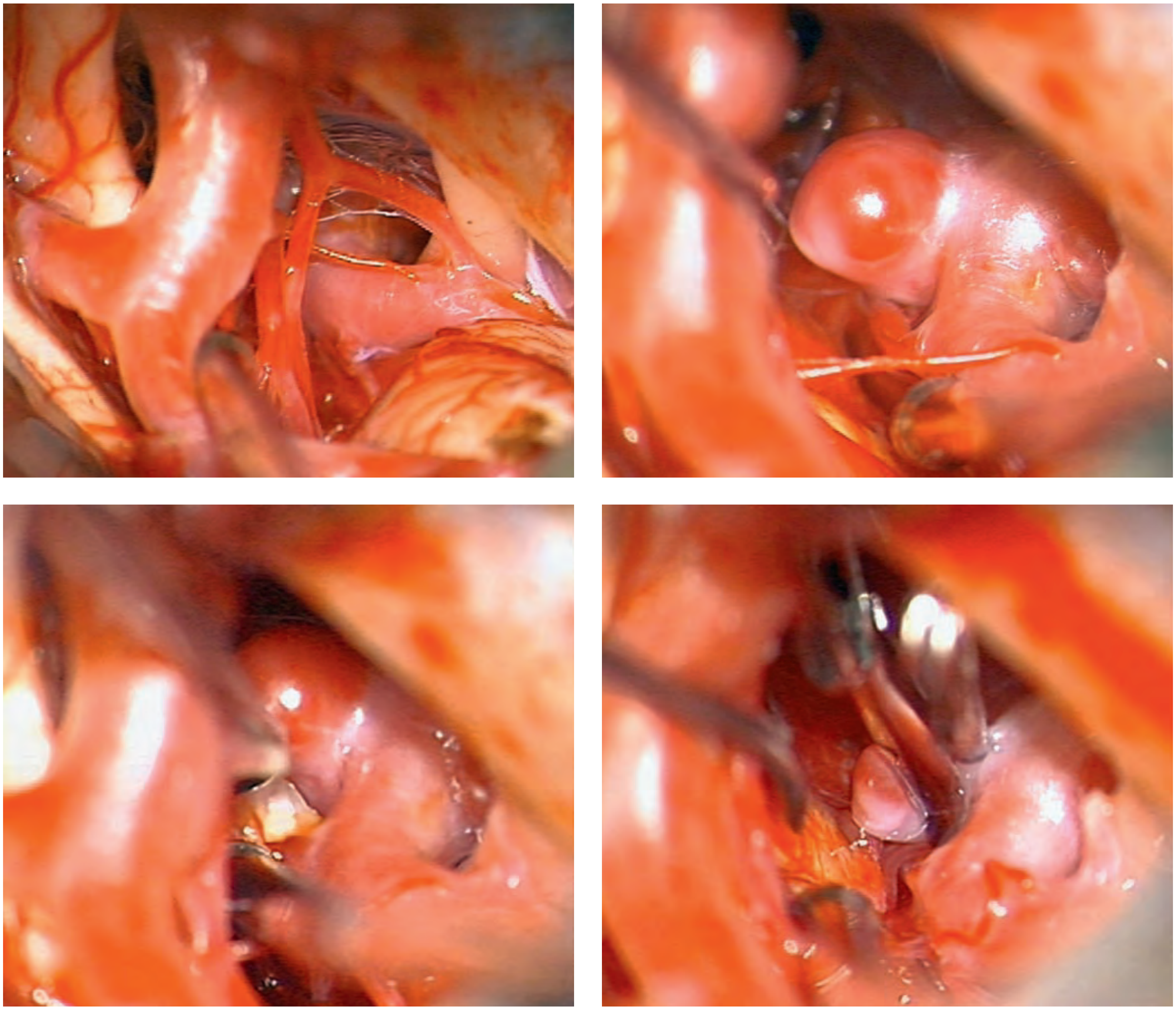


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**Fig. 19.9** This 61-year-old woman had a small basilar artery bifurcation aneurysm with simple anatomy, as seen through a right orbitozygomatic approach. **(A)** The carotid-oculomotor triangle is bordered by the ICA, CN3, and uncus, but it is not really a triangle. The free edge of the tentorium and proximal M1 segment of the MCA also contribute to the borders of this working space. The AChA runs through the triangle and its dissection through the crural cistern detaches the medial temporal lobe. The PCoA also runs through the triangle and is a guiding landmark to the P1-P2 junction of the PCA. **(B)** The aneurysm was easily visualized within the right carotid-oculomotor triangle, along with the five major arteries. A large thalamoperforator originating from the ipsilateral P1 segment coursed behind the neck. **(C)** This perforator was dissected away to open a plane behind the neck. **(D)** The first clip was angled inferiorly to gather all of the neck posteriorly, and the resulting anterior dog-ear was closed with an understacked mini-clip.

Superiorly projecting aneurysms are clipped with an anterolateral clip trajectory, with the blades passing perpendicular to the ascending perforators (**Fig. 19.8A**). Narrow necks accommodate more anterior clip trajectories and simple straight clips (**Figs. 19.9, 19.10, and 19.11**); wide necks require more lateral clip trajectories and stacked clips (**Fig. 19.12**) or tandem clipping. With tandem clipping, the fenestration encircles the proximal perforators and an adherent ipsilateral P1 segment (**Figs. 19.13 and 19.14**).

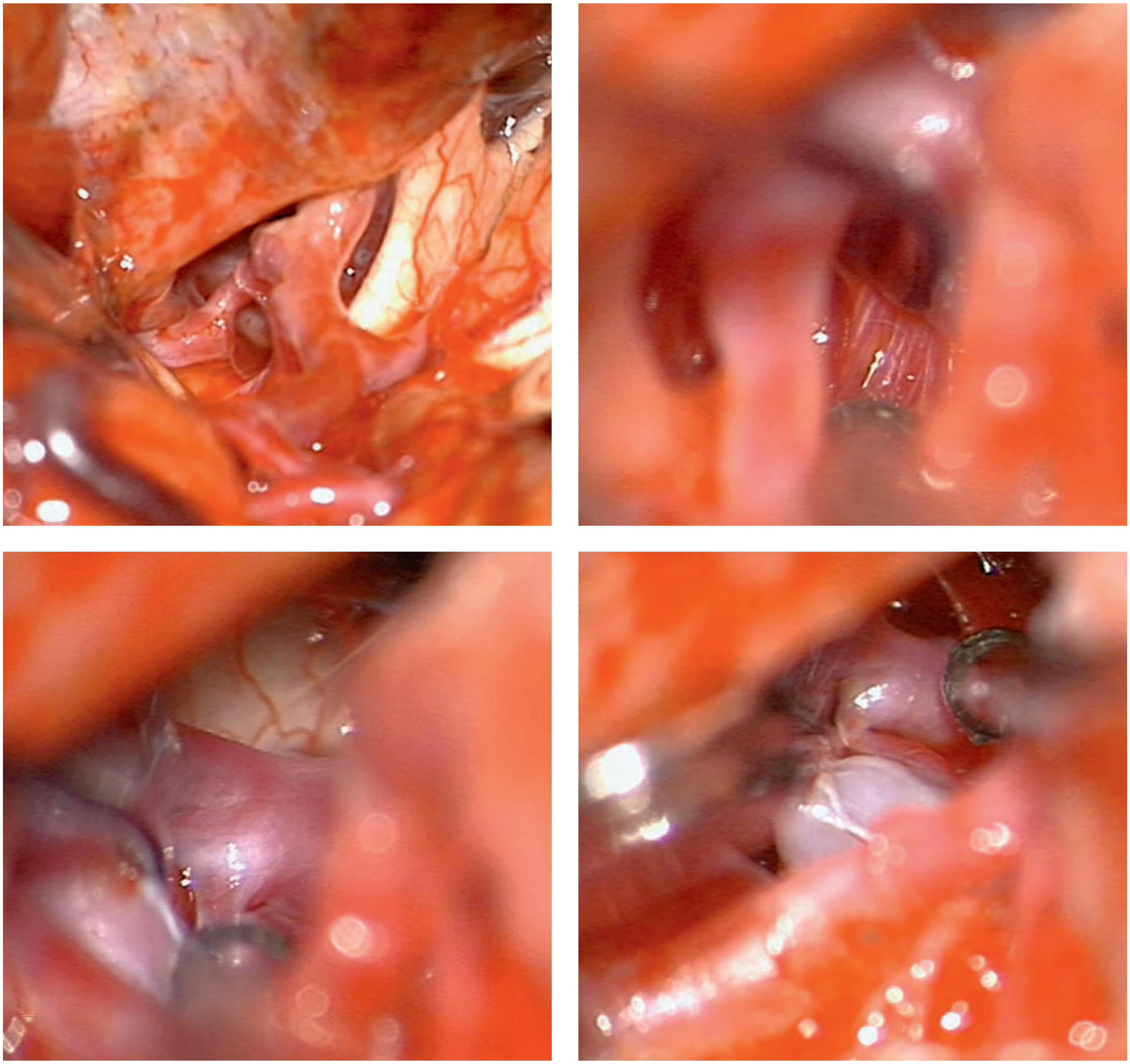

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**Fig. 19.10** **(A)** This superiorly projecting basilar bifurcation aneurysm in a 48-year-old woman was approached through a left orbitozygomatic-pterional craniotomy to better visualize the left PCA, which originated from the side of the aneurysm. **(B)** The view along the left P1 segment and behind the aneurysm demonstrated that all the perforators were on the right side. **(C)** A large artery of Percheron was identified on the right P1 segment (at the sucker tip), and a plane was opened between this perforator trunk and distal aneurysm neck. **(D)** The clip blade fit easily in this plane and occluded the neck.

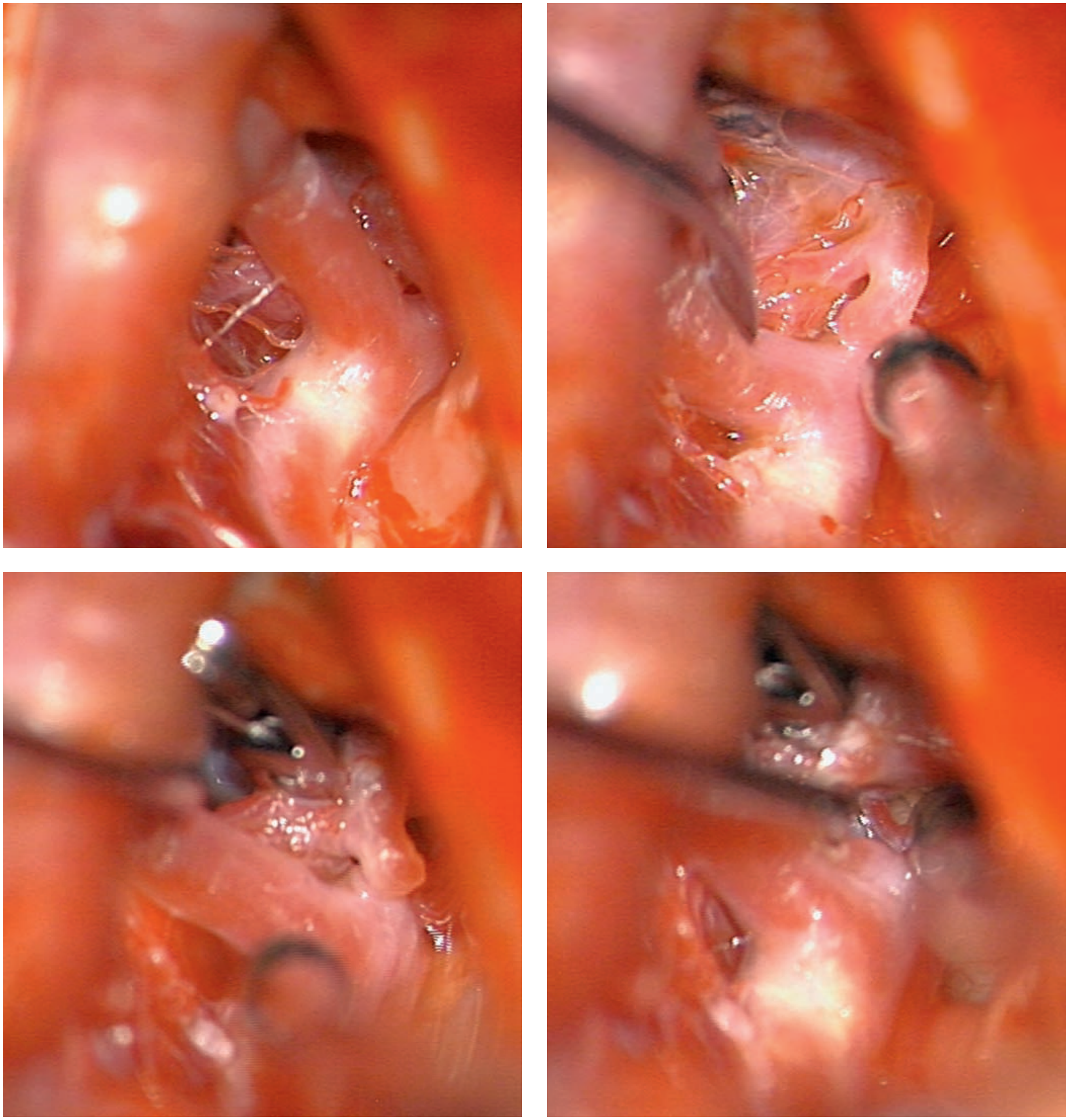

**Fig. 19.11** **(A)** This ruptured basilar bifurcation aneurysm in a 48-year-old man was associated with a fetal right PCA and a hypoplastic P1 segment **(B),** seen joining the fetal PCA at the P1-P2 junction. The thalamoperforators on this P1 segment adhered to the aneurysm, but were mobilized enough to pass the clip blade **(C)**. **(D)** The clip's tips were inspected behind the P1 segment to be certain that none of the posterior perforators were included in the clip.

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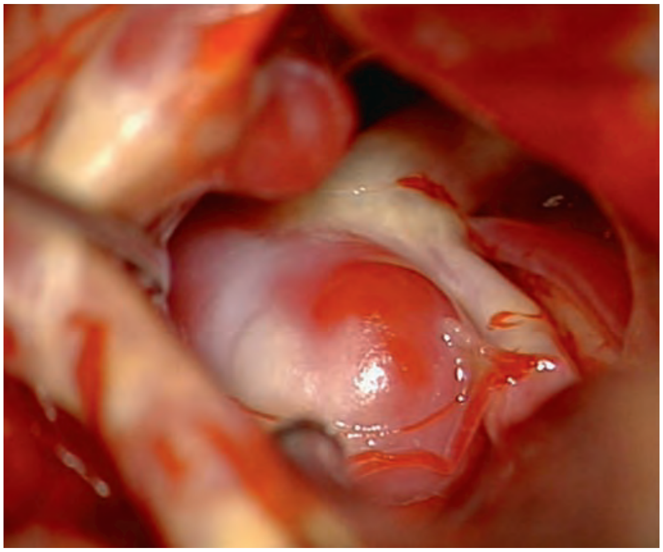

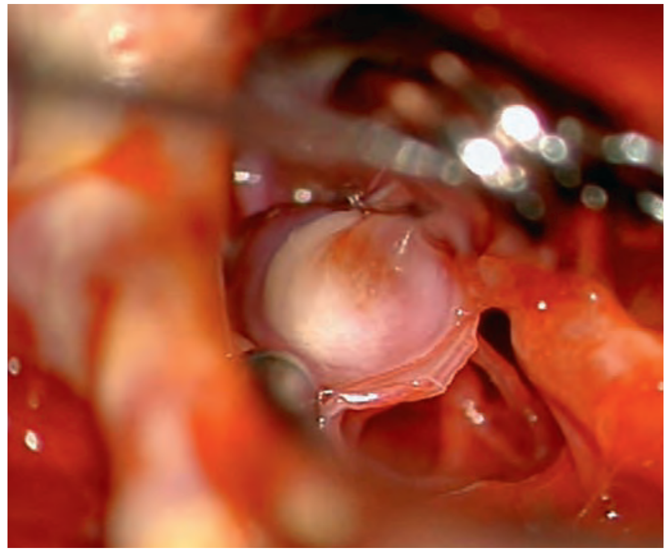
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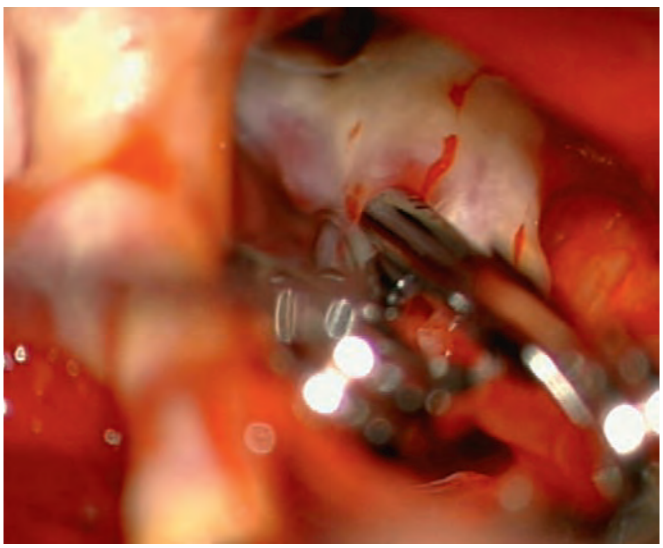


**Fig. 19.12** **(A)** The superiorly projecting basilar bifurcation aneurysm in this 68-year-old woman appeared to have a wide base, but a cleavage plane was opened between the aneurysm and the proximal P1 segment ipsilaterally. Note the PCoA aneurysm originating from the right supraclinoid ICA. The basilar trunk was accessible below the SCA for a temporary clip during permanent clipping. **(B)** Straight clips were slid across the neck medial to the ipsilateral perforator and above the posterior thalamoperforators. **(C)** An understacked straight clip occluded the proximal neck, and a mini-clip between the two regular clips completed the repair.

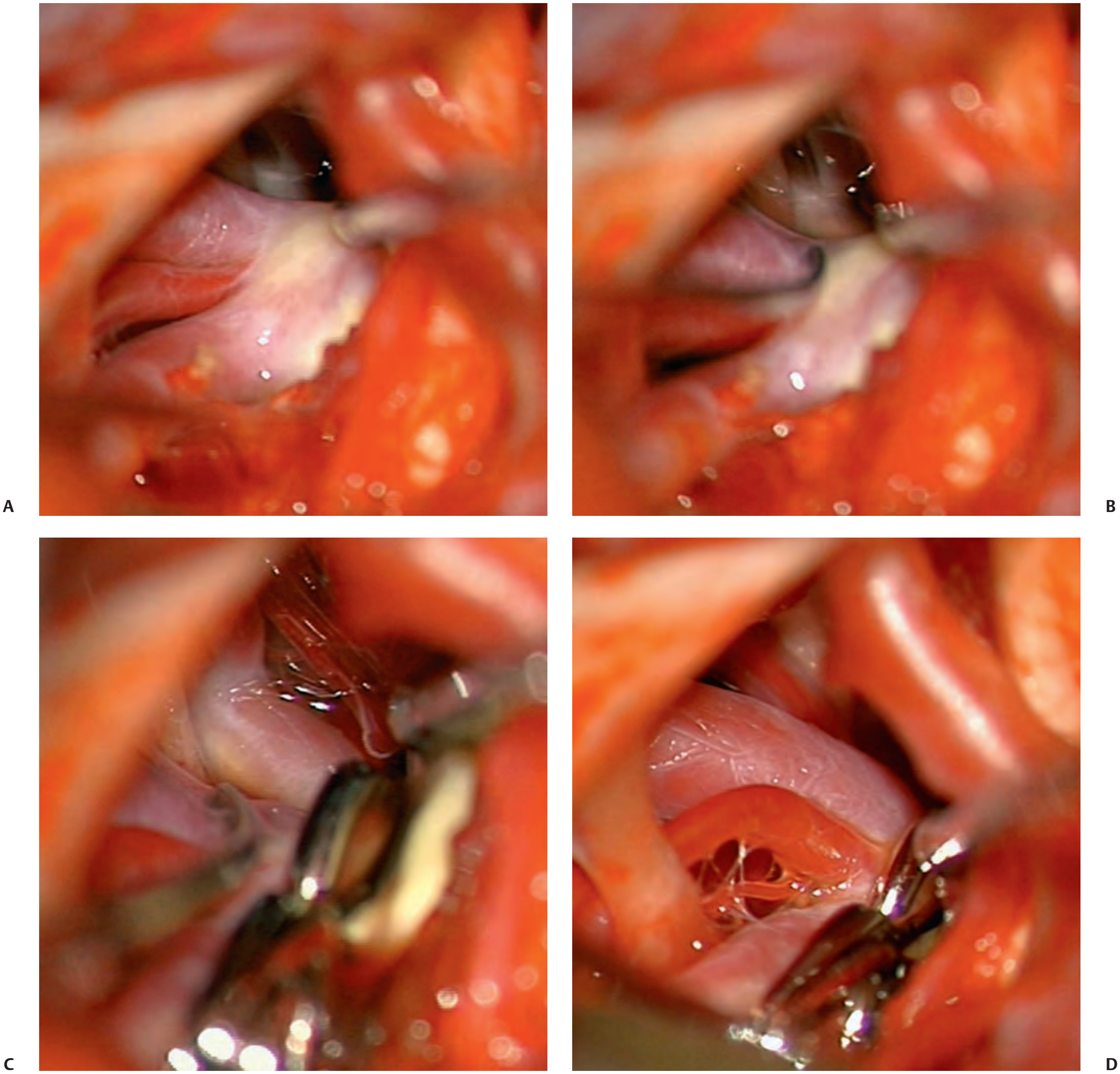
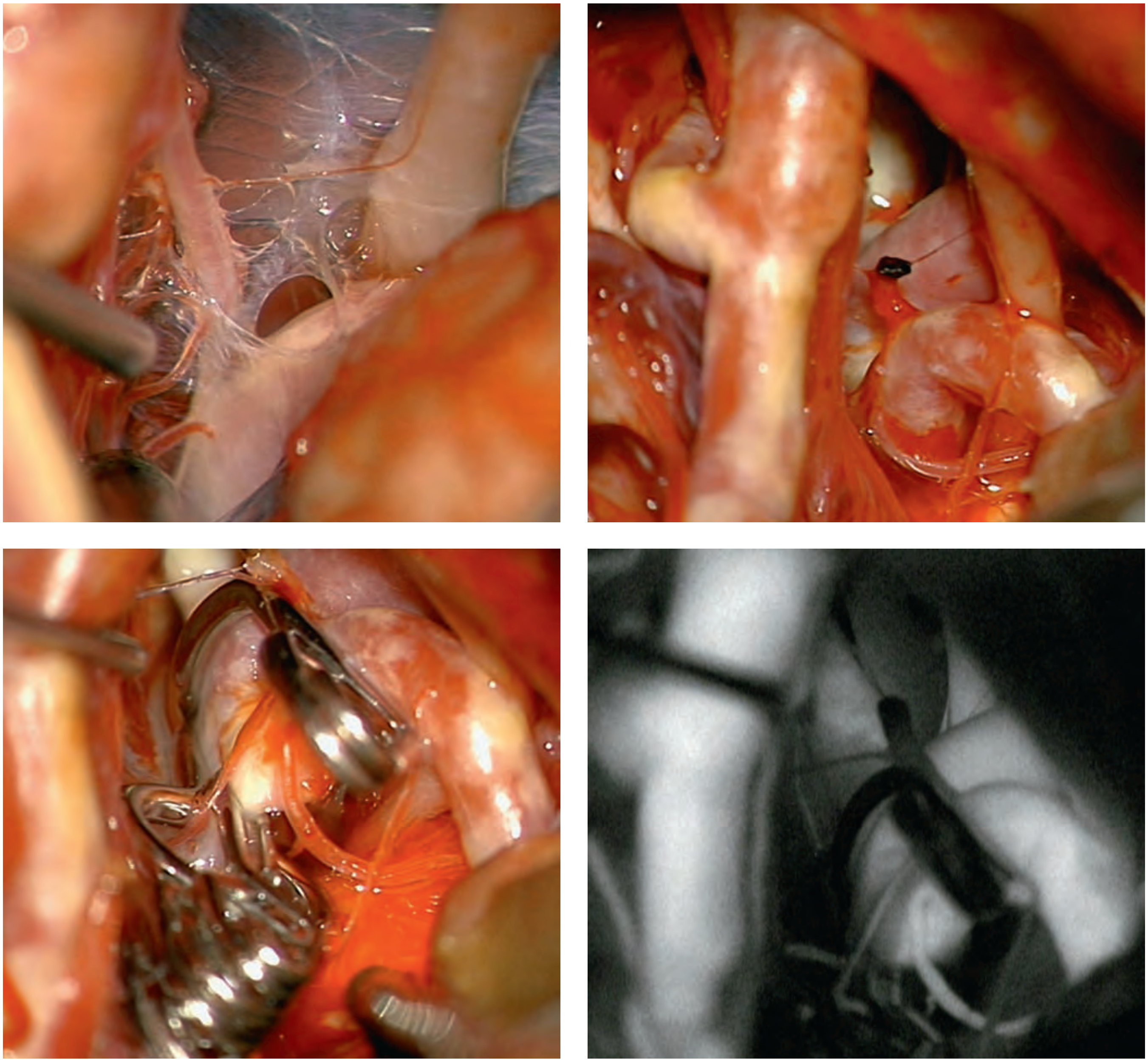


Fig. 19.13 This superiorly projecting basilar bifurcation aneurysm in a 54-year-old woman with a subarachnoid hemorrhage (SAH) had a broad neck the sloped downward from right to left, and was approached from the left side to give a more favorable trajectory for clip application. **(A)** The ipsilateral PCA and SCA descended from the aneurysm base, almost parallel to the afferent basilar trunk. **(B)** The contralateral PCA, PCoA, and oculomotor nerve were visualized across the aneurysm's anterior face. **(C)** This anatomy called for tandem clipping, with the tips of a straight fenestrated clip angled upwards over the shoulder of the contralateral PCA. **(D)** The fenestration and its closing clip left ample lumen for the ipsilateral PCA and SCA, which descended from the fenestration.



A B C D

**Fig. 19.14** **(A)** The PCoA and oculomotor nerve lie on the membrane of Liliequist, which is an arachnoid film crossing the carotid-oculomotor triangle. Liliequist's membrane separates the chiasmatic and interpeduncular cisterns, and is opened with an incision behind the posterior clinoid process and medial to the oculomotor nerve, extending posteriorly to the undersurface of the P1 segment where it pierces the membrane. This incision advances the dissection into the interpeduncular cistern where the undersurface of the P1 segment is followed medially to the SCA and the basilar trunk. **(B)** A diminutive right PCoA tethered the PCA and blocked access to this high-riding basilar bifurcation aneurysm. It was coagulated and divided, avoiding the anterior thalamoperforators and opening a view to the base of the aneurysm. **(C)** Tandem clipping was used to reconstruct the neck, with a bayoneted fenestrated clip used to get additional reach upwards across the distal neck. A straight fenestrated clip and a simple straight clip were applied next to close the proximal neck and transmit the posterior thalamoperforators on the P1 segment. **(D)** Indocyanine green (ICG) videoangiography demonstrated patency of these thalamoperforators and the tortuous course of the ipsilateral PCA through the fenestrated clips.

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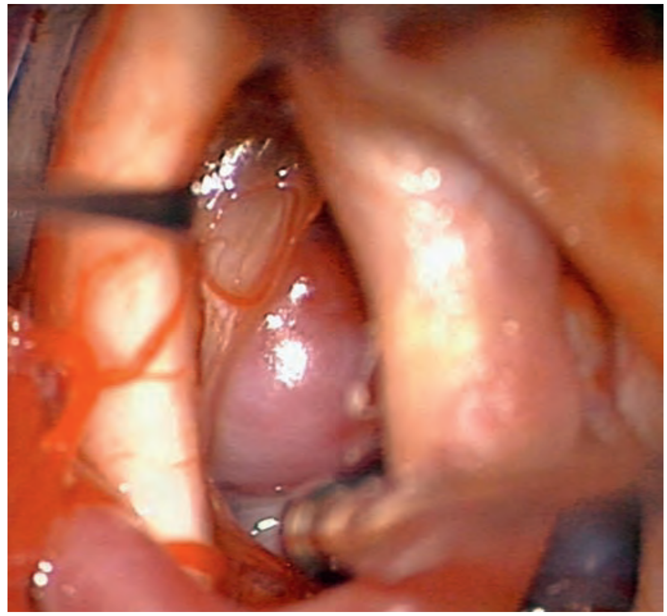

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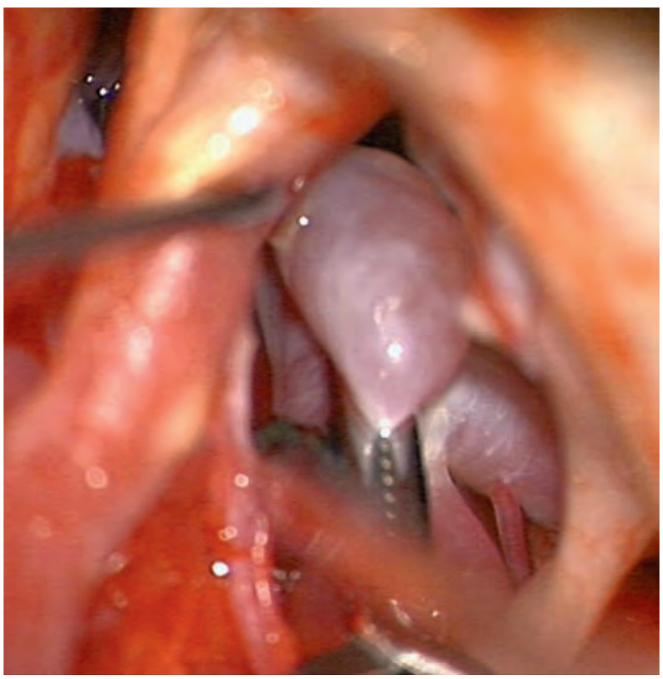
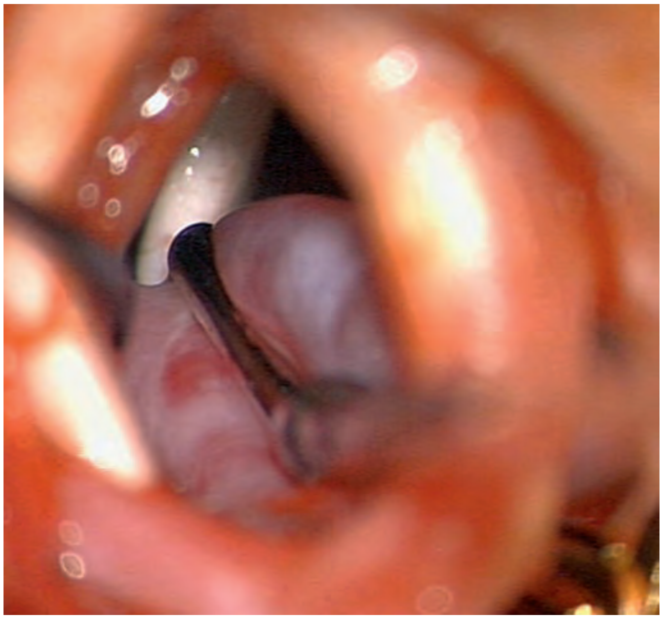


C

**Fig. 19.15** **(A)** This 60-year-old woman's unruptured basilar bifurcation aneurysm projected anteriorly, and adhesions between its dome and dorsum sella were released. The right ICA had to be mobilized superiorly to view the aneurysm. **(B)** Inferior mobilization of the ICA opened the optic-carotid triangle and offered a view of the posterior neck. The pituitary stalk draped over the aneurysm's dome. **(C)** With temporary clipping to soften the aneurysm, the aneurysm was dissected down from the pituitary stalk and mamillary bodies to visualize the distal neck, and then clipped with a straight clip paralleling the PCAs.

Anteriorly projecting aneurysms are clipped with a lateral clip trajectory (**Figs. 19.8B, 19.15, and 19.16**). Perforators usually separate easily from the aneurysm because they course in a different direction. The dome may obscure a full view of the inferior blade, but the superior blade guides clip application, after which the dome can be mobilized upwards to inspect the inferior blade.



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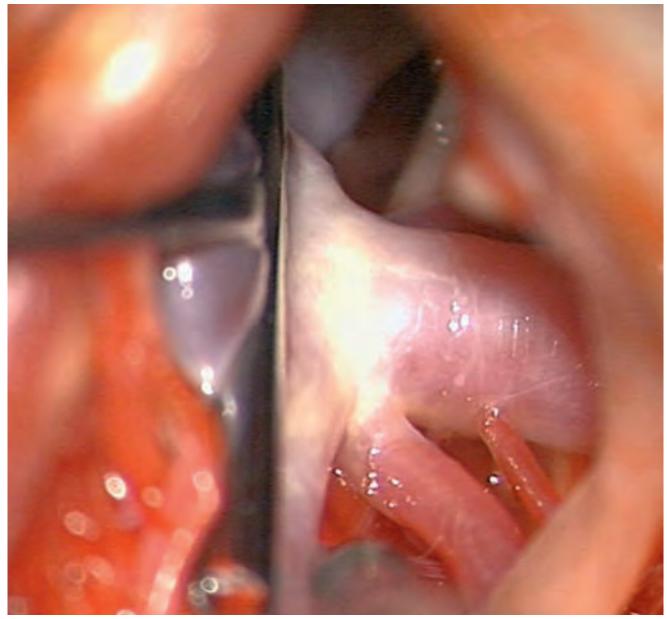
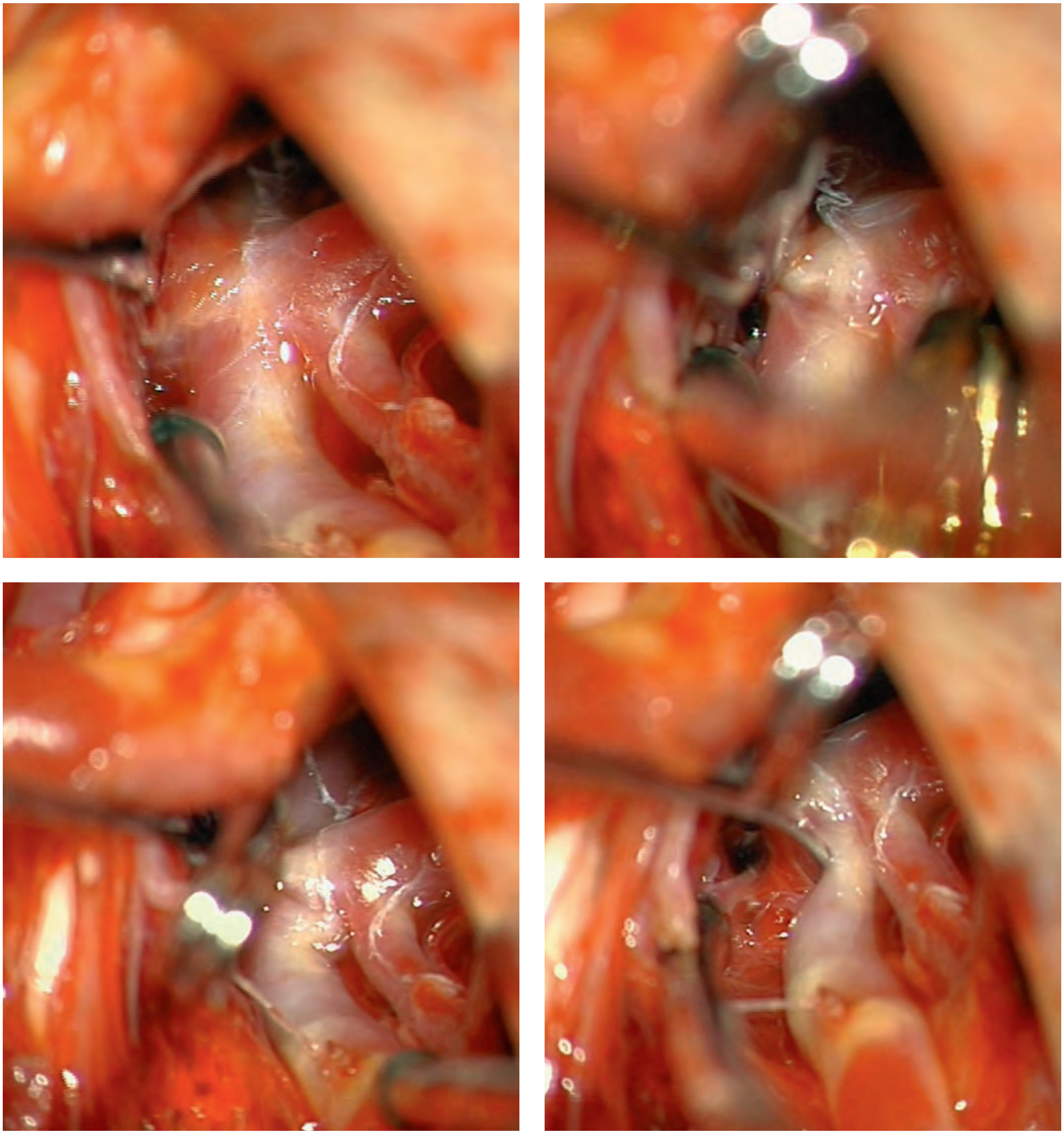


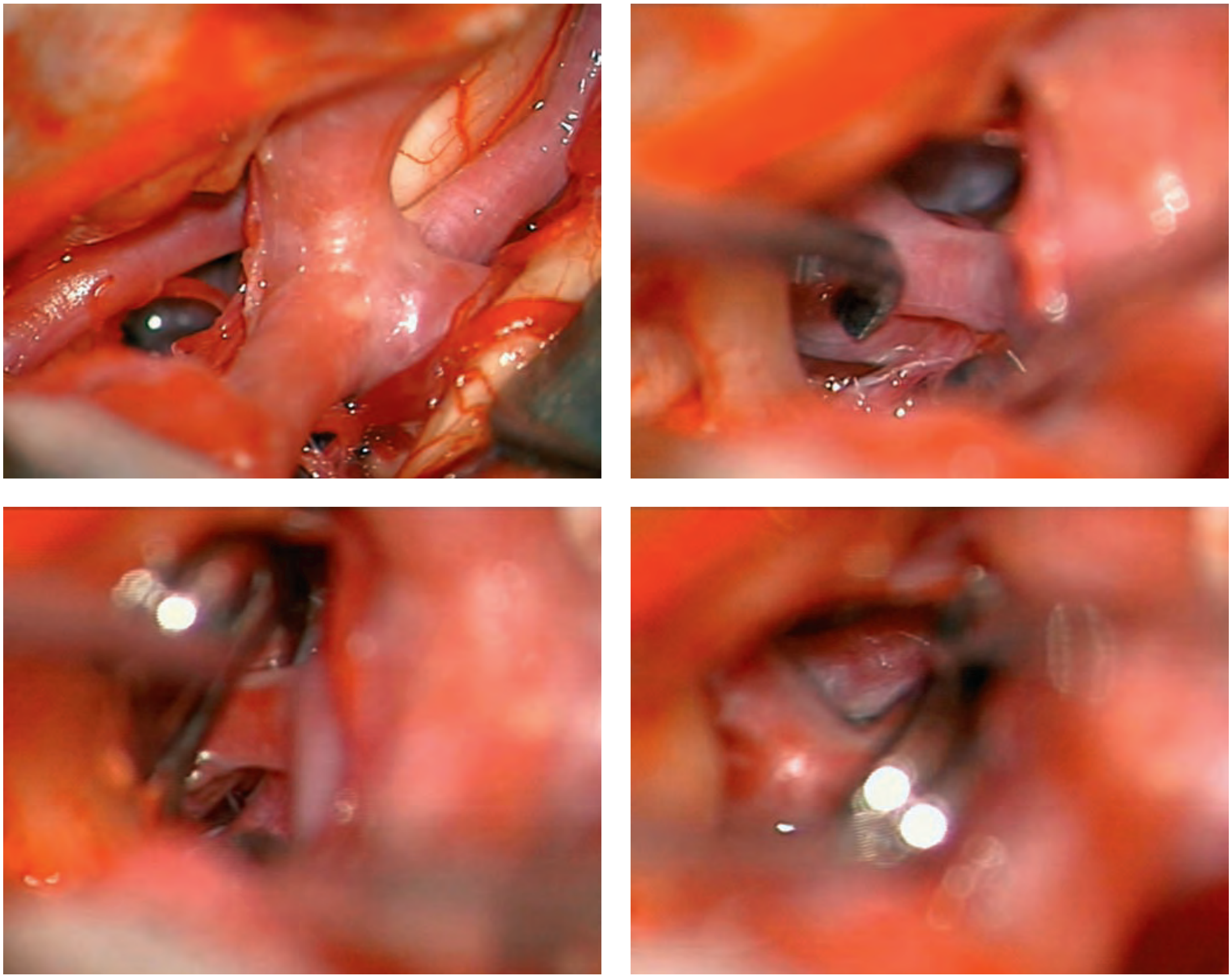
E

**Fig. 19.15** (*Continued*) **(D)** The clip was applied through the carotid-oculomotor triangle, but the view of the clip's tips was through the optic-carotid triangle. The contralateral oculomotor nerve is an orienting landmark beyond the clip. Note the absence of thalamoperforators; they lie on the posterior wall of the PCA away from the aneurysm neck, out of view. **(E)** The clip's inferior blade was incompletely visualized during clip application because of the aneurysm's anteriorly projecting dome, but clip placement was inspected after clipping.



A B C D

**Fig. 19.16** **(A)** This ruptured basilar bifurcation aneurysm projected anteriorly, and its high position required mobilization of the right ICA superiorly to visualize the neck. **(B)** Temporary clipping was used during application of a straight clip across the neck. The temporary clip was applied as low as possible on the basilar trunk to keep it from crowding the field. **(C)** After permanent clipping, the position of the clip's tips on the distal neck and the patency of the contralateral PCA were double-checked. **(D)** The posterior thalamoperforators were coursing behind the bifurcation, away from the neck.

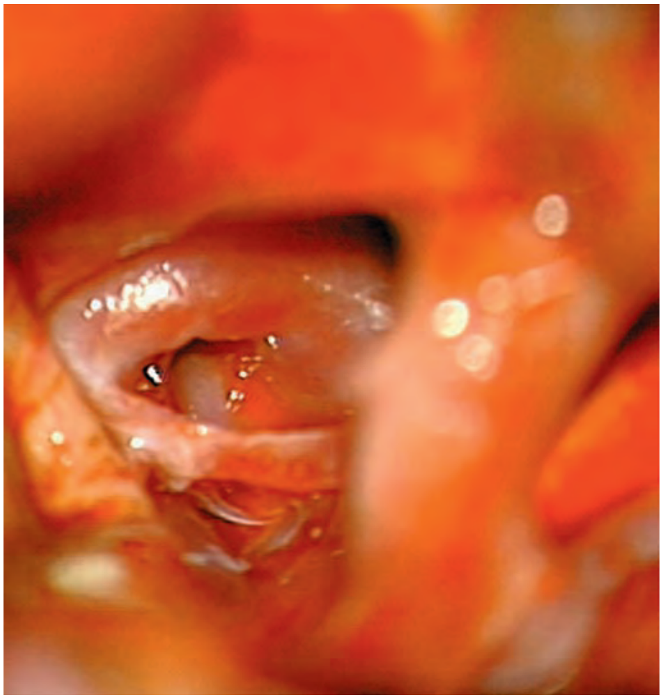


A B C D

**Fig. 19.17** **(A)** Two aneurysms were diagnosed in this 65-year-old woman: a basilar bifurcation aneurysm and a left ICA bifurcation aneurysm. A left orbitozygomatic-pterional approach exposed both aneurysms simultaneously. **(B)** The view through the carotid-oculomotor triangle revealed a posteriorly projecting aneurysm, with the aneurysm hiding behind the ipsilateral PCA. **(C)** A straight fenestrated clip closed the neck, with the ipsilateral PCA transmitted through the fenestration. **(D)** The contralateral PCA coursed anterior to the distal clip blades.

Posteriorly projecting aneurysms are often clipped with fenestrated clips (**Figs. 19.8C, 19.17, and 19.18**). The quadrifurcation is well visualized, but is interposed between the neurosurgeon and the aneurysm neck. The blades must be navigated around and under the ipsilateral PCA, SCA, and the collection of perforators, sometimes with imperfect visualization of the other blade. Tandem clipping can partition the neck reconstruction and avoid adherent perforators. Narrow passageways between the aneurysm neck and adherent perforators can limit or prevent stacking of straight clips and might require additional fenestrated clip. Generous use of fenestrated clips that transmit adherent perforators minimizes perforator dissection and avoids dangerous planes that might tear into the aneurysm. Overlapping fenestrated clips may be useful with aneurysms that have mixed dome projection (**Fig. 19.19**)

High-riding basilar bifurcation aneurysms are difficult to clip because of poor maneuverability in the attic of the interpeduncular cistern and a compromised view (**Figs. 19.13 and 19.14**). Downward curved clips may be needed to offset the steep upward clip trajectory, and curved clips are more cumbersome than straight clips in this deep corridor. High-riding aneurysms often require some downward mobilization to bring them into view and align the clips. The optic-carotid triangle may be needed to visualize the anatomy on the contralateral side, but this triangle is often too small to accommodate a clip applier.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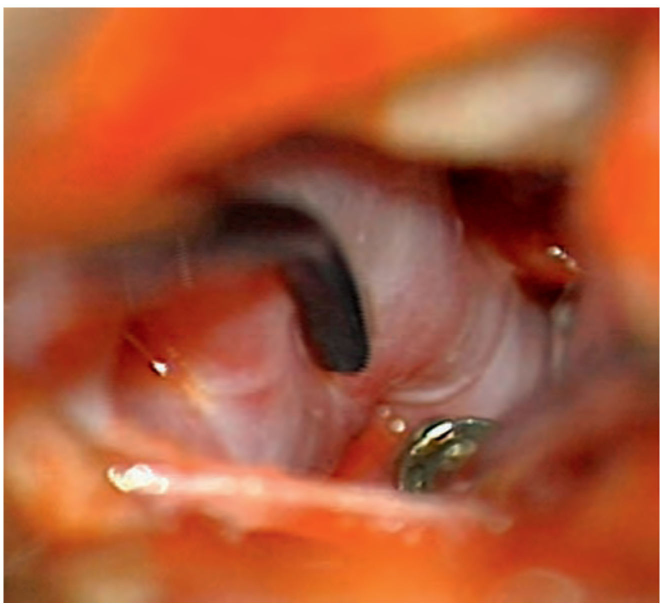
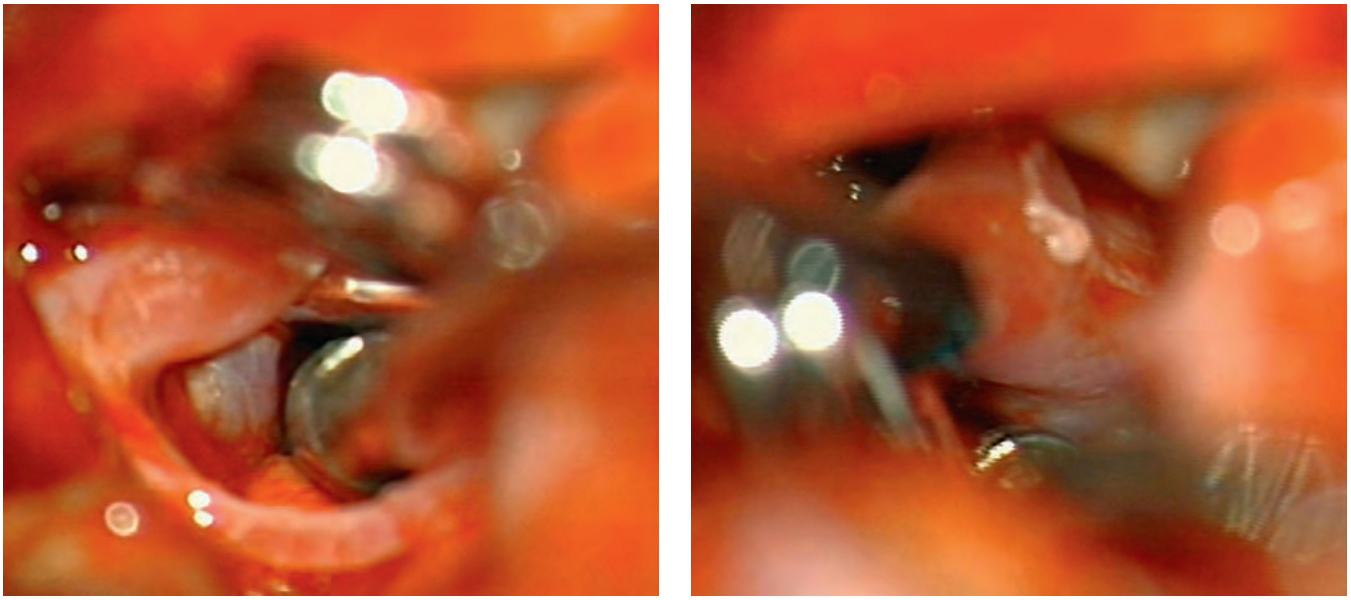

C

**Fig. 19.18** **(A)** This ruptured basilar bifurcation aneurysm in a 56-year-old man was associated with a left MCA aneurysm and was therefore approached from the left side to expose both aneurysms simultaneously. The PCoA provided a guiding landmark from the ICA to the PCA to deepen the dissection. **(B)** The ipsilateral PCA and SCA originated from the aneurysm base, and the aneurysm dome projected posteriorly. The posterior dome projection displaced the thalamoperforators inferiorly and posteriorly. **(C)** The basilar terminus and contralateral PCA were visualized across the base of the aneurysm, completing the view of the quadrifurcation.



D E

**Fig. 19.18** (*Continued*) **(D)** The aneurysm was clipped with a straight fenestrated clip, with the ipsilateral PCA transmitted through the fenestration. **(E)** A view on the other side of the clip demonstrated an intact basilar bifurcation.

Clip application is usually better visualized with low-lying aneurysms (**Fig. 19.20**). However, even extensive posterior clinoidectomy may not allow for temporary clipping. Some low-lying basilar aneurysms, particularly those with lateral deviation, may be exposed by cutting the tentorium. Trochlear nerve is identified under the tentorium's free edge, and the tentorium is cut behind the nerve's entrance into its dural sheath. The tentorium can then be flapped laterally, and the aneurysm can be dissected between the oculomotor and trochlear nerves (**Fig. 19.21**).

Deep operative corridors, surgical blind spots, and vital anatomy make postclipping inspection especially critical with basilar bifurcation aneurysms. Seven points are checked: (1) the aneurysm is occluded; (2) the parent artery, (3) the efferent branches, (4) the perforating arteries, and (5) the adjacent arteries are all patent; (6) there is no neck remnant; and (7) blind spots are clear. The most common problems are residual aneurysm filling, thalamoperforator occlusion, and P1 segment occlusion.

Basilar aneurysms that continue to fill after clipping usually have a distal neck that is not completely occluded. This spot is the deepest and most difficult to see. Tangential views along the clip blades during clip application do not give proper perspective on the relationship between the clip tips and the distal neck. Aneurysms necks ovalize as the blades close, pushing the distal neck beyond the blades. Thick, atherosclerotic tissue between the proximal blades can splay the distal tips. Therefore, when a basilar bifurcation aneurysm still fills after permanent clipping, attention is immediately directed to the distal neck. Correcting other problems at the proximal neck will only be undone by correcting problems at the distal neck. Further dissection and more oblique views of the distal neck will identify the problem. With tandem clipping, minor advancements or adjustments in the initial fenestrated clip will obliterate the distal neck. A stacked fenestrated booster clip can also reinforce the distal neck.

When the distal neck is completely occluded but the aneurysm still fills, the problem may be at the proximal neck. Fenestrated clips encircling the ipsilateral P1 PCA or adherent perforators can allow aneurysm filling at the heels of the blades. Additional stacked clips may be needed to thoroughly close the fenestration.

Thalamoperforator occlusions are identified by tracing the clip blades from heel to toe on both sides of the neck. A perforator caught in a clip is usually one not seen before or during permanent clipping. It is often visualized only after the permanent clip has collapsed or gathered the aneurysm. Therefore, that clip should be tentatively left in place while the perforator is dissected from the aneurysm. Sometimes a perforator can be maneuvered from the tips without removing the clip, and other times the clip must be removed and reapplied. Puncturing and deflating the aneurysm may help visualize deep perforators and confirm their exclusion from the clip blades.

Preservation of the P1 segment can be challenging with wide aneurysm necks, dolichoectatic morphology, underhanging P1 segments, or a broad wedge (>90 degrees) at the aneurysm base between the front and back walls. P1 segment preservation is also difficult with giant aneurysms,

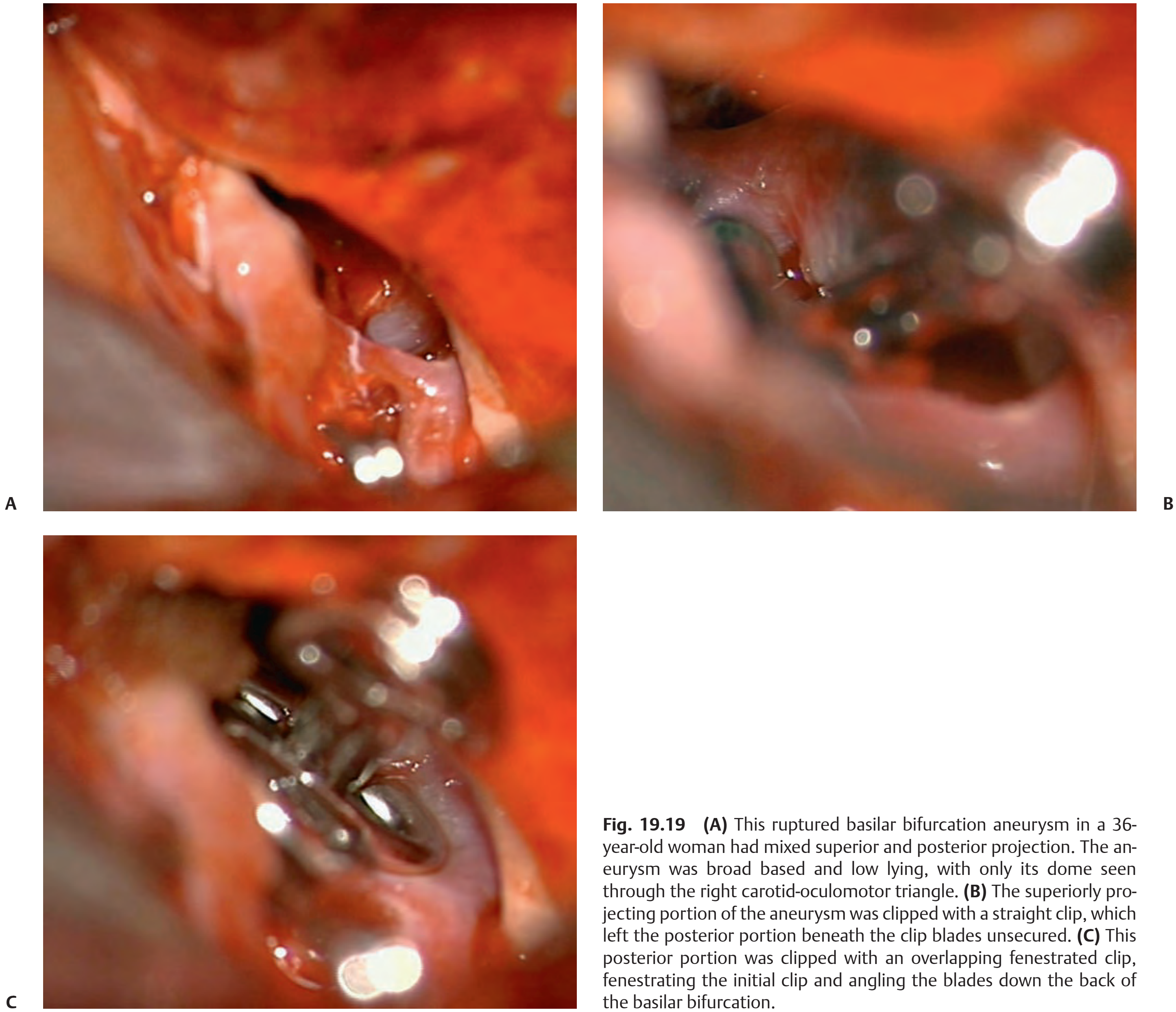
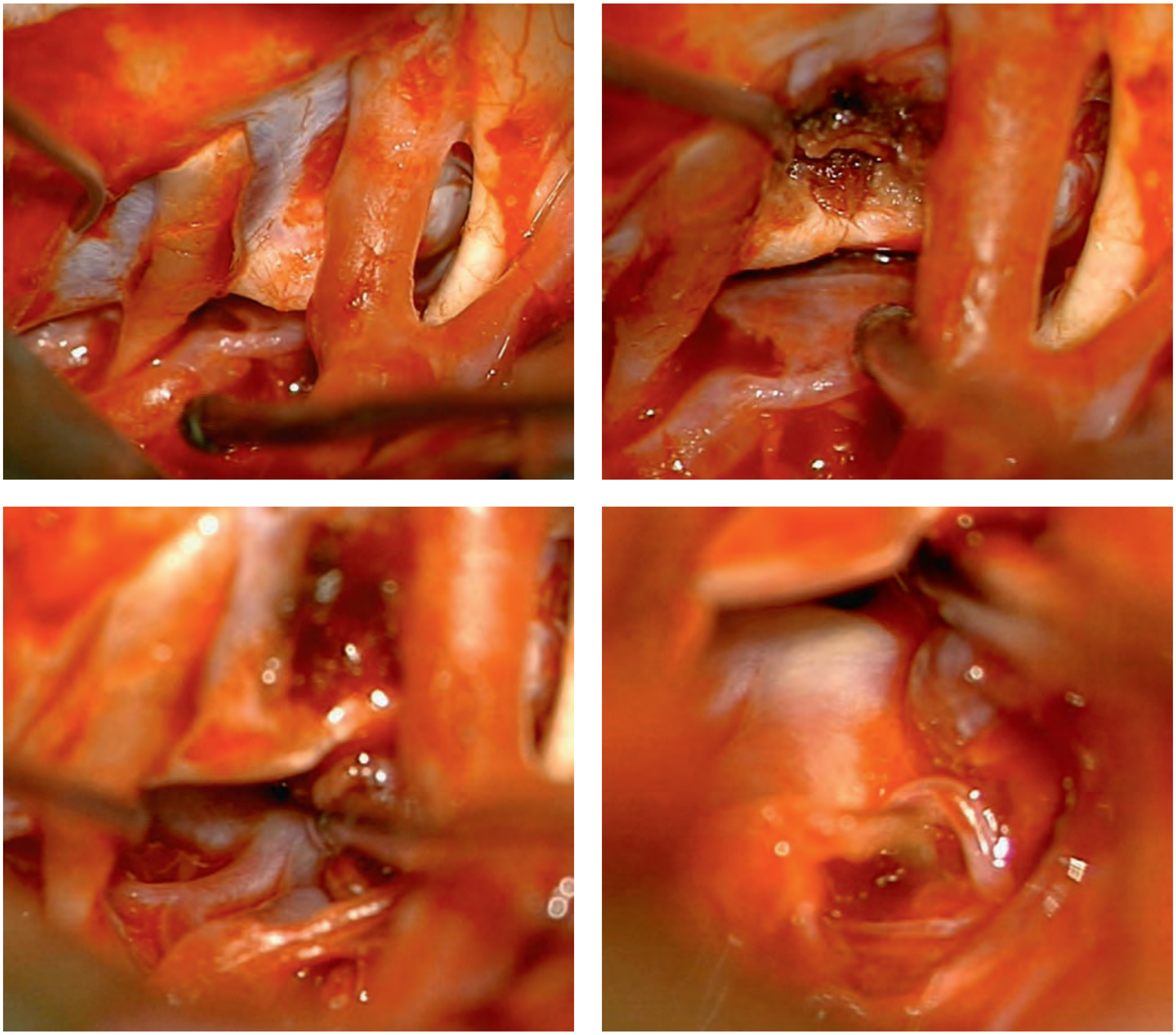
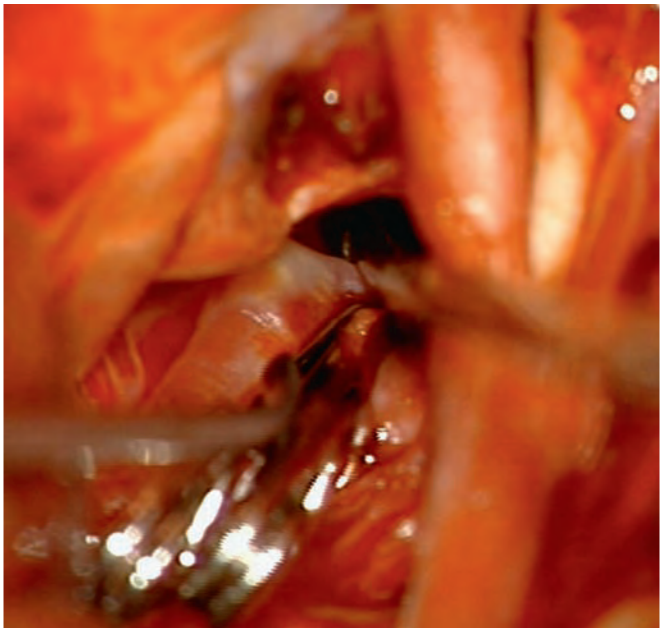



**Fig. 19.19** **(A)** This ruptured basilar bifurcation aneurysm in a 36-year-old woman had mixed superior and posterior projection. The aneurysm was broad based and low lying, with only its dome seen through the right carotid-oculomotor triangle. **(B)** The superiorly projecting portion of the aneurysm was clipped with a straight clip, which left the posterior portion beneath the clip blades unsecured. **(C)** This posterior portion was clipped with an overlapping fenestrated clip, fenestrating the initial clip and angling the blades down the back of the basilar bifurcation.



A B C D

**Fig. 19.20** Low-lying basilar bifurcation aneurysms descend out of the carotid-oculomotor window and often require posterior clinoidectomy. **(A)** This low-lying ruptured aneurysm in a 54-year-old man had a prominent trunk of thalamoperforators that originated from the left base of the aneurysm, and was therefore exposed from the left side to better visualize this anatomy. The posterior clinoid process occupied the anterior portion of the carotid-oculomotor triangle and blocked the view of the basilar apex. **(B)** Fibrin glue was injected into the cavernous sinus through a puncture site within the dura of the oculomotor triangle. The dura over the PCP was incised, and this bone was removed with a diamond drill bit. **(C)** After opening the arachnoid of the interpeduncular cistern, the ipsilateral PCA, SCA, and basilar trunk were exposed and proximal control was established. **(D)** The aneurysm projected anteriorly, making it difficult to see the contralateral PCA. The artery of Percheron was seen at its base. (*continued on next page*)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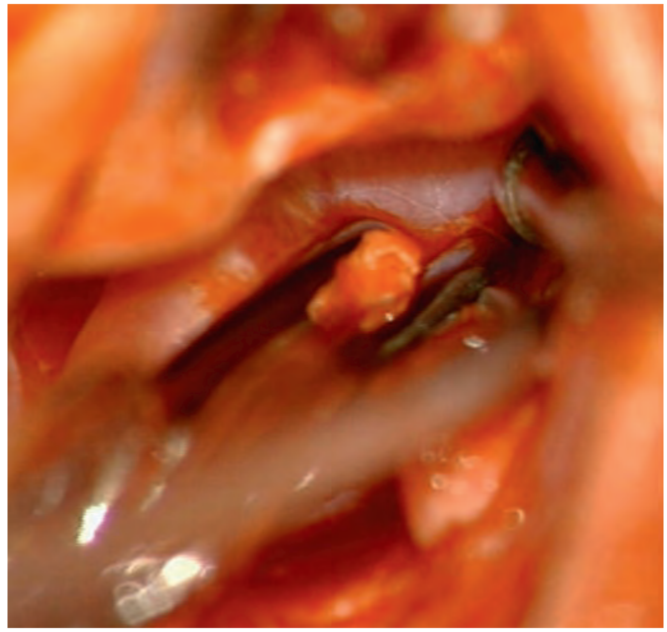
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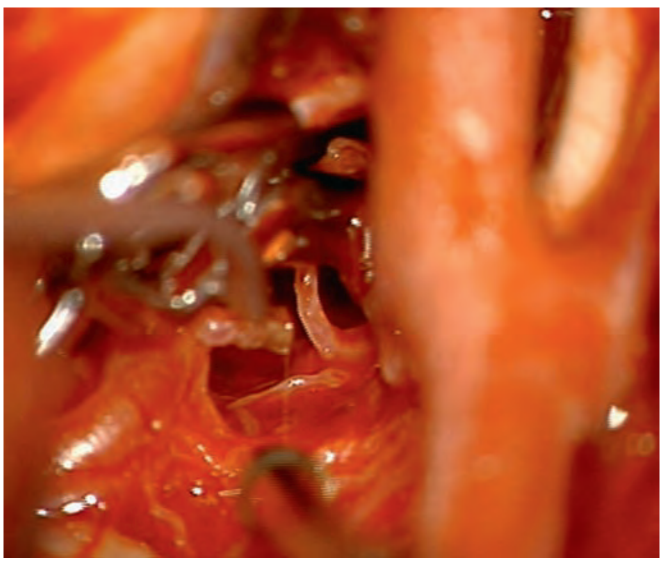
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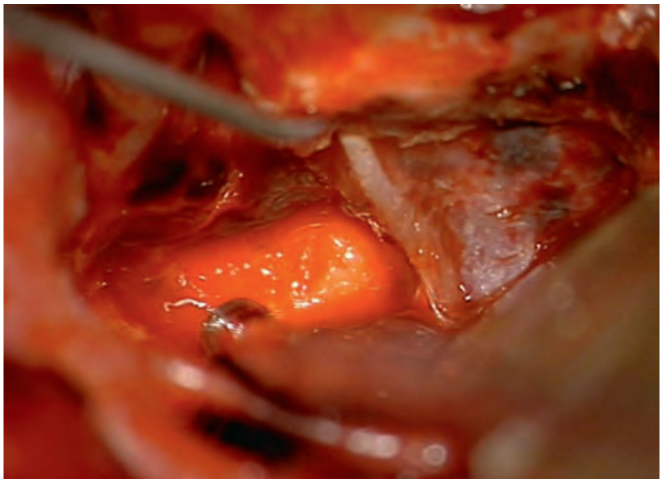
**Fig. 19.20** (*Continued*) **(E)** The aneurysm was clipped initially with a straight clip, but inspection revealed that the clip occluded the contralateral PCA. Backing the clip off this PCA restored its patency, but the clip migrated superiorly on the neck and ruptured the aneurysm. A second straight clip was slid under this initial clip to close the neck and control the bleeding. **(F)** The relationship between the clip tips and the contralateral PCA was seen at higher magnification. **(G)** The artery of Percheron coursed beneath the clip blades, and its patency was confirmed with ICG videoangiography.

atherosclerosis, previous coiling, and intraluminal thrombus. Clips can migrate even after skillful placement, sliding down onto and occluding the P1 segments. These initial clips can be used as tentative clips, stacking additional clips higher on the neck. These stacked permanent clips may grab the neck better because tentative clips eliminate aneurysm inflow. After generously rebuilding the origin of the P1 segment, tentative clips slide off the neck and restore P1 segment flow. When multiple stacked clips crowd the surgical field, dog-ear remnants may require long straight clips that only use their tips to pinch the remnant, while keeping the clip's coiled spring and the clip appliers outside of the interpeduncular fossa.

Some of these complex aneurysms may not be clippable. Patients with large PCoAs may tolerate proximal aneurysm occlusion. A clip on the basilar trunk may alter the hemodynamics in the aneurysm and promote its thrombosis. This option may be as effective as direct clipping, and is a useful "last resort" when clipping fails (**Fig. 19.22**).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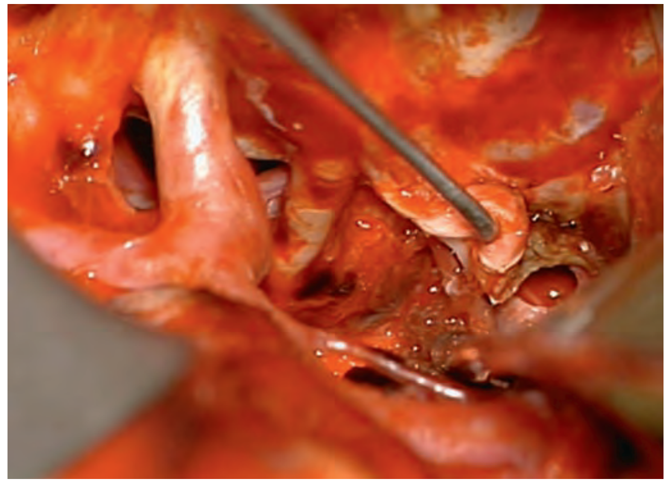
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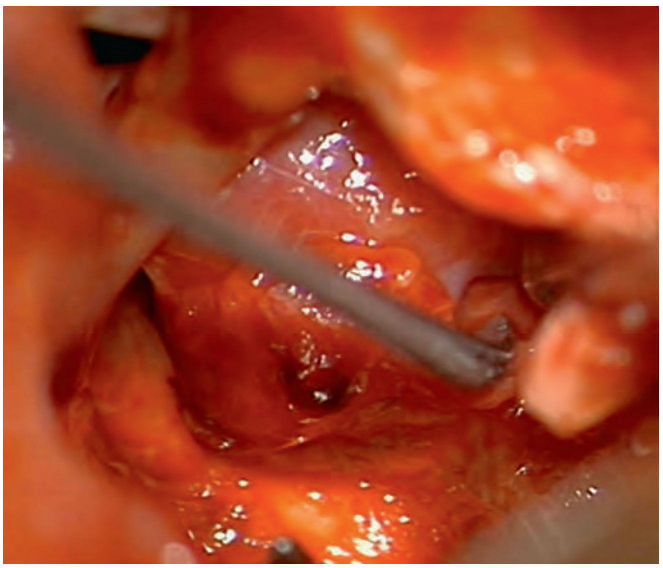
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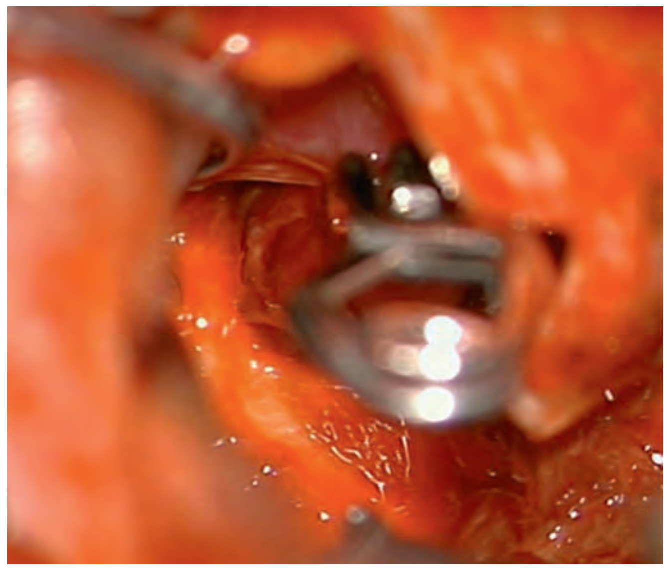
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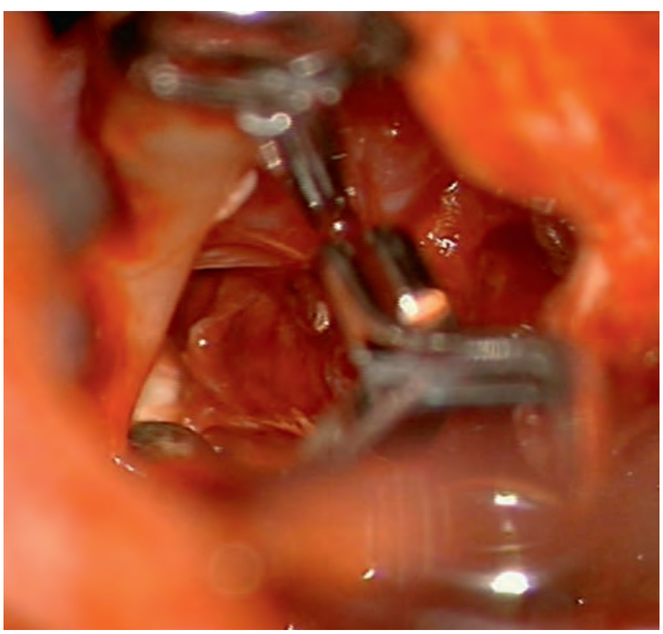
E

**Fig. 19.21** Low-lying basilar artery aneurysms with lateral deviation can be accessed through the tentorium. **(A)** This 55-year-old woman presented with SAH and a small, sessile aneurysm on a tortuous basilar artery that curved under the right tentorium. Exposure of the proximal basilar artery required cutting the tentorium. The trochlear nerve was identified under the tentorium's free edge, and the tentorium was cut behind the nerve's entrance into its dural sheath. **(B)** The tentorium was flapped laterally. **(C)** The aneurysm was found between the oculomotor and trochlear nerves, capped with a thrombus. **(D)** A bayoneted mini-clip was applied along the posterior neck of the aneurysm, and **(E)** an intersecting straight mini-clip was applied along the anterior neck.

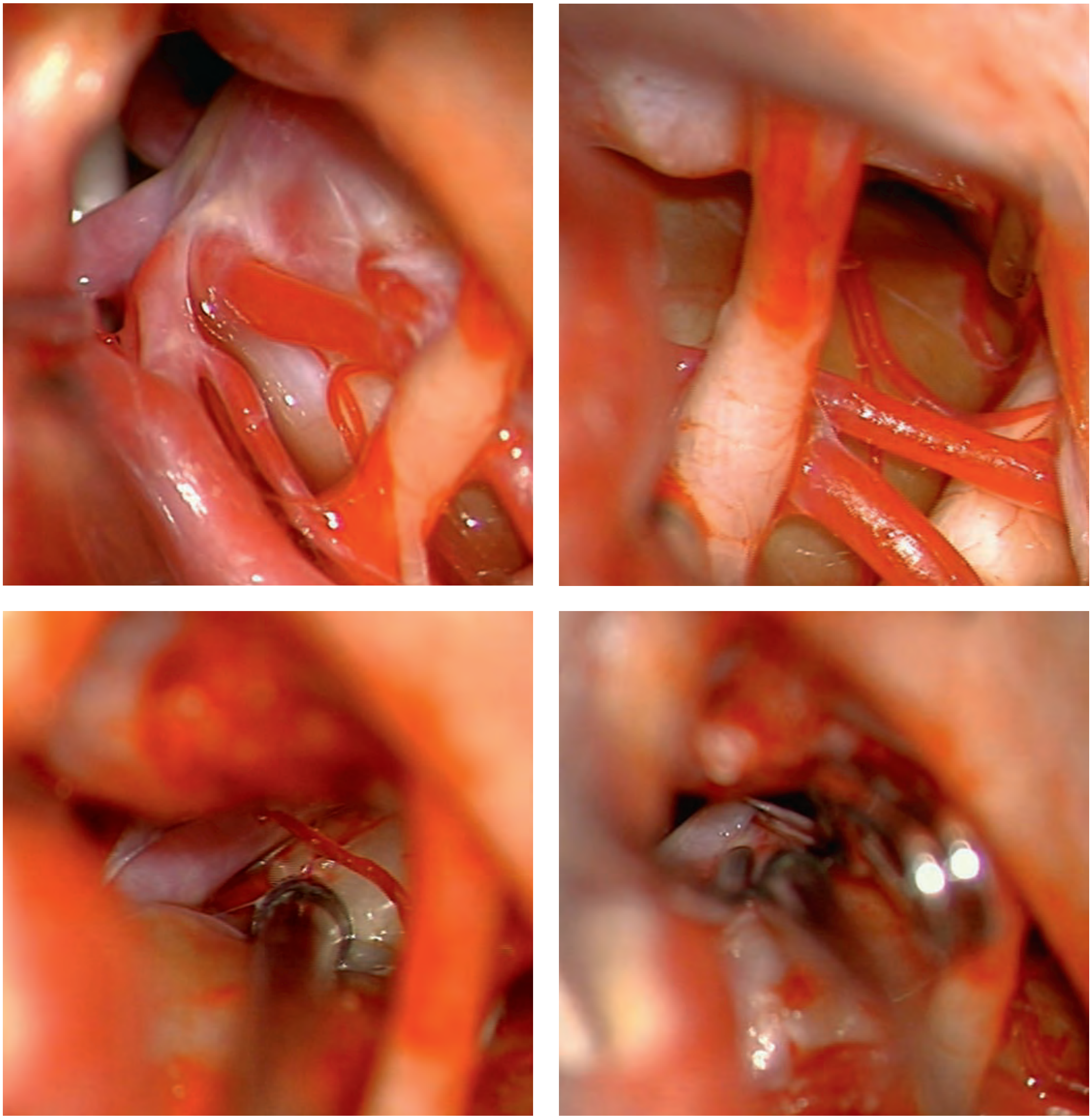

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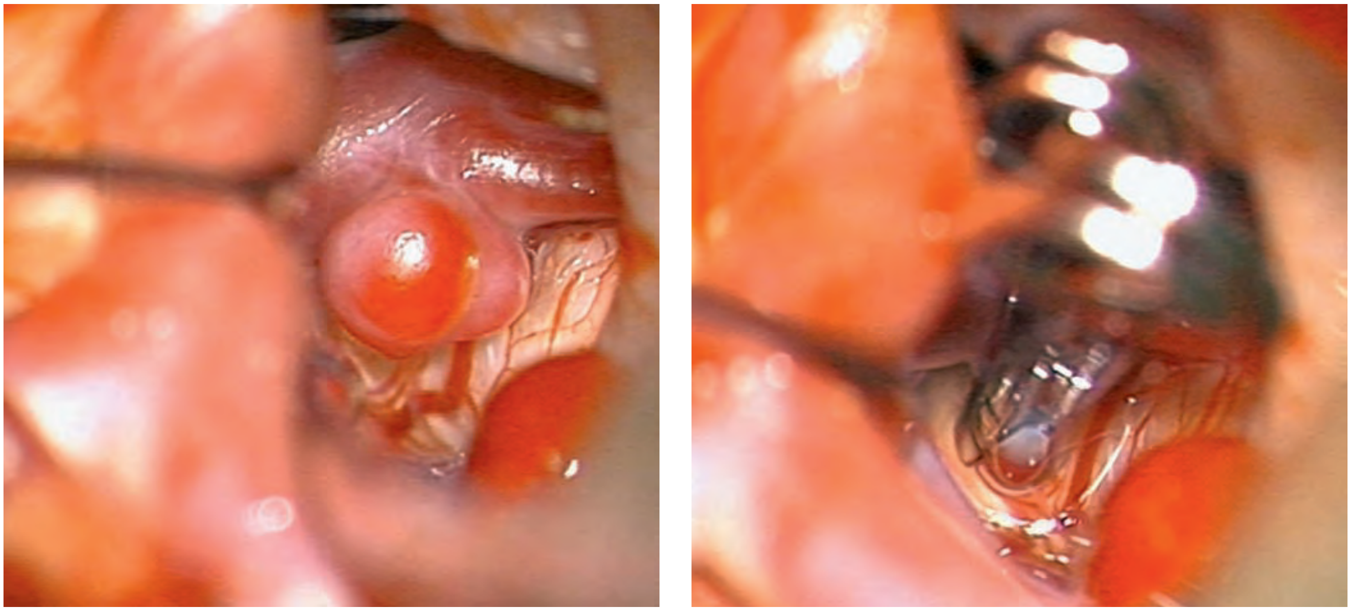
**Fig. 19.22** **(A)** This dolichoectatic basilar trunk aneurysm presented with compressive symptoms in this 66-year-old woman. Both PCAs and both SCAs originated from the top of the aneurysm, which did not have a defined neck. **(B)** In addition, the posterior-inferior portion of the aneurysm was thrombotic, with a greenish color seen through the wall. The aneurysm was deemed unclippable. The posterior clinoid process obscured access to the proximal basilar artery. **(C)** After posterior clinoidectomy, the proximal basilar artery was visualized entering the aneurysm. **(D)** The patient had large PCoAs bilaterally, and therefore the aneurysm was treated with proximal clip occlusion. Postoperative angiography demonstrated significant thrombosis of the aneurysm lumen, and 6-month follow-up angiography demonstrated nearly complete thrombosis of the aneurysm lumen.



A B

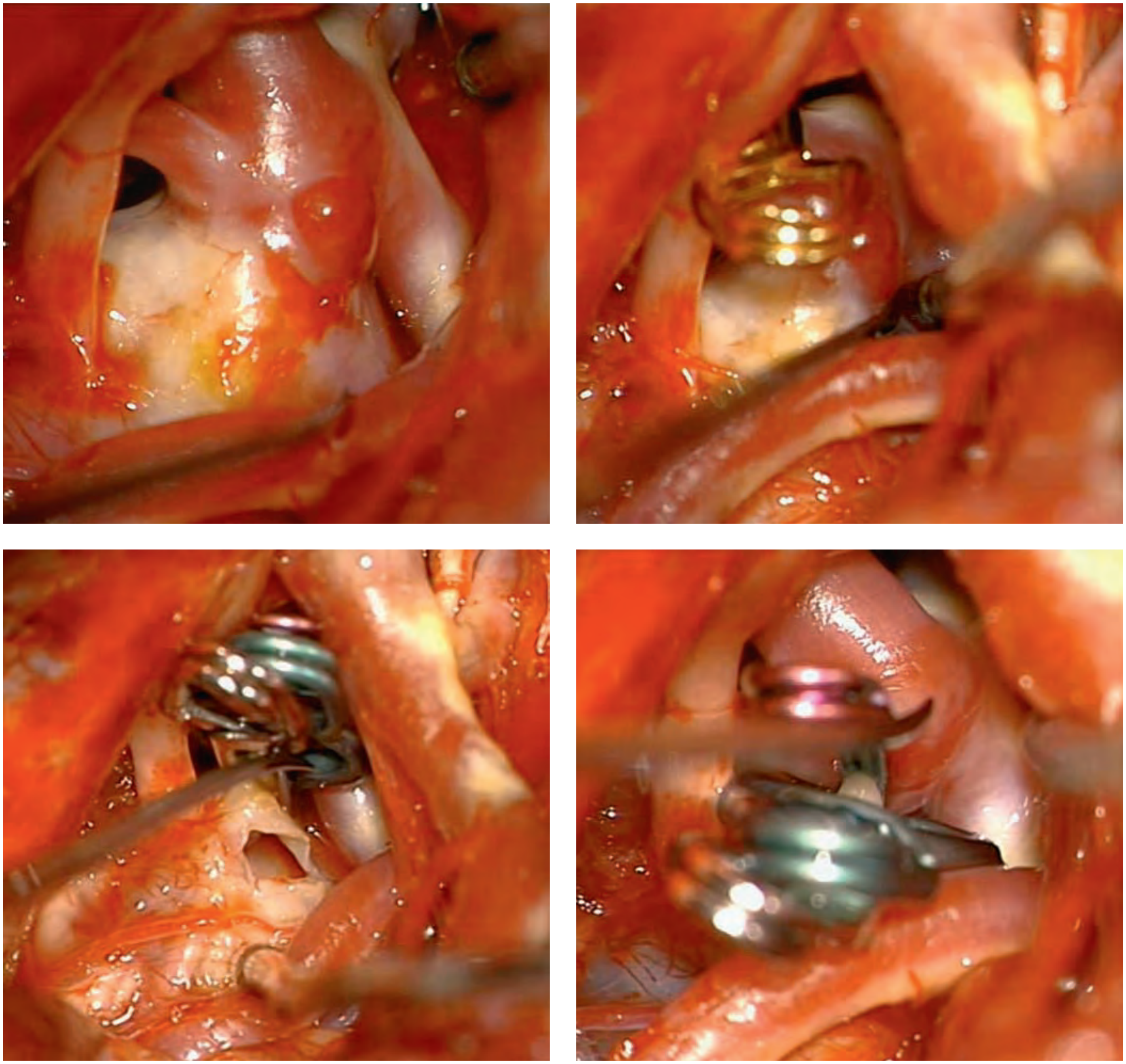
**Fig. 19.23** **(A)** SCA aneurysms are often small, are not intimate with the thalamoperforating arteries, lie off the midline, and are well visualized within the carotid-oculomotor triangle, like this unruptured right SCA aneurysm. **(B)** It was clipped with two stacked mini-clips.

## Superior Cerebellar Artery Aneurysms

Although basilar bifurcation aneurysms are more common, SCA aneurysms are more favorable for microsurgical clipping because they are not intimate with the thalamoperforating arteries. SCA aneurysms push away critical thalamoperforators along the posterior-superior walls of the P1 segment and along the posterior wall of the basilar artery. Perforators do not originate from the axilla of the P1 PCA or the shoulder of the SCA where the neck of an SCA aneurysm is dissected. Consequently, they do not adhere to SCA aneurysms as they frequently do with basilar bifurcation aneurysms. SCA aneurysms lie off the midline, below the basilar bifurcation, well within the carotid-oculomotor triangle, which improves their visualization relative to basilar bifurcation aneurysms. Not having to work across the midline where there are treacherous blind spots and hidden perforators makes SCA aneurysms different from basilar bifurcation aneurysms. There are no high-riding SCA aneurysms as with basilar bifurcation aneurysms, and low-lying aneurysms can be visualized by descending into the posterior fossa with a posterior clinoidectomy. The PCA and SCA can be identified distally on either side of the oculomotor nerve and dissected proximally to their convergence at the neck. There is considerable variation in aneurysm size and morphology here, but most aneurysms can be clipped directly (**Figs. 19.23 and 19.24**).

## Perforators

Rhoton's fourth rule warns about perforators associated with every aneurysm. With some aneurysms, such as the basilar bifurcation aneurysms, perforator dissection, more that any other element of the operation, determines its success or failure. One occluded thalamoperforator is all that it takes to devastate a patient, a fact not associated with any other aneurysm. Their visualization requires anticipation and painstaking dissection. No neurosurgeon ever finishes this operation without diligently checking for perforators caught inadvertently in the clip. Still, small hypodensities on the postoperative computed tomography (CT) scan are painful reminders of how well some perforators can hide, and of where the focus needs to be redirected. With experience, the neurosurgeon generates respect for the perforating arteries. What is perceived as the crux of this operation is transformed from clip application to perforator dissection.



A B C D

**Fig. 19.24** **(A)** This giant left SCA aneurysm presented with progressive right hemiparesis from compression of the left cerebral peduncle. The aneurysm projected to the left, and the ipsilateral P1 segment continued vertically over the dome. The contralateral P1 segment coursed perpendicular to this basilar artery–left PCA junction. The ipsilateral SCA originated from the aneurysm base, almost paralleling the afferent basilar artery. **(B)** Temporary clipping softened the aneurysm and facilitated dissection between the distal neck and the ipsilateral PCA. **(C)** Tandem clipping closed the neck, and the aneurysm was opened and drained to relieve a mass effect. **(D)** A small mini-clip was applied within the fenestration to close the aneurysmal bleb at the aneurysm's base.

# 20 Posterior Inferior Cerebellar Artery Aneurysms

## Microsurgical Anatomy

Vertebral artery originates from the subclavian artery, ascends through the transverse processes of the upper six cervical vertebrae, swings behind the lateral mass of the atlas, passes anterior to the lateral border of the atlanto-occipital membrane, and pierces the dura behind the occipital condyle. The initial intradural vertebral artery (VA) segment passes over the dorsal and ventral roots of the first cervical nerve, and crosses anterior to the dentate ligament and the spinal portion of the accessory nerve. The VA courses from the lower lateral to upper the anterior surface of the medulla, giving off perforators along the way. It passes across the pyramid, joins the contralateral VA at or near the pontomedullary sulcus, and forms the vertebrobasilar junction and basilar trunk (**Fig. 20.1**).

The posterior spinal artery is the first intracranial branch from the VA, although it sometimes arises extradurally and travels with the VA through the dural ring into the subarachnoid space. The posterior spinal artery courses medially behind the dentate ligament, where it divides into ascending and descending branches that supply the dorsal columns and portions of the dorsal cervical spinal cord.

The posterior inferior cerebellar artery (PICA) is the next branch and is the VA's largest, most clinically significant branch. The PICA has five segments defined by its relationship to the lower cranial nerves as it winds around the medulla and the posterior surface of the cerebellum: anterior medullary, lateral medullary, tonsillomedullary, telovelotonsillar, and cortical segments. The *anterior medullary segment* (p1 segment) begins at the PICA's origin, lies anterior to the medulla, and extends past the hypoglossal rootlets at the medial edge of the inferior olive. The *lateral medullary segment* (p2 segment) extends from olive to the rootlets of CN9, CN10, and CN11 at the lateral edge of the olive. The *tonsillomedullary segment* (p3 segment) begins where the PICA passes under or between the rootlets of the CN9 to CN11 triad, descends to the inferior pole of the cerebellar tonsil, reverses course in the caudal or infratonsillar loop, and ascends along the medial tonsil to its midpoint. The *telovelotonsillar segment* (p4 segment) begins at the midpoint of the PICA's ascent along the medial tonsil, continues toward the roof of the fourth ventricle, turns around again to form a cranial or supratonsillar loop, and courses downward and posteriorly to the tonsillobiventral fissure. The telovelotonsillar segment derives its name from its branches to the choroid plexus of the fourth ventricle (tela choroidea) and its association with the roof of the fourth ventricle (inferior medullary velum). The *cortical segment* (p5 segment) begins as the PICA emerges from the tonsillobiventral fissure, where the tonsil, the vermis, and the biventral lobule of the cerebellar hemisphere meet. This segment consists of numerous trunks and branches, with a medial trunk supplying the vermian surface and a lateral trunk supplying the tonsillar and hemispheric surfaces.

The anterior spinal artery is the last branch of the VA proximal to the vertebrobasilar junction (VBJ). It joins the contralateral artery to form a single midline anterior spinal artery that descends through the foramen magnum on the ventral surface of the medulla and spinal cord in or near the anterior median fissure. It supplies the pyramids and their decussation, the medial lemniscus, and the hypoglossal nuclei and nerves.

The spinal accessory nerve is an orienting landmark around the foramen magnum because it traverses the entire field in a far-lateral exposure, from its origin from the cervical spinal rootlets, through the foramen magnum, across the VA, to the jugular foramen. CN11 leads to its partners in the jugular foramen, CN9 and CN10. Rootlets of CN9, CN10, and CN11 originate in the groove between the lateral surface of the olive and the posterolateral medulla (*retro-olivary sulcus*). Rootlets of the hypoglossal nerve originate more anteromedially in the groove between the medial edge of the olive and the medullary pyramids (*preolivary sulcus*). CN12 rootlets course laterally to the hypoglossal canal, which runs above the anterior third of the occipital condyle. The VA always passes anterior to rootlets of CN9, CN10, and CN11, but can split rootlets of CN12.

## Aneurysm Dissection Strategy

Ideally, the arachnoid of the cisterna magna is preserved until the microscope is in the field to keep blood out of the subarachnoid space. Once the microscope is in, this arachnoid is incised in the midline from the vermis down to the

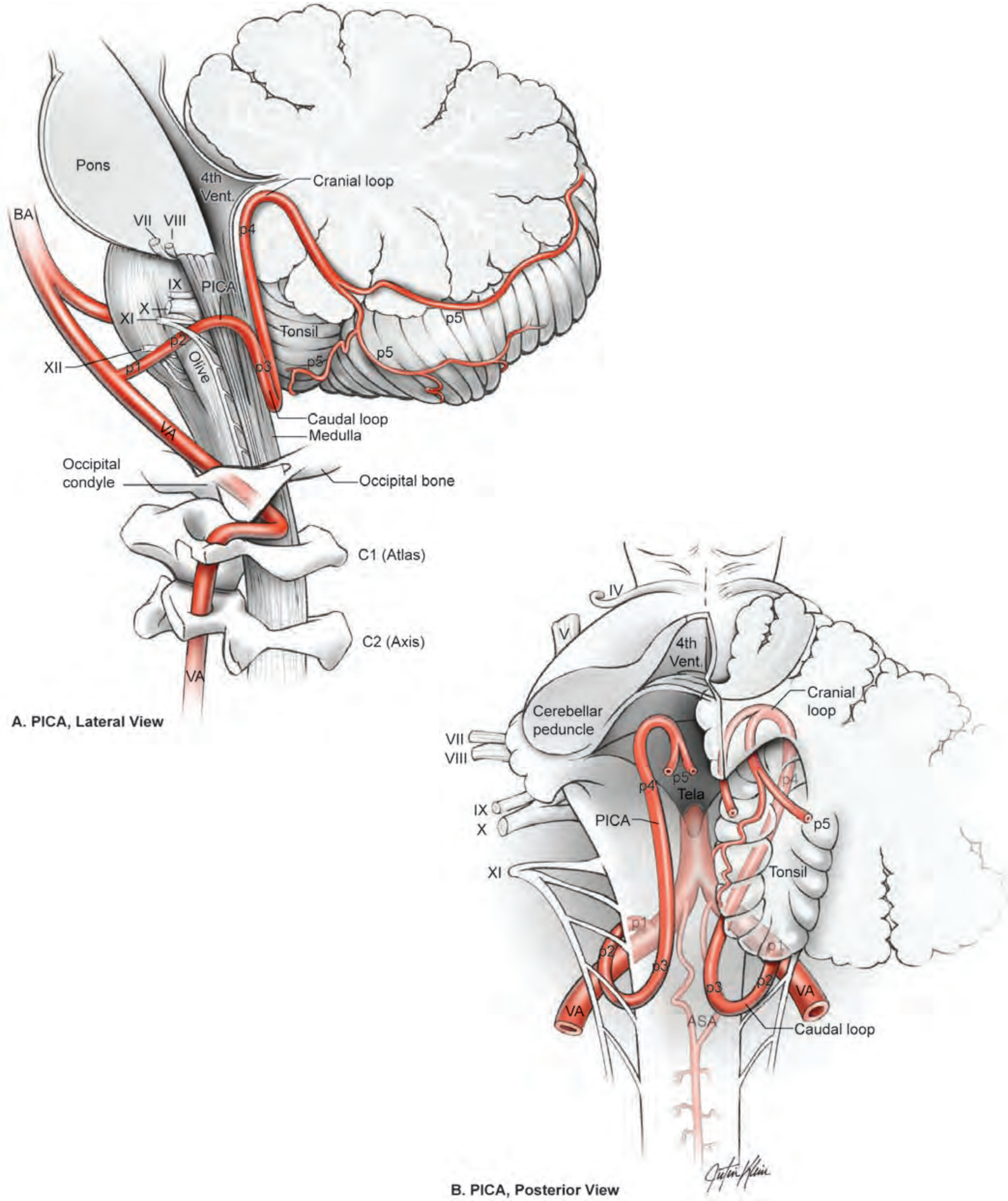



**Fig. 20.1** Microsurgical anatomy of the vertebral artery (VA) and posterior inferior cerebellar artery (PICA). Lateral **(A)** and posterior **(B)** views of the PICA and its relationship to the medulla and cerebellum. The PICA segments are seen: p1, anterior medullary segment; p2, lateral medullary segment; p3, tonsillomedullary segment; p4, telovelotonsillar segment; and p5, cortical segments. ASA, anterior spinal artery; BA, basilar artery.

cervical spinal cord, and incised laterally under the tonsil, which allows the arachnoid to flap laterally against the dura.

Proximal control is gained first by identifying the VA as it pierces the dura under the dentate ligament. The dentate ligament is a white, fibrous sheet that attaches to the lateral margin of the spinal cord between the dorsal and ventral rootlets along the length of the spinal cord. This fibrous sheet inserts on the lateral dura at each level with triangular tooth-like processes, which give this ligament its name. The dentate ligament begins at the foramen magnum where it inserts on the dura above the VA's dural penetration and fans out inferiorly to over the VA. The dentate ligament is often cut at its origin at the foramen magnum and at C1 to access the VA anteriorly. The dentate ligament's pure white, fibrous appearance distinguishes it from the spinal accessory nerve, which lies posteriorly on the dentate ligament, has an off-white color, has perforating arteries, merges with cervical spinal rootlets, and continues beyond the foramen magnum to the jugular foramen. Cutting the dentate ligament also detaches the upper cervical spinal cord to widen the surgical corridor. A segment of the VA just distal to its dural penetration is prepared for temporary clipping, and a clear path to the point of proximal control is established through this lattice of the accessory nerve crossing the VA obliquely, the C1 rootlets draping the back of the VA, and perforating and posterior spinal arteries coursing to the spinal cord.

The dissection to PICA aneurysms is relatively simple because both the VA and the PICA are identifiable landmarks that lead directly to the aneurysm. The VA is identified under the dentate ligament as described above, and the PICA is identified under the tonsil in the cerebellomedullary fissure, if the caudal loop of the PICA is not already visible in the cisterna magna. One or both arteries are traced proximally to their convergence, and the aneurysm lies just beyond this convergence. Arteries do not traverse a difficult fissure or require extensive dissection. The caudal loop of the PICA at the inferior tonsil is apparent early or with tonsillar retraction. The medulla and the anterior tonsil are easily separated because their surfaces are smooth, distinct, and never interdigitated like some other fissures. As the tonsil retracts superiorly, the cerebellomedullary fissure widens to expose the proximal tonsillomedullary segment of the PICA.

The PICA–VA convergence is obstructed by the lower cranial nerves, and the dissection pathway to the aneurysm

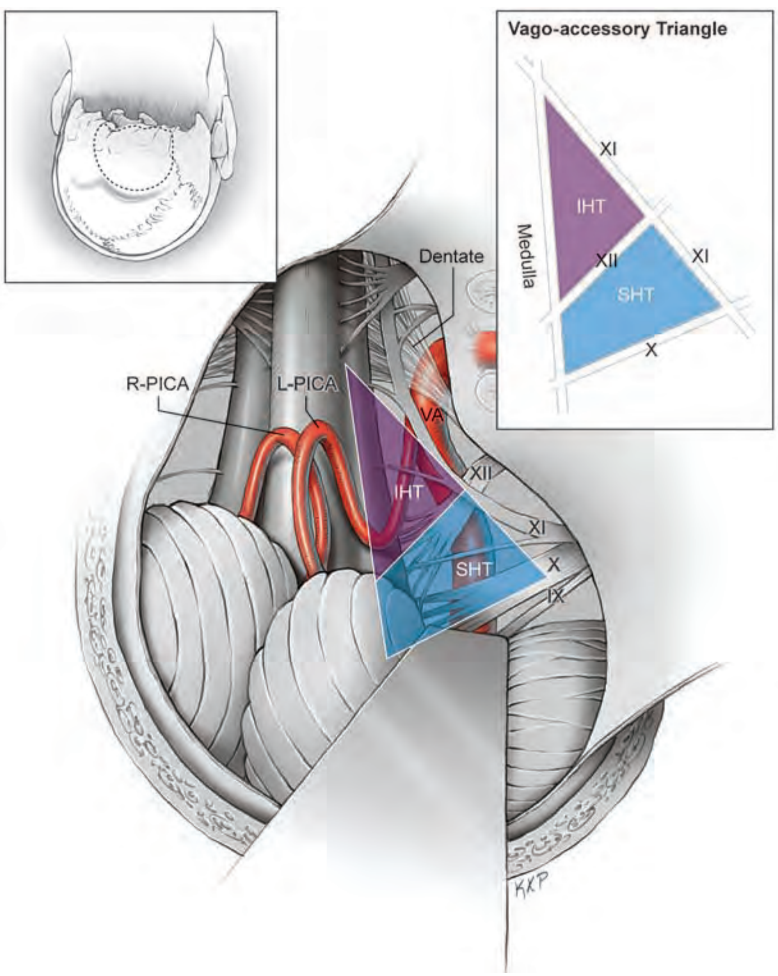



**Fig. 20.2** Three anatomical triangles defined by the lower cranial nerves as exposed by the far-lateral approach (*inset*): the vagoaccessory triangle; the suprahypoglossal triangle (SHT); and the infrahypoglossal triangle (IHT). These triangles clarify the dissection routes through the lower cranial nerves to PICA aneurysms.

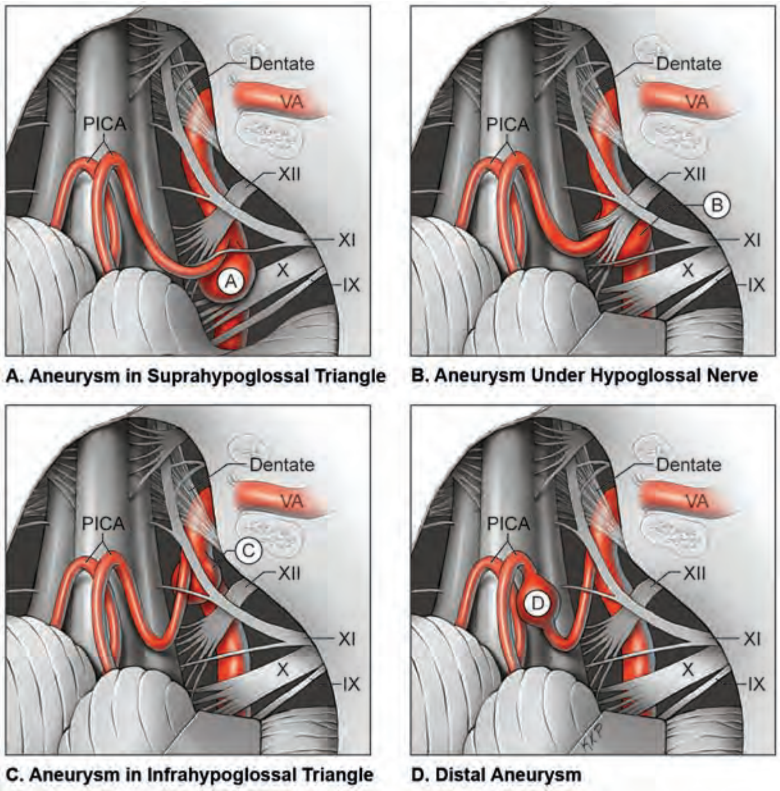



**Fig. 20.3** PICA aneurysms reside in different anatomic triangles depending on variations in PICA anatomy, VA tortuosity, and aneurysm pathology. **(A)** PICA aneurysms can lie in the suprahypoglossal triangle (aneurysm A), with hypoglossal nerve rootlets in the axilla of the PICA. **(B)** PICA aneurysms can lie directly under the hypoglossal nerve at the border between the supra- and infrahypoglossal triangles (aneurysm B), with hypoglossal nerve rootlets both in the axilla and over the shoulder of the PICA. **(C)** PICA aneurysms can lie in the infrahypoglossal triangle (aneurysm C), with hypoglossal nerve rootlets between the distal aneurysm neck and the VA. **(D)** PICA aneurysms can lie outside the vagoaccessory triangle (aneurysm D), separate from the lower cranial nerves.

traverses this neural lattice. Three anatomic triangles clarify the dissection routes: the *vagoaccessory triangle,* the *suprahypoglossal triangle,* and the *infrahypoglossal triangle* (**Fig. 20.2**). The vagoaccessory triangle is defined by the vagus nerve superiorly, the accessory nerve laterally, and the medulla medially. This triangle is the natural working window of the far-lateral approach. The accessory nerve lies along the skull base and prevents dissection anterolateral to the nerve; vagus and glossopharyngeal nerve rootlets fan out from the retro-olivary sulcus to prevent dissection superiorly, and most PICA aneurysms do not extend above this nerve complex. CN9, CN10, and CN11 originate from the retro-olivary sulcus and course to the jugular foramen, whereas CN12 originates from the preolivary sulcus and courses to the hypoglossal foramen. Consequently, the course and depth of the hypoglossal nerve differs from that of the vagus and accessory nerves. The vagoaccessory triangle is divided into two smaller triangles by the hypoglossal nerve as it traverses laterally. The suprahypoglossal triangle is the area in the vagoaccessory triangle above the hypoglossal nerve, between CN10, CN11, and CN12. The infrahypoglossal triangle is the area in the vagoaccessory triangle below the hypoglossal nerve, between CN11, CN12, and the medulla.

These triangles through two layers of nerve roots are opened to reach the PICA–VA confluence. Variability in arterial anatomy, tortuosity, and aneurysm pathology makes the route different with each case (**Fig. 20.3**). For example, a proximal PICA origin positions the aneurysm inferolaterally in the vagoaccessory triangle, and the route to the aneurysm is through the infrahypoglossal triangle. A distal PICA origin positions the aneurysm superomedially, and the route to the aneurysm is through the suprahypoglossal triangle. The dissection beyond the retro-olivary sulcus follows the PICA's lateral medullary segment around the olive to the preolivary sulcus and hypoglossal nerve rootlets. These rootlets drape the VA perpendicular to the artery's axis like the rungs of a ladder. They are easy to work through, but can settle in the aneurysm's cleavage planes: in the axilla of the PICA as it originates from the VA, over the shoulder of the PICA against the proximal neck, or in the crotch between the distal neck and the distal VA. Dissection beyond the preolivary sulcus through the hypoglossal nerves follows the anterior medullary segment and arrives at the PICA–VA confluence with aneurysms deep in the suprahypoglossal triangle.

Posterior inferior cerebellar artery anatomy is highly variable, and can originate anywhere along the VA trunk and in some cases even extradurally. The PICA originating inferiorly may be lateral to the medulla and not have an anterior medullary segment. An elongated or tortuous VA can move a PICA aneurysm away from the lower cranial nerves. Some aneurysms displace and drape lower cranial nerves. Therefore, it is often more useful to apply the anatomic zones that define PICA segments to the aneurysm location instead (**Fig. 20.4**). Aneurysms that lie in the *anterior medullary zone*, where the anterior medullary segment would normally reside, require working through CN10, CN11, and CN12 to

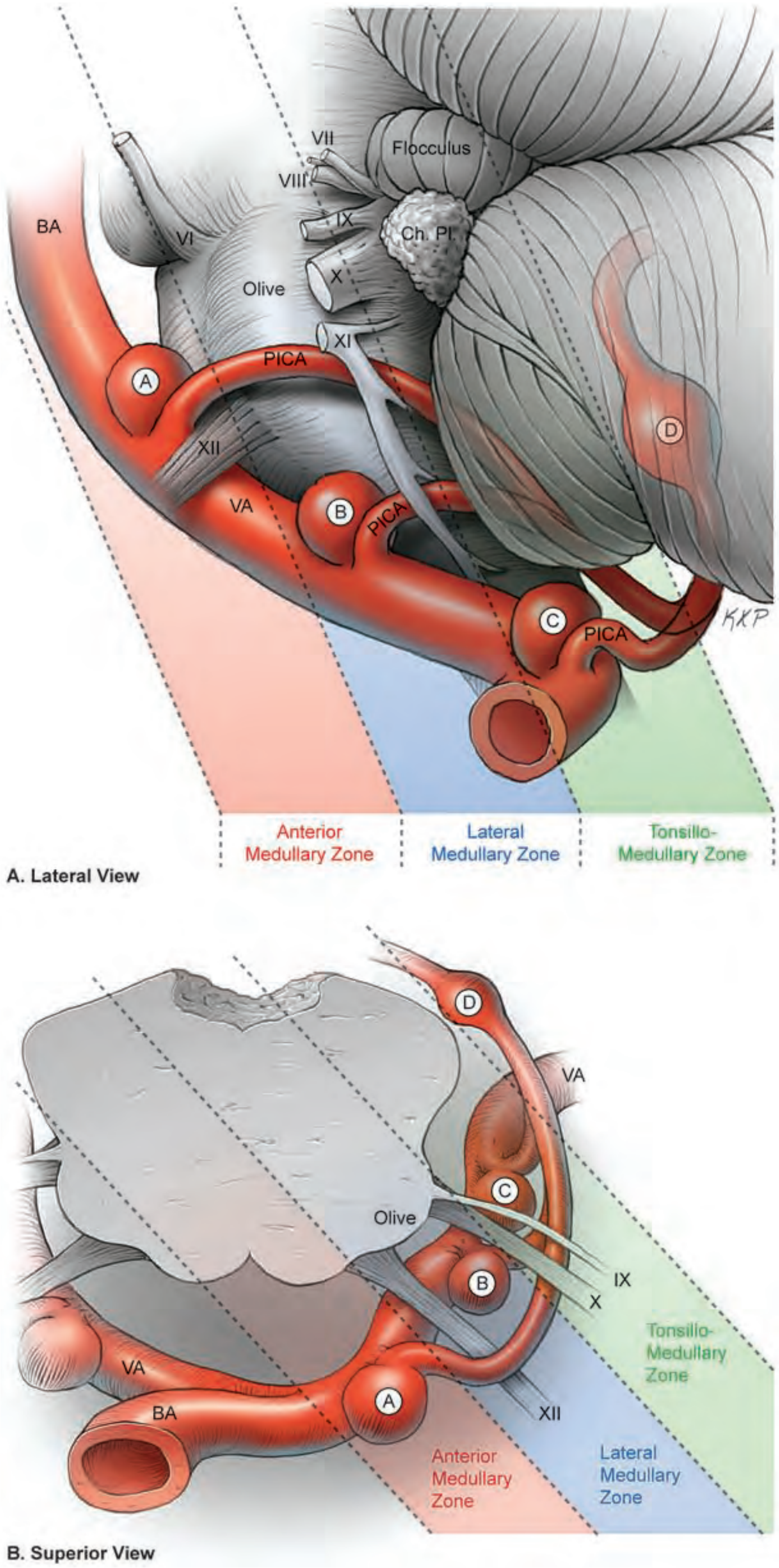



**Fig. 20.4** **(A)** The PICA's origin on the VA can be distally located, moving the aneurysm into the *anterior medullary zone* medial to CN9, CN10, CN11, and CN12 (aneurysm A). The PICA's origin on the VA can be proximally located, moving the aneurysm into the *lateral medullary zone* medial to CN9, CN10, and CN11 (aneurysm B). The PICA's origin on the VA can be more proximal, moving the aneurysm into the *tonsillomedullary zone* lateral to the lower cranial nerves (aneurysm C). Distal PICA aneurysms typically are not involved in the lower cranial nerves (aneurysm D). Ch. Pl., choroid plexus. **(B)** PICA aneurysms and their relationships with the lower cranial nerves and medullary zones, as viewed from a superior axial perspective.

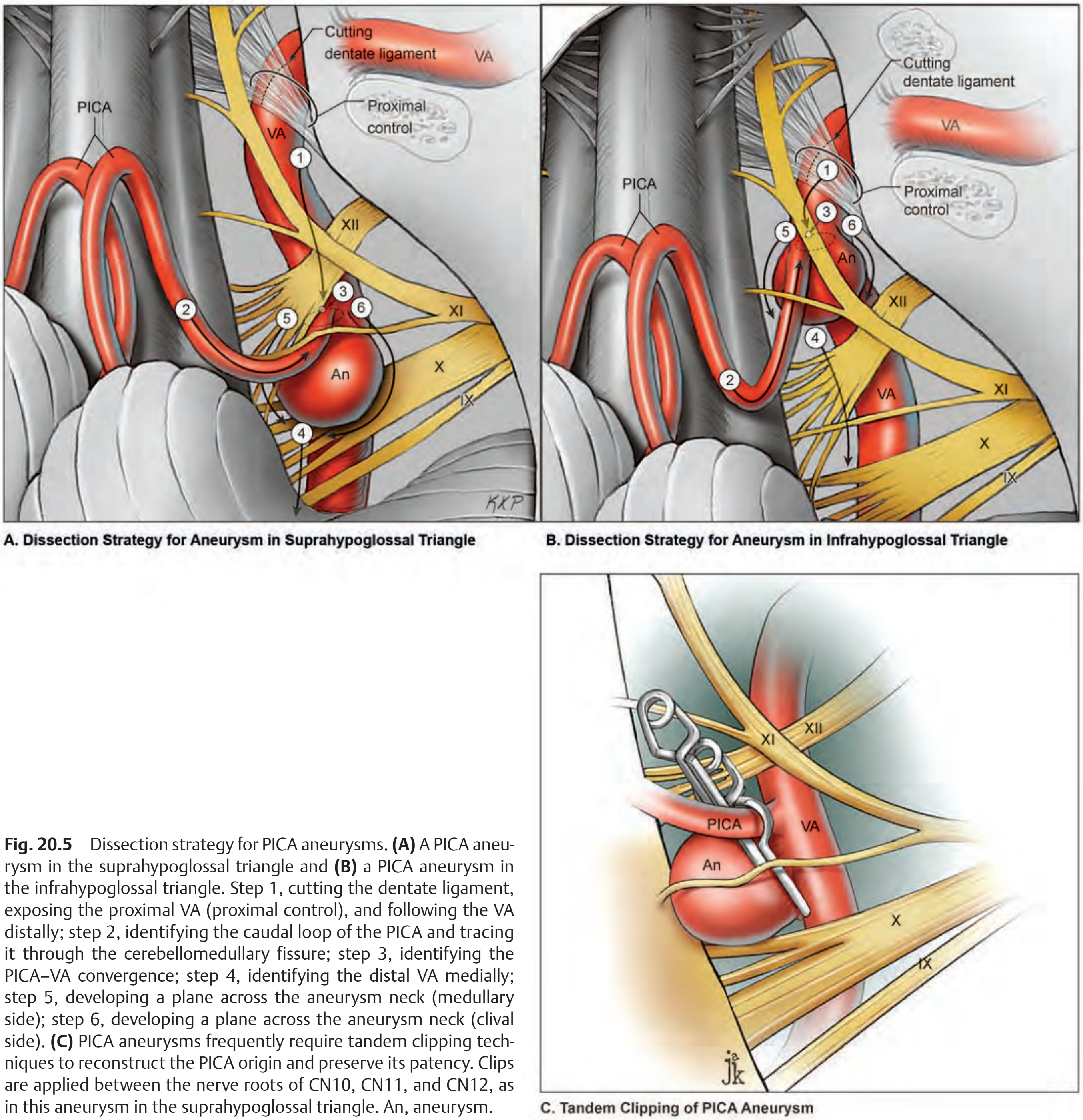



**Fig. 20.5** Dissection strategy for PICA aneurysms. **(A)** A PICA aneurysm in the suprahypoglossal triangle and **(B)** a PICA aneurysm in the infrahypoglossal triangle. Step 1, cutting the dentate ligament, exposing the proximal VA (proximal control), and following the VA distally; step 2, identifying the caudal loop of the PICA and tracing it through the cerebellomedullary fissure; step 3, identifying the PICA–VA convergence; step 4, identifying the distal VA medially; step 5, developing a plane across the aneurysm neck (medullary side); step 6, developing a plane across the aneurysm neck (clival side). **(C)** PICA aneurysms frequently require tandem clipping techniques to reconstruct the PICA origin and preserve its patency. Clips are applied between the nerve roots of CN10, CN11, and CN12, as in this aneurysm in the suprahypoglossal triangle. An, aneurysm.

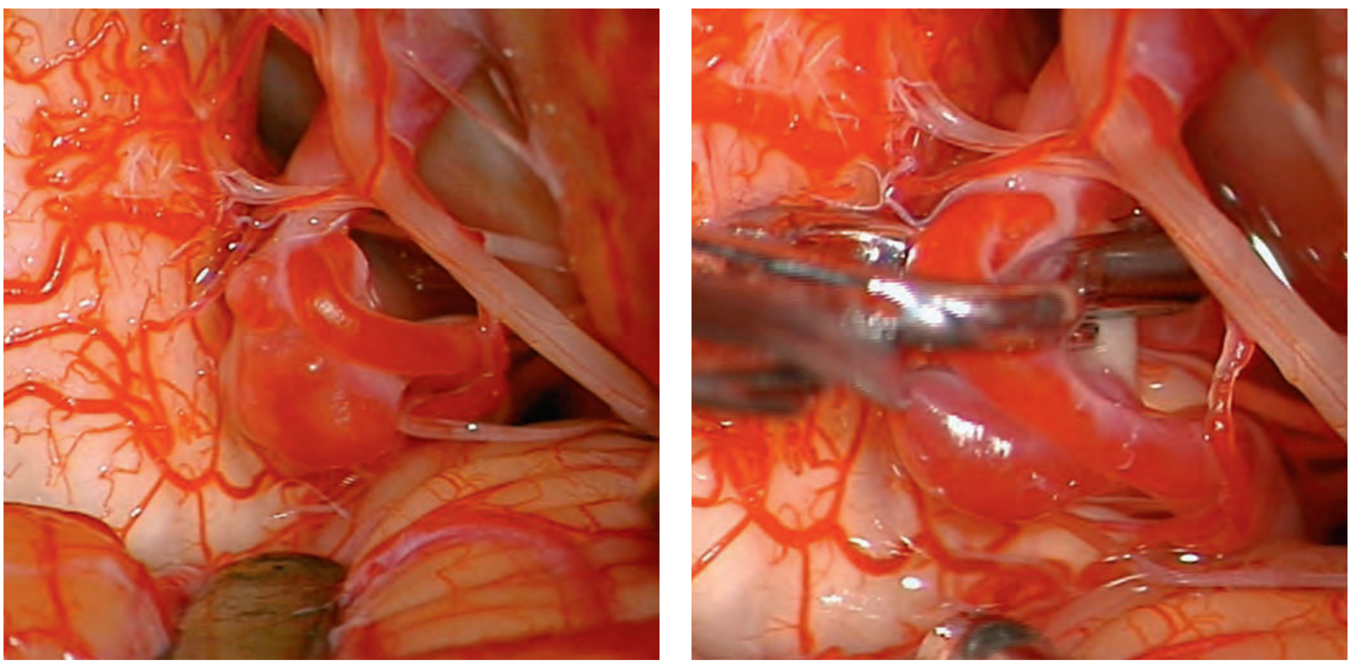
reach the PICA–VA convergence. Aneurysms that lie in the *lateral medullary zone*, where the lateral medullary segment would normally reside, require working through CN10 and CN11. Aneurysms that lie in the *tonsillomedullary zone*, in the cerebellomedullary fissure where the tonsillomedullary segment would normally reside, do not require traversing any nerves. Aneurysms in the tonsillomedullary zone have an early PICA origin or a distal PICA aneurysm. This survey clarifies aneurysm location relative to the medulla and helps in planning the dissection route.

Antegrade dissection along the VA (**Fig. 20.5**, step 1) and retrograde dissection along the PICA (**Fig. 20.5**, step 2) leads to the PICA–VA convergence, which is a point below the aneurysm base (**Fig. 20.5**, step 3). Most PICA aneurysms project superiorly according to Rhoton's third rule. Lateral dome projection can push the PICA–VA convergence toward the medulla, and the medial dome projection can push the convergence away from the medulla. The typical view is up the dome's axis, with the PICA recurring toward the neurosurgeon. The distal VA may be hidden beyond the aneurysm, but it veers medially toward the VBJ and can be identified by following the medial surface of the VA around the anterolateral medulla (**Fig. 20.5**, step 4). Visualization of the distal VA may require some lateral traction on the aneurysm base, or some medial traction on the medulla. Small perforating branches to the medulla in this plane are preserved. The distal VA shoulders the clip's tip and therefore is visualized clearly for permanent clipping. Once the distal VA is identified, the medial (medullary) and lateral (clival) sides of the neck are dissected to open a plane for each of the clip blades (**Fig. 20.5**, steps 5 and 6).

These six steps for PICA aneurysms in the suprahypoglossal triangle (**Fig. 20.5A**) are the same for aneurysms in the infrahypoglossal triangle (**Fig. 20.5B**), but the corridors between the lower cranial nerves are different.

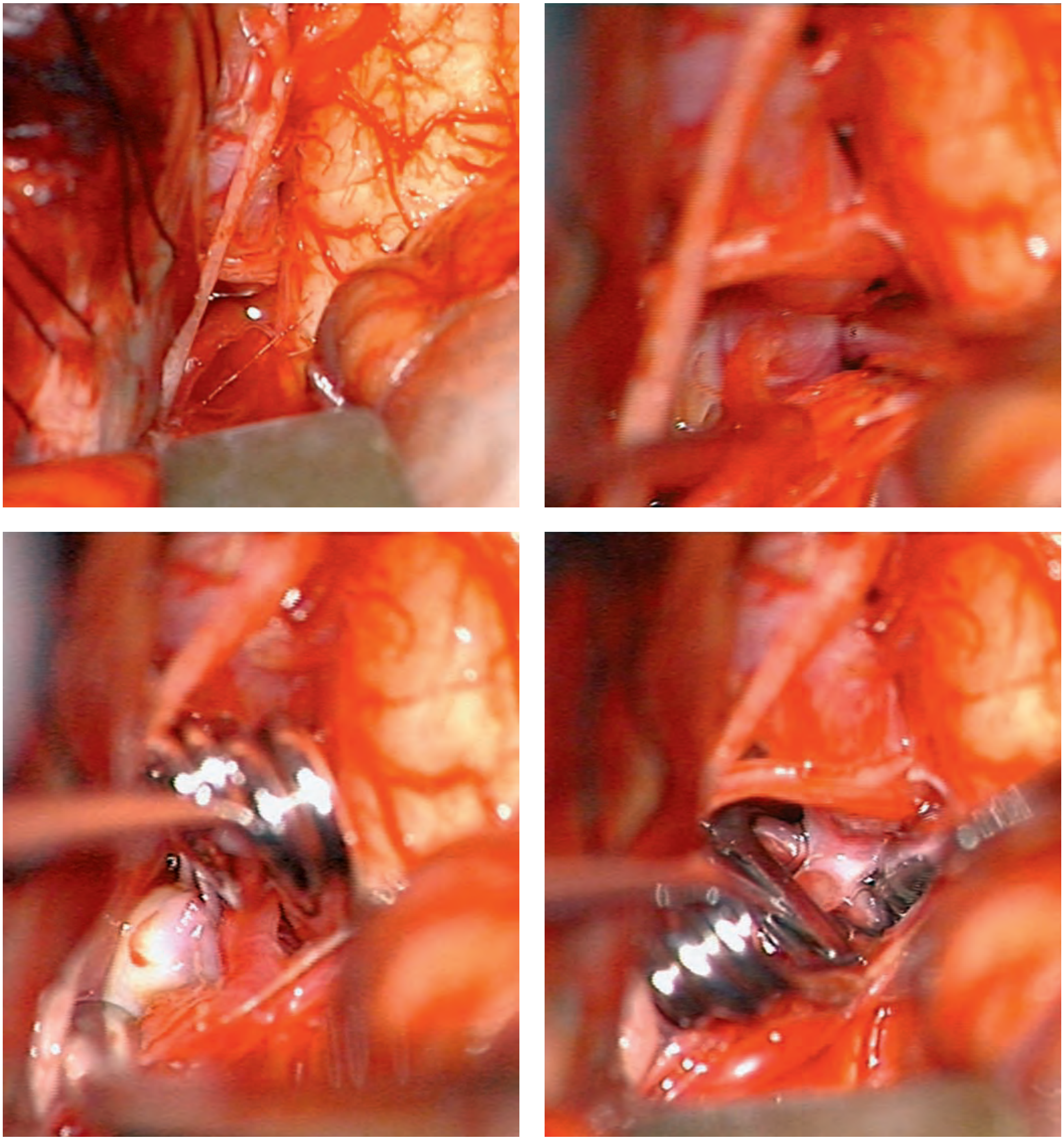
## Clipping Technique

Tandem clipping is common with PICA aneurysms because the far-lateral approach provides a view along the axis of the VA, the aneurysms project superiorly, and the PICA often originates from the aneurysm base (**Fig. 20.5C**). An initial straight fenestrated clip obliterates most of the neck. The blades parallel the efferent VA and the fenestration encircles the PICA origin. A stacked straight clip over the fenestration completes the aneurysm closure and generously reconstructs the PICA's origin (**Fig. 20.6**). Straight clips in a tandem configuration can be maneuvered through the lower cranial nerves, even with deep aneurysms in the anterior medullary zone (**Fig. 20.7**). A fenestrated clip in a tandem configuration can also encircle and transmit the cranial nerves that adhere to the aneurysm neck (**Fig. 20.8**).



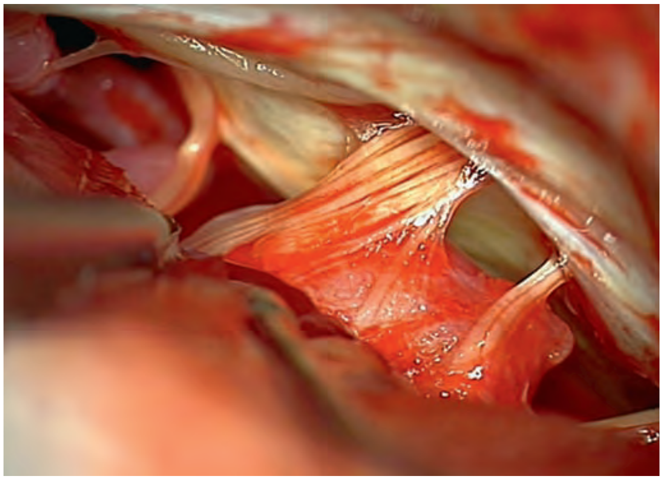
A B

**Fig. 20.6** **(A)** This left PICA aneurysm in a 60-year-old woman with a prior subarachnoid hemorrhage (SAH) from a middle cerebral artery (MCA) aneurysm sat inferomedially in the vagoaccessory triangle, with the aneurysm in the tonsillomedullary zone. The rootlets of the accessory nerve coursed on either side of the aneurysm, but the vagus nerve was above and the hypoglossal nerve was deep to the aneurysm, giving unobstructed access. Many PICA aneurysms have dysmorphic features, and this one had two daughter lobes on each side of the PICA's origin at the aneurysm base. **(B)** Tandem clipping was used to close the aneurysm, with a stacked straight mini-clip closing the fenestration.



A B C D

**Fig. 20.7** **(A)** This right PICA aneurysm in a 53-year-old woman was located distally on the VA, in the anterior medullary zone and deep in the suprahypoglossal triangle. The boundaries of the vago-accessory triangle were clearly seen, as was the hypoglossal nerve dividing this triangle and draping the VA. **(B)** The vagus nerve was mobilized superiorly, and the PICA and VA were followed to their convergence at the aneurysm base. **(C)** The aneurysm dome projected laterally, and the neck was clipped with tandem clipping. **(D)** The fenestration encircled the PICA origin and the closing clip slid alongside the PICA.



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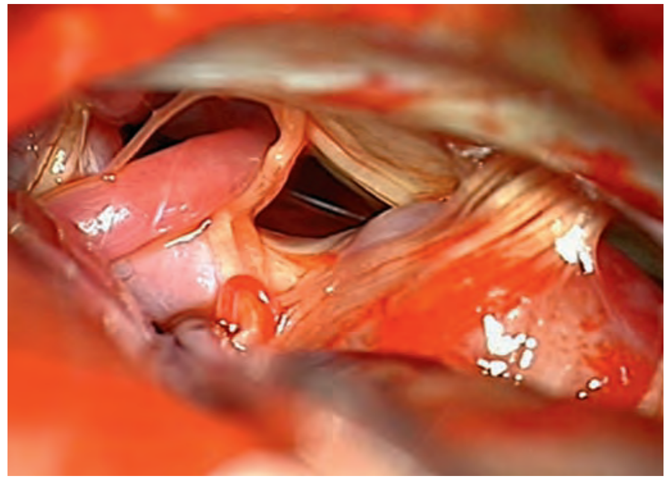

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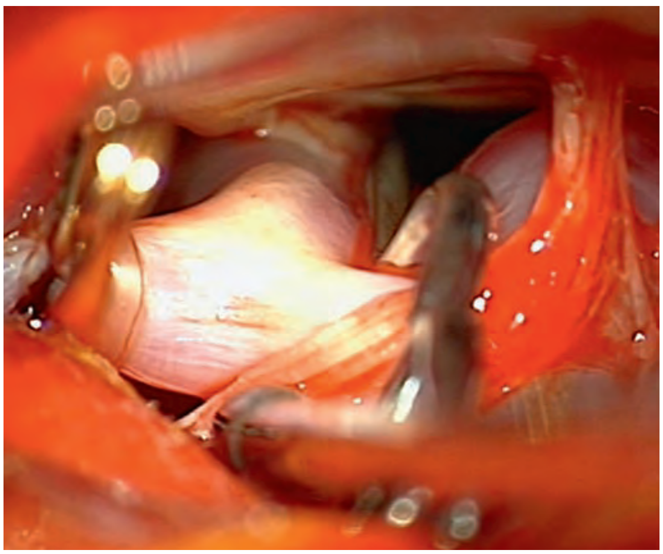
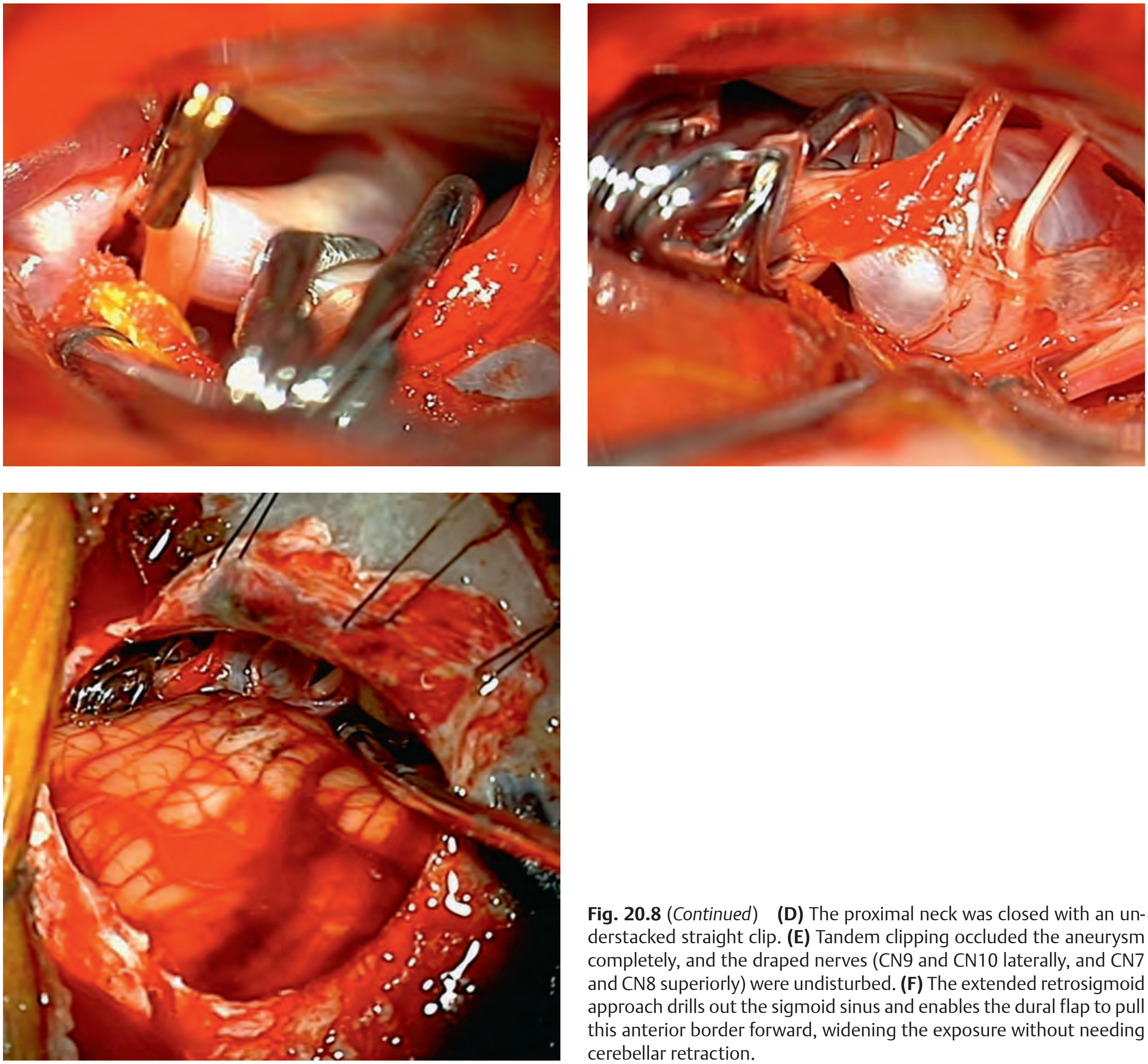


C

**Fig. 20.8** Some PICA and VA aneurysms are located so distally that they are accessed better through an extended retrosigmoid approach than through a far-lateral approach. This elderly woman presented with an SAH from a large distal VA aneurysm on the left side, which was exposed through a left extended retrosigmoid approach. **(A)** The aneurysm was seen in the cerebellopontine angle, medial to the vagus and glossopharyngeal nerves, in the apex of the vagoaccessory triangle. Aneurysm exposure through a far-lateral approach would have been limited, whereas exposure through this retrosigmoid approach was sufficient, without using a retractor. The vestibulocochlear-facial nerve complex was seen above the aneurysm dome. **(B)** Proximal control was gained in the vagoaccessory triangle below the aneurysm. Hypoglossal nerve rootlets draped the VA, as did a tortuous and enlarged PICA. **(C)** Temporary clipping on the proximal VA softened the aneurysm and enabled permanent aneurysm clipping with a straight fenestrated clip, with the fenestration encircling the vagus nerve. The clip blades paralleled the efferent VA, which coursed medially. (*continued on next page*)



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E

F

**Fig. 20.8** (*Continued*) **(D)** The proximal neck was closed with an understacked straight clip. **(E)** Tandem clipping occluded the aneurysm completely, and the draped nerves (CN9 and CN10 laterally, and CN7 and CN8 superiorly) were undisturbed. **(F)** The extended retrosigmoid approach drills out the sigmoid sinus and enables the dural flap to pull this anterior border forward, widening the exposure without needing cerebellar retraction.

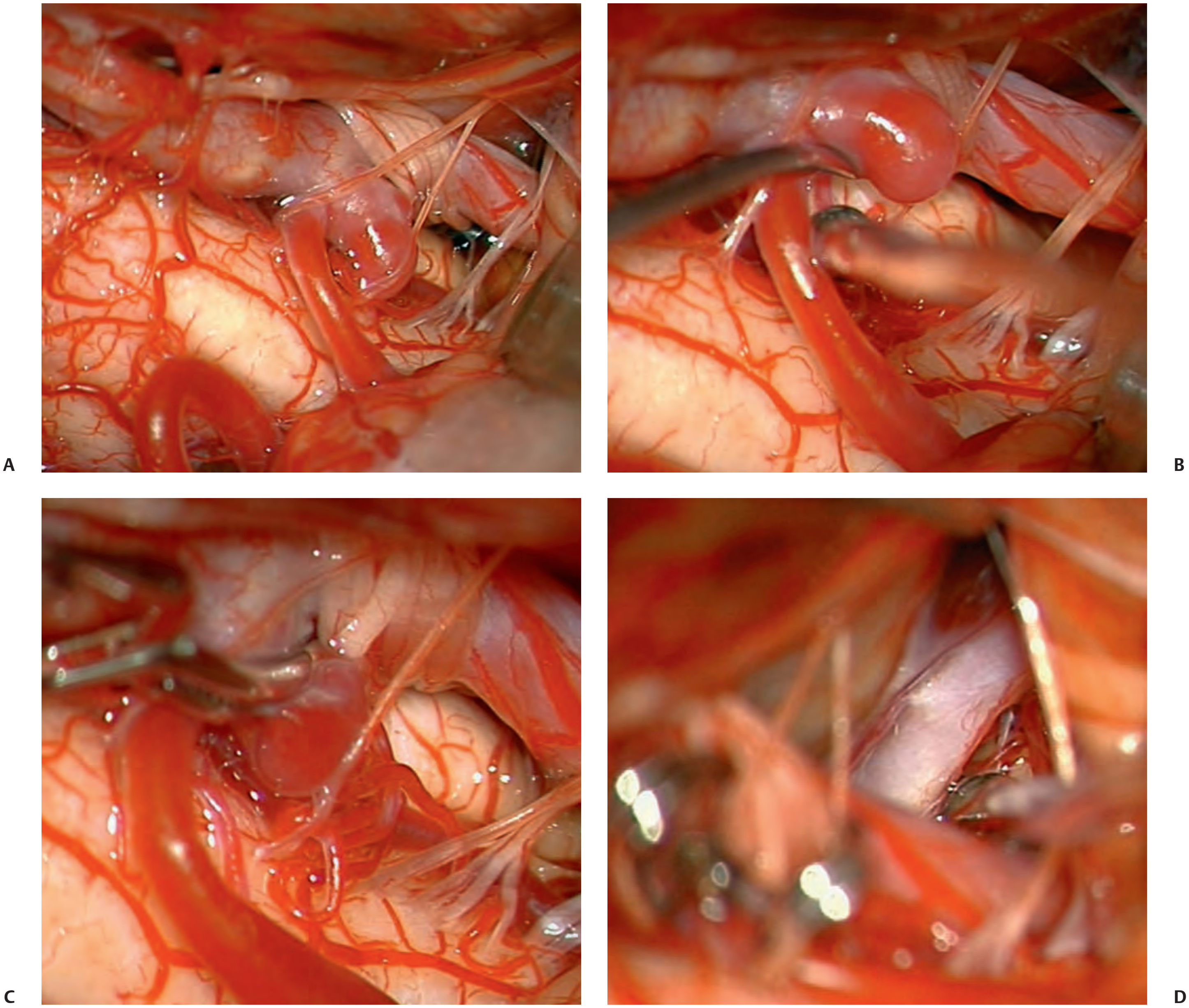
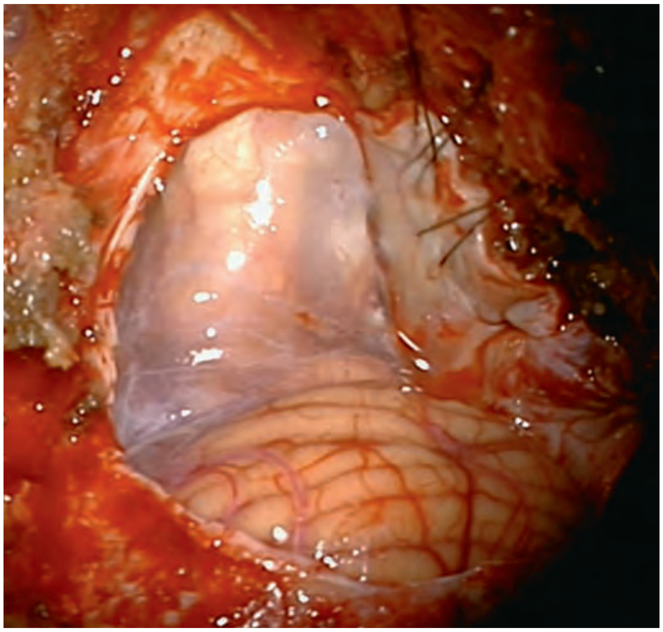



**Fig. 20.9** **(A)** The left PICA aneurysm in this 48-year-old woman was located in the lateral medullary zone and the infrahypoglossal triangle. The caudal loop of the PICA was easily identified between the tonsils, and gentle retraction on the left tonsil opened the cerebellomedullary fissure. The hypoglossal nerve was draped over the left VA in the cleft above the distal aneurysm neck. **(B)** The distal VA was easily visualized, and the aneurysm was mobilized away from the olive to prepare the medial side of the aneurysm neck. This dissection was performed in the lateral medullary zone, deep to rootlets of the accessory nerve. **(C)** The aneurysm was clipped simply with a down-curved clip, avoiding the hypoglossal rootlets just beyond the tips. **(D)** The contralateral right VA just proximal to vertebrobasilar junction was seen through the suprahypoglossal triangle, working anterior to the distal left VA.

Simple clipping is used with small aneurysms and those located inferiorly in the vagoaccessory triangle (**Fig. 20.9**). Distal PICA aneurysms can be exposed widely, and clips can be maneuvered easily (**Figs. 20.10 and 20.11**). Deeper aneurysms in the suprahypoglossal triangle and anterior medullary zone can be clipped simply when small size and simple anatomy permits (**Figs. 20.12 and 20.13**). Multilobulated PICA aneurysms can be repaired by simply clipping each lobe as a distinct aneurysm (**Fig. 20.14**).



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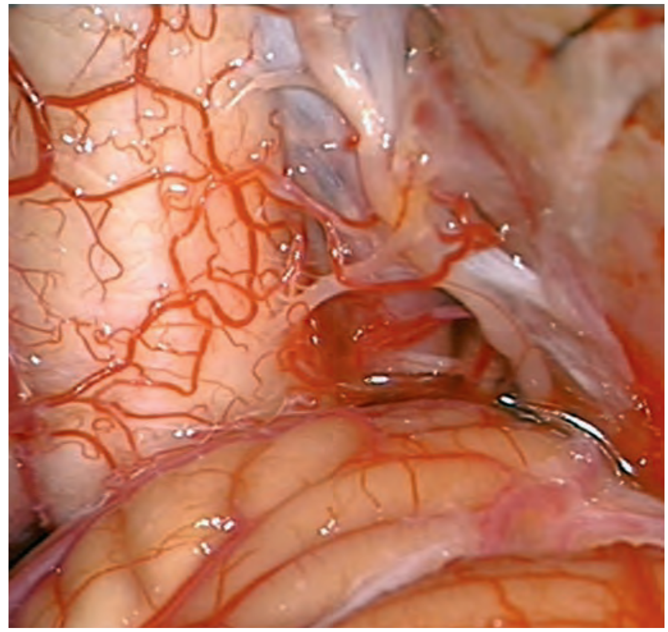

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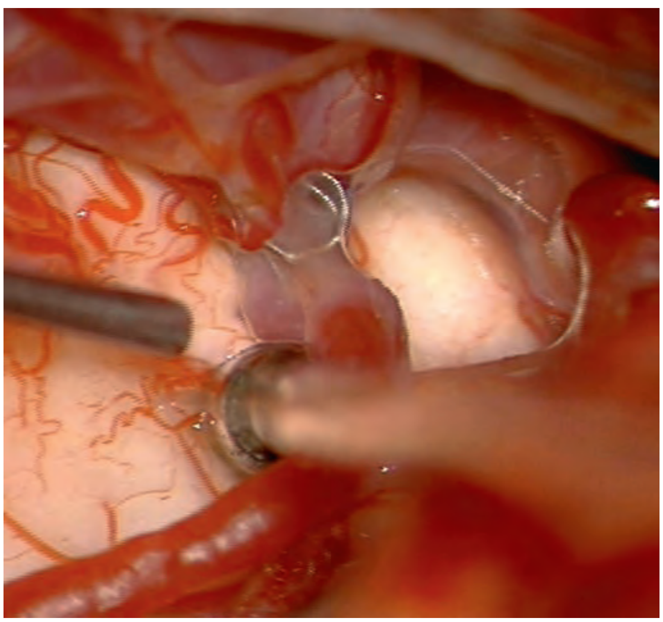

C

**Fig. 20.10** This 46-year-old woman had a SAH from this left distal PICA aneurysm and was treated with endovascular coiling. Follow-up angiography demonstrated coil compaction. **(A)** Preservation of the arachnoid around the cisterna magna during the opening keeps the subarachnoid space clear of blood, as seen after opening the dura in a left far-lateral approach. **(B)** The dentate ligament covers the VA as it pierces the dura, and the VA is exposed for proximal control by cutting the dentate ligament. The accessory nerve lies on top of the dentate ligament, as seen from this operative perspective. Note that the dentate ligament ends at its insertion in the dura around the foramen magnum whereas the accessory nerve continues superiorly. Also note the difference in color; the dentate ligament is white and the accessory nerve is off-white. **(C)** This distal PICA aneurysm was located at a bend in the PICA approximately 2 cm from its origin, which is seen at the right edge of the photograph. Coils were extruded through the dome and adhered to the hypoglossal nerve as it draped over the VA.

D

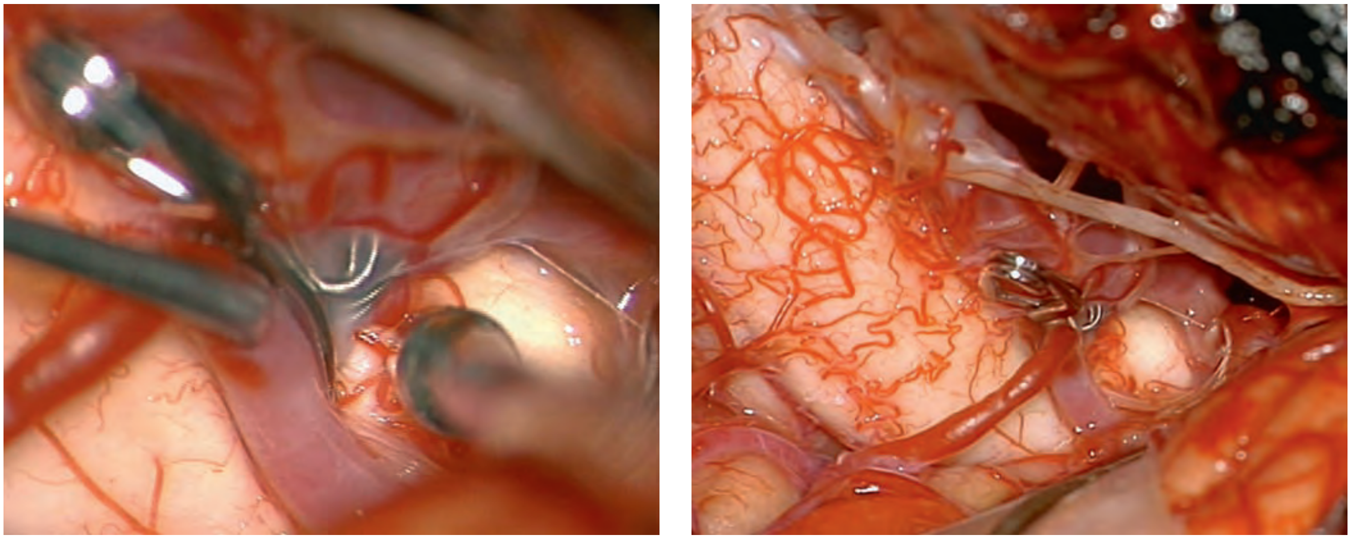

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**Fig. 20.10** (*Continued*) **(D)** Coils compacted enough to clip the neck beneath the coils. **(E)** This aneurysm sat on the border between the supra- and infrahypoglossal triangles. Distal PICA aneurysms often reside in the tonsillomedullary zone superficial to the lower cranial nerves.

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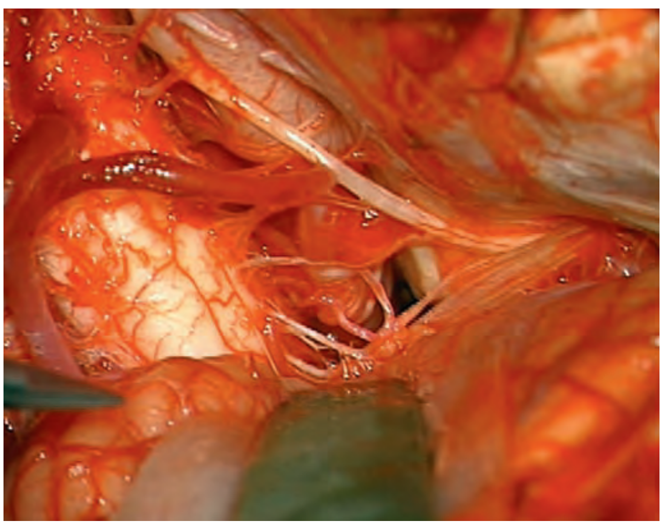

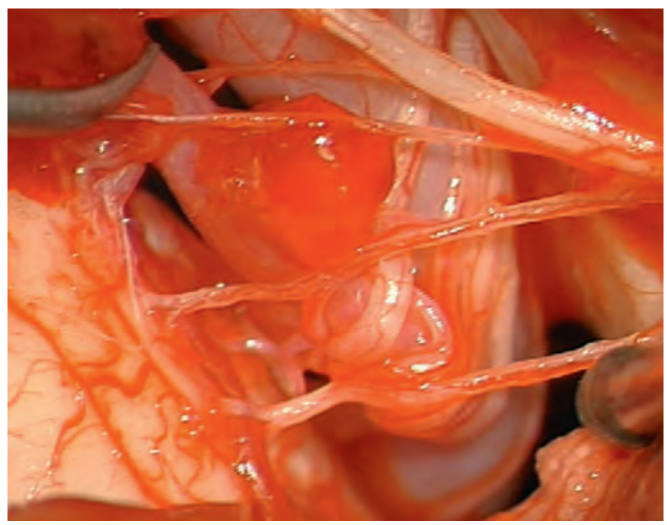

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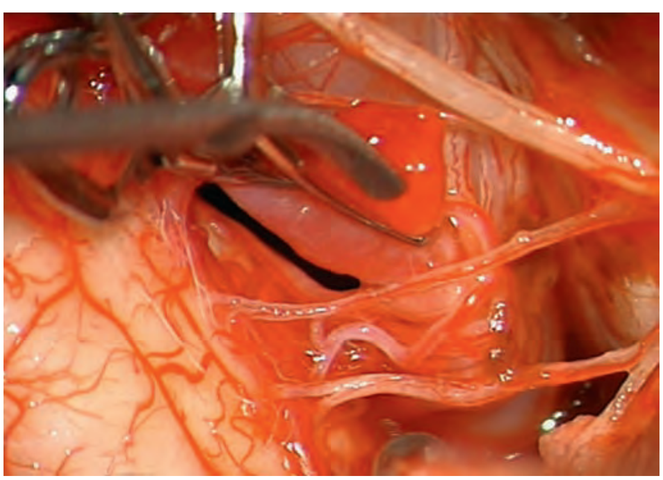

**Fig. 20.11** **(A)** This left distal PICA aneurysm in a 49-year-old man presenting with a SAH was located in the infrahypoglossal triangle, **(B)** but it was deep to rootlets of the accessory nerve in the lateral medullary zone. **(C)** The neck was clipped with two slightly curved clips applied parallel to the PICA between the rootlets of the accessory nerve.

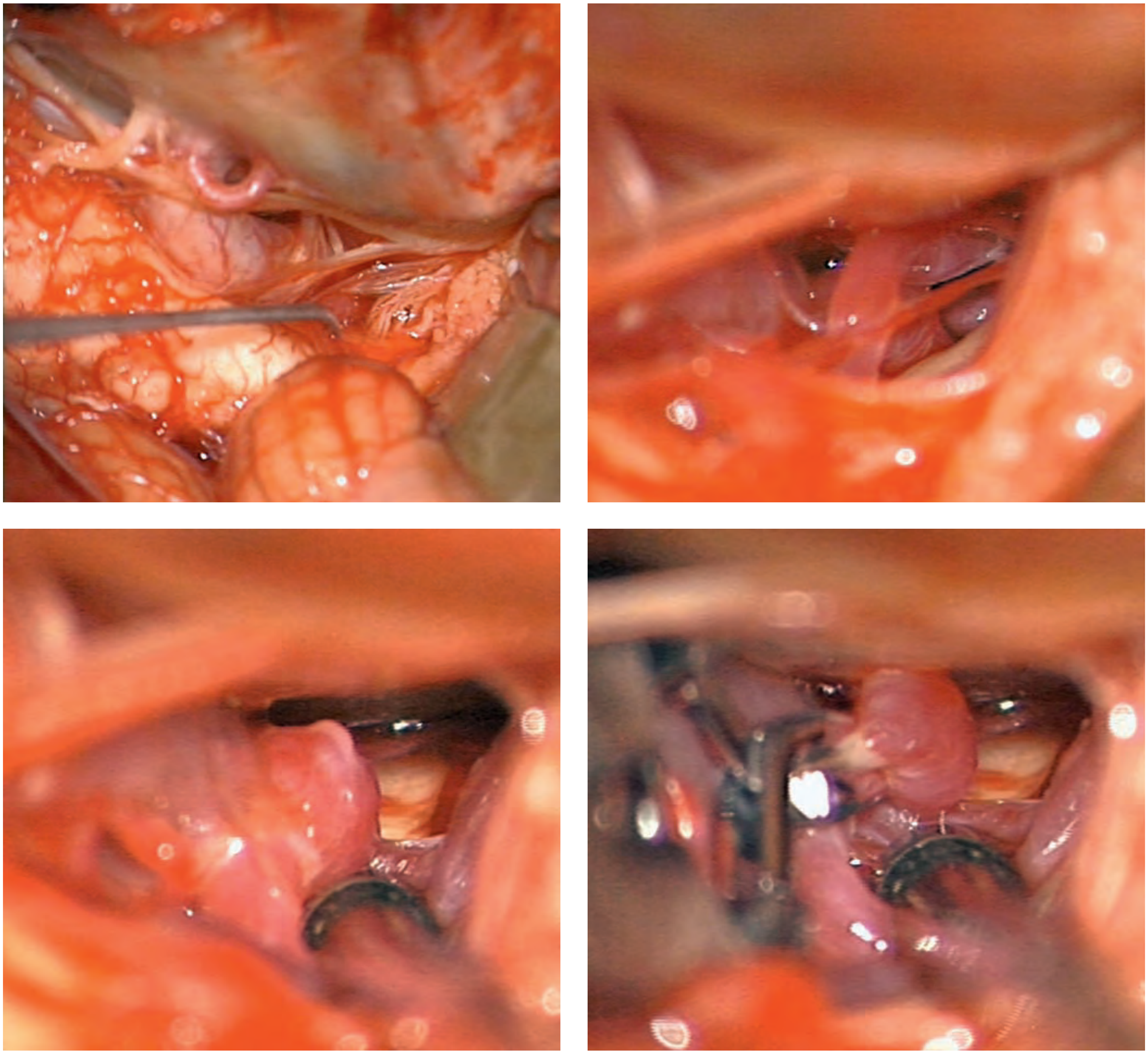

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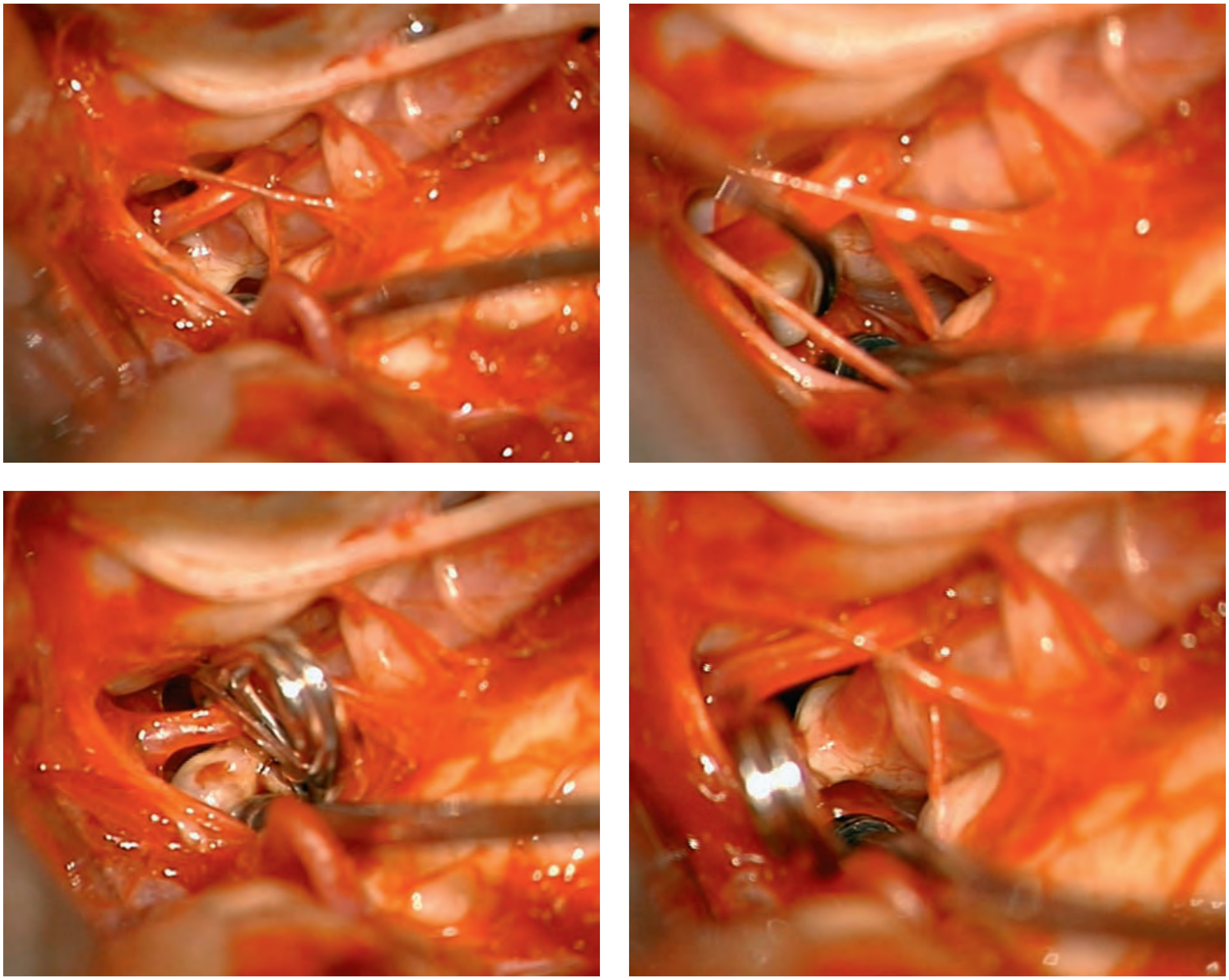
**Fig. 20.12** **(A)** This left PICA aneurysm in a 63-year-old woman was located in the anterior medullary zone and in the suprahypoglossal triangle. Retraction on the left tonsil exposed the convergence on CN11, CN10, and CN9, with the choroid plexus from the foramen of Luschka lying on top of the glossopharyngeal nerve. The hypoglossal nerve was visualized in the angle between the vagus and the accessory nerves, draped over the left VA. The PICA aneurysm was not visible without opening these triangular corridors. **(B)** The suprahypoglossal triangle was enlarged by mobilizing vagus nerve rootlets posteriorly. The PICA was seen in the center of this triangle and traced retrograde to its convergence with the VA. **(C)** The superiorly projecting aneurysm was identified at the PICA–VA convergence. **(D)** The aneurysm was clipped with a simple down-curved clip.



A B C D

**Fig. 20.13** **(A)** When the PICA originates distally from the VA, the associated aneurysm typically resides in the anterior medullary zone and deep in the suprahypoglossal triangle, as in this 59-year-old woman who presented with a SAH. The aneurysm dome projected superiorly and the right PICA recurred toward the neurosurgeon under a hypoglossal rootlet. The distal VA veered medially toward the vertebrobasilar junction (VBJ) and was hidden by the medulla. **(B)** The distal VA was identified by following the medial surface of the VA beyond the aneurysm and around the anterolateral medulla, with some lateral traction on the aneurysm neck with a No. 6 dissector. **(C)** The aneurysm was clipped with a straight clip, **(D)** with the blades paralleling the distal VA.

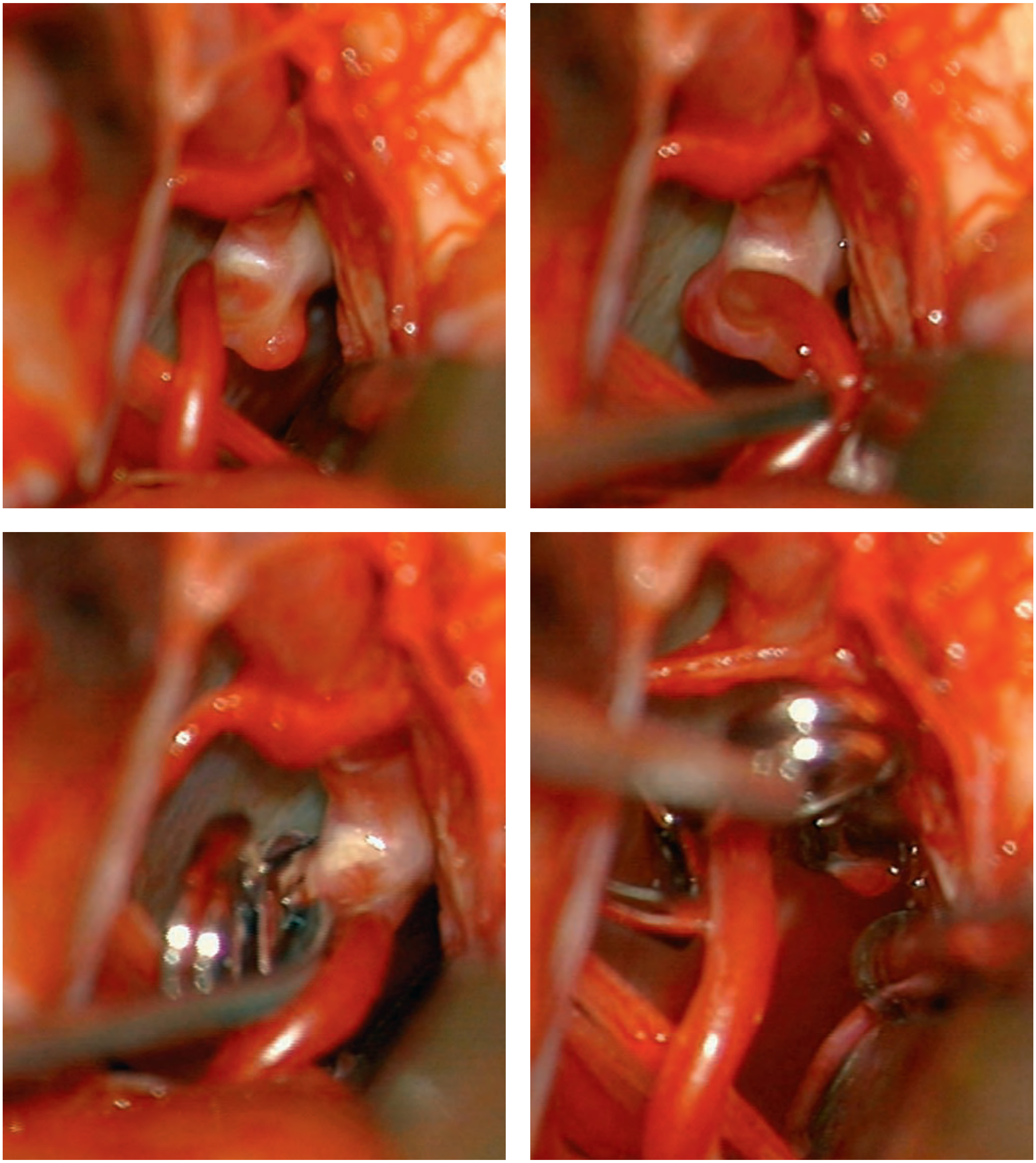


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**Fig. 20.14** **(A)** Some PICA aneurysms located in the anterior medullary zone are accessed best through the infrahypoglossal triangle. This right PICA aneurysm in a 61-year-old woman had two lobes, one on each side of the PICA origin. The aneurysm was deep to the hypoglossal nerve, which was seen coursing under the PICA. The PICA–VA convergence was in the center of the infrahypoglossal triangle, and the distal VA bent medially in front of the medulla. **(B)** Medial mobilization of the PICA demonstrated the lateral lobe of the aneurysm, **(C)** which was clipped with a straight clip. **(D)** The medial lobe was clipped with a curved clip that paralleled the distal VA and the other clip. The surgical corridor was below the hypoglossal nerve rootlets, seen in the lower left corner of the field.

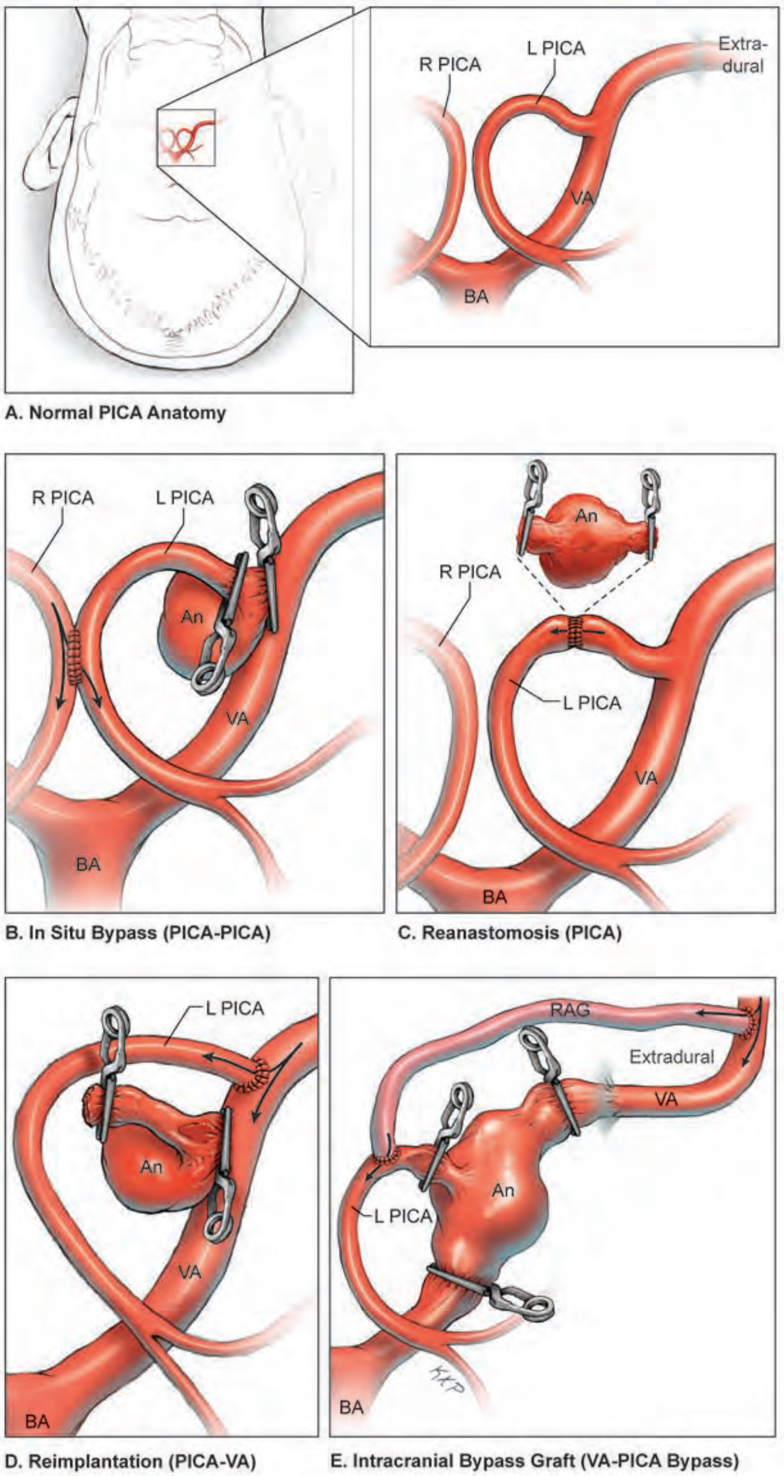


**Fig. 20.15** Bypass techniques for PICA aneurysms. **(A)** Normal PICA anatomy. **(B)** An in situ bypass approximates the right and left caudal loops of the PICA with a side-to-side anastomosis, allowing the aneurysm to be trapped (PICA–PICA bypass). **(C)** Fusiform PICA aneurysms with one inflow artery and one outflow artery can be excised and the parent artery reconstructed with an end-to-end anastomosis (*PICA excision-reanastomosis*). **(D)** When the PICA is compromised by the clipping or cannot be preserved, it can be transected from the aneurysm and reimplanted proximally on the VA with an end-to-side anastomosis (*PICA reimplantation*). **(E)** Large and complex aneurysms involving the VA–PICA complex can be reconstructed with a *radial artery bypass graft*, using extradural VA at the C1 level as the proximal donor site for an end-to-side anastomosis, and using the PICA as the distal recipient site for another end-to-side anastomosis. The aneurysm can then be trapped. If the involved VA is the dominant artery supplying the posterior circulation, the aneurysm complex can be proximally occluded, and the bypass will supply the posterior circulation via retrograde flow in the proximal PICA.

Unusual anatomy so often associated with PICA aneurysms calls for alternative techniques, such as trapping and bypass, when clipping is unsuccessful. For the PICA there are a variety of excellent bypass options, including an extracranial-to-intracranial bypass that uses the occipital artery as the donor artery. The anatomy around the foramen magnum lends itself to the intracranial-to-intracranial bypasses that use the contralateral PICA (*PICA–PICA bypass*) and reconstructive techniques such as end-to-end *reanastomosis* or end-to-side *reimplantation* of the PICA onto the proximal VA (**Fig. 20.15**). Intracranial-to-intracranial bypasses eliminate the need for harvesting the occipital artery, which is a tedious

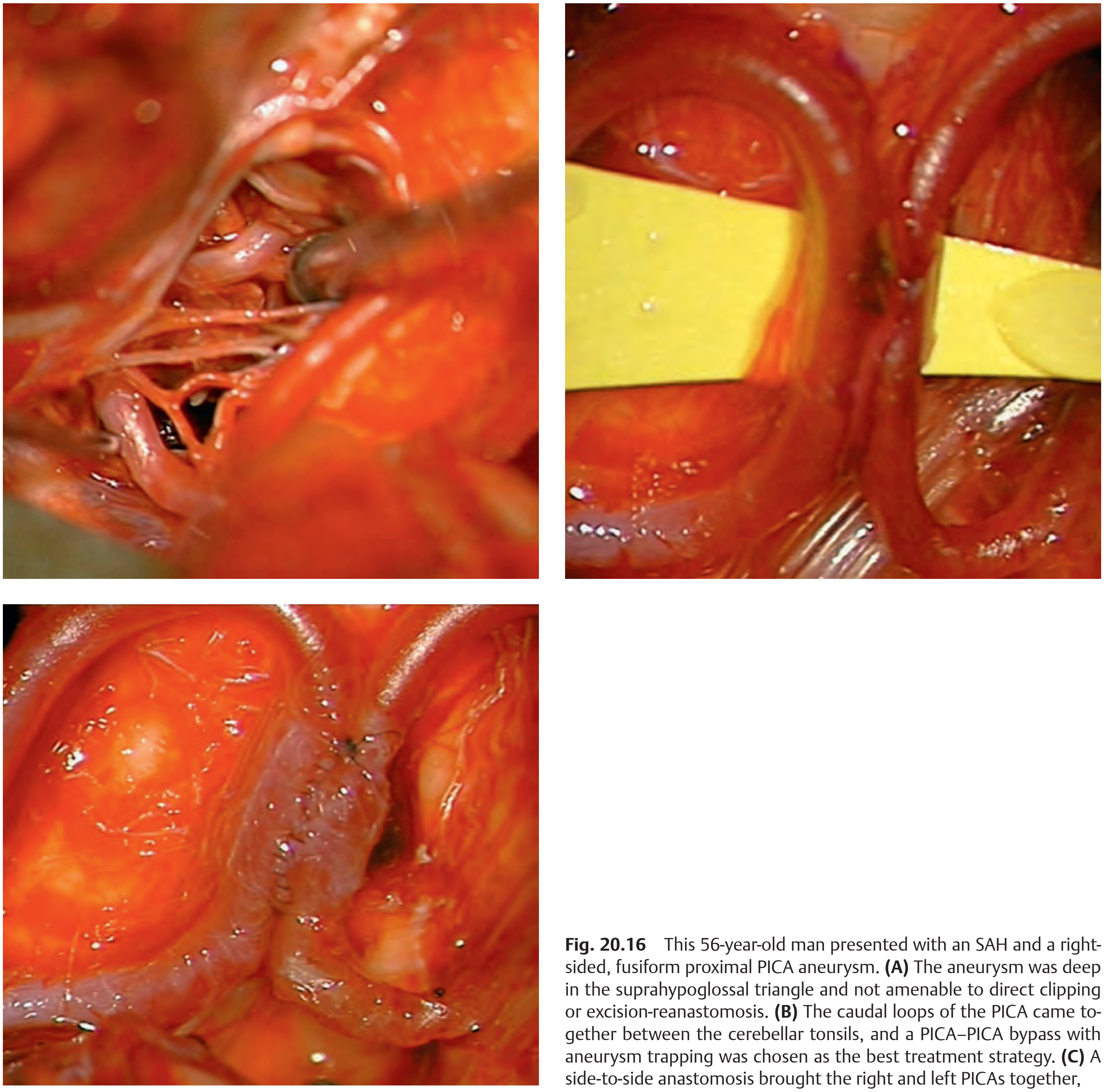

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**Fig. 20.16** This 56-year-old man presented with an SAH and a right-sided, fusiform proximal PICA aneurysm. **(A)** The aneurysm was deep in the suprahypoglossal triangle and not amenable to direct clipping or excision-reanastomosis. **(B)** The caudal loops of the PICA came together between the cerebellar tonsils, and a PICA–PICA bypass with aneurysm trapping was chosen as the best treatment strategy. **(C)** A side-to-side anastomosis brought the right and left PICAs together,

dissection for an often diminutive artery. The surgical corridor for PICA bypasses is deep but wide, visualization is excellent, temporary arterial occlusion is well tolerated, and the results are favorable.

Tonsillomedullary segments of the PICA distal to their caudal loop lie parallel and in close proximity to one another as they course around the posterior medulla in the cisterna magna. The PICA–PICA bypass joins these arteries with a side-to-side anastomosis (**Fig. 20.16**). Anterograde blood flow in an efferent PICA that is lost with permanent clipping of the aneurysm is replaced by retrograde blood flow from the anastomosis. These in situ bypasses are appealing

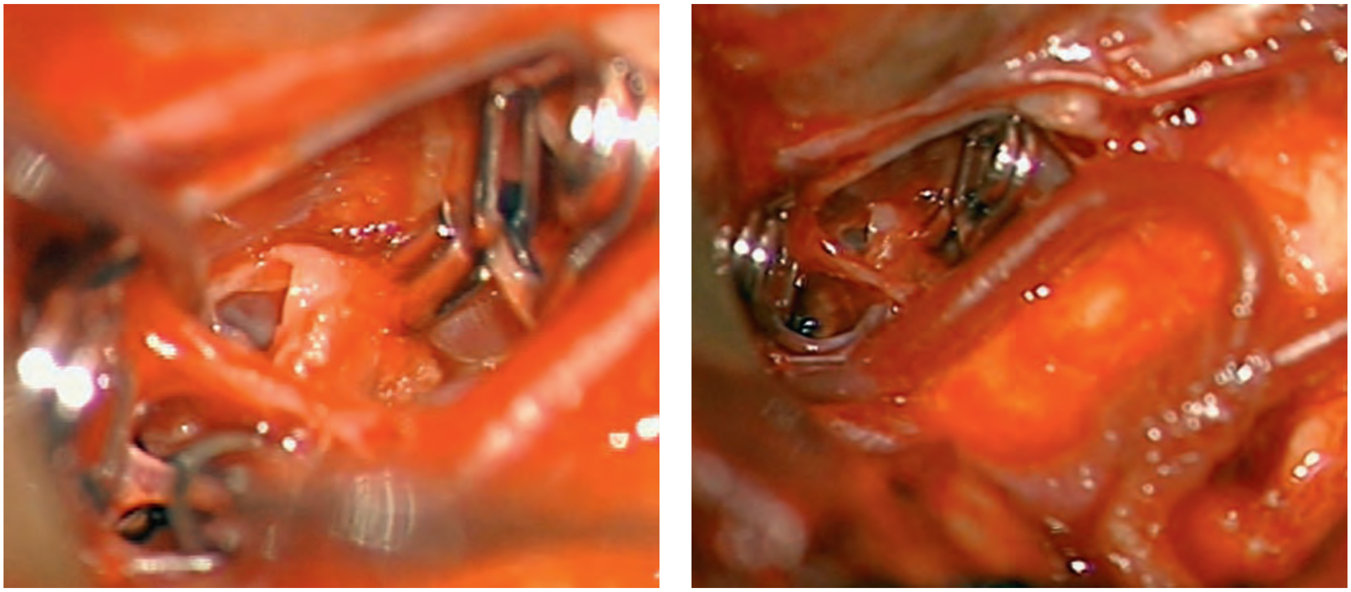


**Fig. 20.16** (*Continued*) **(D)** which enabled the fusiform aneurysm to be trapped and opened. **(E)** The standard far-lateral approach provided adequate exposure for both the PICA–PICA bypass and the aneurysm trapping.

because they are entirely intracranial, are less vulnerable to injury or occlusion, do not require harvesting an occipital artery, use donor and recipient arteries with diameters that are well matched, and require just one anastomosis.

Reanastomosis requires completely detaching afferent and efferent arteries from the aneurysm and rejoining them with an end-to-end anastomosis (**Fig. 20.17**). This bypass is ideal with fusiform aneurysms that are small or medium in size, and distally located away from the PICA's origin. Larger aneurysms may be difficult to reanastomose because the ends of the parent artery may be too far apart. These ends of afferent and efferent arteries must be mobile to enable the first stitch to pull them together. If the gap in the parent artery is too long, or if there is tension from branch arteries, the suture will tear through the artery wall as it is tightened. The PICA often has redundancy in the parent artery that facilitates reconstruction. Reanastomosis is appealing because, like the in situ bypass, it is entirely intracranial, is less vulnerable to injury, does not require harvesting an extracranial artery, uses no donor artery, and requires just one anastomosis.

Reimplantation is useful when the clip application obliterates the neck but fails to preserve the PICA. This problem is encountered with dysmorphic aneurysms and branches that originate from the aneurysm base. The branch artery can be reconstituted with end-to-side reimplantation onto the proximal VA, which is accessible in the foramen magnum and is not as deep as the native PICA origin (**Fig. 20.18**). Gaps between the origins of perforators along the anterior medullary segment and their medullary penetration allow for some mobilization. Reimplantation is appealing because it is entirely intracranial, is less vulnerable to injury or occlusion, does not require harvesting an extracranial graft, and requires just one anastomosis.

Large and complex aneurysms involving the PICA–VA complex can be reconstructed with an intracranial bypass graft, usually the radial artery (**Fig. 20.19**). Extradural VA at the C1 level serves as the proximal donor site for an end-to-side anastomosis, and the PICA is used as the distal recipient site for another end-to-side anastomosis. The aneurysm can then be trapped. If the involved VA is the dominant artery supplying the posterior circulation and the contralateral VA terminates in the PICA, the aneurysm complex can be proximally occluded rather than trapped. The bypass will supply the posterior circulation via retrograde flow in the proximal PICA.

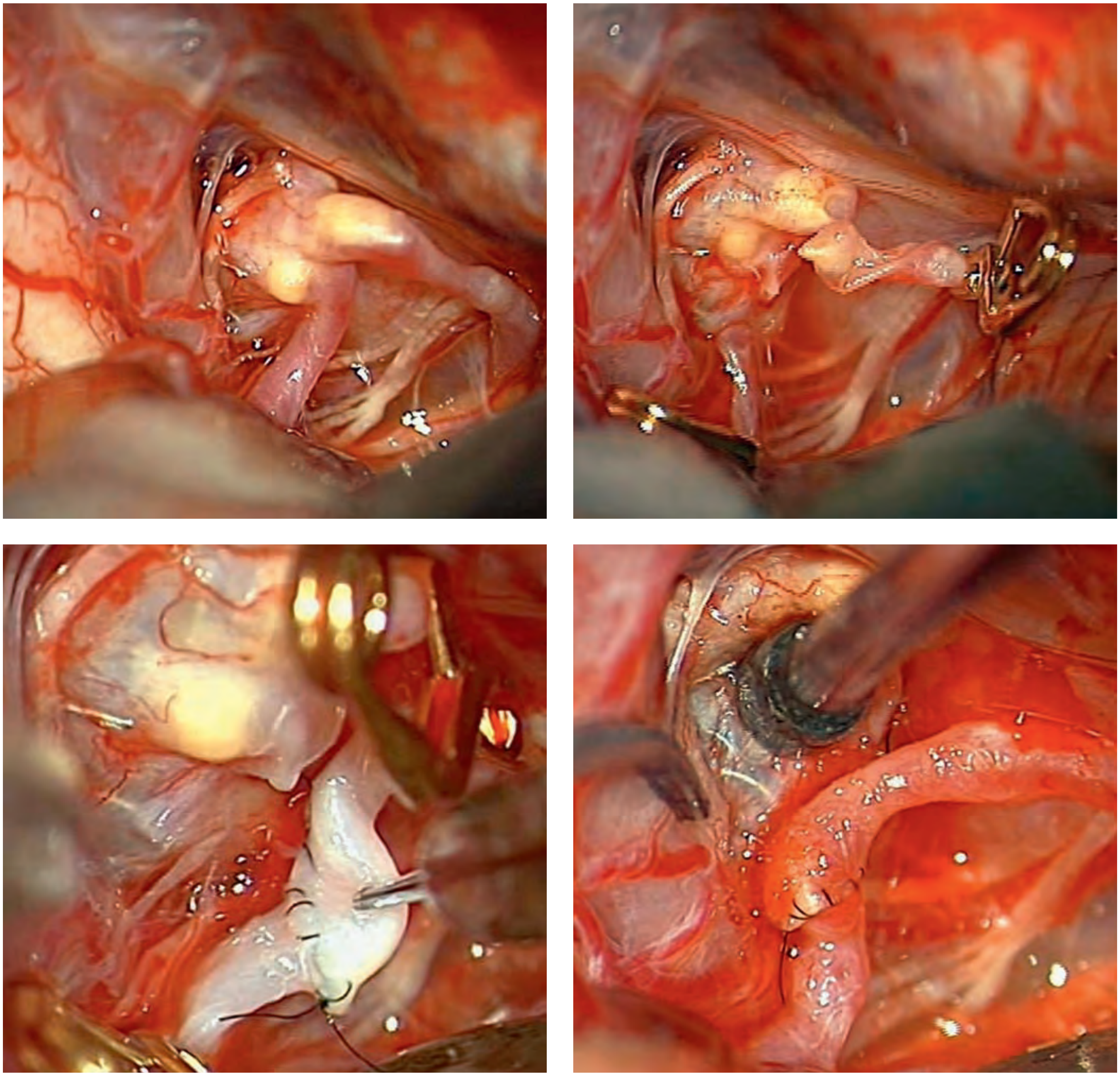

Fig. 20.17 Some distal PICA aneurysms are fusiform or have unclippable necks, and are treated best with excision and reanastomosis of the parent artery. **(A)** This 69-year-old woman had a recurrent left distal PICA aneurysm after endovascular coiling. Inflow and outflow arteries were perpendicular, and the aneurysm neck had significant atherosclerosis. **(B)** There was ample working space in the infrahypoglossal triangle to apply temporary clips proximally and distally, transect these arteries, and **(C)** suture them together with an end-to-end anastomosis. **(D)** The aneurysm was excluded completely, and the PICA was reconstructed without an extracranial donor artery.

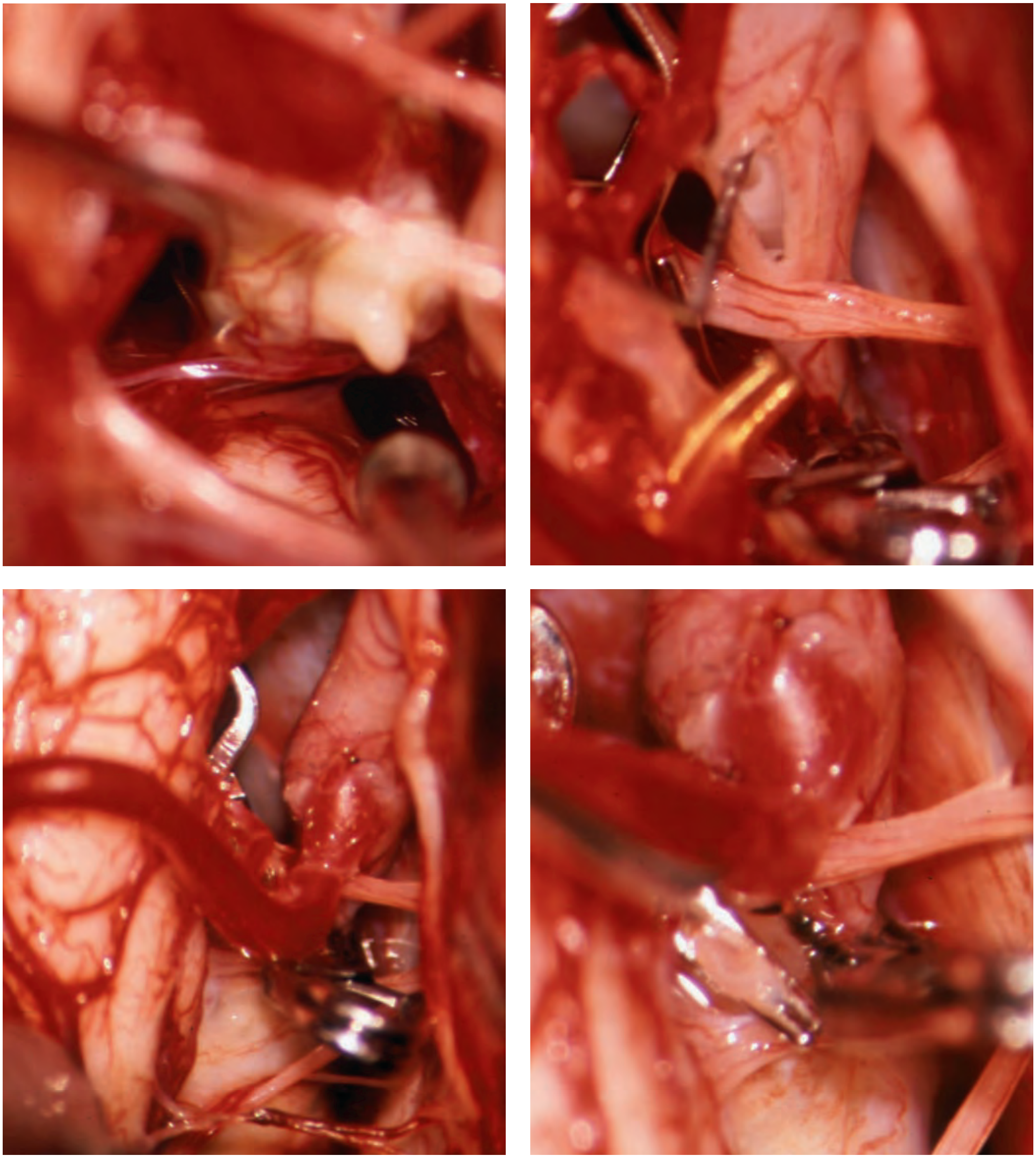

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**Fig. 20.18** This left-sided giant PICA aneurysm was treated endovascularly 3 years earlier and recurred with coil compaction. **(A)** The aneurysm was broad based, with the VA flowing into the aneurysm and the PICA originating from its base. Proximal aneurysm occlusion with PICA reimplantation was selected as the treatment strategy. **(B)** The hypoglossal nerve crossed the VA in the center of the surgical field. The PICA was transected as it exited the aneurysm in the suprahypoglossal triangle, and the VA was incised in the infrahypoglossal triangle. **(C)** The PICA was then reimplanted onto the proximal VA with an end-to-side anastomosis. This anastomosis was performed deep in the anterior medullary zone. **(D)** The clipped stump of PICA was visualized as it exited the aneurysm. The VA was clipped as it entered the aneurysm, and this proximal occlusion caused the aneurysm lumen to thrombose completely.

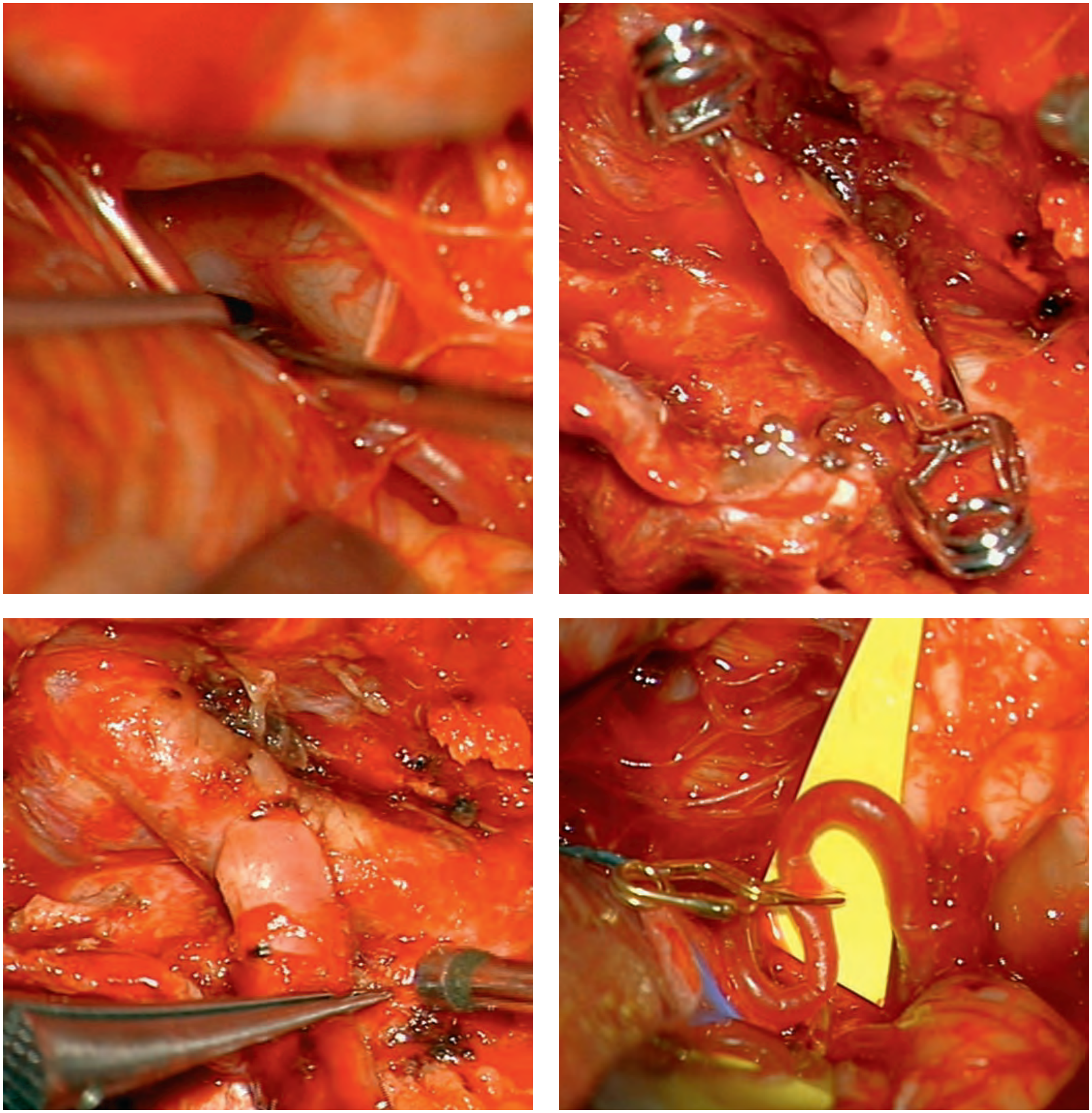
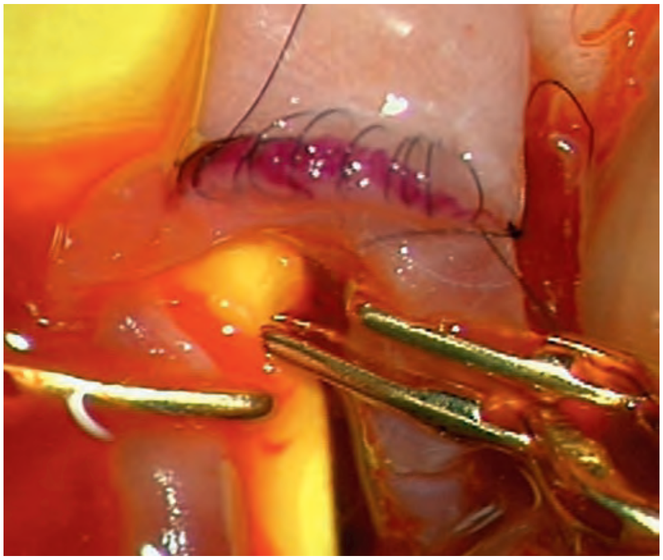



**Fig. 20.19** This 65-year-old man presented with an SAH and a right, fusiform VA aneurysm. Endovascular occlusion of the right VA was not possible because left the VA terminated in the PICA and the patient had small posterior communicating arteries (PCoAs) bilaterally. A bypass from the extradural VA to the right PICA using a radial artery graft was planned, to trap the VA aneurysm. **(A)** The upper end of the fusiform aneurysm was visualized in the anterior medullary zone through the apex of the suprahypoglossal triangle. **(B)** The extradural VA, from the sulcus arteriosus of C1 to its dural ring, was trapped with aneurysm clips and opened with an aortic punch. **(C)** The radial artery graft was sutured to the VA with an end-to-side anastomosis. **(D)** The caudal loop of the PICA was used as the graft's recipient artery.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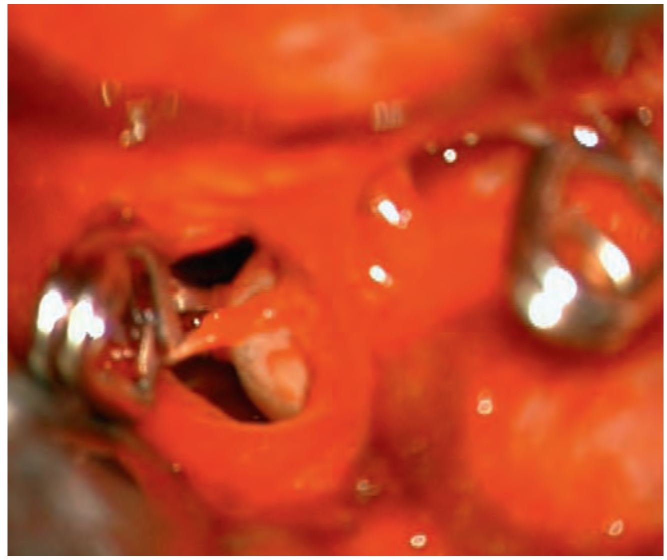
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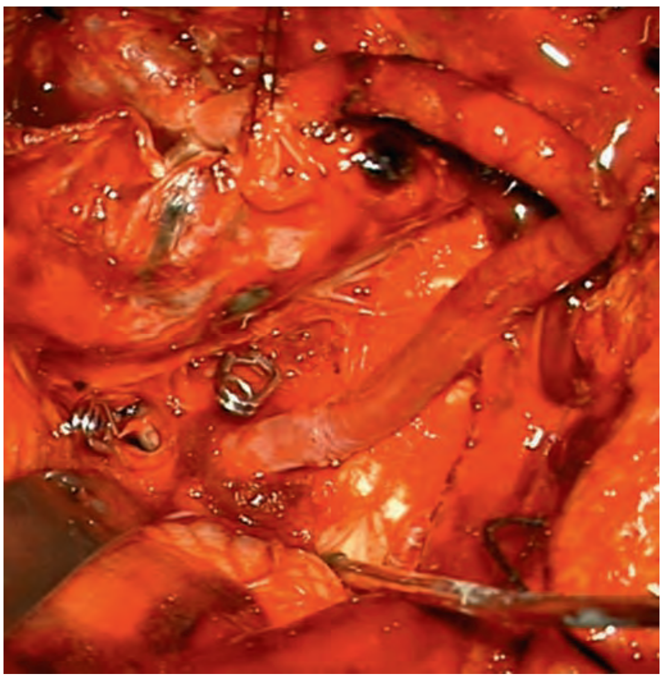
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**Fig. 20.19** (*Continued*) **(E)** The graft was sutured to the PICA with an end-to-side anastomosis. Continuous sutures are placed loosely and tightened after all sutures are in place. **(F)** The VA aneurysm was then trapped with two aneurysm clips. **(G)** The bypass fills the PICA, with antegrade flow in the distal PICA and retrograde flow in the proximal PICA that supplies the distal vertebrobasilar circulation.

# 21 Conclusion

Technical development does not come from reading a book; it comes from operating. Neurosurgeons develop microsurgical skills through a combination of repetition, technical mistakes, outside learning, and high standards.

The secret of success with aneurysm surgery is case volume. Splitting fissures, drilling clinoids, deciphering aneurysm anatomy, dissecting perforators, and applying clips all get easier with practice. Therefore, aneurysm surgery is no different from any other art or sport that combines physical and cognitive training. Aspiring neurosurgeons do not shy away from high case volume; they covet it, make personal sacrifices to acquire it, and endure its side effects. Aneurysm surgery is exhausting and stressful, and repetition can blunt the thrill and add pressure from rising personal expectations. However, high volume helps in developing efficiency, confidence, and experience. A steady stream of patients often requires an academic practice, subspecialization in vascular neurosurgery, a collaborative team of endovascular surgeons and vascular neurologists, and regional prominence that will attract referrals.

Mistakes are unavoidable. Master neurosurgeons who train residents teach them to clip aneurysms, but seldom make “rookie” mistakes. As a result, residents do not see the missteps the mentor might have made when he or she was a young neurosurgeon, and residents may not appreciate the nuanced techniques of their mentor that avoid these mistakes. Technical errors with aneurysms often result in morbidity or death. These cases are dark and indelible moments that call for introspection. These cases replay in the mind, or on intraoperative video, to determine better moves for next time. Notes from similar cases are reviewed, sifting through past lessons and searching for new ones. The advice of other neurosurgeons may help. Preoperative and postoperative angiograms may clarify intraoperative findings. This process illuminates where improvement is needed. Failures, more than successes, stimulate technical development. Success becomes an expectation and good outcomes are quickly forgotten, but failure is the catalyst that transforms and matures young neurosurgeons, advancing them forward along the learning curve. Poor outcomes and dead patients are impossible to forget and can be haunting. Neurosurgeons ill equipped to absorb these blows react with fear and avoidance at one extreme, or callous insensitivity at the other extreme. In between are humility, introspection, and discipline. Neurosurgeons redeem themselves by maintaining their confidence, committing themselves to learning, and applying what they have learned to future patients.

Outside learning is important in cognitive development. There will be those aneurysms that are too difficult, beyond the neurosurgeon’s ability. These cases call for time spent in the cadaver laboratory, course work with experts, and reading. This book is meant to help with this learning process.

Clipping an aneurysm is the prototypical neurosurgical operation. It is the classic confrontation between surgeon and pathology; it requires manual dexterity, knowledge of anatomy, and a delicate touch rather than gadgetry and high technology. The stakes are high—patients live or die depending on the neurosurgeon’s skill. This iconic operation has made aneurysm surgeons into icons of neurosurgery: Dandy, Yasargil, Drake, Sundt, Spetzler, and others. These acknowledged masters have been mentors to many aneurysm surgeons, and an important part of technical development is adopting their high standards of excellence. These lofty standards require dedication, commitment, and some of our very best neurosurgeons. The end result is technical skill, grateful patients, personal fulfillment, and the perpetuation of aneurysm surgery. Aneurysm surgery is and should remain an important element of neurosurgical culture, even as endovascular techniques advance in popularity and sophistication. More importantly, neurosurgeons will be needed to deal with the complex aneurysms that cannot be managed any other way. The complexity of open aneurysm surgery will continue to increase as endovascular therapy addresses the simpler cases. Modern aneurysm techniques offer excellent solutions for the seven types of aneurysm discussed in this book, and must be saved for those aneurysms that require them.

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