The Endovascular Treatment of Cerebral Aneurysms

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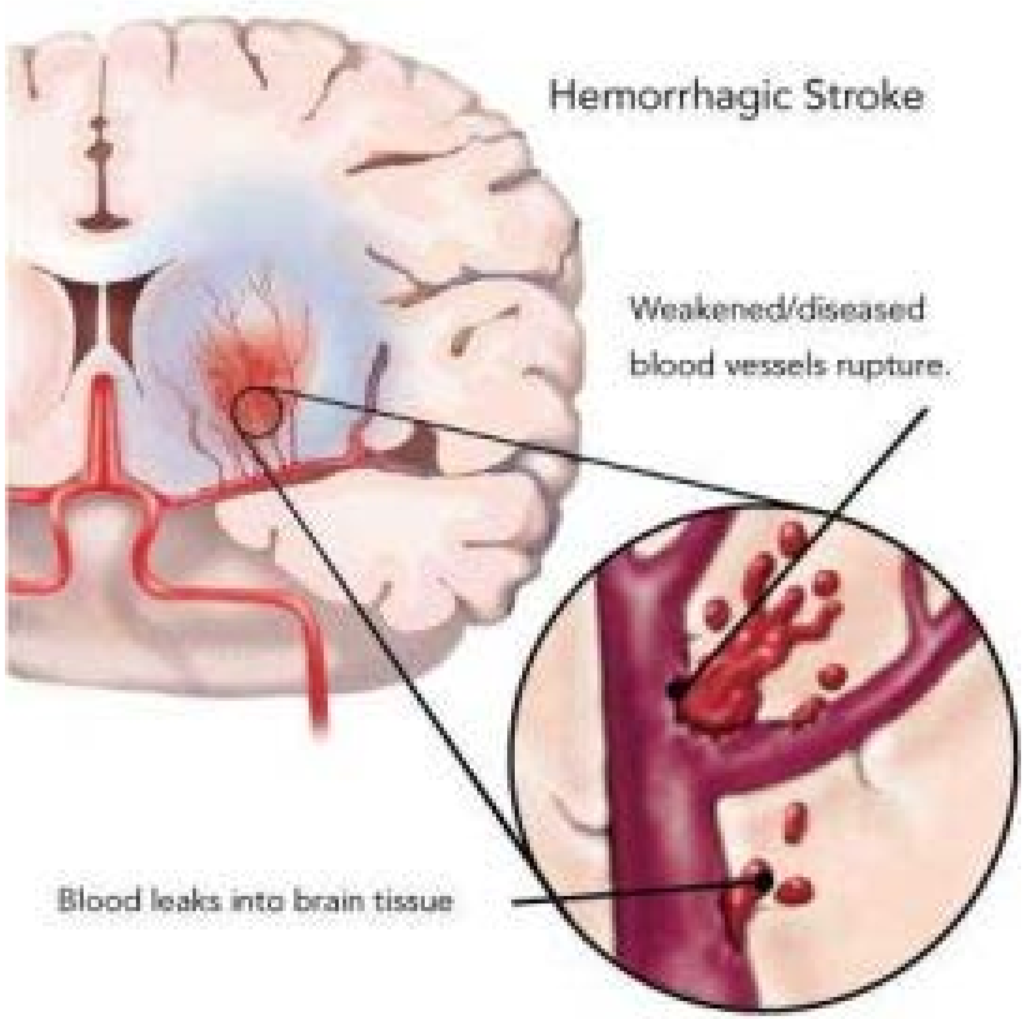
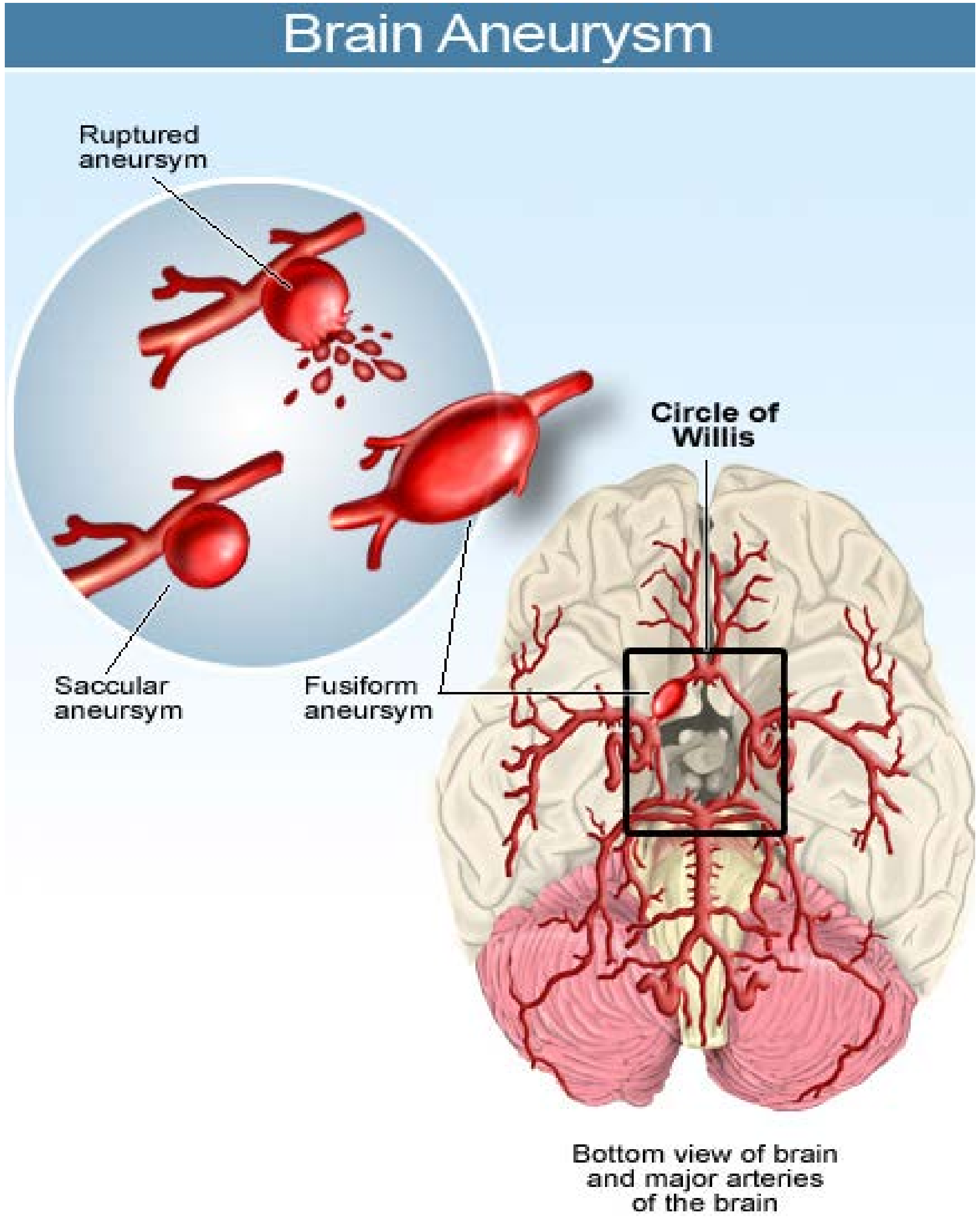
Types of Stroke and Their Causes

- Ischemic (87%): due to blockage of blood flow
  - Narrowed or occluded artery in the neck or brain
  - Blood clot migrating to the brain especially from the heart (50% from A-fib) or from a narrowed blood vessel
- Hemorrhagic (13%):
  - Bleeding in the brain especially due to HTN
  - Rupture of a brain aneurysm
  - Vascular malformation (AVM or DAVF)





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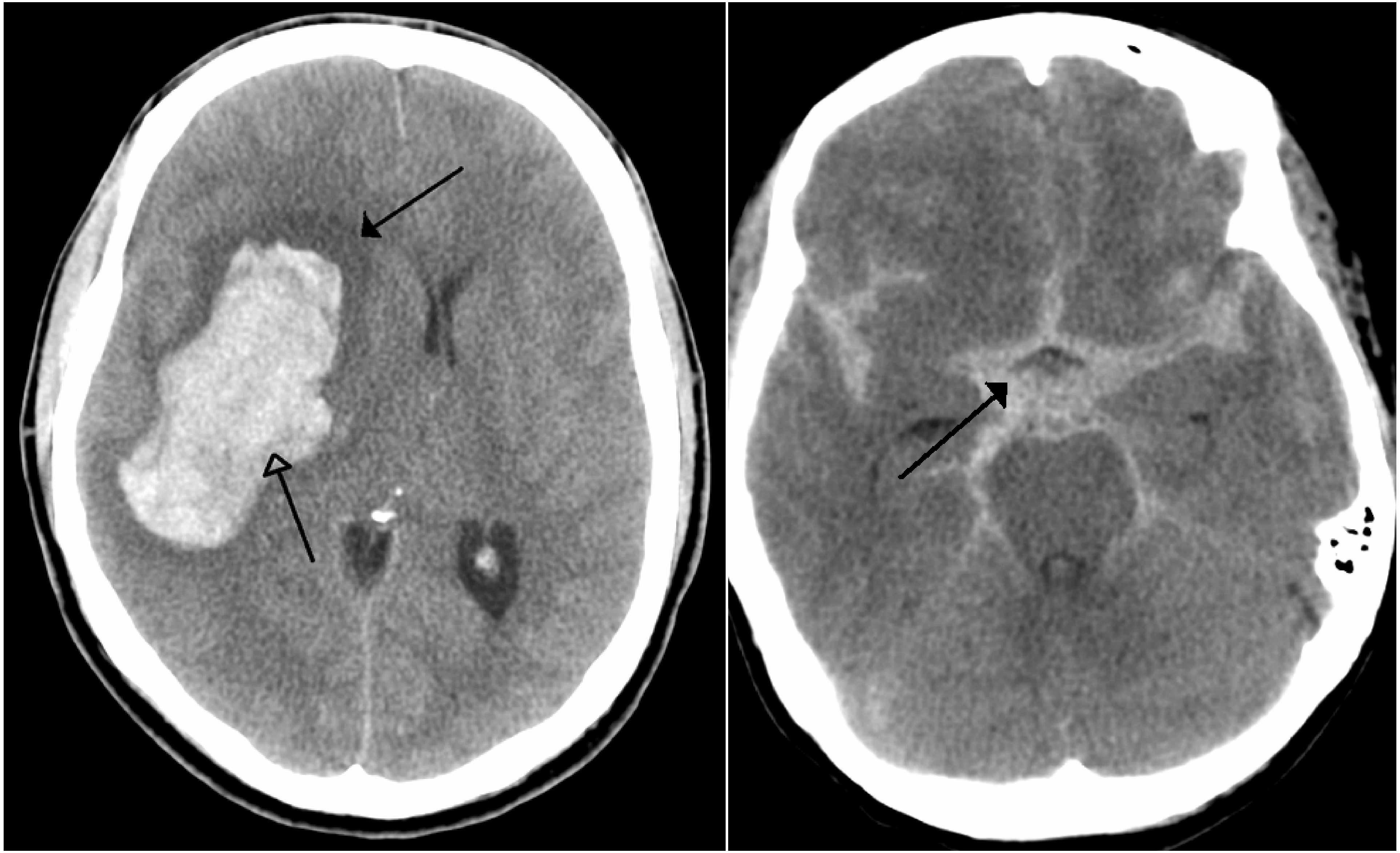

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The Hunt and Hess scale describes the severity of subarachnoid haemorrhage, and is used as a predictor of survival

grade 1

asymptomatic or minimal headache and slight neck stiffness
70% survival

grade 2

moderate to severe headache; neck stiffness; no neurologic deficit except cranial nerve palsy
60% survival

grade 3

drowsy; minimal neurologic deficit
50% survival

grade 4

stuporous; moderate to severe hemiparesis; possibly early decerebrate rigidity and vegetative disturbances
20% survival

grade 5

deep coma; decerebrate rigidity; moribund
10% survival

Fisher CT grading scale for SAH (1980)

I – no blood

II – diffuse deposition of SAH without clots or layers of blood >1mm

III – localized clots and/or vertical layers of blood 1mm or > thickness

IV – diffuse or no subarachnoid blood but intracerebral or intraventricular clots

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Intracranial Aneurysms

- Usually due to congenital weak spot on brain artery that balloon out over time causing “bubble” on brain artery prone to rupture.
- Can also be due to infection (“mycotic” aneurysm), polycystic kidney disease, fibromuscular dysplasia, NF, aortic coarctation, trauma, vascular dissection, AVMs, and can uncommonly be familial.
- Aneurysm rupture usually presents as “the worst headache of my life,” but can also cause collapse, coma, seizure, and immediate death. Acute bleed usually causes marked HTN and bradycardia.
- May also be discovered due to compression of a cranial nerve → diplopia, ptosis, etc.
- U.S. prevalence: 2-5% of population
- Finish unruptured aneurysm study estimated annual risk of aneurysm rupture approx. 1.3%. Risk greater for large (>10 mm) and giant (>25 mm) size and vertebrobasilar aneurysms
- Two or more aneurysms can be present in same patient in up to 34% of cases

Intracranial Aneurysms

- Cause 30-40,000 SAH annually in U.S.
- Risk factors: age >60, size >10mm, smoking, previous SAH, HTN, hyperlipidemia, female sex
- 1st bleed: 40% die, 50% of survivors disabled, 50% rebleed rate w/ no Rx. 70% mortality w/ 2nd bleed.
- Delayed effects of SAH: vasospasm, seizure, hydrocephalus, hyponatremia, Takotsubo (octopus pot) cardiomyopathy
- Data reveals that coiling of aneurysms is less risky than surgery w/ recent SAH (ISAT Trial)
- At PSJMC, >90% of aneurysms now treated with endovascular methods
- Neuroform, LVIS, and Enterprise intracranial stents have made treatment of "wideneck" aneurysms possible
- Pipeline embolization device (tightly woven stent) treats wideneck/fusiform large (>10 mm) and giant (>25 mm) aneurysms with flow diversion

Annual Risk of Aneurysm Rupture

- Wiebers et al reported 5 year risk of anterior circulation lesions <7mm=0% (Lancet 2003;362(9378):90-1)
- However, small (<10 mm) aneurysms have accounted for 75% and 70% of aneurysmal ruptures at UCLA and Johns Hopkins U, respectively (Western Stroke Symposium, 2005)
- Yonekura reported an annual rupture risk of incidental aneurysms <5mm in diameter = 0.8% (Neurol Med Chir (Tokyo) 2004;44(4):213-4)
- Juvela et al reported the annual risk of hemorrhage from a non-ruptured aneurysm is 1.3% (J Neurosurg 2000;93(3):379-87)

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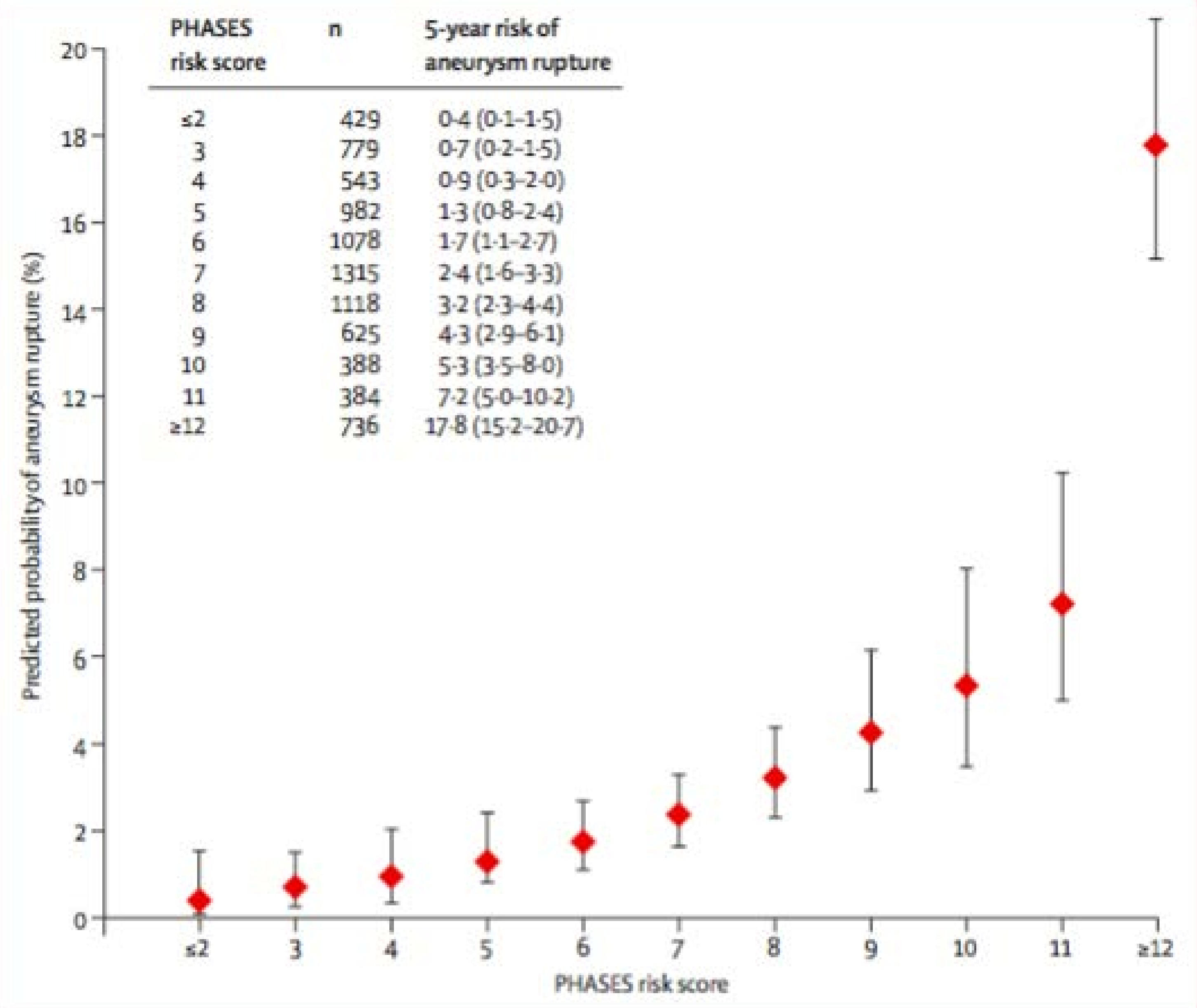
Risk Factors for Cerebral Aneurysm Rupture

- Hypertension
- Age > 60 yrs
- Size of aneurysm >10 mm
- Rapid recent growth and/or complex shape
- Previous SAH
- Female sex
- Posterior circulation aneurysms
- Increased risk during sex and straining to defecate

PHASES aneurysm risk score	Points
(P) Population	
North American, European (other than Finnish)	0
Japanese	3
Finnish	5
(H) Hypertension	
No	0
Yes	1
(A) Age	
<70 years	0
≥70 years	1
(S) Size of aneurysm	
<7·0 mm	0
7·0–9·9 mm	3
10·0–19·9 mm	6
≥20 mm	10
(E) Earlier SAH from another aneurysm	
No	0
Yes	1
(S) Site of aneurysm	
ICA	0
MCA	2
ACA/Pcom/posterior	4



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Open Surgical Clip Ligation of Cerebral Aneurysm

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A Tribute to Dr. Fedor A. Serbinenko, Founder of Endovascular Neurosurgery

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FROM HUMBLE BEGINNINGS in the former Soviet Union, Fedor A. Serbinenko, M.D., Ph.D., became a leading figure at Moscow's famed Burdenko Neurosurgery Institute. While there, he invented and perfected the technique of balloon embolization, which was destined to change the practice of neurovascular surgery forever. We present the life and achievements of the father of endovascular neurosurgery. (Neurosurgery 46:462-470, 2000)

Keywords: Embolization balloon, Endovascular surgery, Fedor A. Serbinenko, Neurosurgical history

It is difficult to imagine the practice of modern neurovascular surgery without the collaboration and assistance of interventional neuroradiology, also known as endovascular neurosurgery. The management of complex central nervous system arteriovenous malformations (AVMs), dural arteriovenous fistulae (AVFs), vascular head, neck, and spinal tumors, intracranial aneurysms, postsubarachnoid hemorrhage vasospasm, carotid-cavernous fistulae (CCFs), acute stroke, and even carotid stenoses is increasingly the responsibility of the new breed of physician known as the neurointerventionalist.

Equally as impressive as the variety of diseases now treated by neurointerventionalists are the endovascular tools currently at their disposal. From braided hydrophilic catheters to aneurysm coils with new and complex shapes to vascular stents suitable for intracranial applications, these modern devices are a wonder of advanced engineering techniques combined with human ingenuity. Just 5 or 6 years ago, however, many of today's neurointerventional devices were either nonexistent or in a developmental stage. Just 10 years ago, detachable aneurysm coils did not exist, and the choice of available guidewires and catheters for neurointerventional work was extremely limited. Endovascular stents for peripheral and coronary procedures were still in clinical trials. Twenty years ago, only a few physicians worldwide performed neurointerventional procedures. Before the advent of magnetic resonance scanners and with only crude computed tomography, they used rudimentary catheter and embolic agent technology guided by primitive predigital era imaging systems. Today, one can only imagine the frustrations these trailblazers must have faced. Now, consider the enormous difficulties and challenges confronting a pioneering neurosurgeon struggling to develop novel catheter-based therapies for neurovascular diseases more than 30 years ago in Soviet Russia. This pioneer was Fedor Serbinenko (*Fig. 1*).

SERBINENKO'S CHILDHOOD AND EDUCATION

Fedor Andreevitch Serbinenko was born May 24, 1928, in the small village of Dmitriovsk in the Stavropol region of Northern Caucasus, in what was then the Soviet Union (*Fig. 2*). When he was a small boy, Serbinenko's family moved to Mineralnye Vody City, Northern Caucasus, where his father, Andrey, worked as a mechanic in the local flour mill, and his mother, Anastasia, was a homemaker (*Fig. 3*). His middle school studies were interrupted by World War II (the Great Patriotic War), during which his older brother, Yuri, was killed. His father, also a soldier, survived the war. To support his mother and grandmother during the conflict years of 1941 to 1945, young Serbinenko went to work at age 14 as an apprentice machinist. After the war, he continued working as a machinist but also studied at night; he completed secondary school with honors in 1948. He was then admitted to the I.M. Sechenov First

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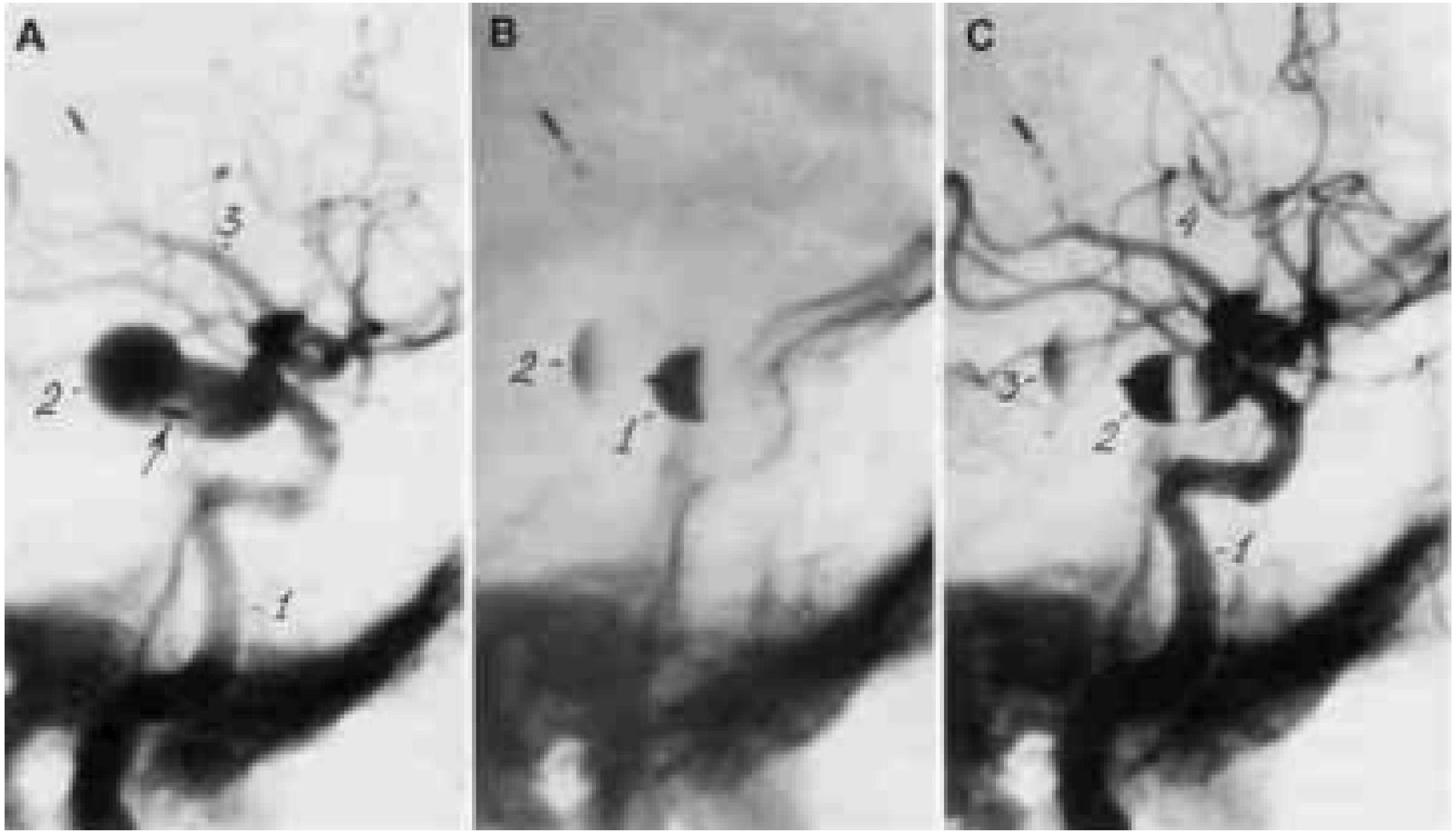

FIGURE 6. Occlusion of a posterior communicating artery saccular aneurysm performed by Serbinenko in the early 1970s using his detachable balloon device. *A*, lateral carotid angiogram immediately after placement of noninflated balloon with radiopaque marker within the aneurysm cavity.

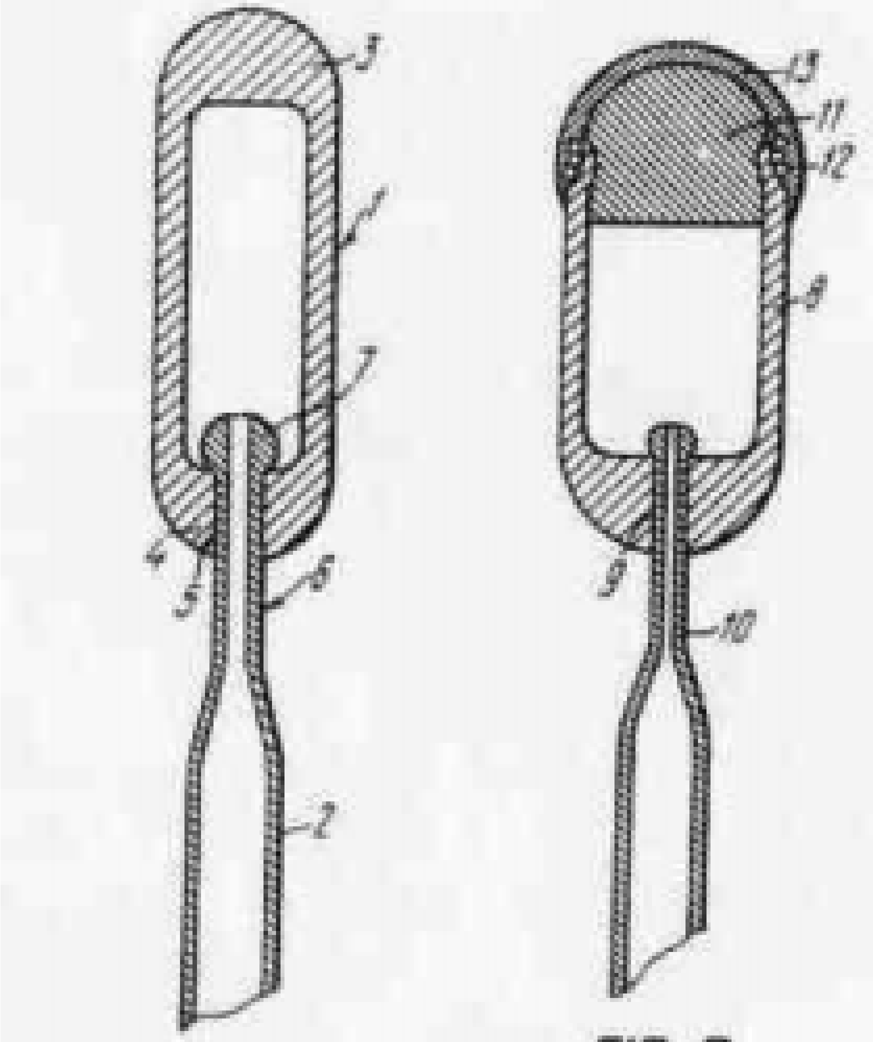

FIG.1

FIG. 2

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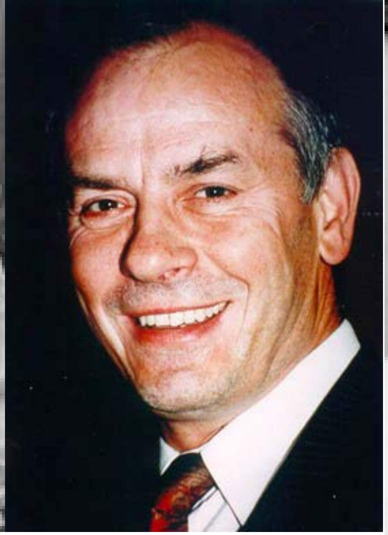
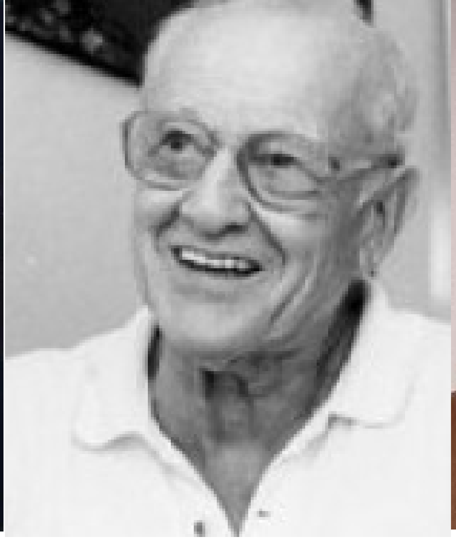
Shcheglov

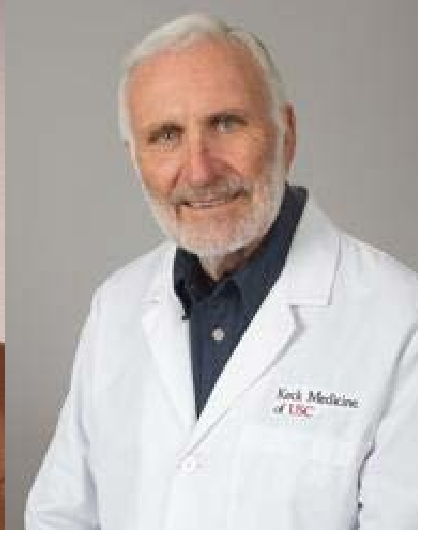


Zubkov



Debrun

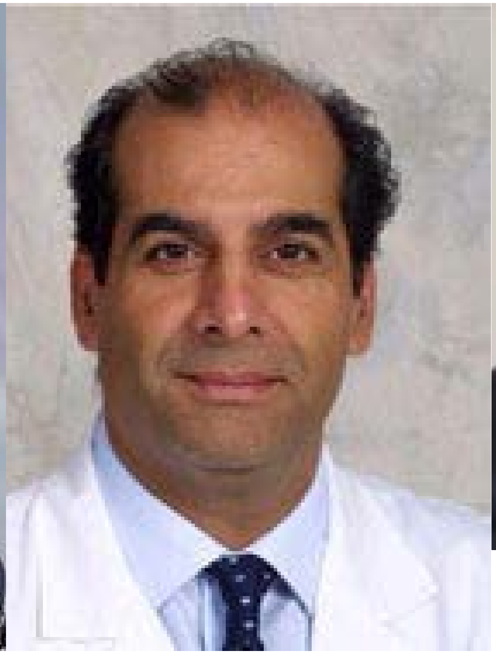
Hieshima



Daniels

Guglielmi

Moret



Wakalu

Bose

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Milestones in Endovascular Treatment of Cerebral Aneurysms

- 1960's-1970's: Serbinenko's invention of detachable latex balloon for treatment of CCFs, AVMs and cerebral aneurysms
- 1970's: Introduction of CT and DSA
- 1970's-1980's: Further development and clinical use of detachable silicone and latex balloon embolization devices by Hieshima, Shcheglov and Debrun for intra-saccular and proximal vessel sacrifice for aneurysm treatment
- 1980s: Zubkov's use of Serbinenko's balloon catheter for PTA of cerebral vasospasm due to SAH
- 1980's: Development of an advanced microcatheter, the Tracker 18, by Target Therapeutics
- 1991: Guglielmi's development at UCLA (in assoc. w/ Target Therapeutics) of a detachable platinum aneurysm coil for use through Tracker catheters. FDA-approved in 1995
- 1990's: Moret's introduction of balloon remodeling of coils within wide neck aneurysms

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- 1990’s: Introduction of intra-arterial infusion of Papaverine for cerebral vasospasm
- 1990’s: Concept of flow-diversion suggested by Wakalu
- 1990’s: Multiple companies enter aneurysm coil market. Competition encourages great technological improvements
- 1990’s: Advances in 3-D image reconstruction from rotational angiography and CTA
- 1990’s: Advanced anti-platelet regimens introduced
- 2003: FDA-approval of Bose’s Neuroform stent for stent-assisted coil embolization. Later used in Y-configurations for branch point aneurysms
- 2000’s: Onyx liquid embolic agent used for treatment of large & wide neck aneurysms
- 2000’s: Chestnut Medical introduces much improved catheter technology
- 2011: FDA approval of Pipeline flow-diversion device after years of successful use abroad
- Present: Work continues on intra-aneurysmal flow-diversion devices and devices for branch point aneurysms
- Future: Endovascular devices that elude their own anti-platelet agents, obviating the need for systemic therapy

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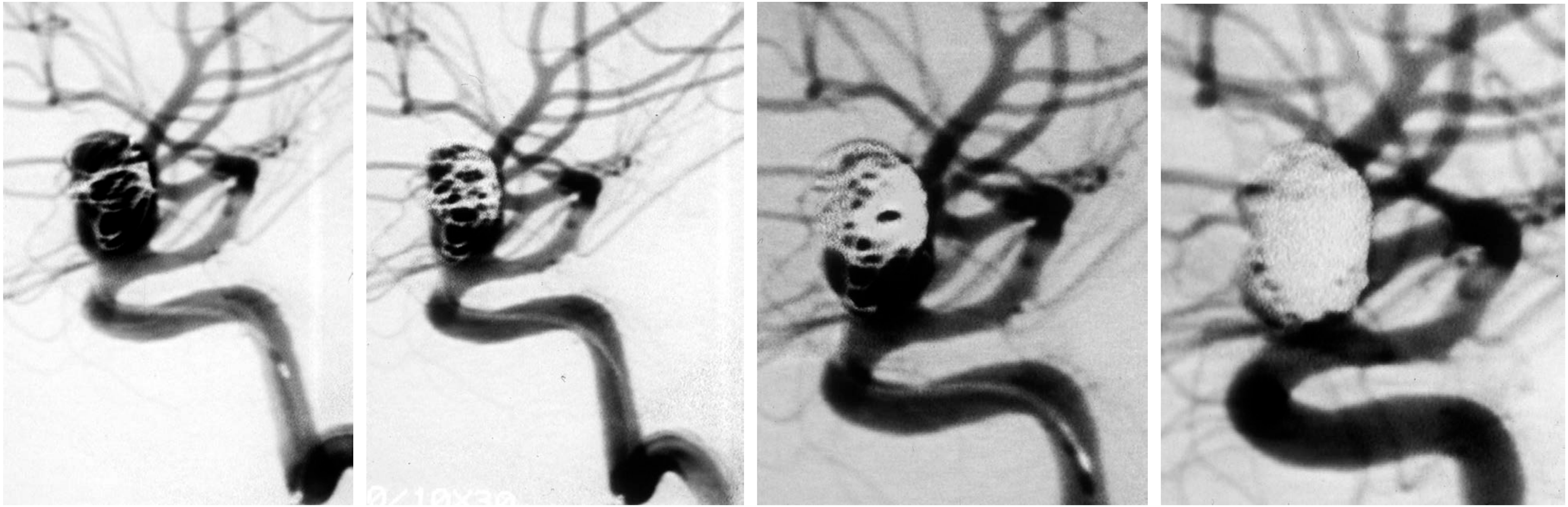
Aneurysm Coil Embolization



2/2

Carotid Stenting Associated with Recurrent Aneurysm Coil Embolization

- 64 yo F with recurrent Rt PCOM aneurysm 30 yrs S/P clip ligation.
- Found to have 60% stenosis of proximal Rt ICA.
- Rt. ICA PTA + stenting performed with cerebral balloon protection in order to allow intracranial access.
- Aneurysm successfully coil embolized.

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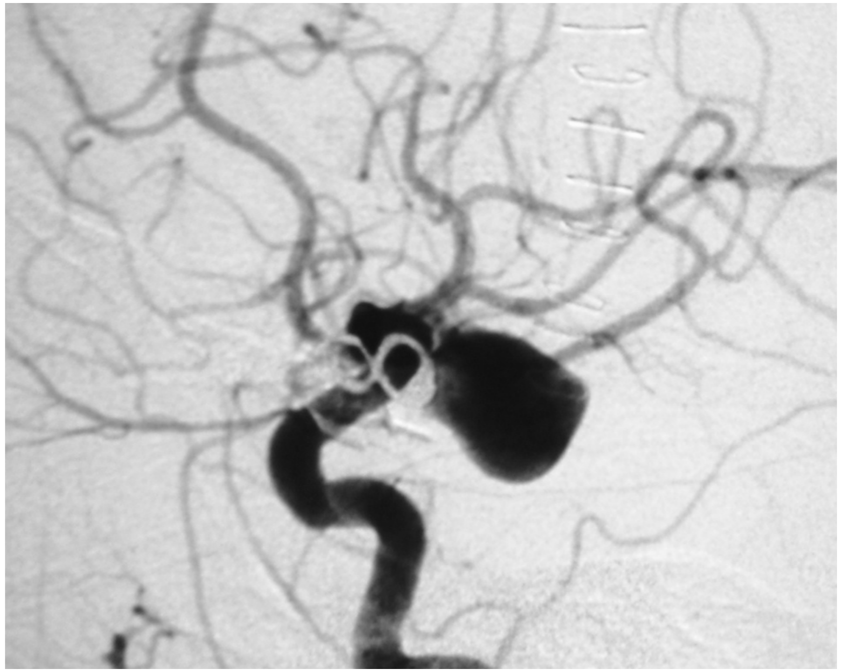

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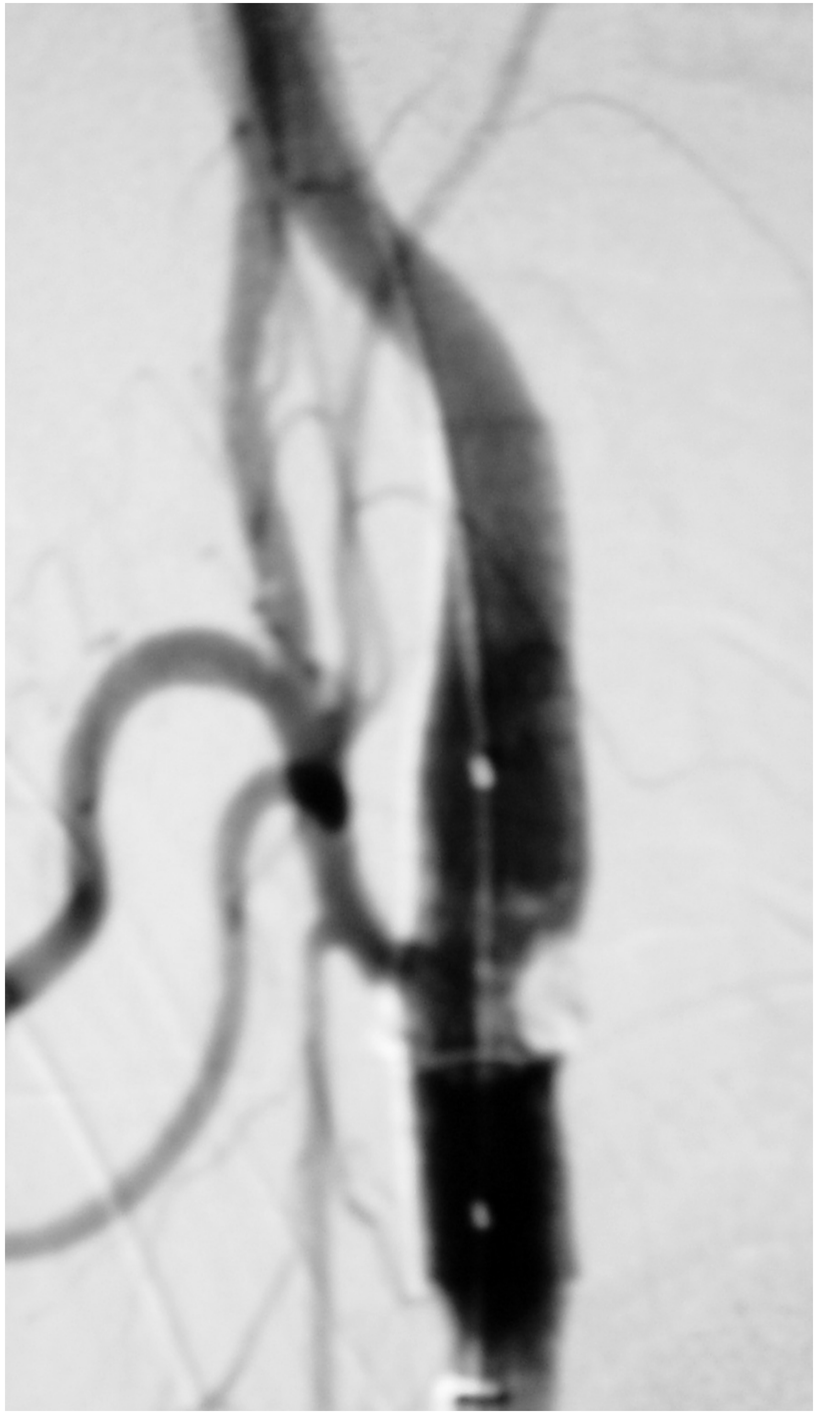

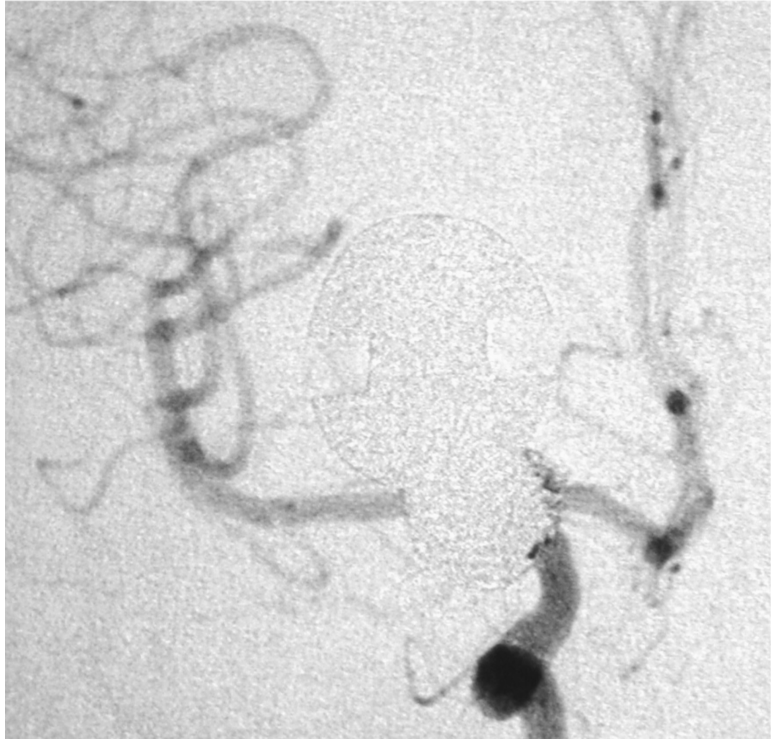

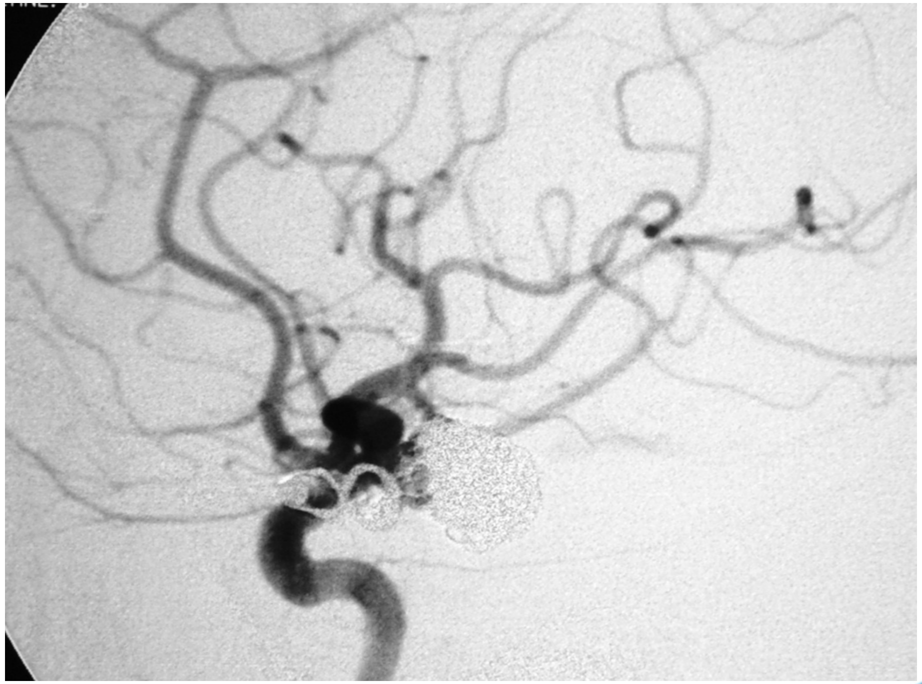

Balloon Remodeling Coil Embolization

- 70 yo F with long smoking Hx and coronary + peripheral atherosclerotic disease, presented with progressively increasing vertigo and headache pain
- MR study suggested a distal right vertebral artery partially-thrombosed aneurysm compressing the inferior pons
- Patient prepped with ASA + Plavix

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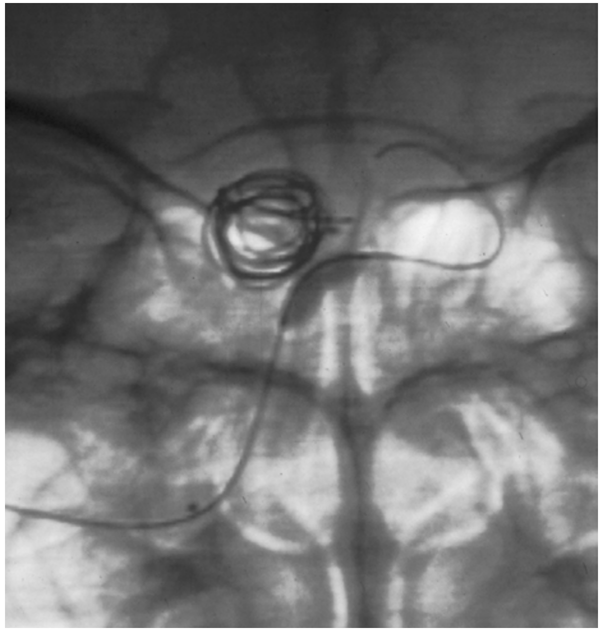
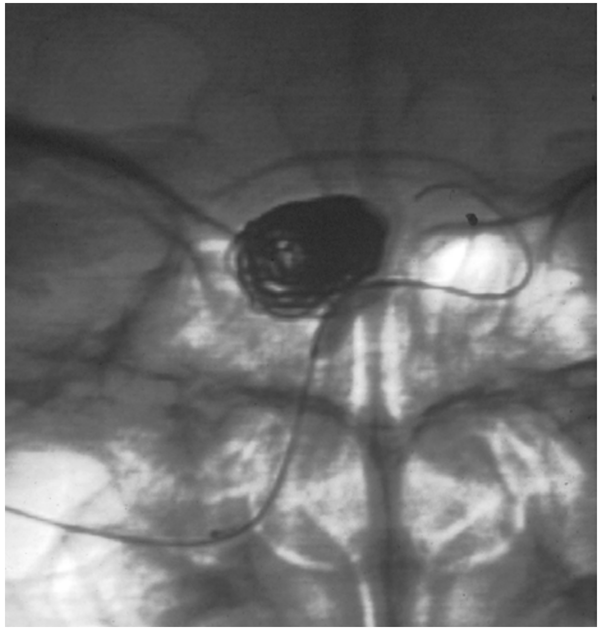

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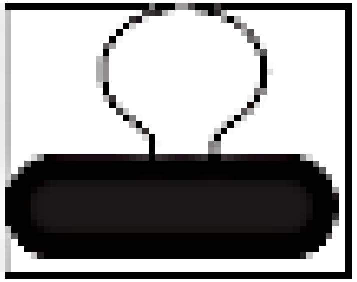
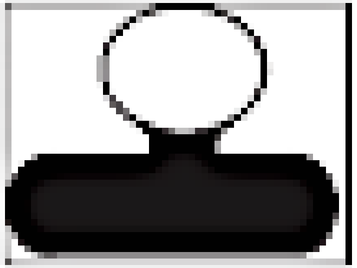
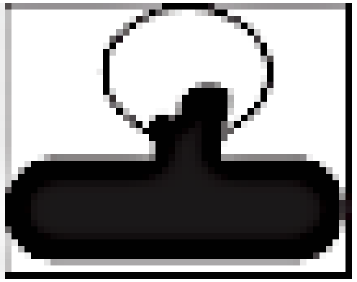
Class 1: Complete obliteration



Class 2: Residual neck



Class 3: Residual aneurysm

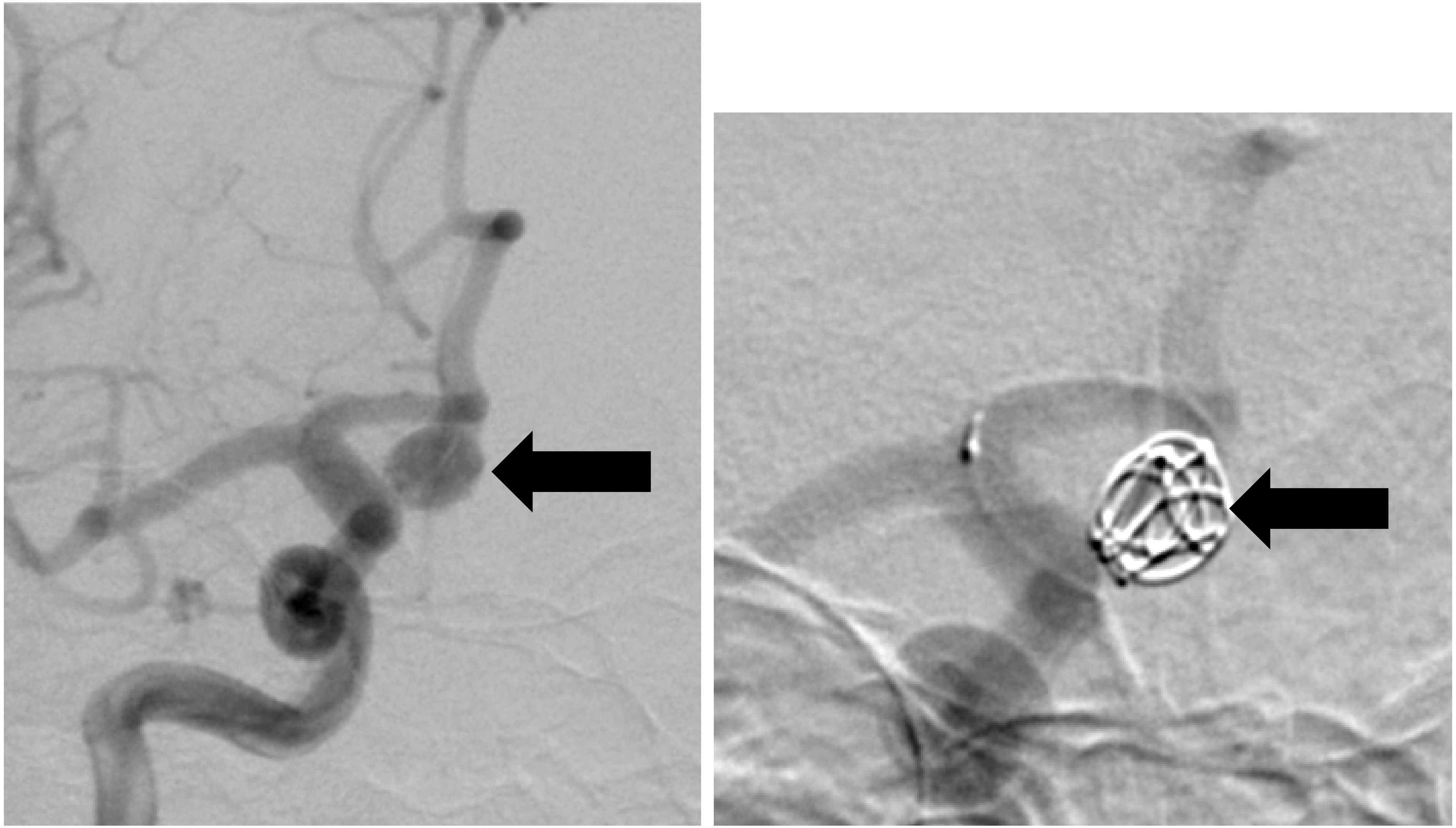


Raymond-Roy occlusion classification.

Recanalization Rates of 49 Coiled Ruptured vs 49 Unruptured Cerebral Aneurysms

- 46.8% of ruptured aneurysms vs. 34.7% of unruptured aneurysms were completely obliteration on the initial post treatment angiogram.
- The ruptured group had a higher rate of recanalization (40.4% versus 20.4%).
- 25.5% of aneurysms had significant recanalization in the ruptured group versus 6.1% in the unruptured group (p=0.009).
- The retreatment rate was higher in the ruptured group (21.3% versus 6%).
- Ruptured aneurysms took a shorter time to recanalize with a mean time of 5.3±3.8 months versus 12.4±7.7months (p=0.003).
- Neck size, wide neck morphology, larger aneurysm diameter and ruptured aneurysms were significant predictors of recanalization.
- The majority of patients in both groups had a good clinical outcome w/ GOS =5 (85.7% and 83.7%) but two deaths occurred in the ruptured group.

Interv Neuroradiol. 2011 Mar; 17(1): 27–35.



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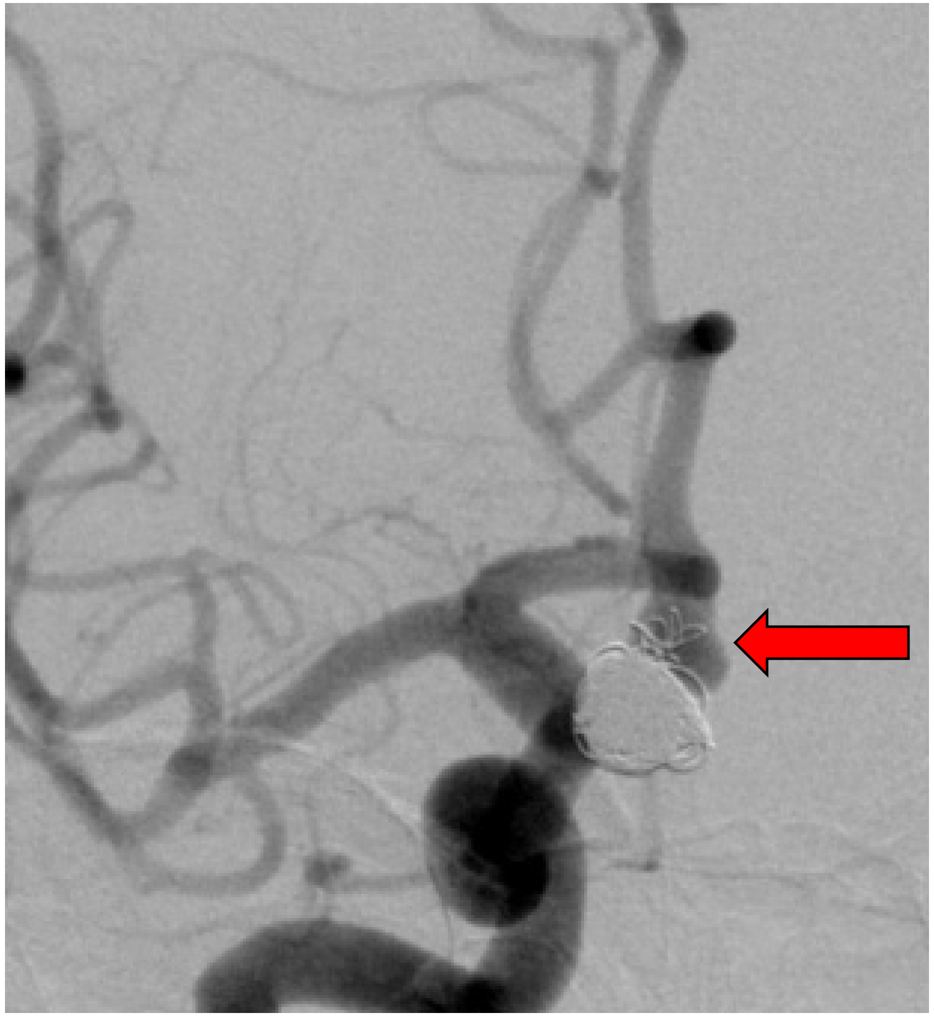
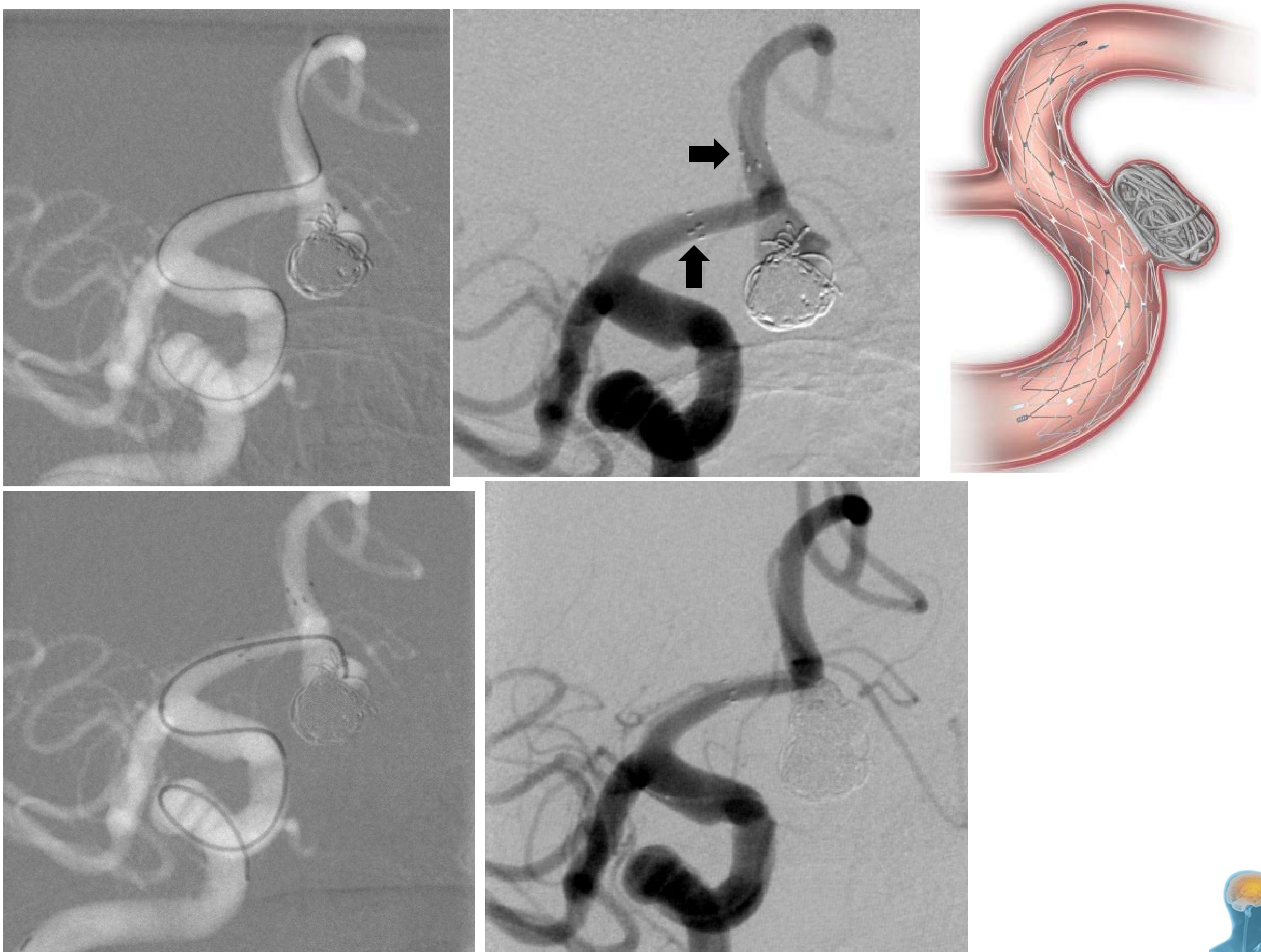
Six months later





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Fate of Aneurysms with Minor Recanalization at Time of Six Month F/U Angio

- 36.9% progressed to major recanalization and thus had an increased risk of rupture
- Stent deployment significantly reduced the progression to major recanalization
- Antiplatelet therapy, posterior location, and additional aneurysm coil embolization were unrelated
- Aneurysms showing minor recanalization at 6 months should be monitored diligently, particularly in the absence of stent placement.

AJNR Am J Neuroradiol. 2016 Aug;37(8):1490-5.

Current State of Embolization of Wide Neck Aneurysms

The literature shows that wide neck aneurysms are difficult to treat.

- 60% of large and 74% of giant aneurysms do not achieve complete embolization* with coils.[1]
- Neck remnants are observed in 40% of large and 64% of giant aneurysms
- 6-7% of cases experience a failure to deliver coils
- Aneurysm perforation during coil delivery
- Recanalization rates of large aneurysms treated with coils= 35.3%
- Recanalization rates of giant aneurysms treated with coils= 59%
- Due to superimposition of the parent artery, visualization can be difficult and there is uncertainty of coils that may have herniated causing parent artery occlusion
- Coils are thrombogenic to the parent artery

[1] Muryama Y, Nien YL, Duckwiller G, et al. **Gugliemi detachable coils embolization of cerebral aneurysms: 11 years experience.** *J Neurosurg* 2003;98:959–966

*embolization was considered complete when there was no contrast filling the dome, body or neck of aneurysm

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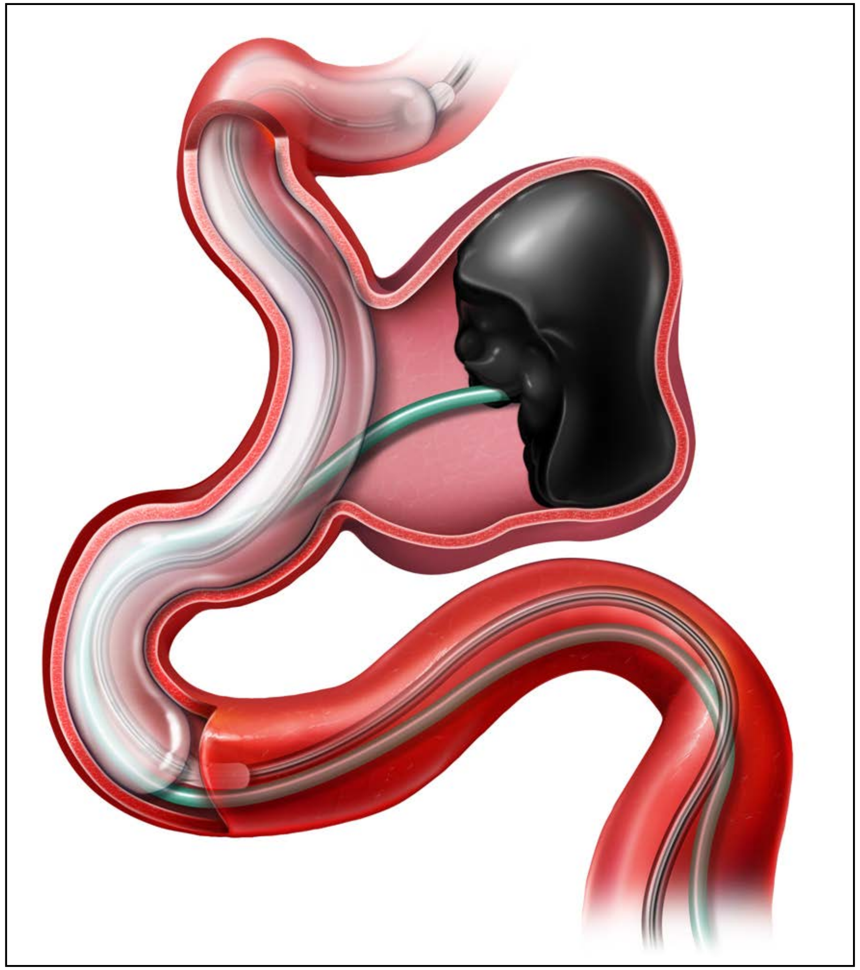
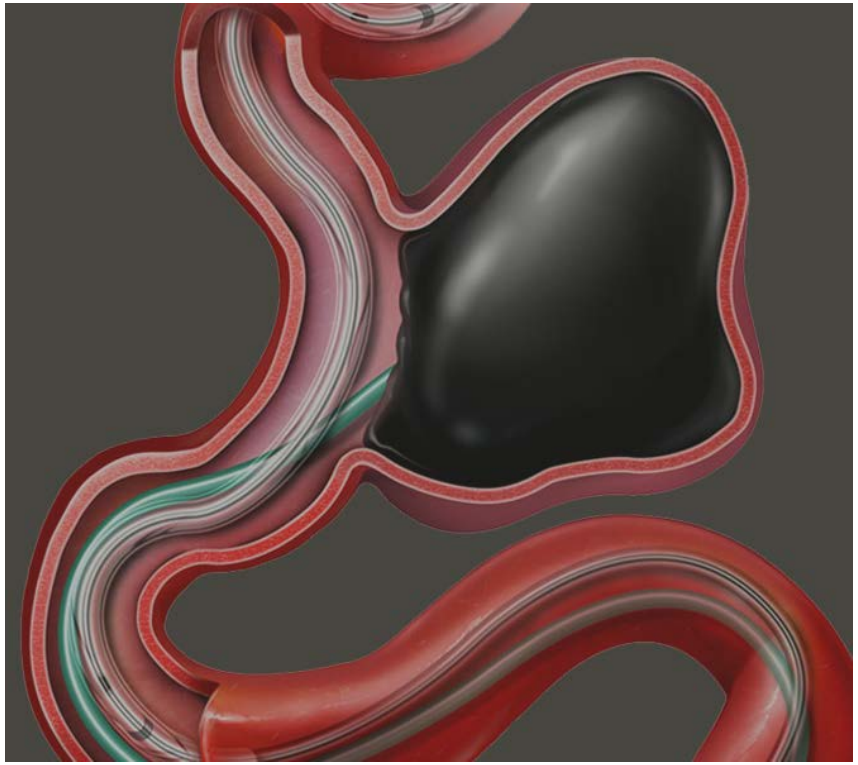
Onyx for Aneurysms Treatment





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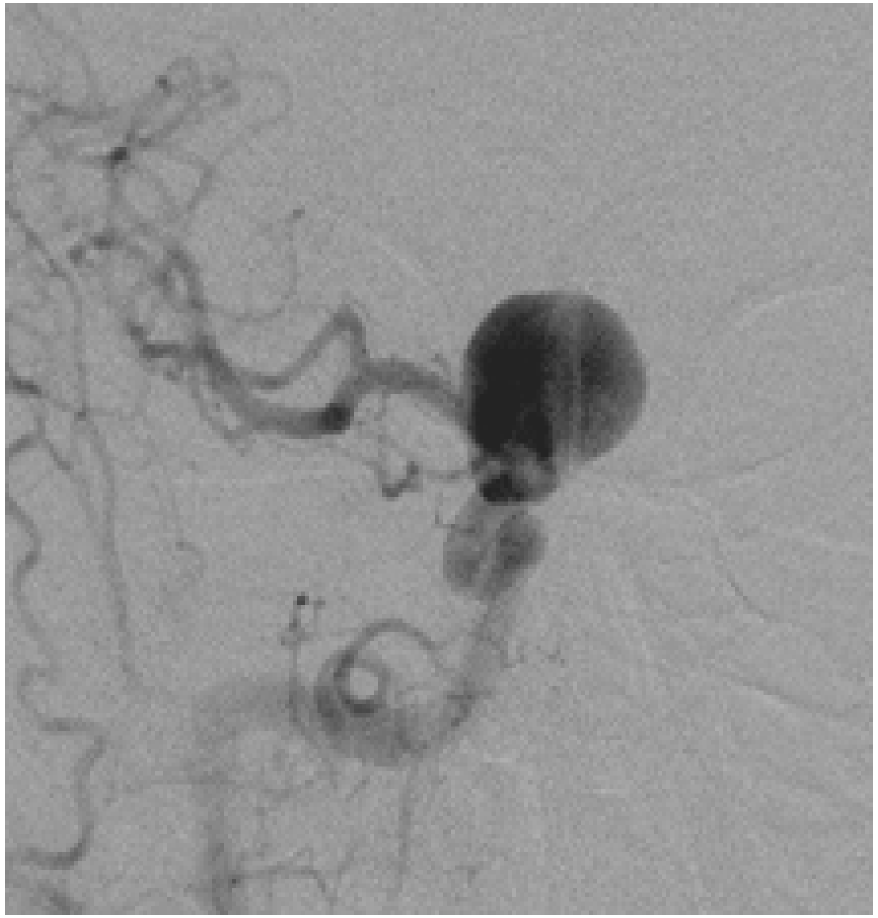
Onyx Example Case

Pre-Procedure



Post-Procedure

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Pipeline Embolization Device

- Designed for large and giant petrocavernous ICA wide-neck/fusiform aneurysms
- Basically a self-expanding tube of braided fine metal wires
- Acts as a flow diverter that leads to aneurysm flow stagnation. However, wire interstices allow for flow to vital side branch arteries
- Patients kept on Plavix x 3-6 mos and ASA for life after device placement
- 6 mo F/U angiogram performed to assess aneurysm occlusion
- Data reveal > 90% aneurysm occlusion rate beyond one year

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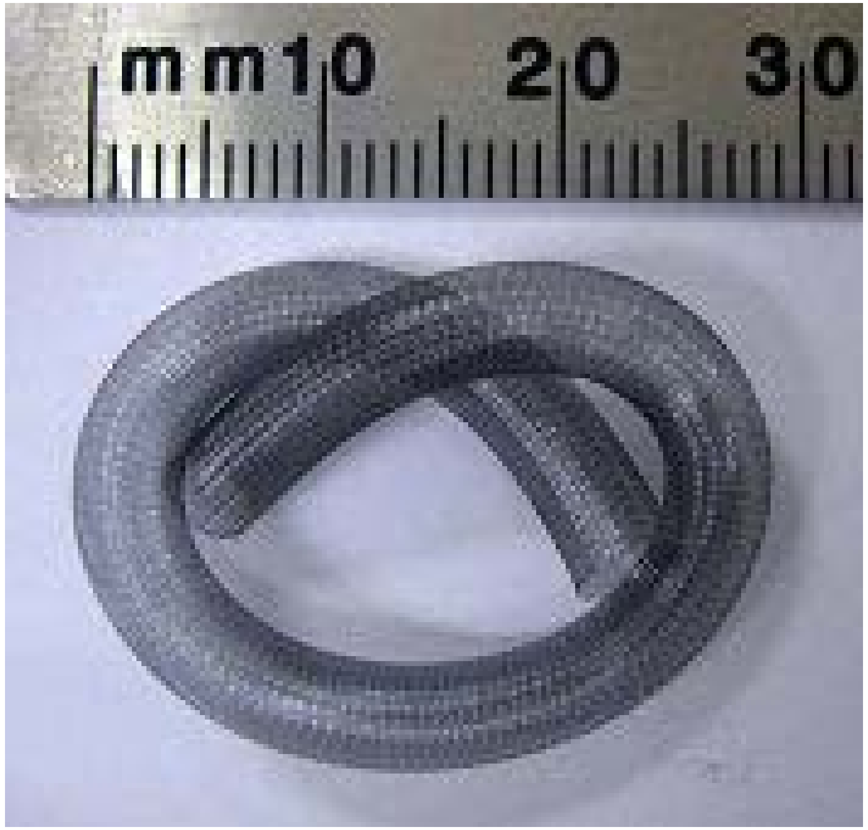

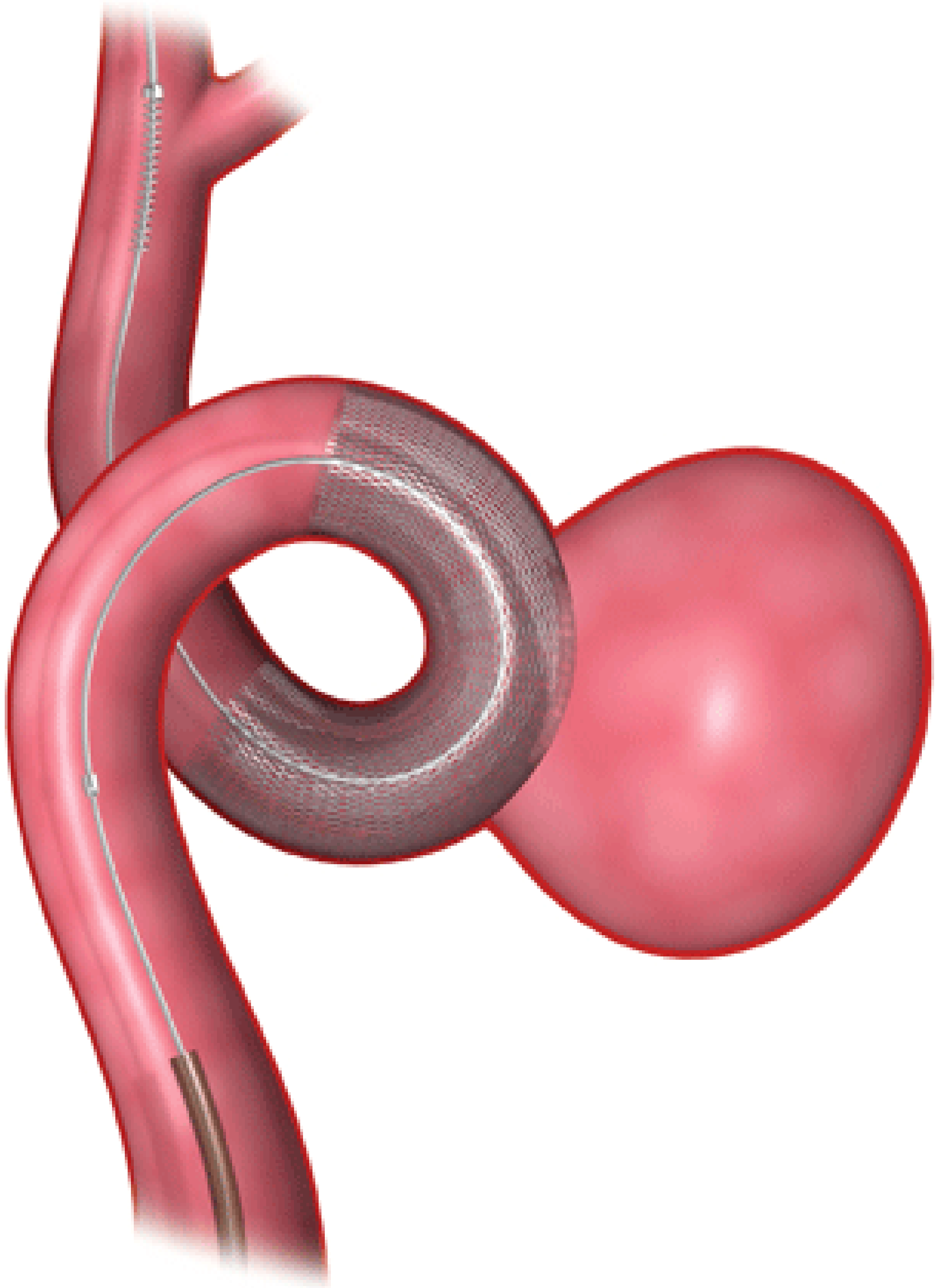

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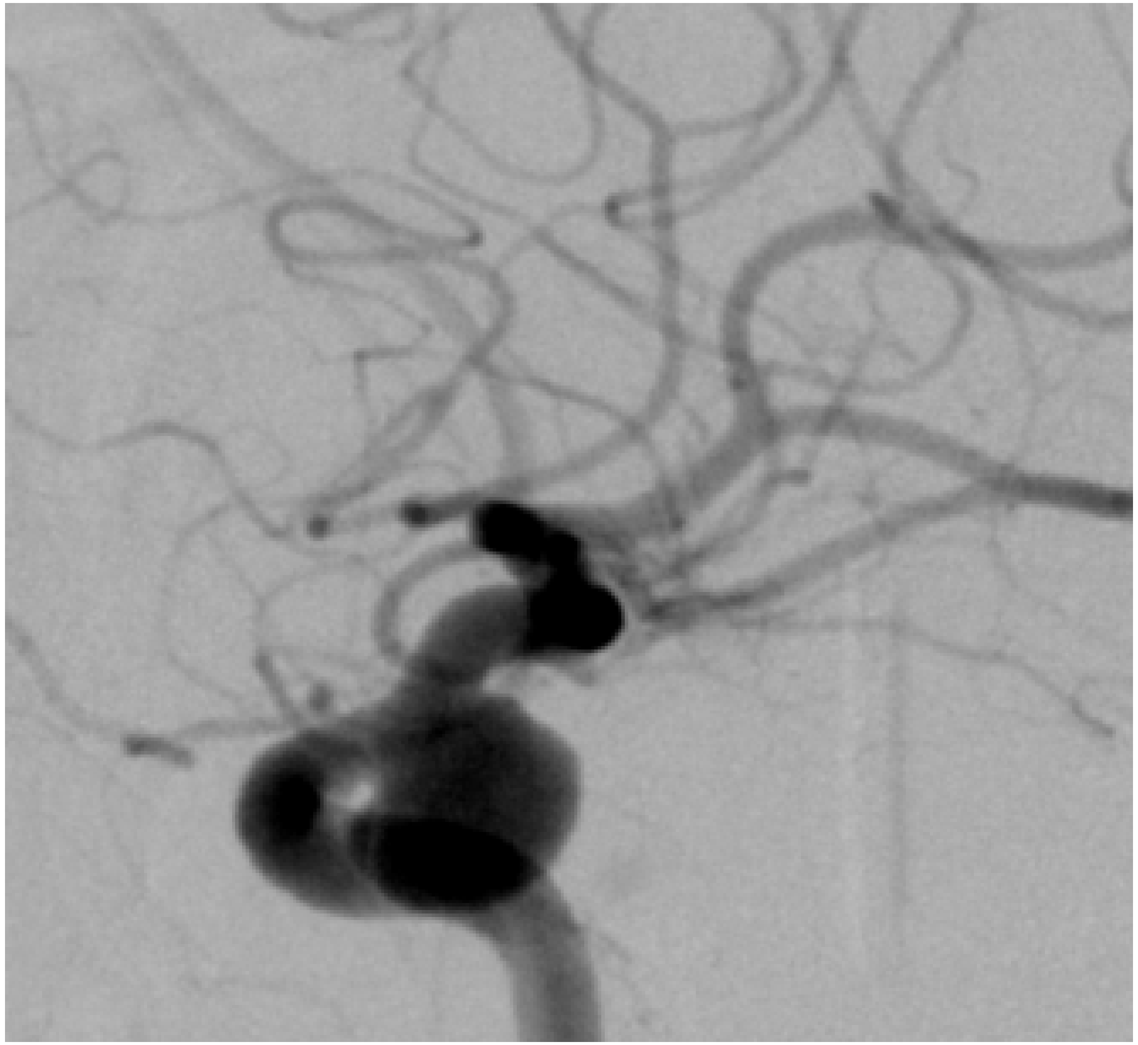
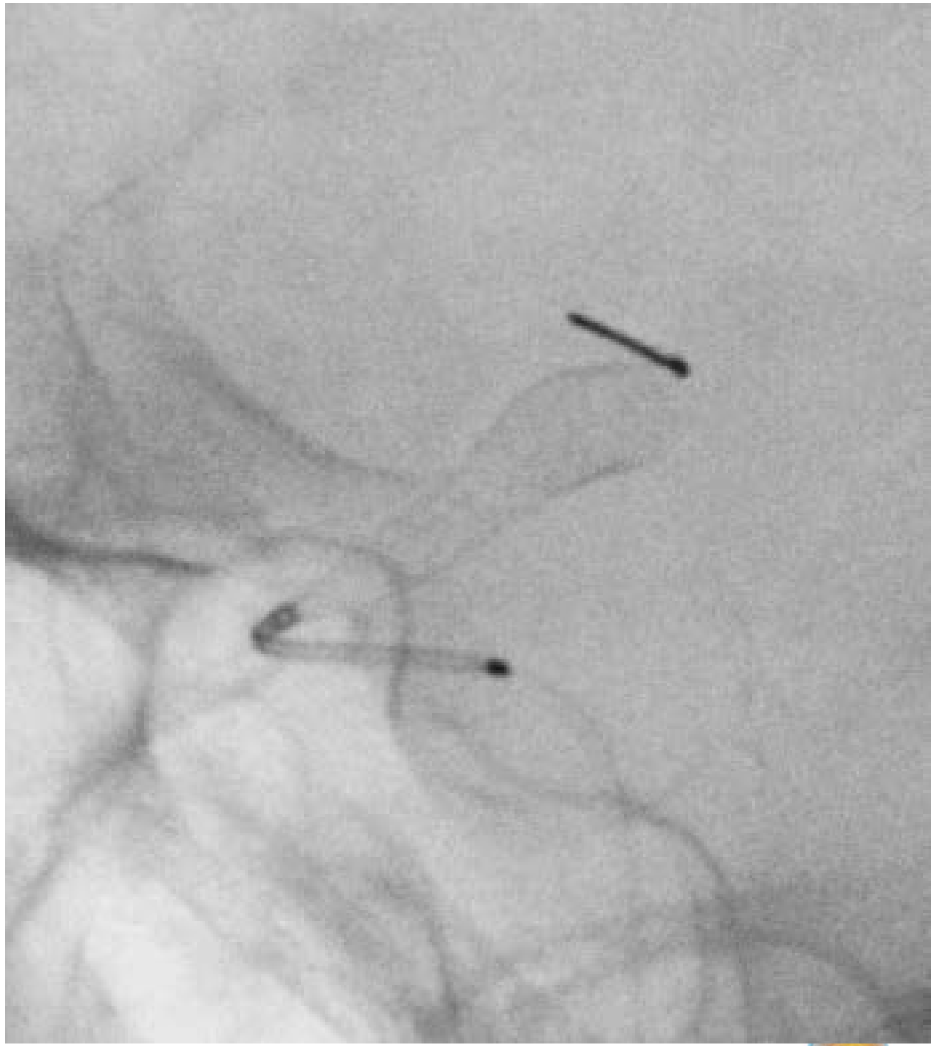
77 yo Female with Headache





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Immediately after Pipeline deployment.

7 months following Pipeline deployment. Aneurysm completely occluded.

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65 yo female with FMD, severe right retro-orbital headache and ptosis

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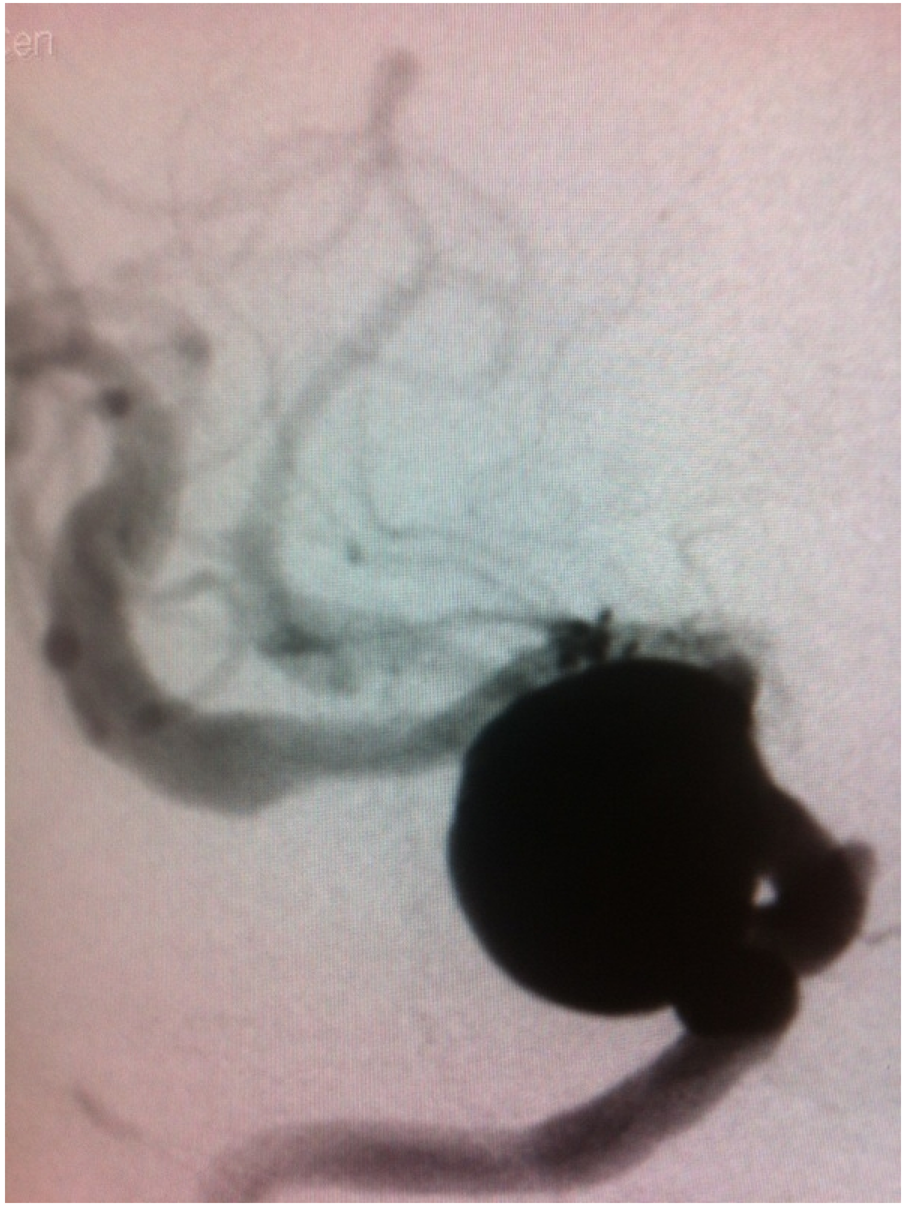
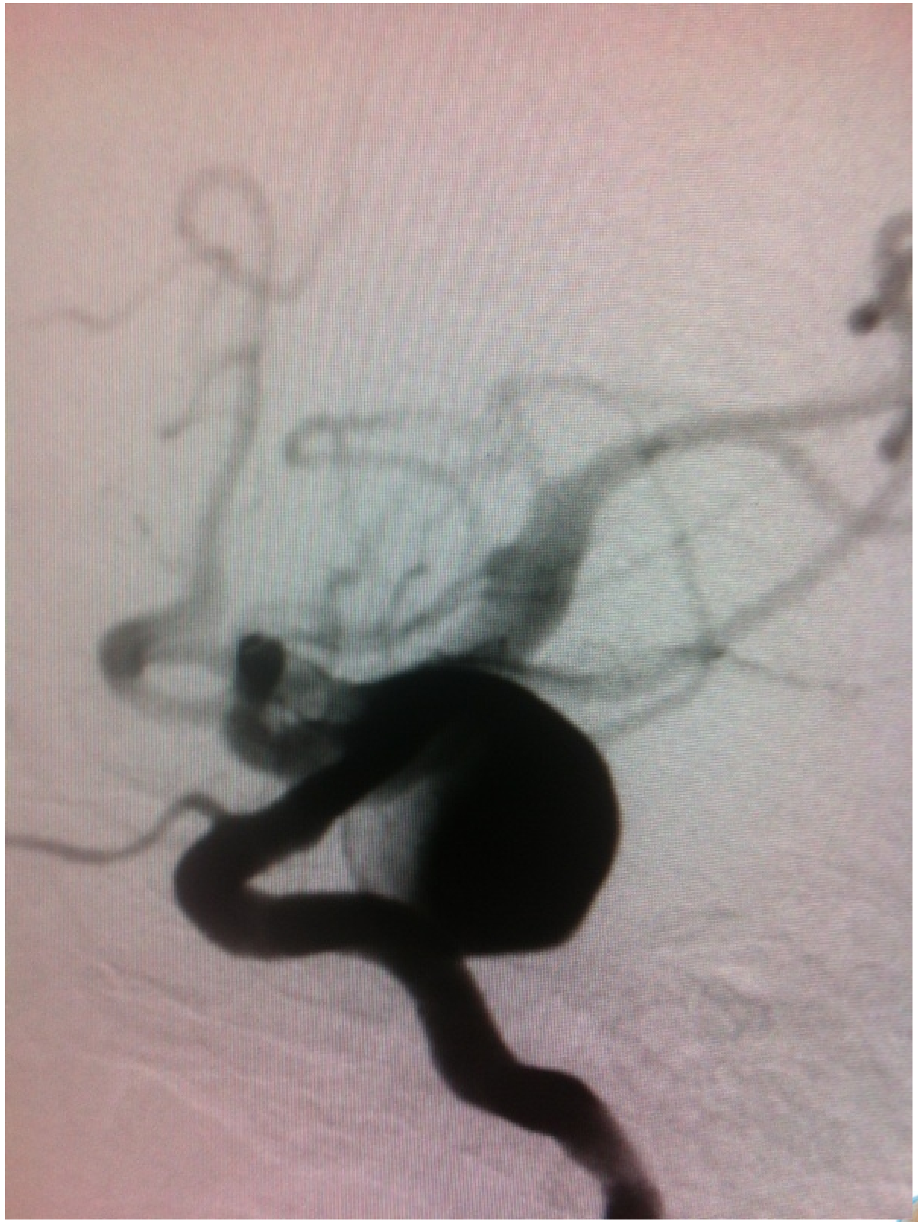
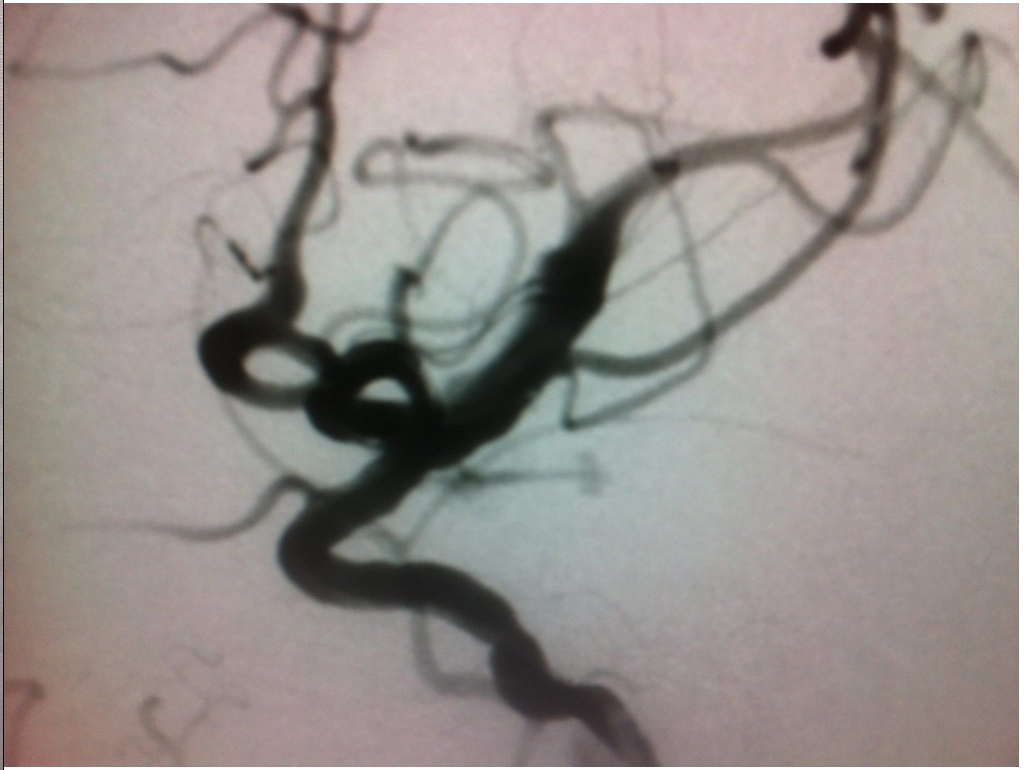




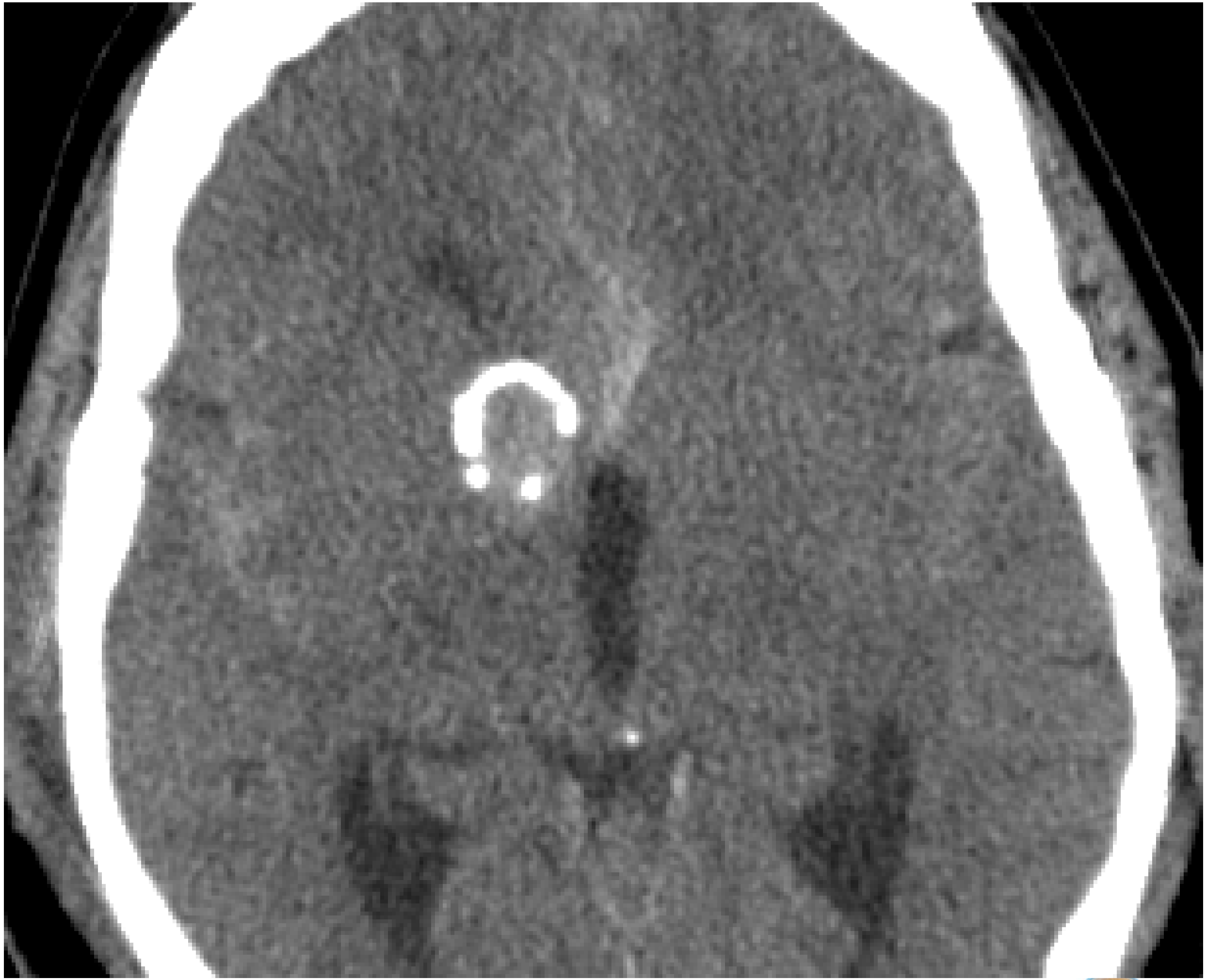


Long Term Results with Pipeline Device

- Fifty- three patients (age range, 11–77 years; average age, 55.2 years; 48 female) with 63 intracranial aneurysms treated with the PED.
- Small (n 33), large (n 22), and giant (n 8) wide-necked aneurysms.
- A single PED used in 44 aneurysms, 2 overlapping PEDs in 17 aneurysms, and 3 overlapping PEDs in 2 aneurysms.
- Complete angiographic occlusion was achieved in 56%, 93%, and 95% of aneurysms at 3 (n 42), 6 (n 28), and 12 (n 18) months, respectively.
- The only aneurysm that remained patent at the time of the 12-month follow- up examination had been treated previously with stent- assisted coiling.
- The presence of a preexisting endovascular stent (e.g., Neuroform, LVIS or Enterprise stents) may limited the efficacy of the PED due to lack of optimum luminal apposition causing “endoleak.”
- ***No aneurysms demonstrated recanalization in F/U angiograms.***
- No major complications (stroke or death) were encountered during the study period.
- Three patients (5%), all with giant aneurysms, experienced transient exacerbations of preexisting cranial neuropathies and headache after the PED treatment. All 3 were successfully treated with corticosteroids.

Neurosurgery 64:632–643, 2009

46 yo F presenting with SAH



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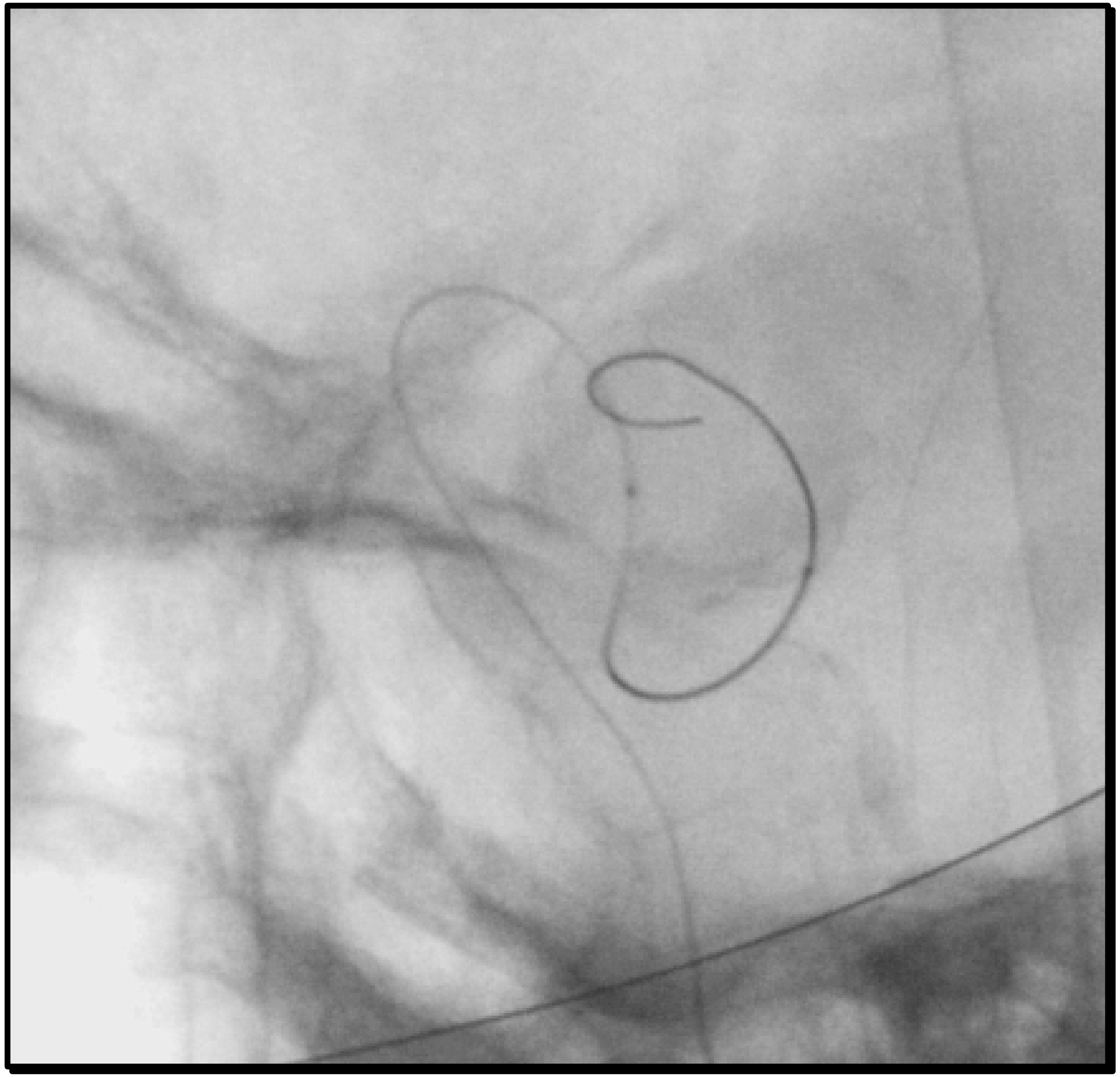

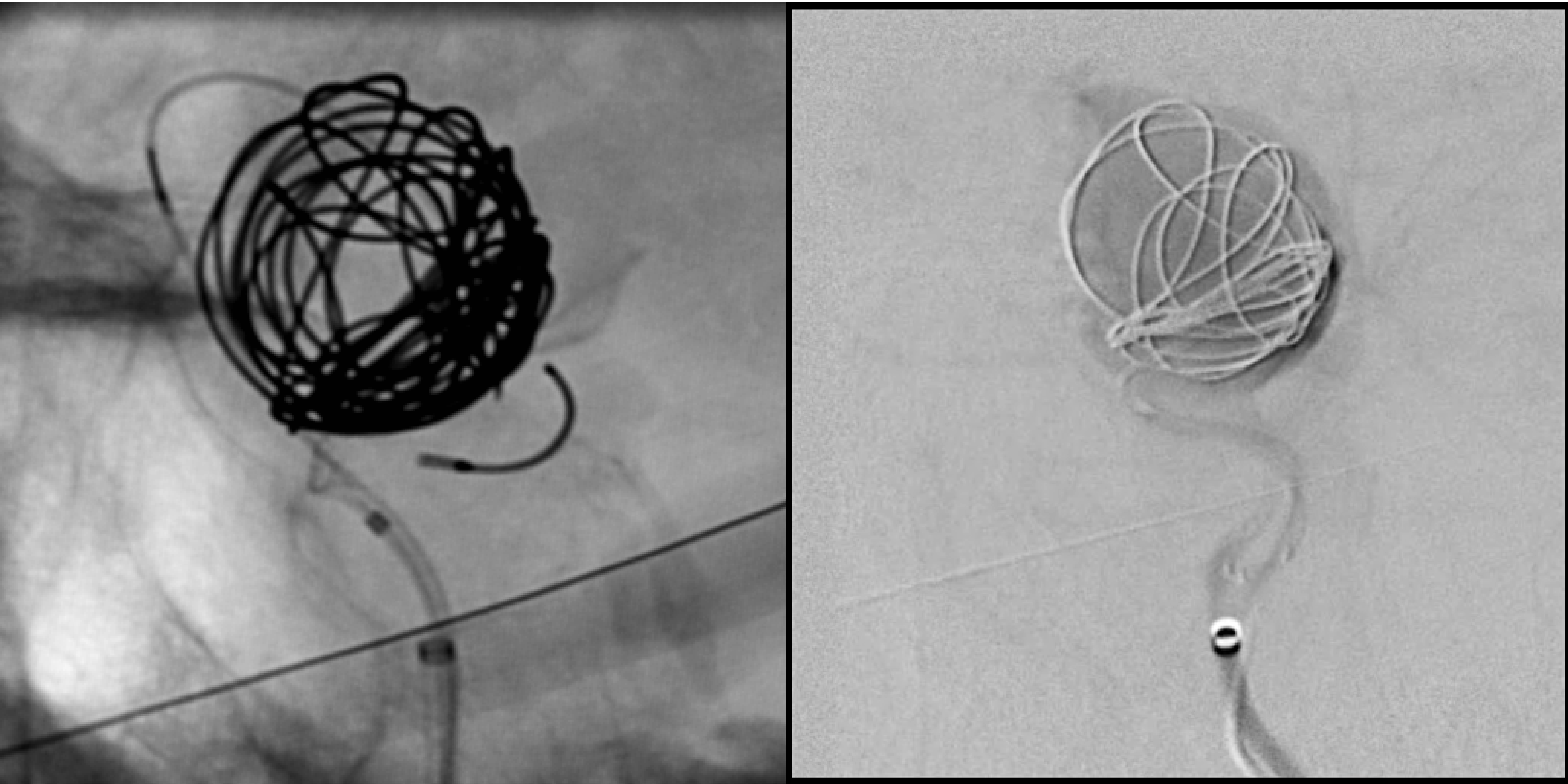

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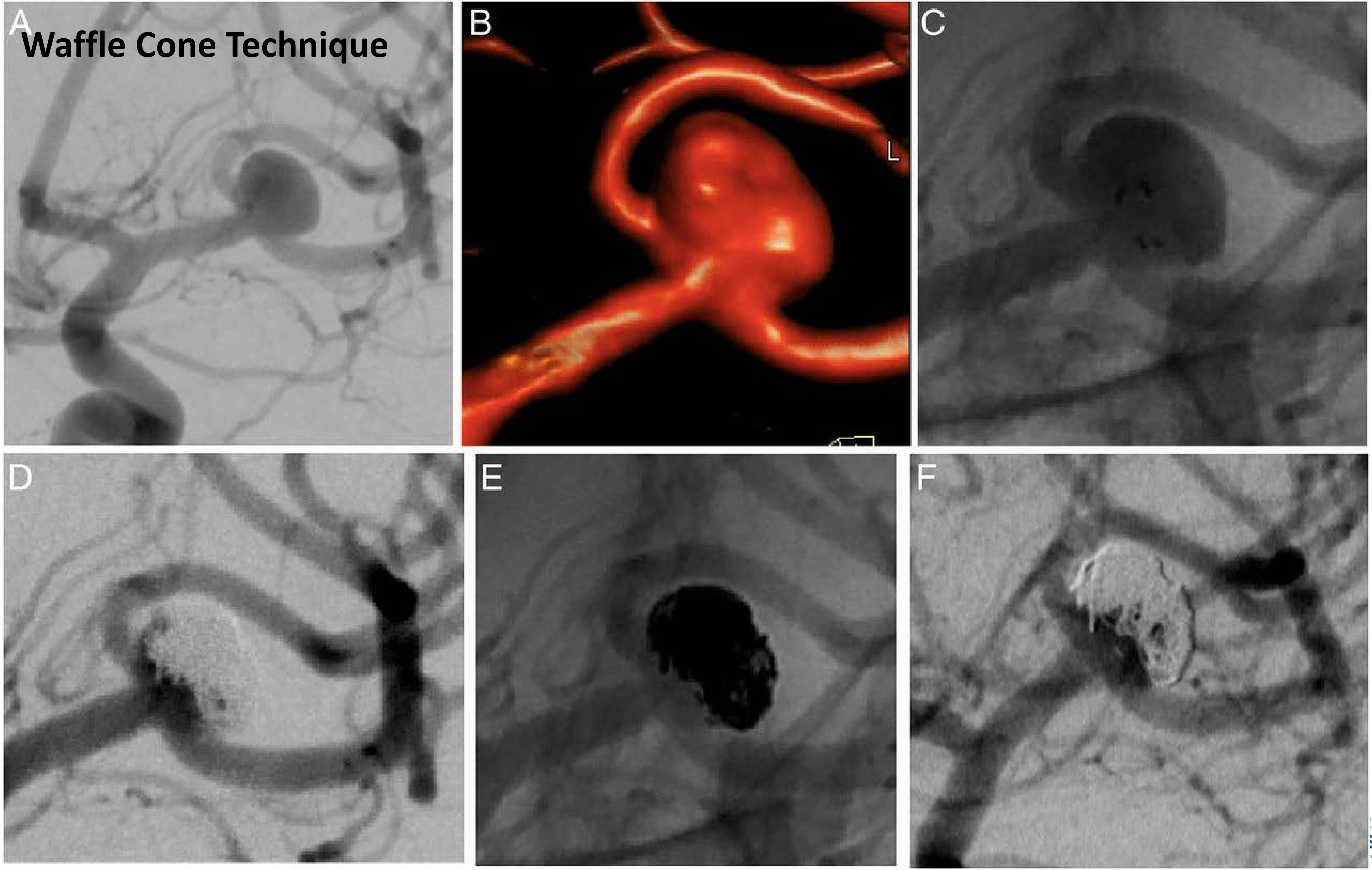
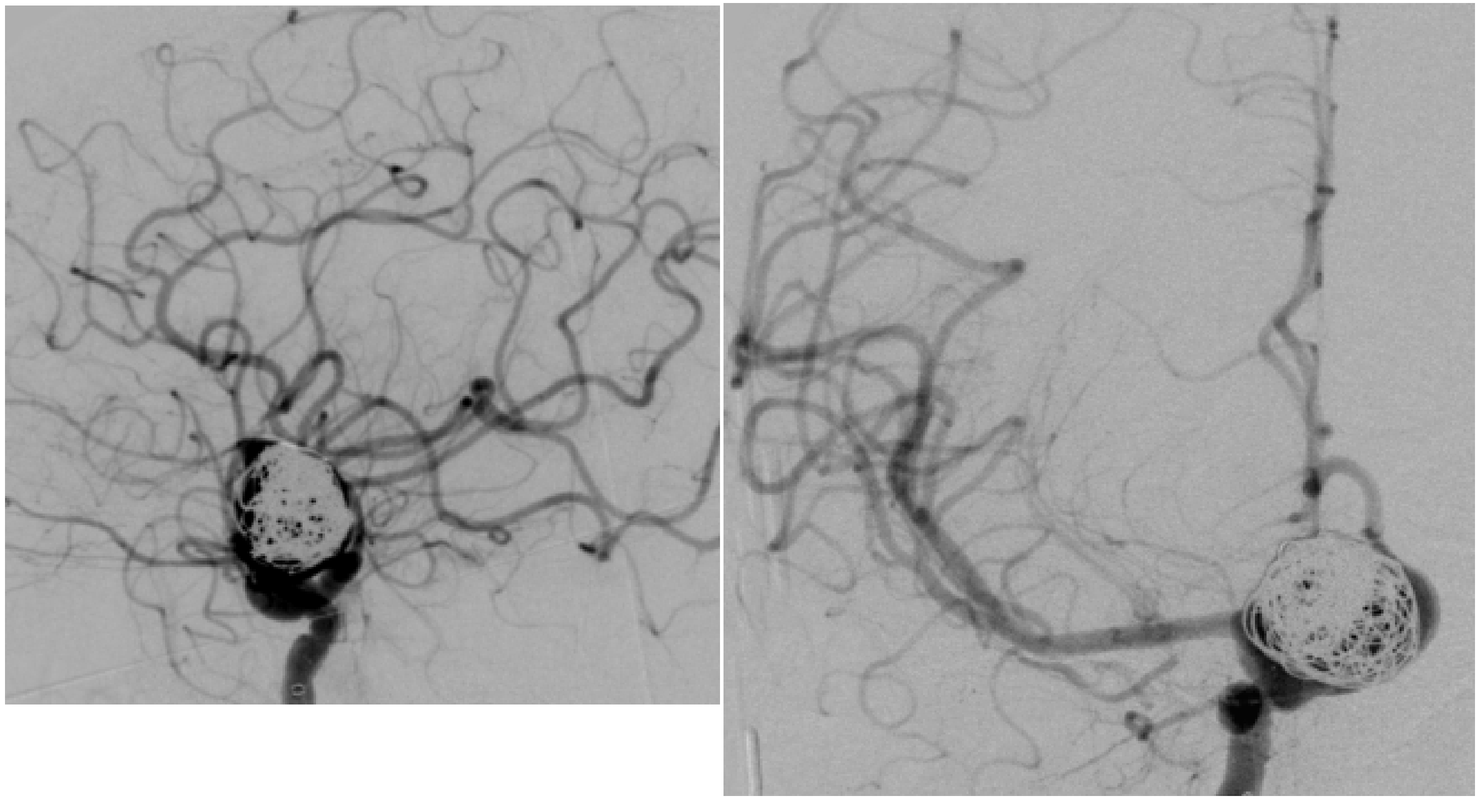
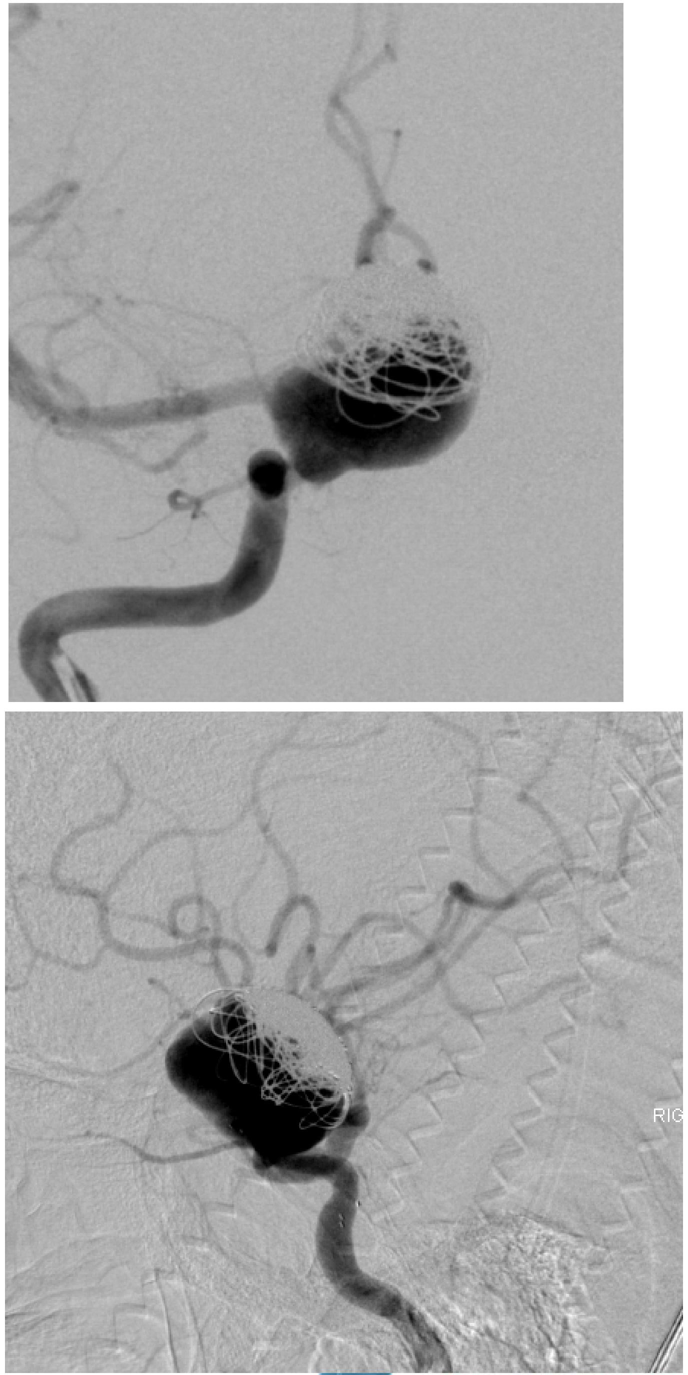
Waffle Cone Technique





7 months later



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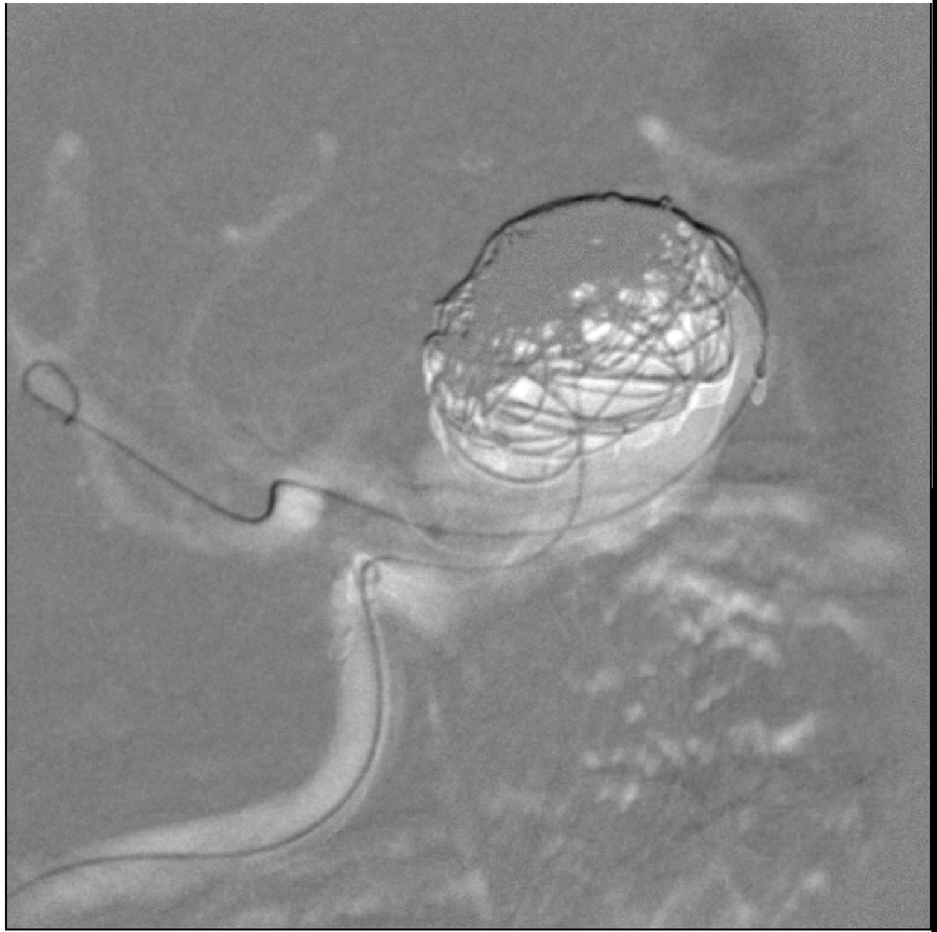

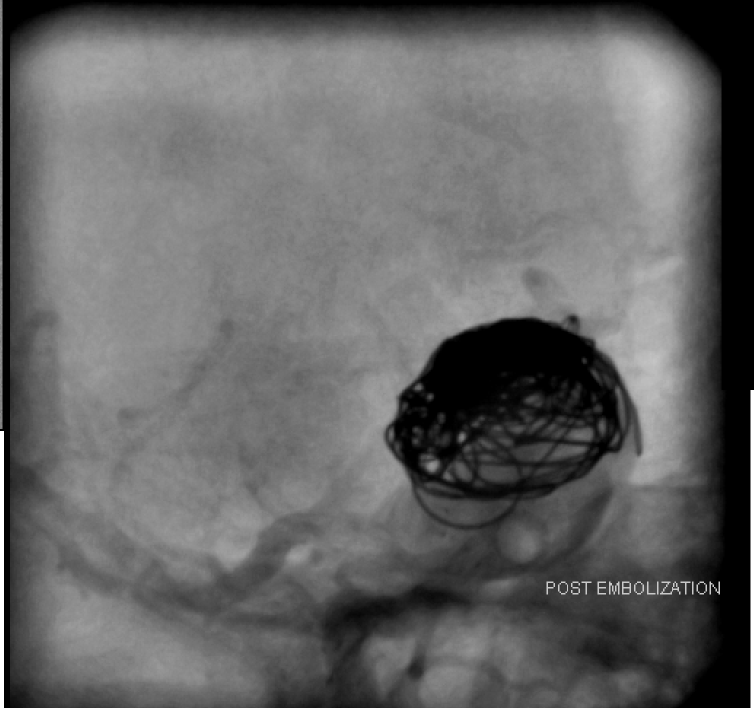

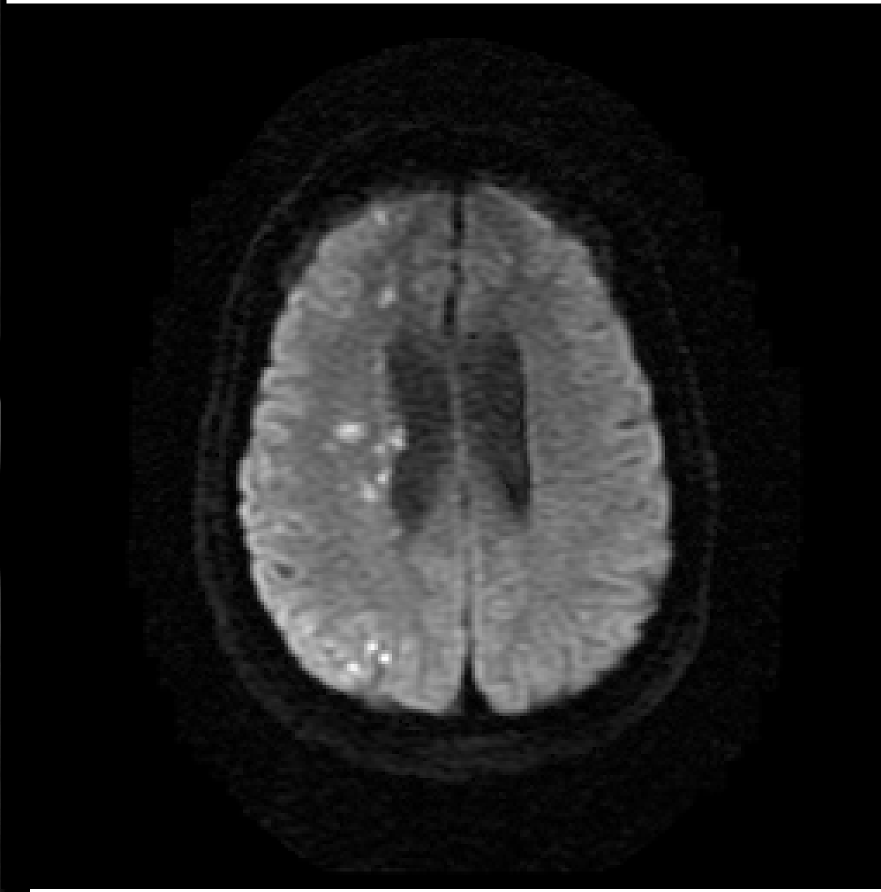

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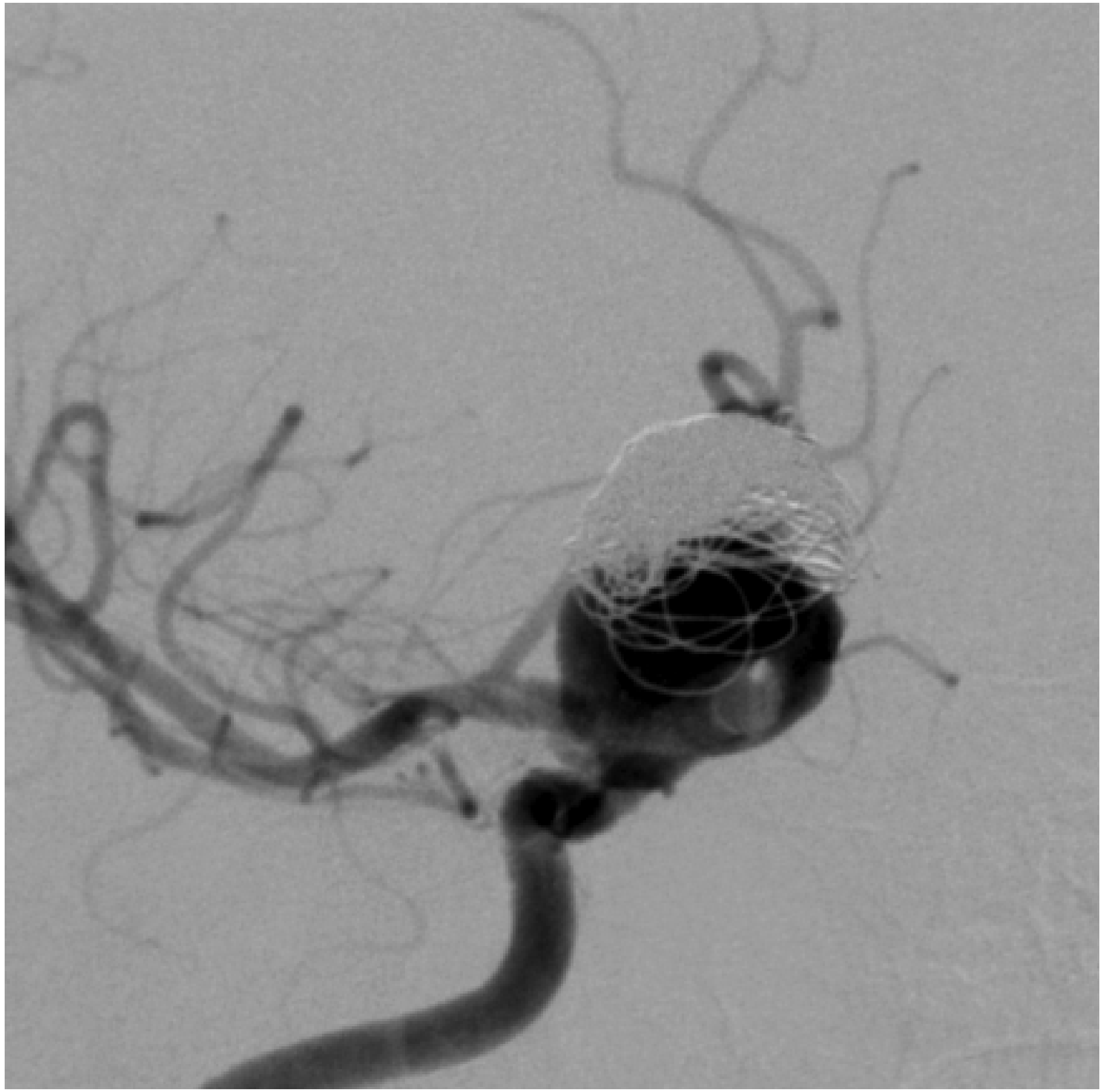
6 months later



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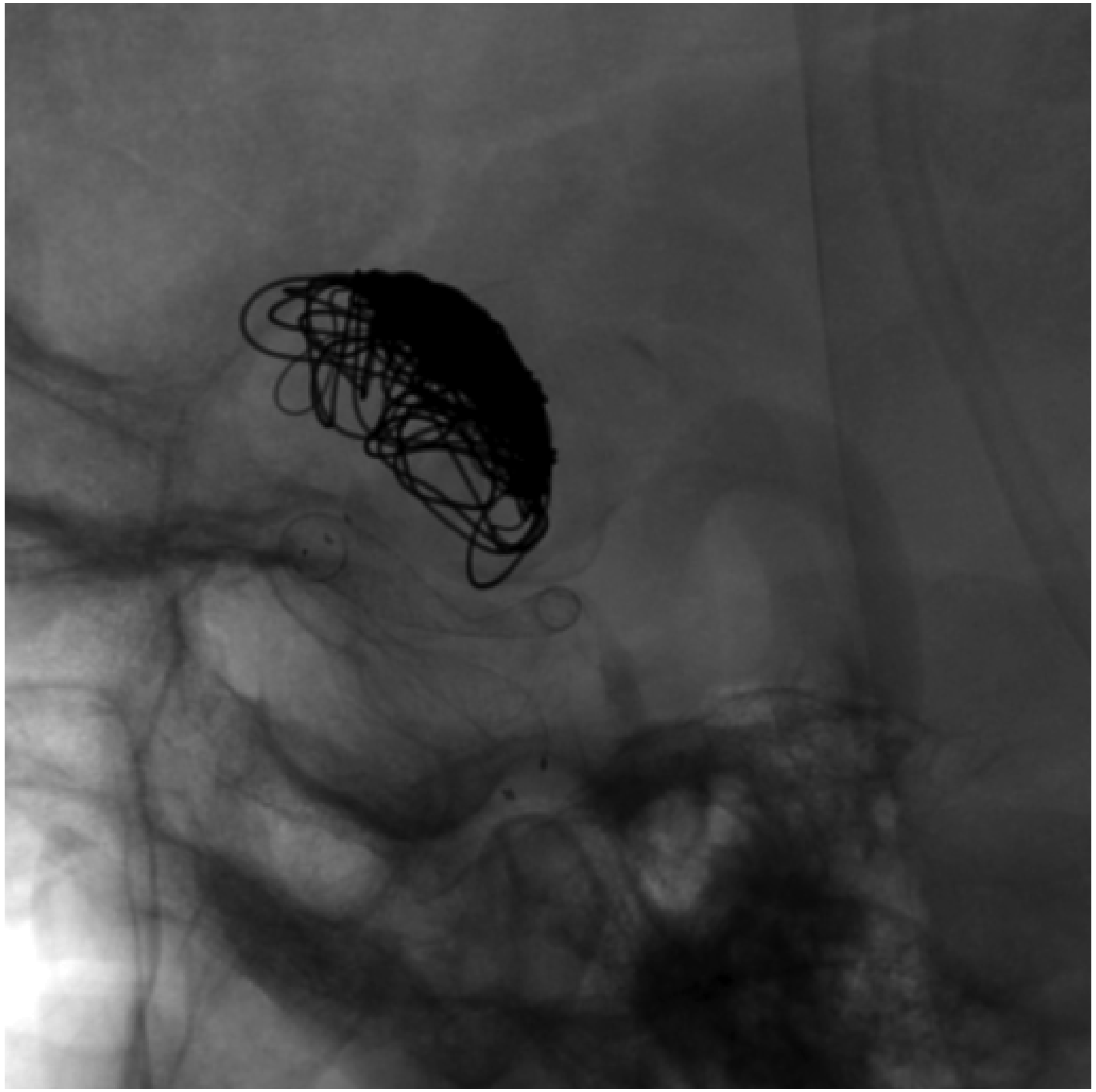

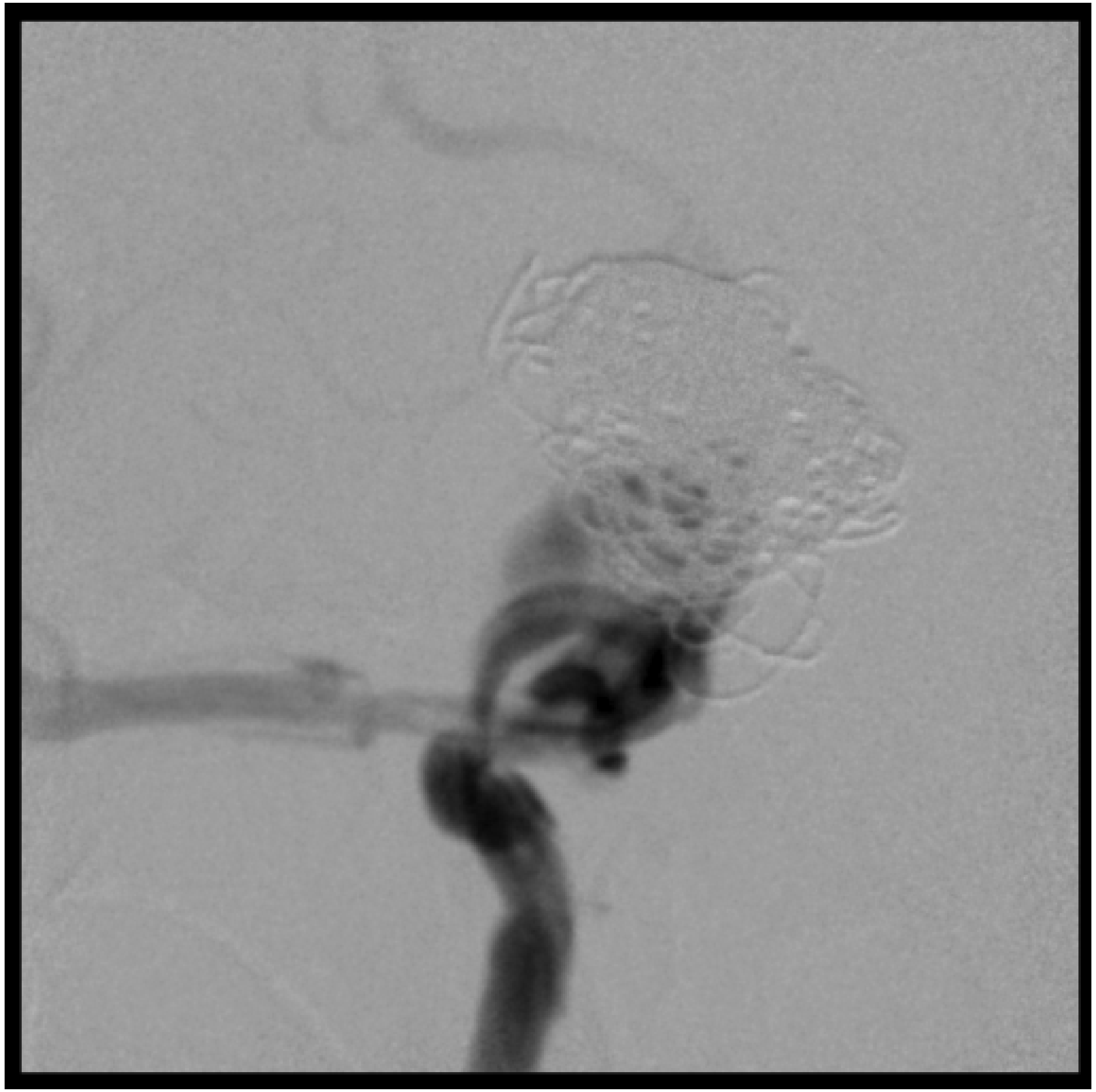

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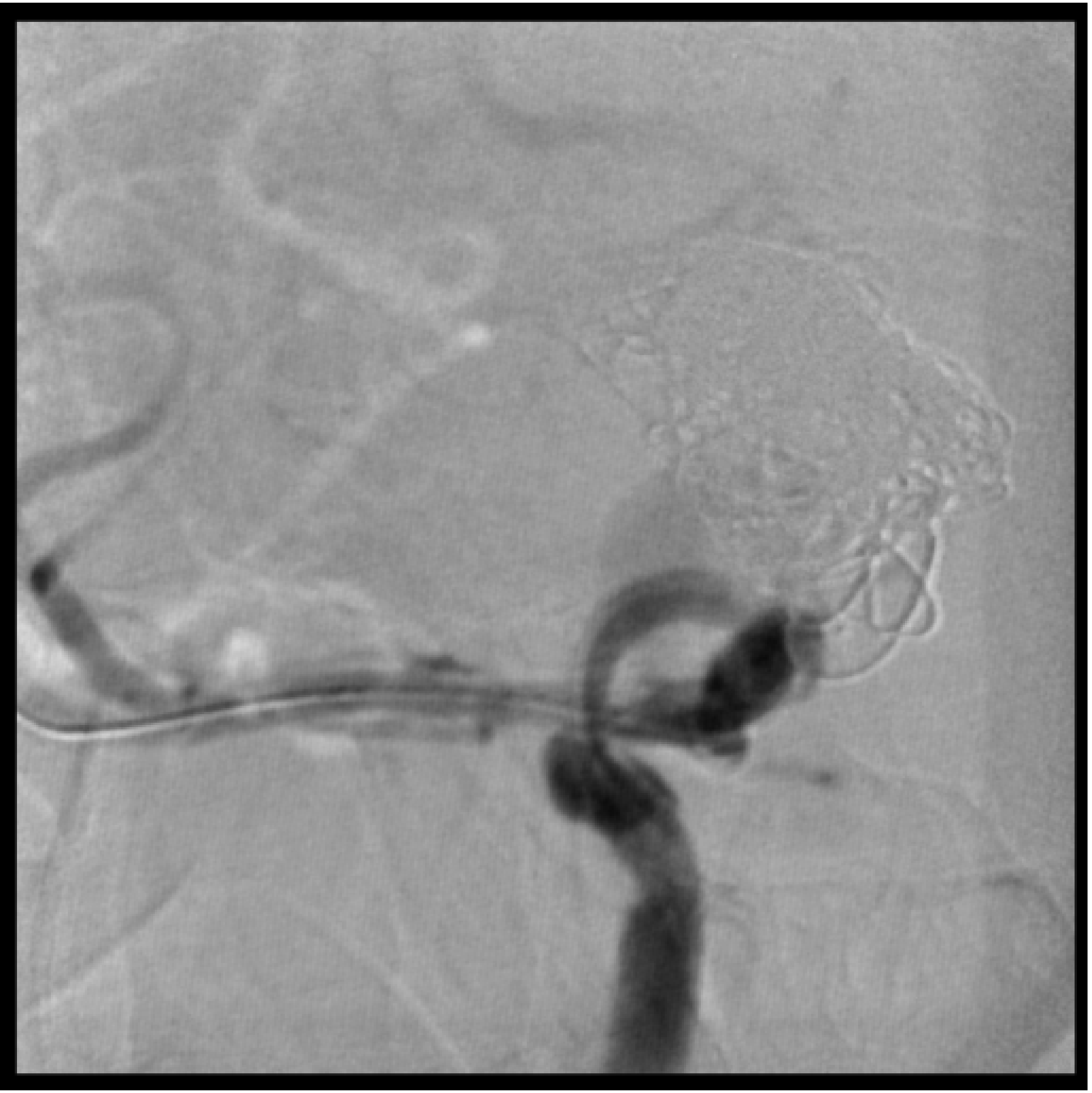

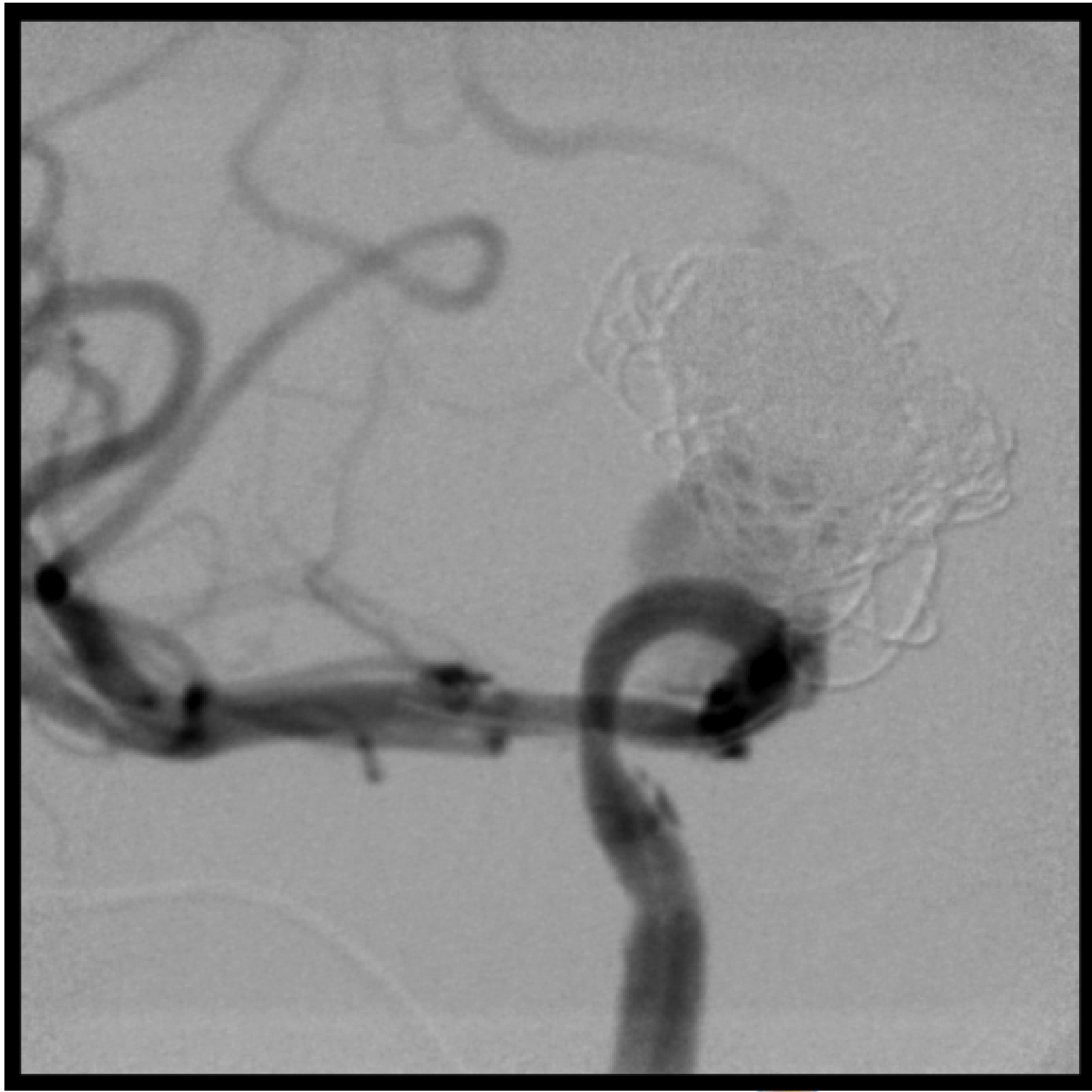

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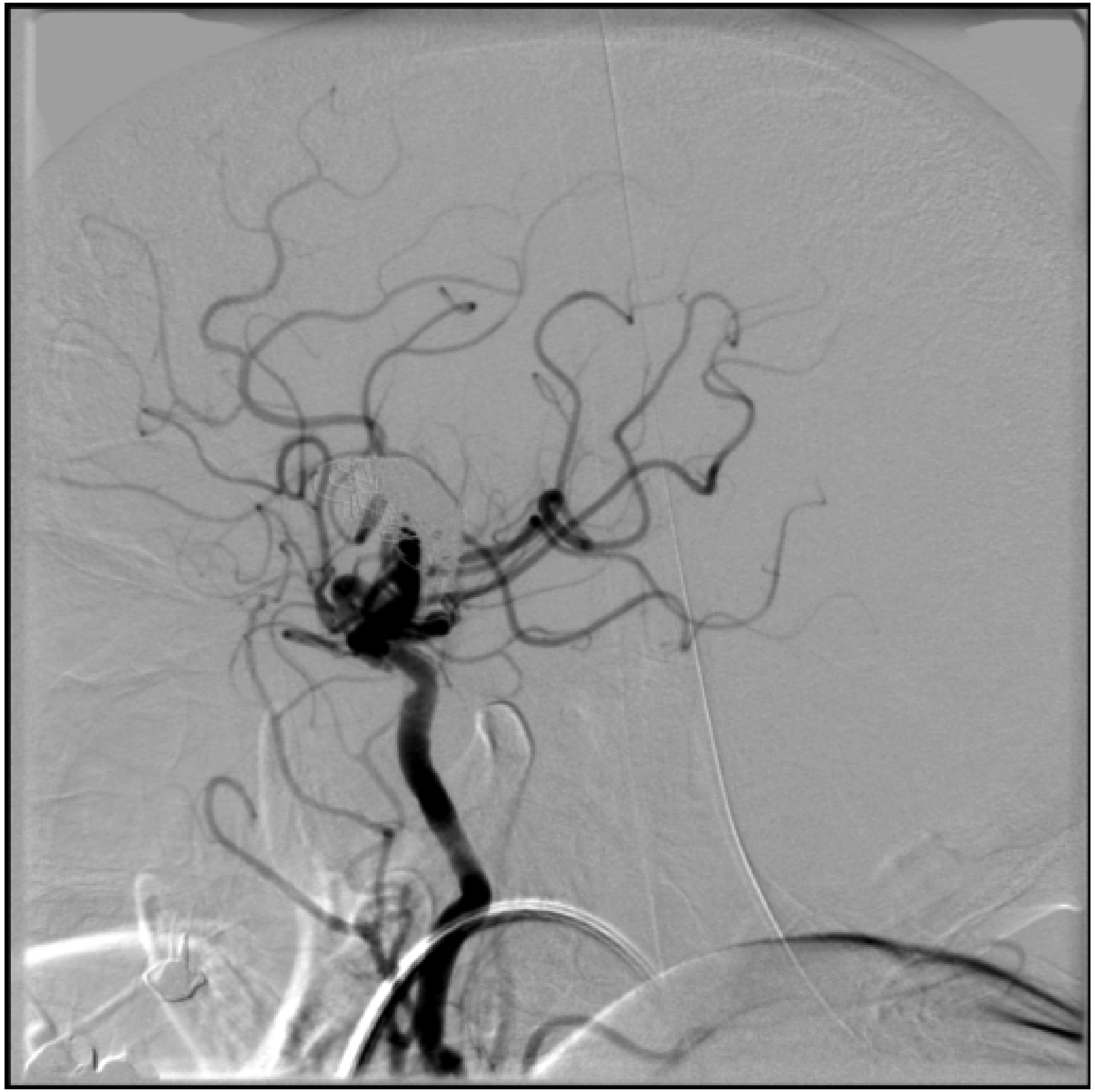

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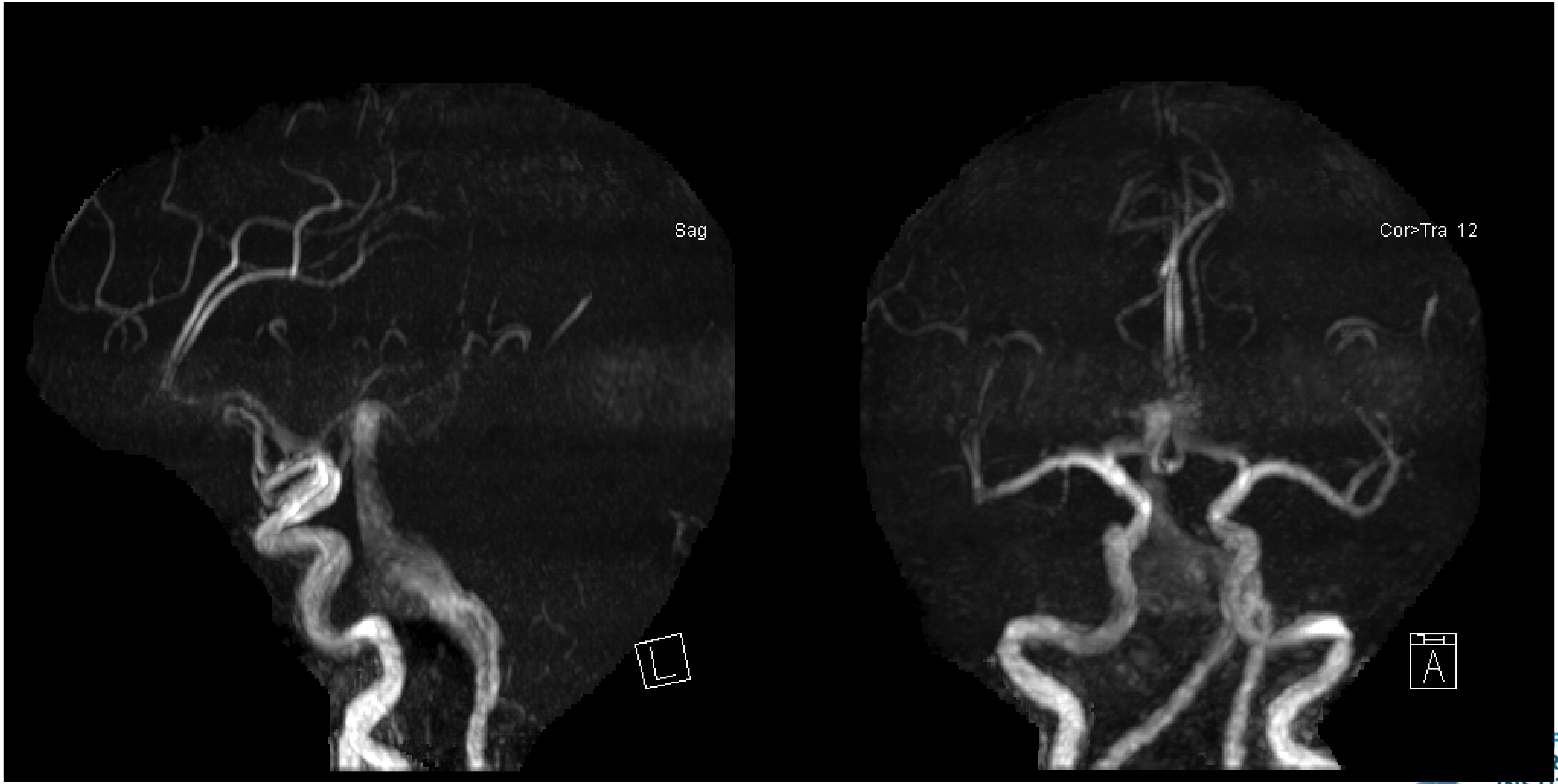
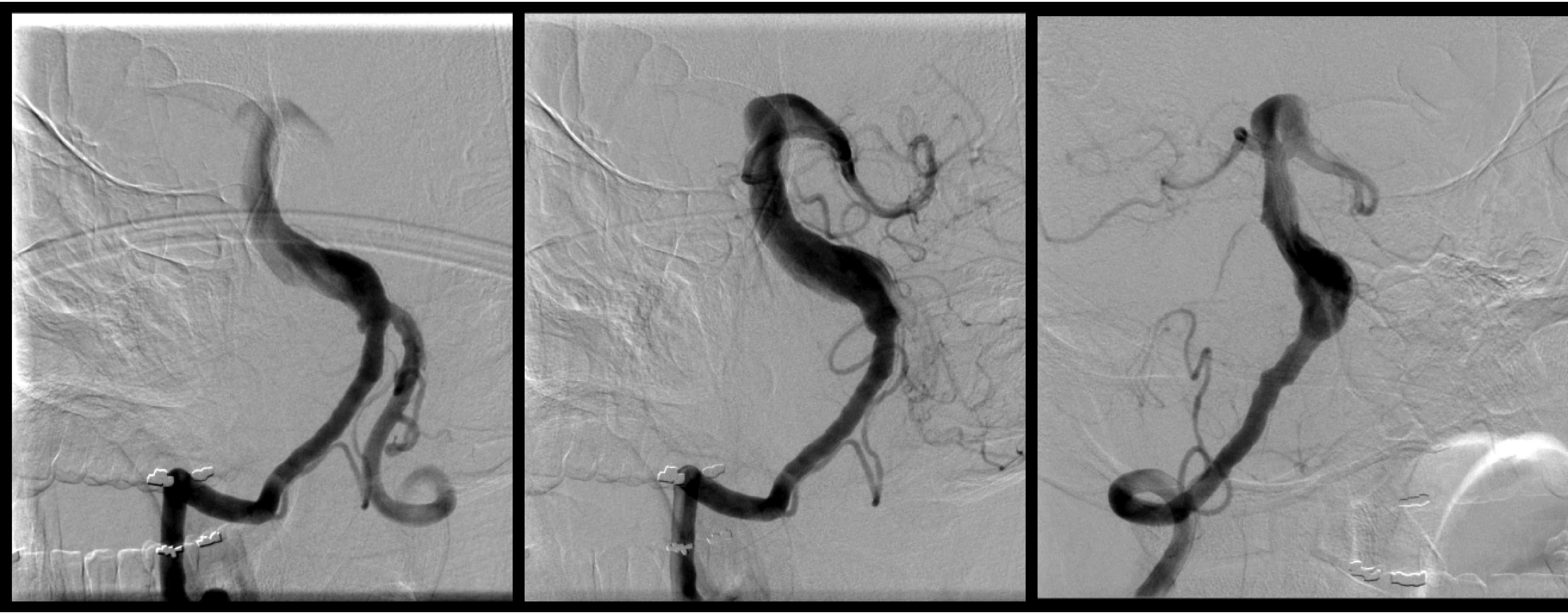
39 yo M with severe headache, dizziness and nausea





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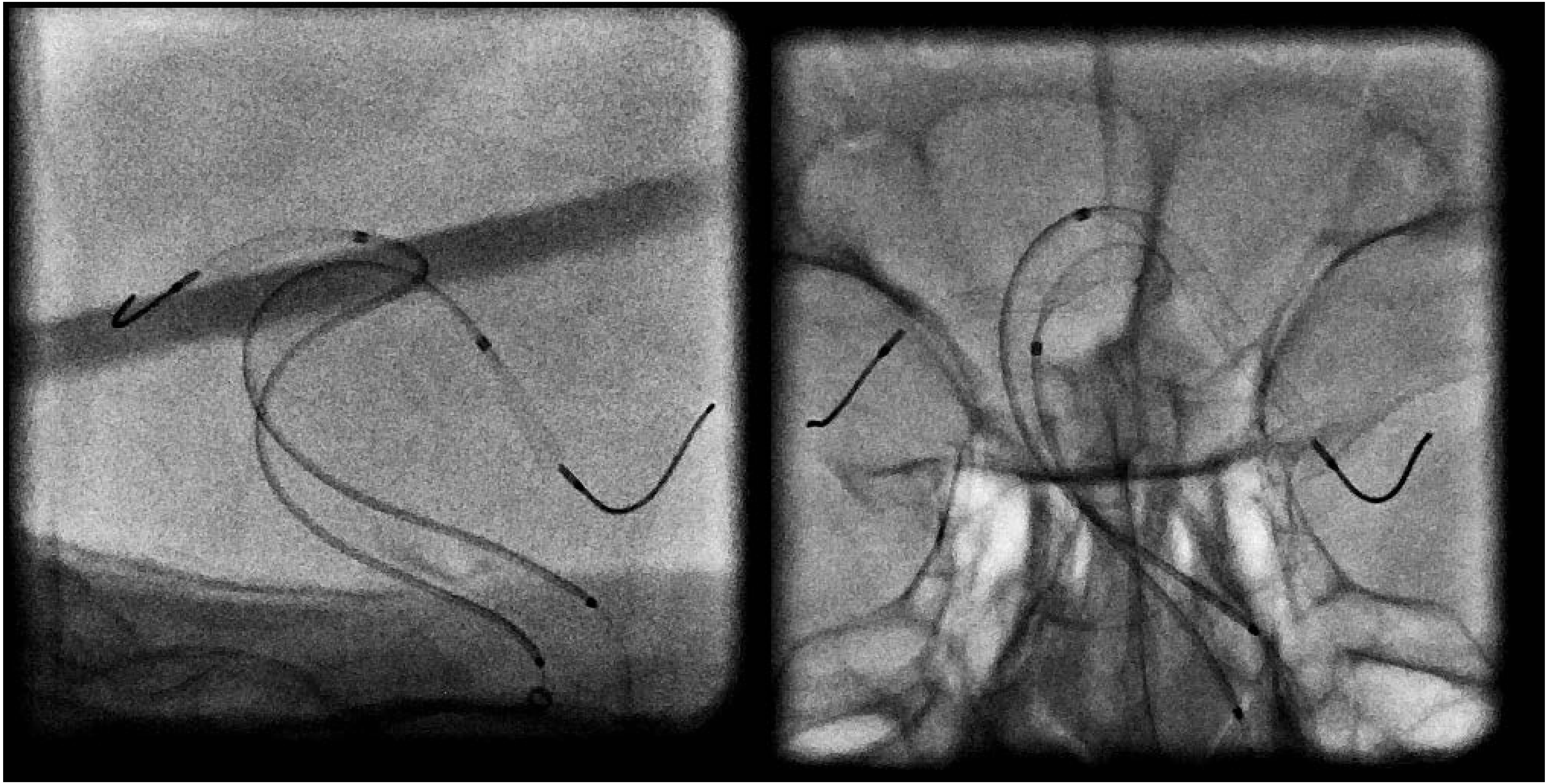

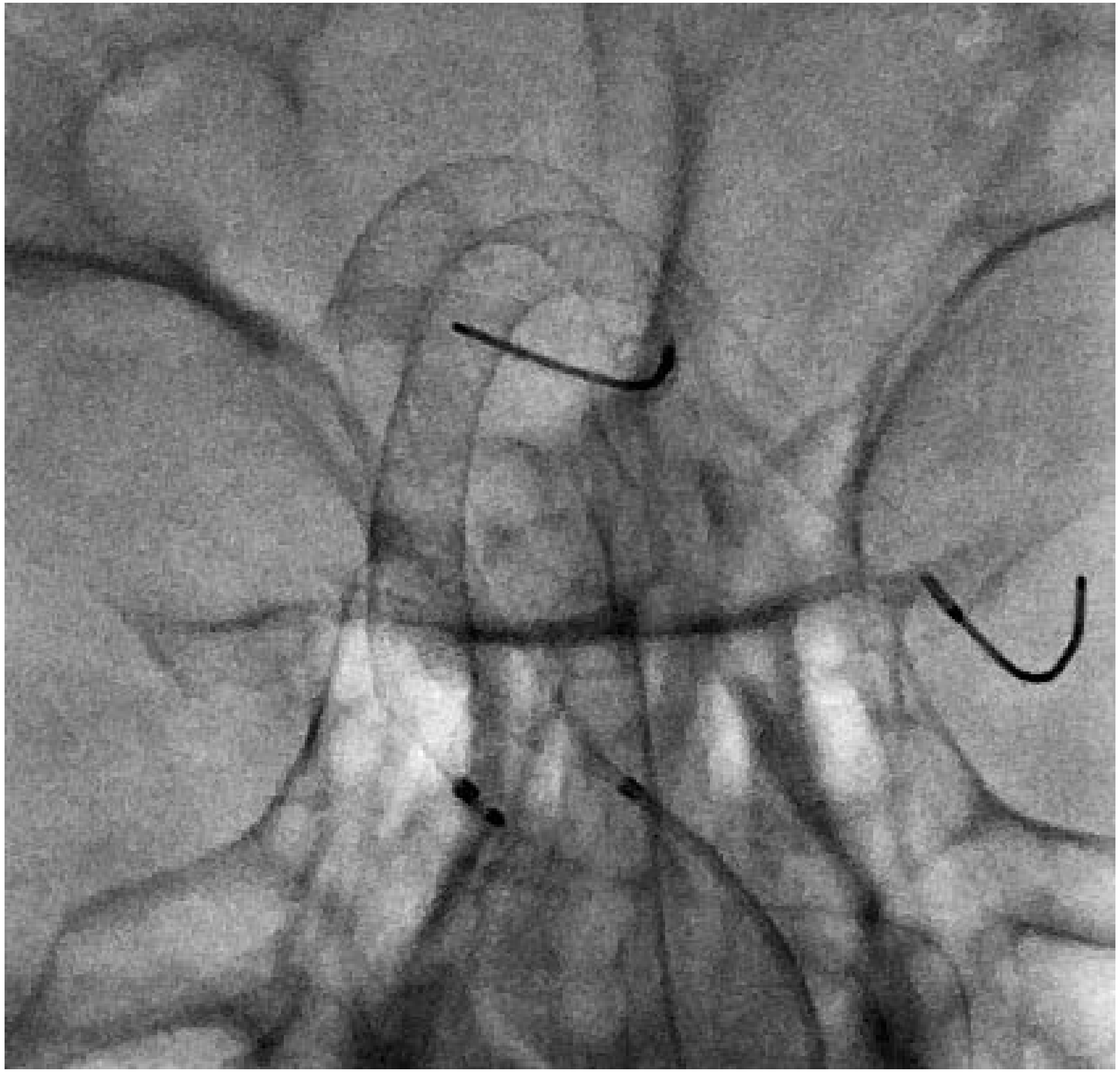

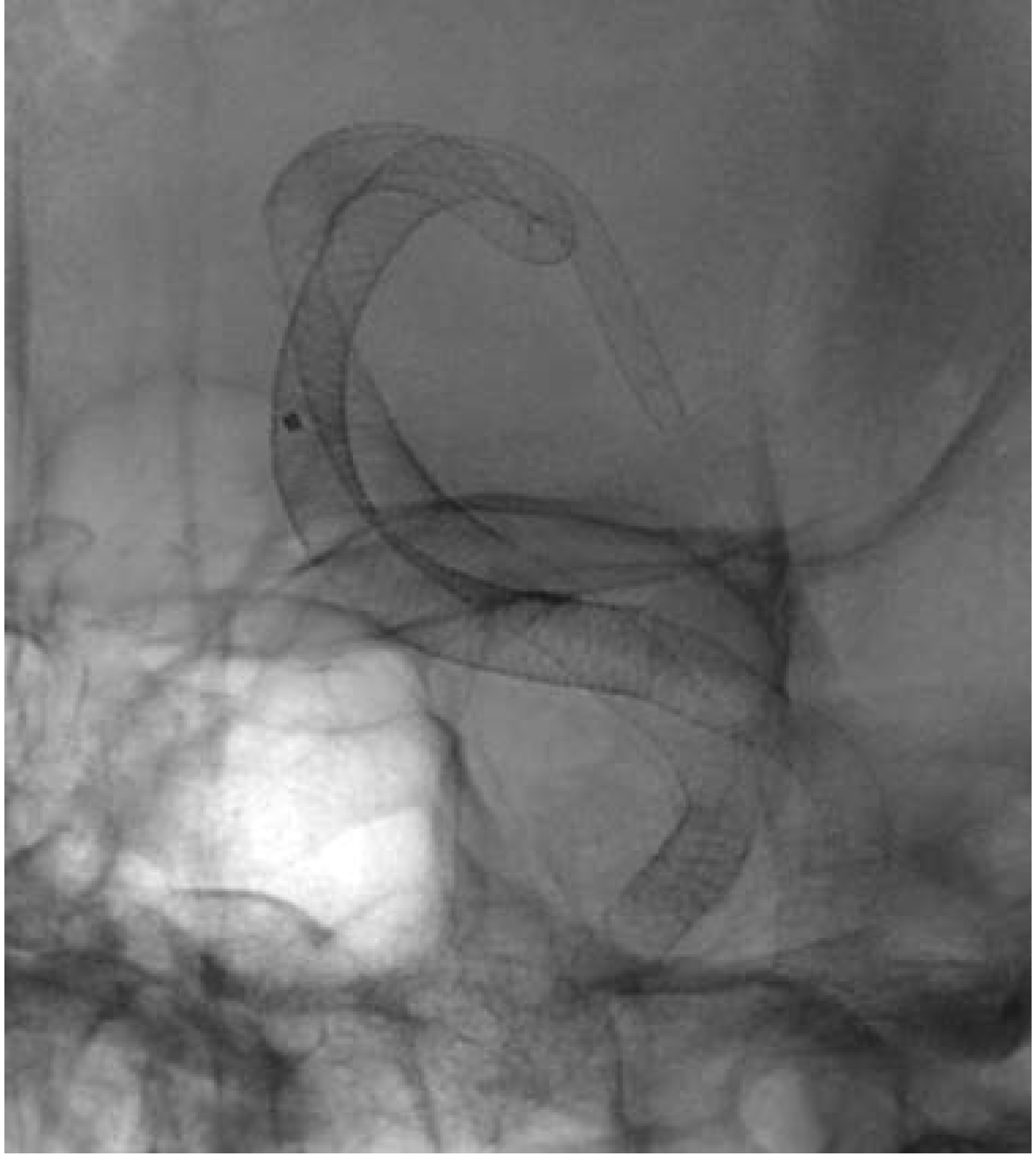

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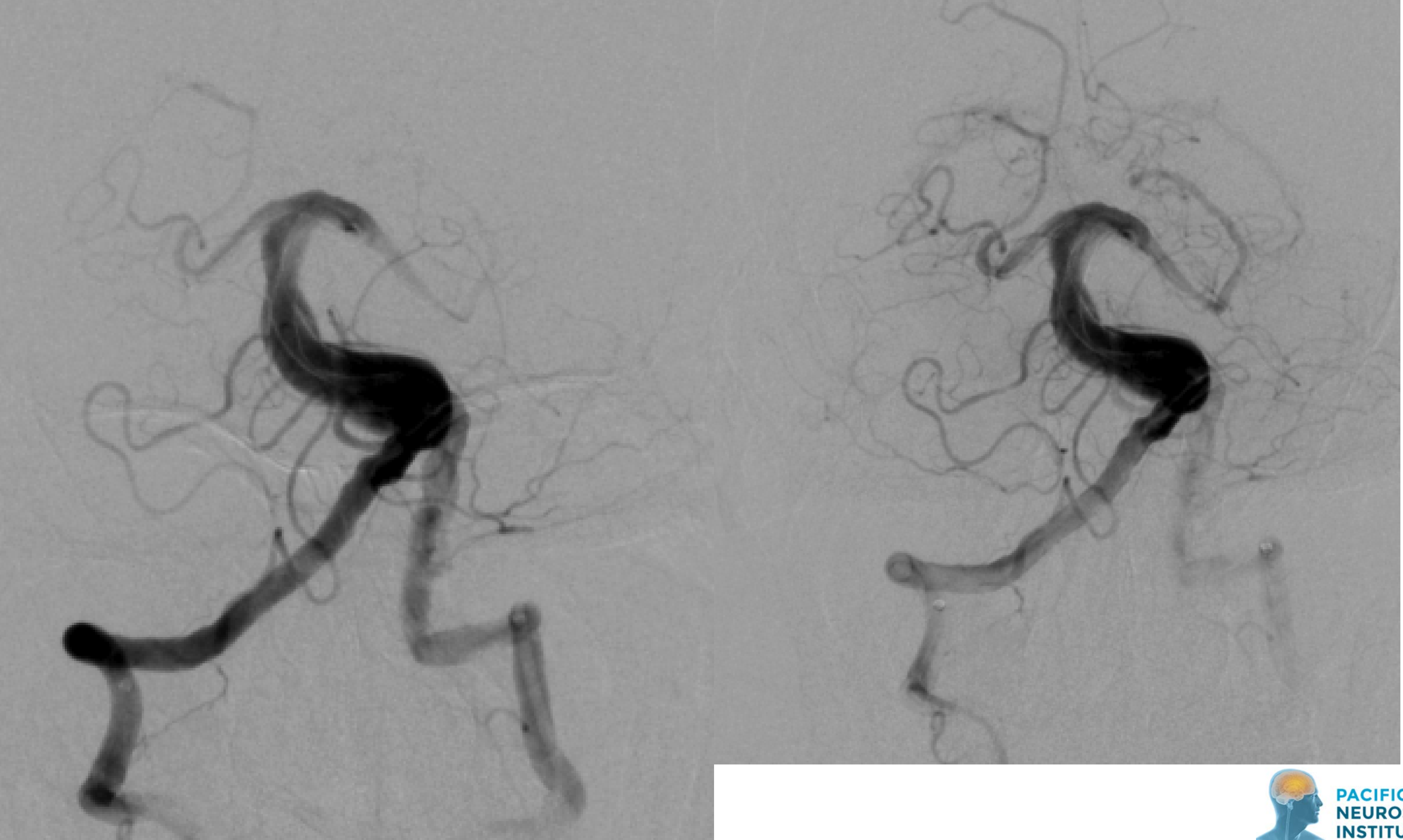

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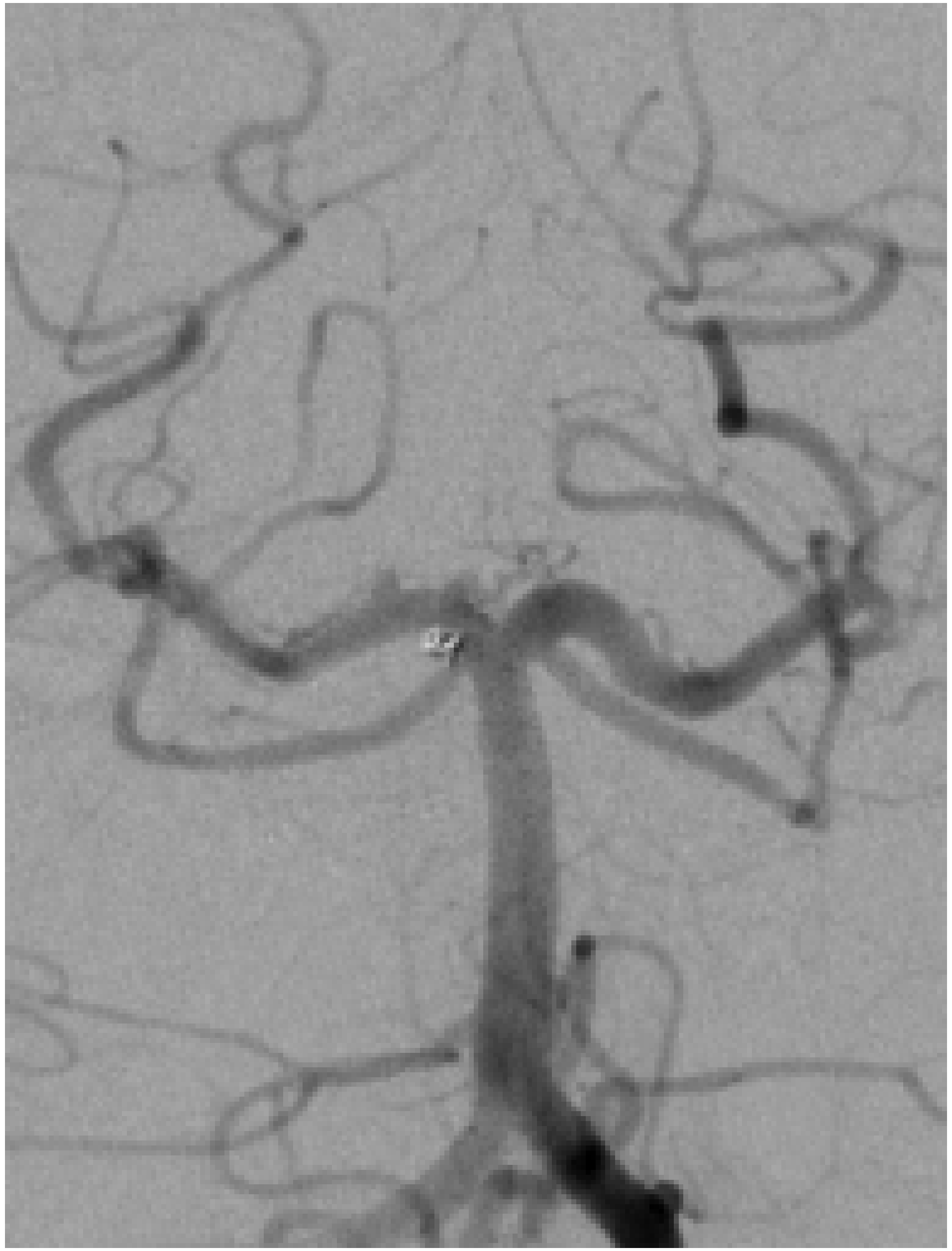
Post-Embolization Course

- Maintained on Plavix, ASA, and Coumadin
- Discharged to home four days later without new neuro deficit
- Soon lost to follow-up despite extensive efforts to locate him and his family
- After several months, we assumed the worst
- However, more than a year later, we were informed by a Kaiser Sunset neurointerventionalist that he presented to clinic…alive. He had suffered a small pontine stroke but was ambulating with a walker and was reasonably independent. F/U angio planned at Kaiser.

62 yo F w/ two siblings who suffered aneurysmal SAH in their 50's. Her sister underwent clip ligation of a small basilar tip aneurysm. The patient had the incidental discovery of one right SCA and two right PCA 2-3 mm aneurysms.



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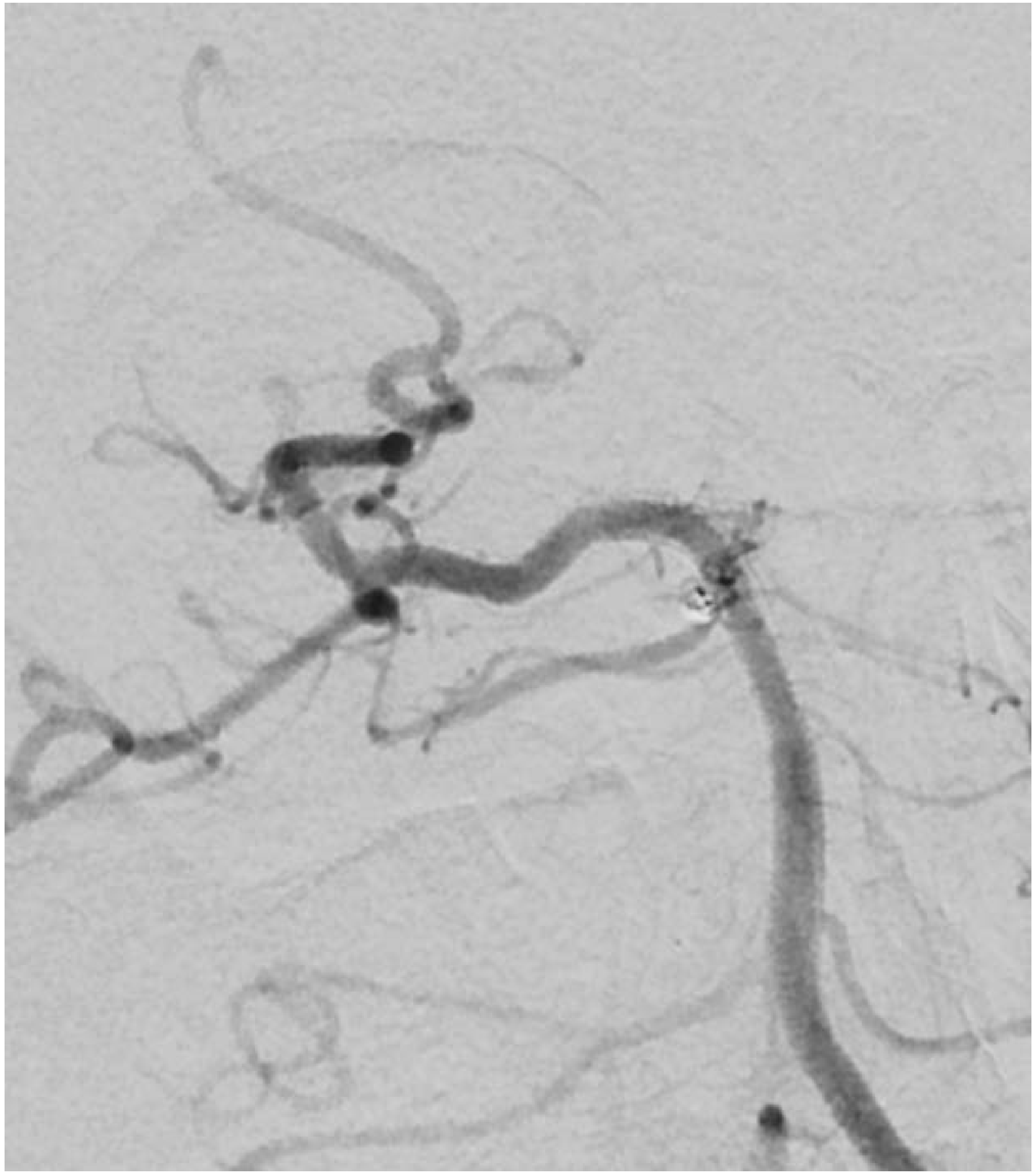
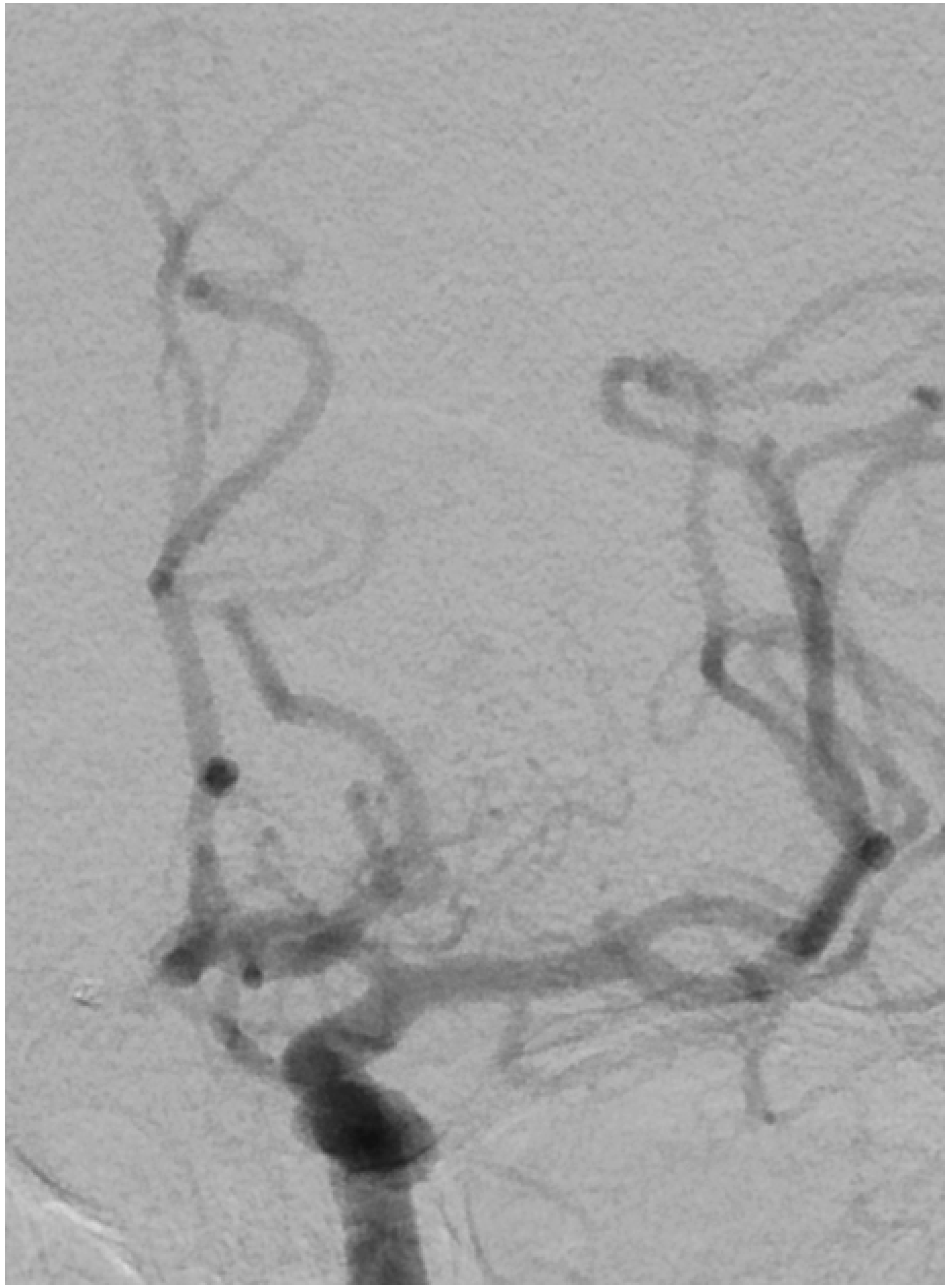
9 months later





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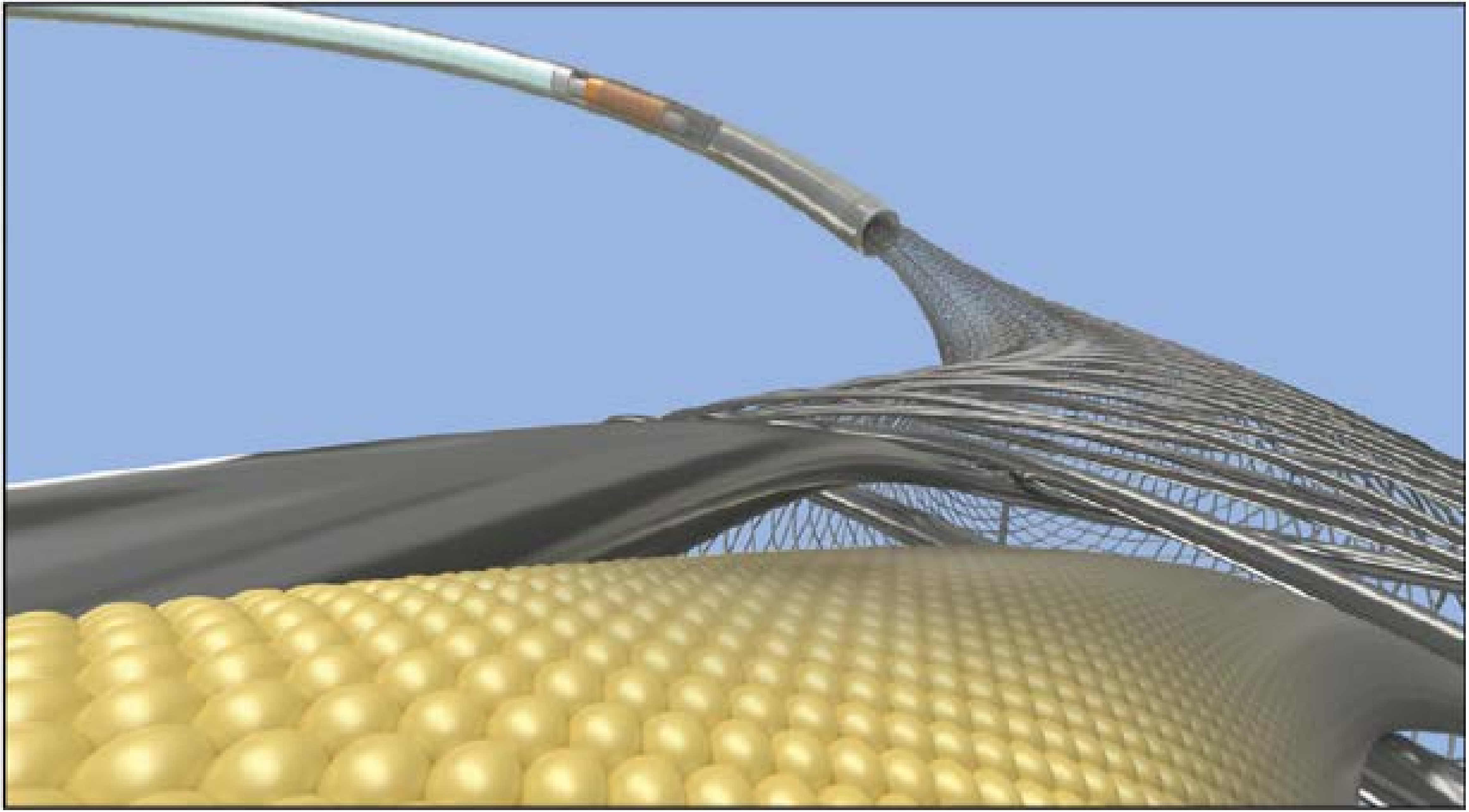

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Intra-aneurysmal Flow Diversion

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WEB Device

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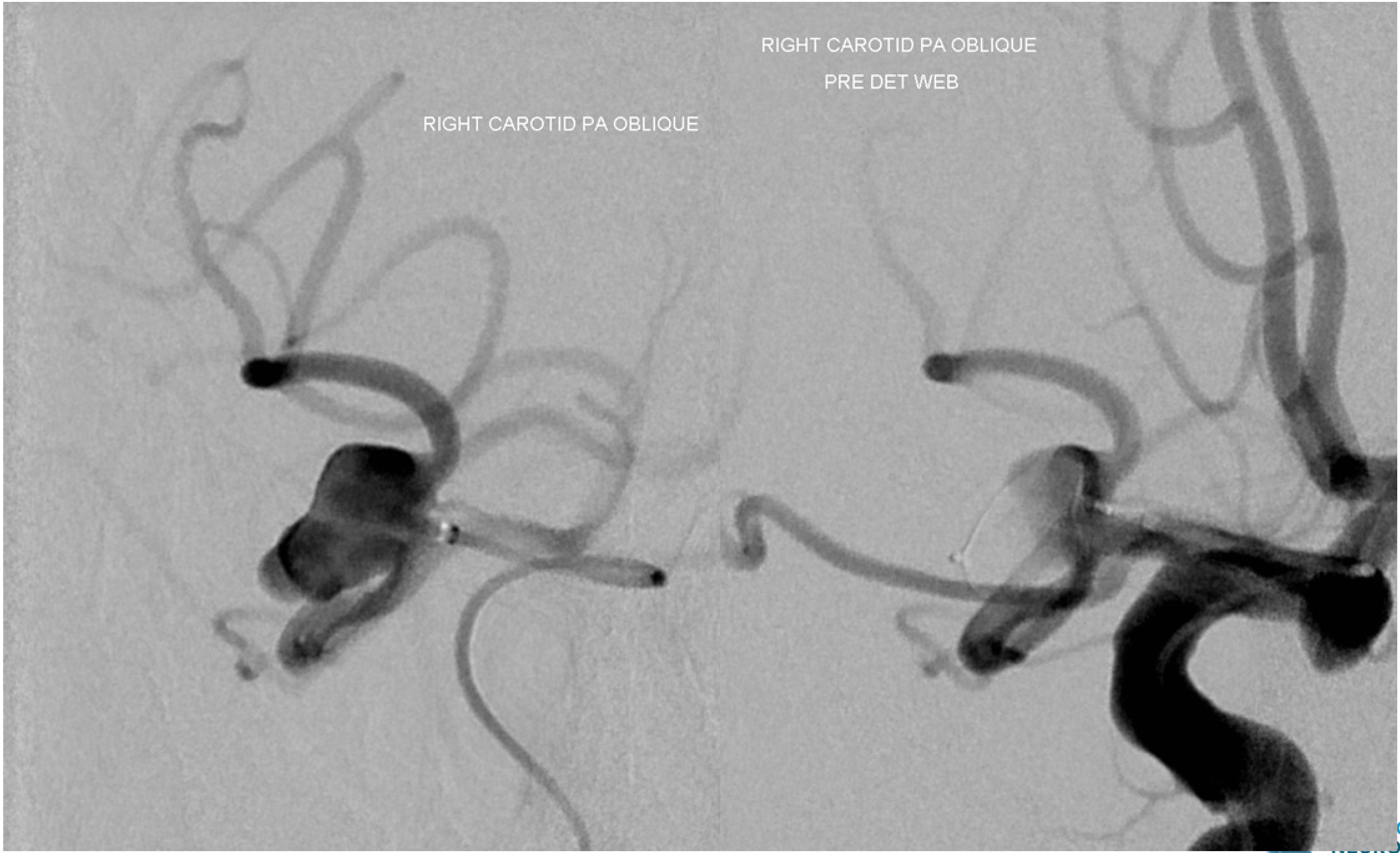
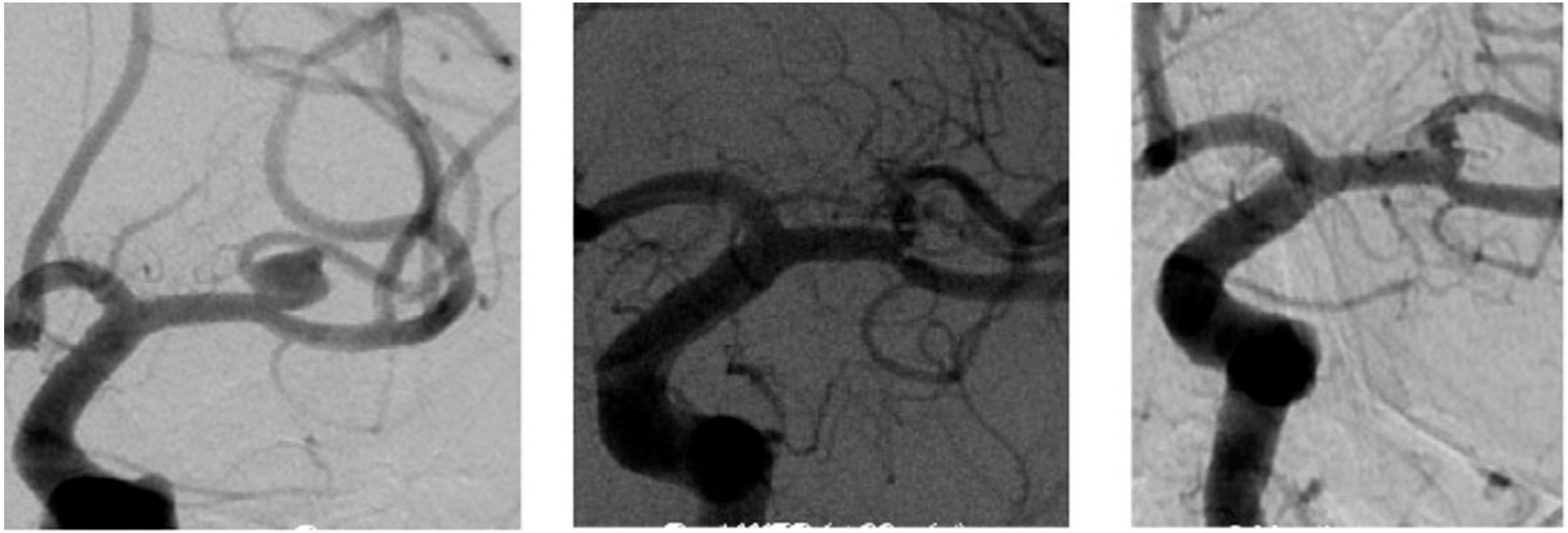
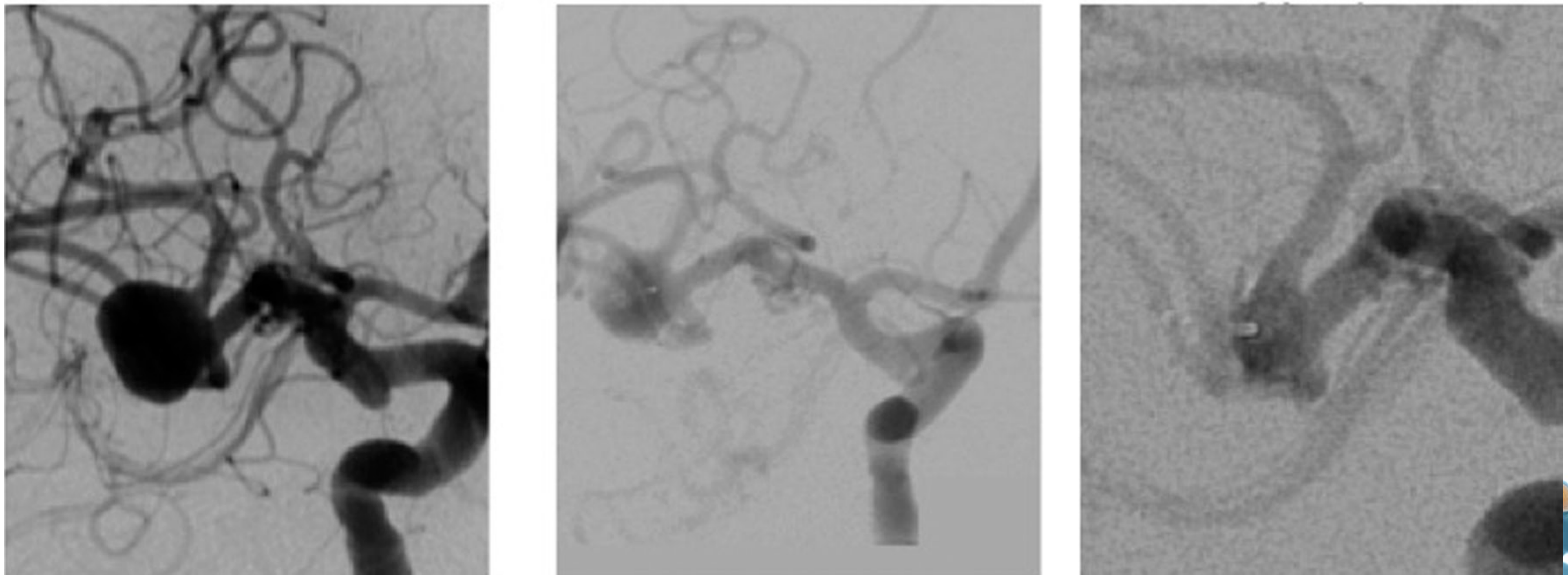

RIGHT CAROTID PA OBLIQUE
RIGHT CAROTID PA OBLIQUE
PRE DET WEB



Pre | Post-WEB (≤ 30 d) | Follow-up 3-6 mo



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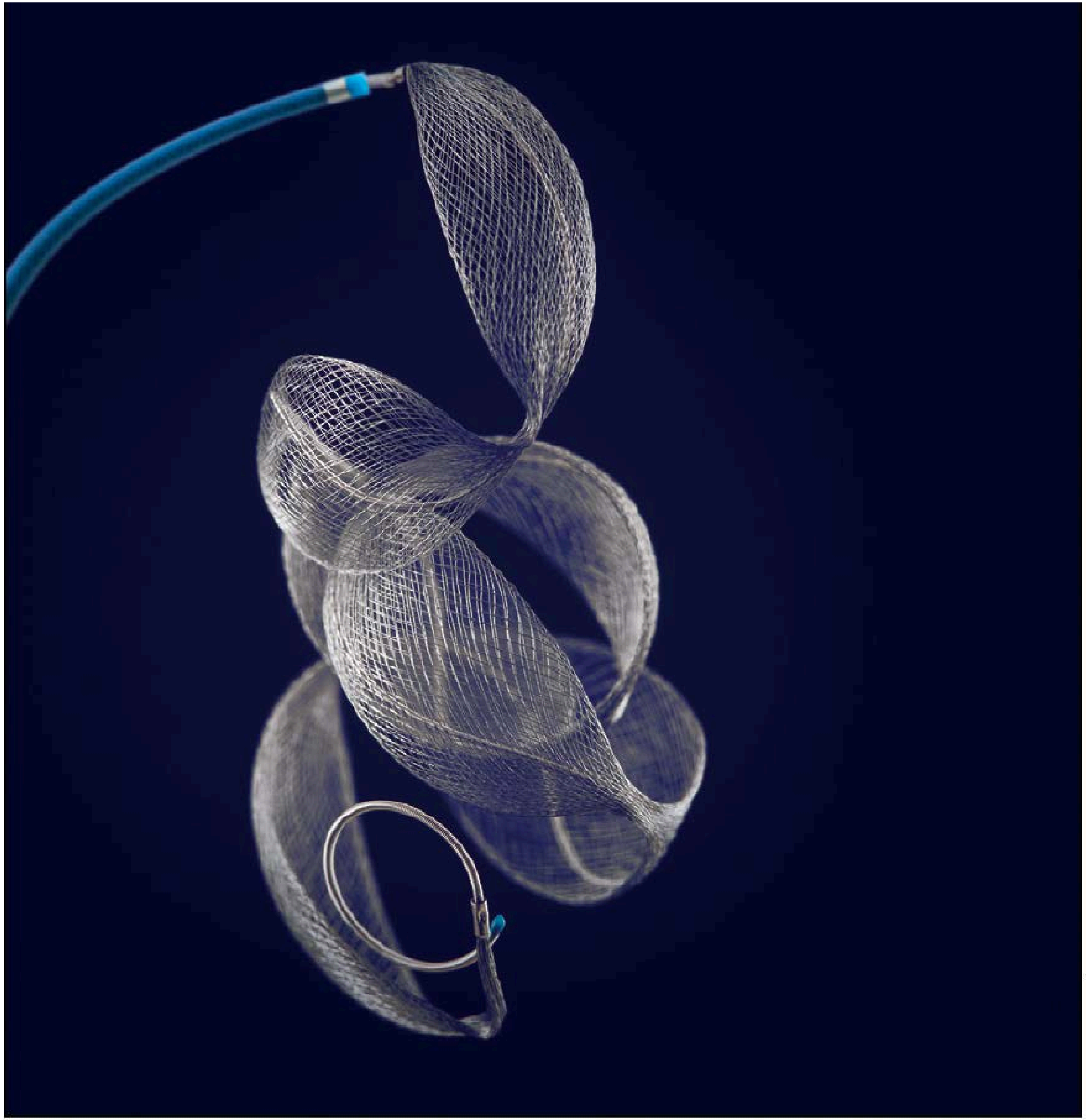
Courtesy of Medtronic.



Courtesy of Medtronic.

Branch Point Aneurysms

62 yo female with left MCA wide neck trifurcation aneurysm

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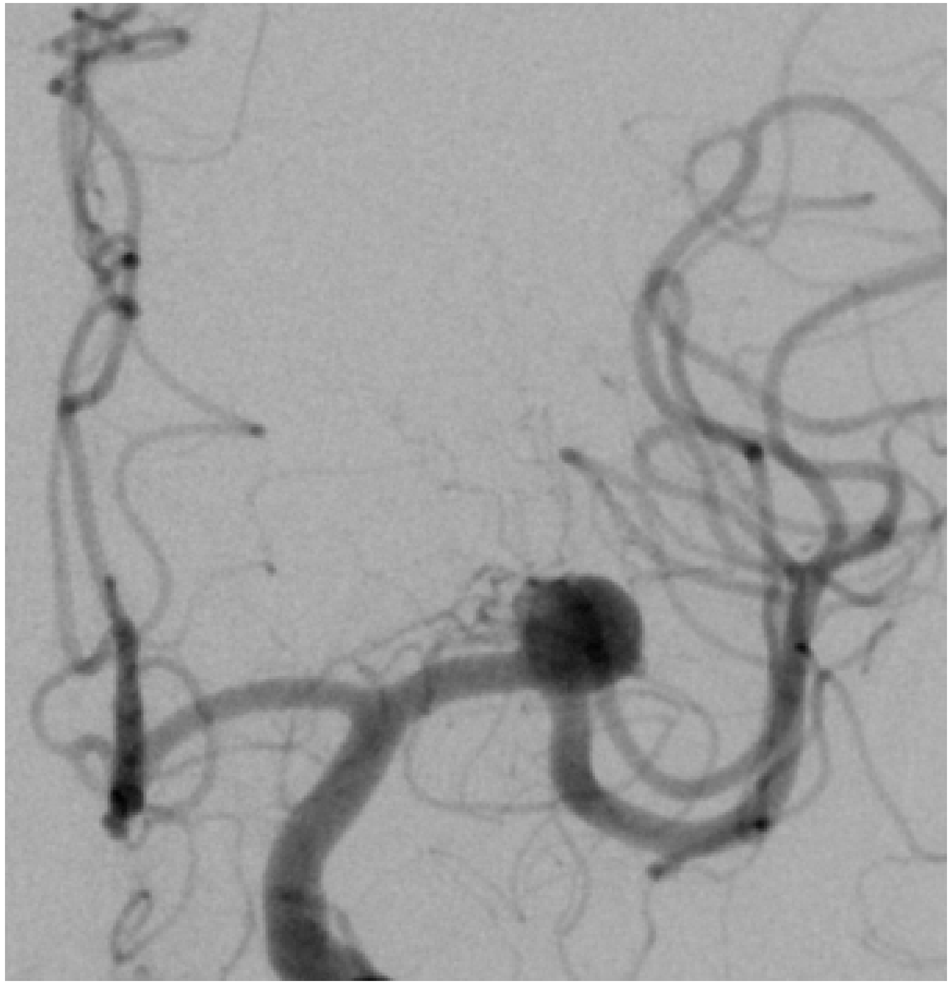

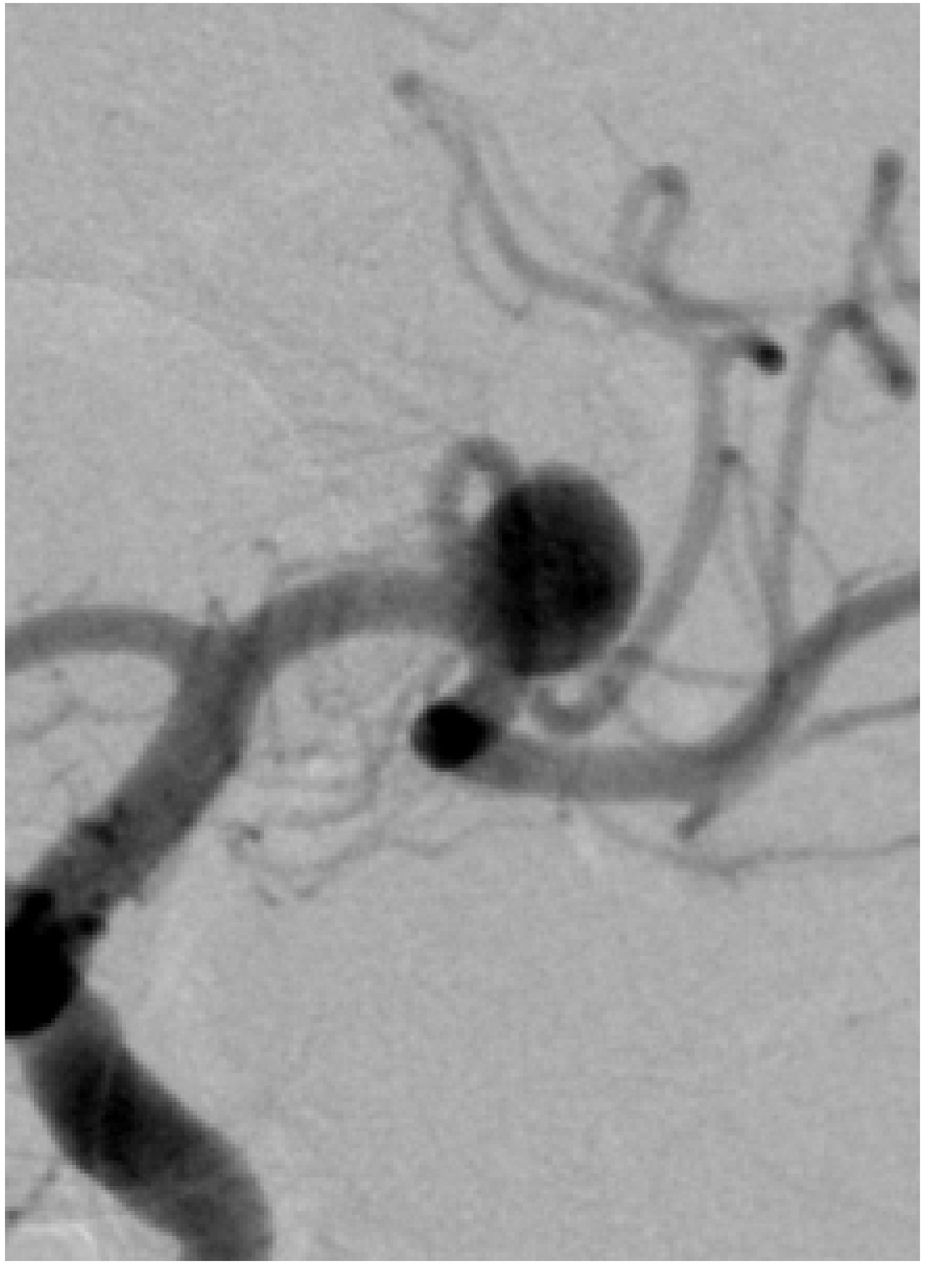

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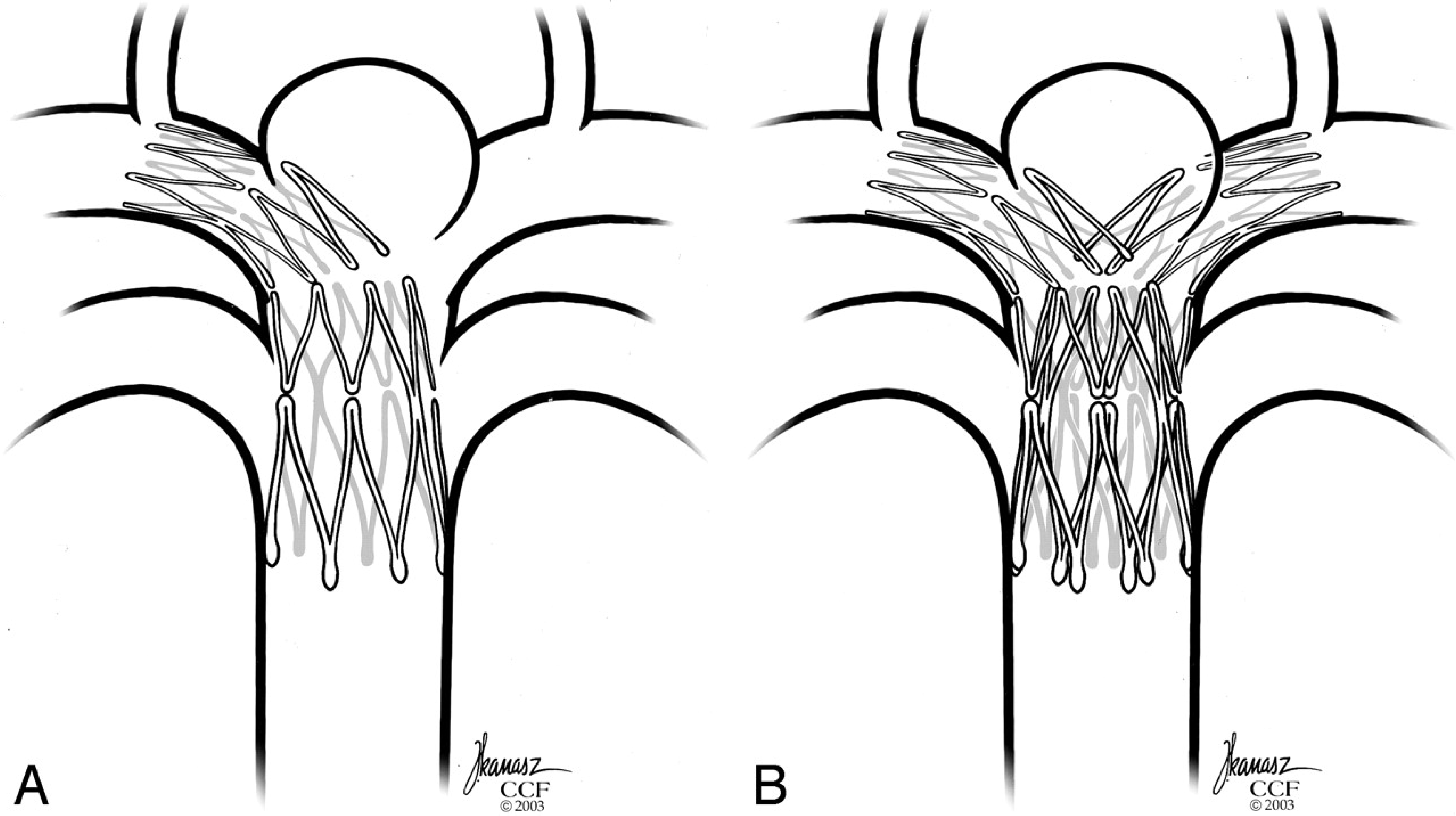
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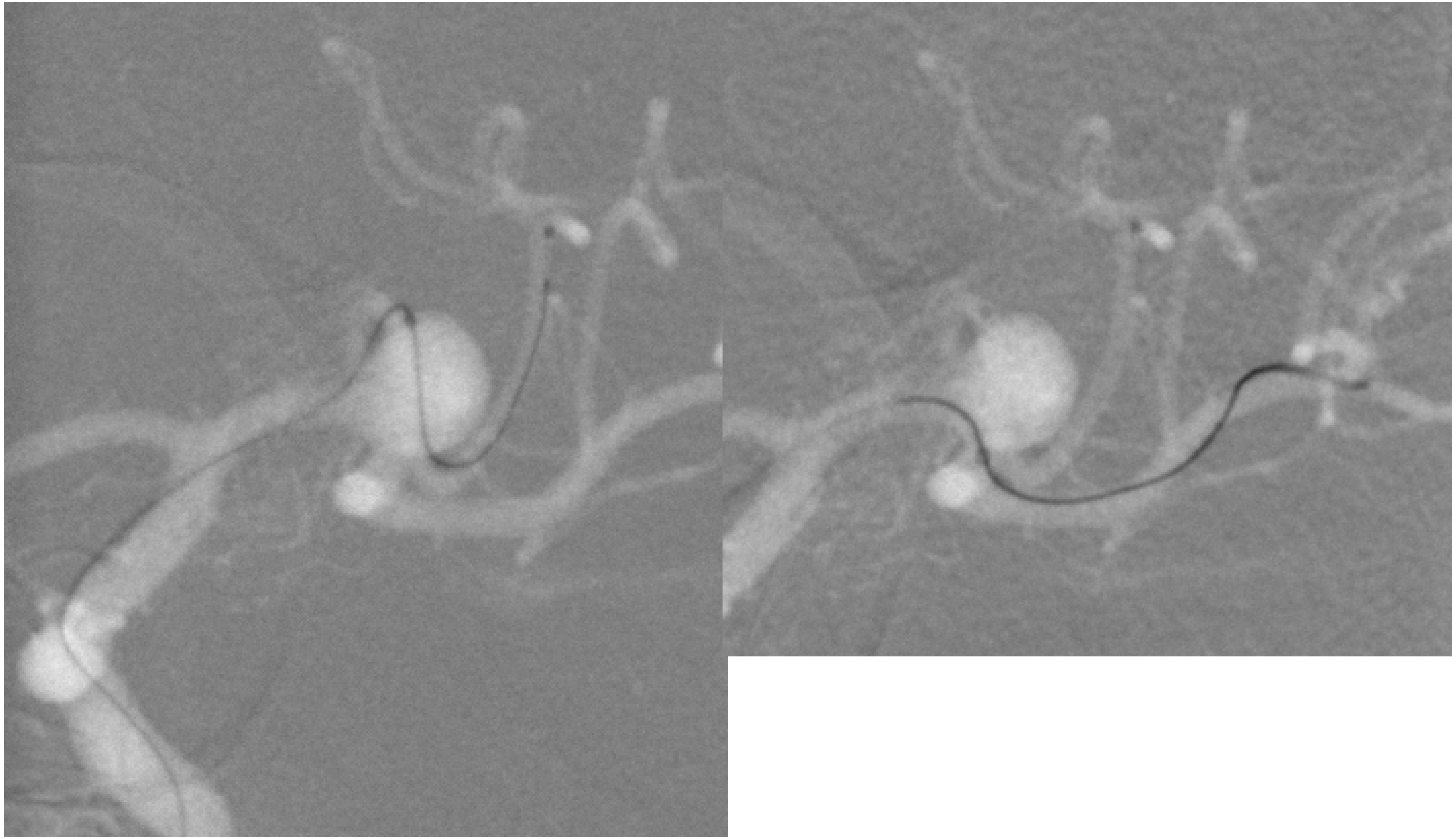

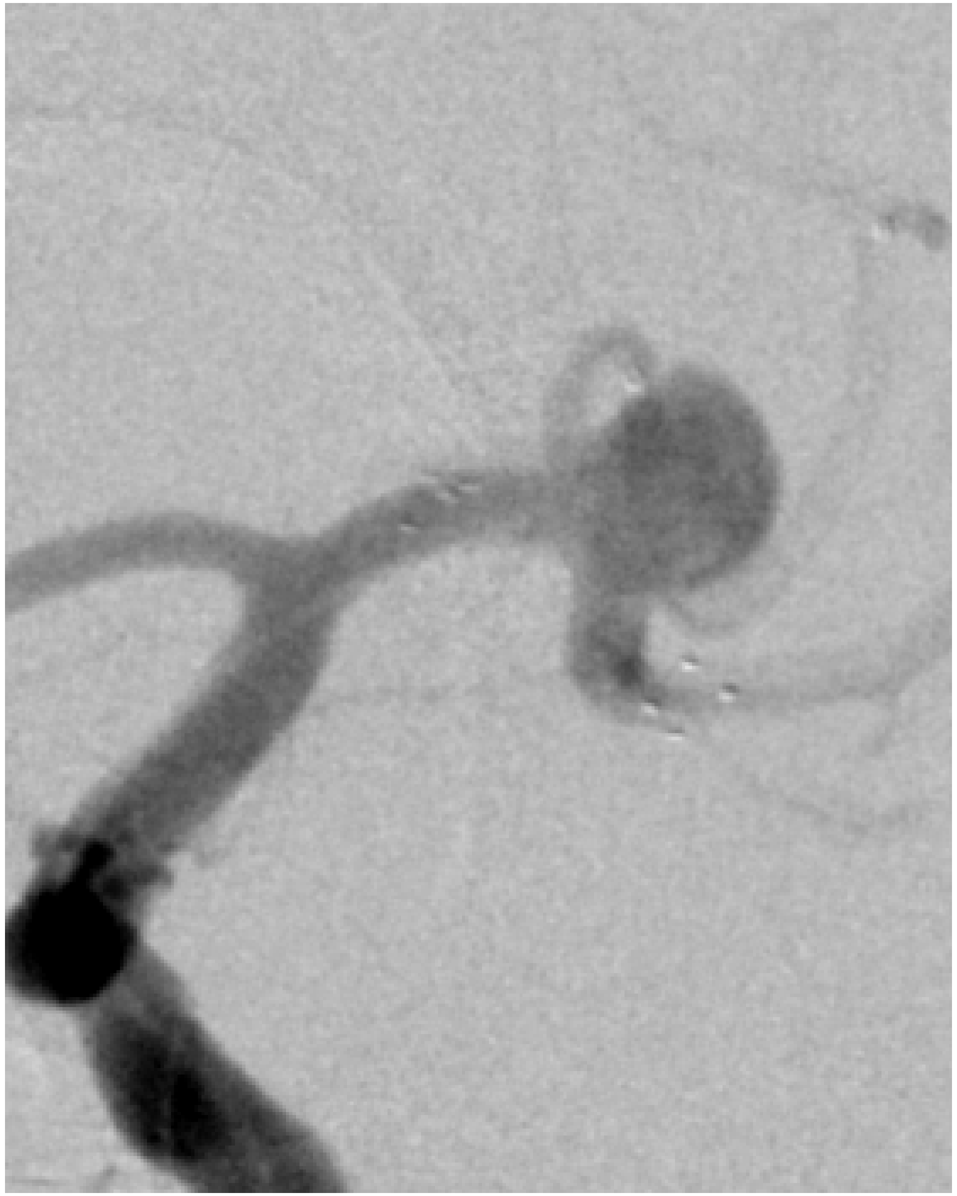

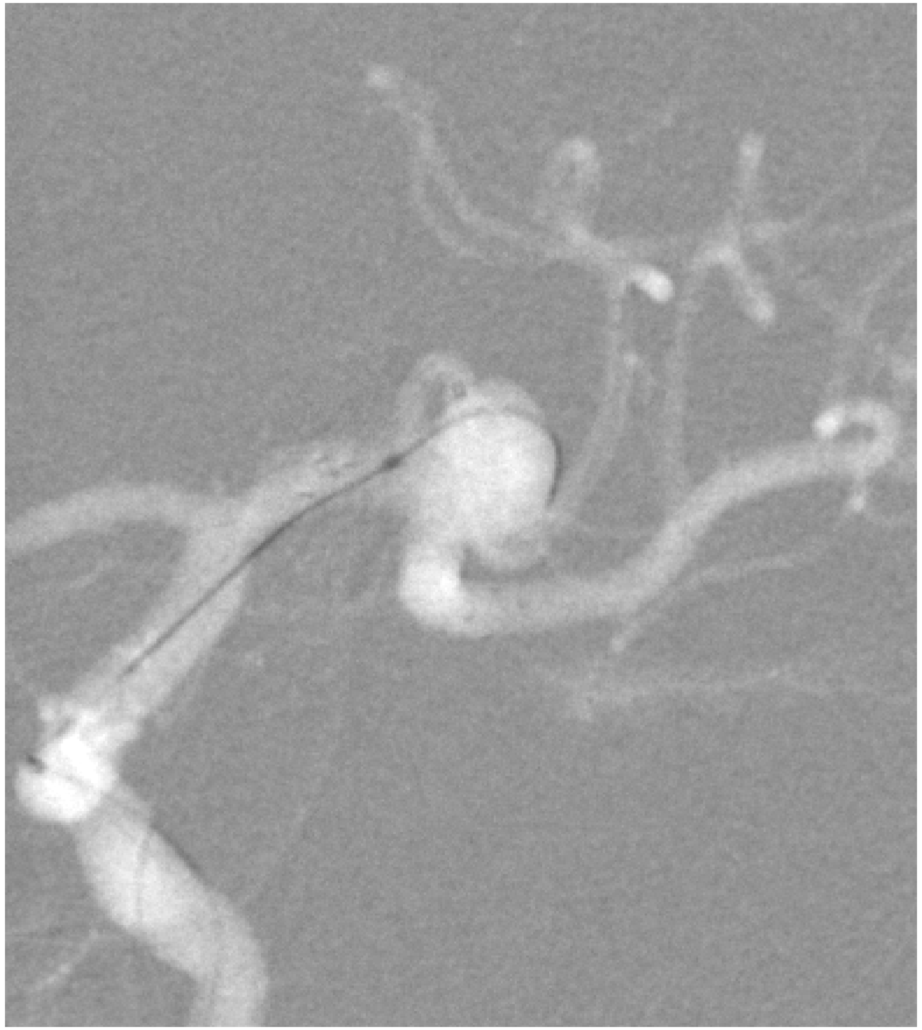

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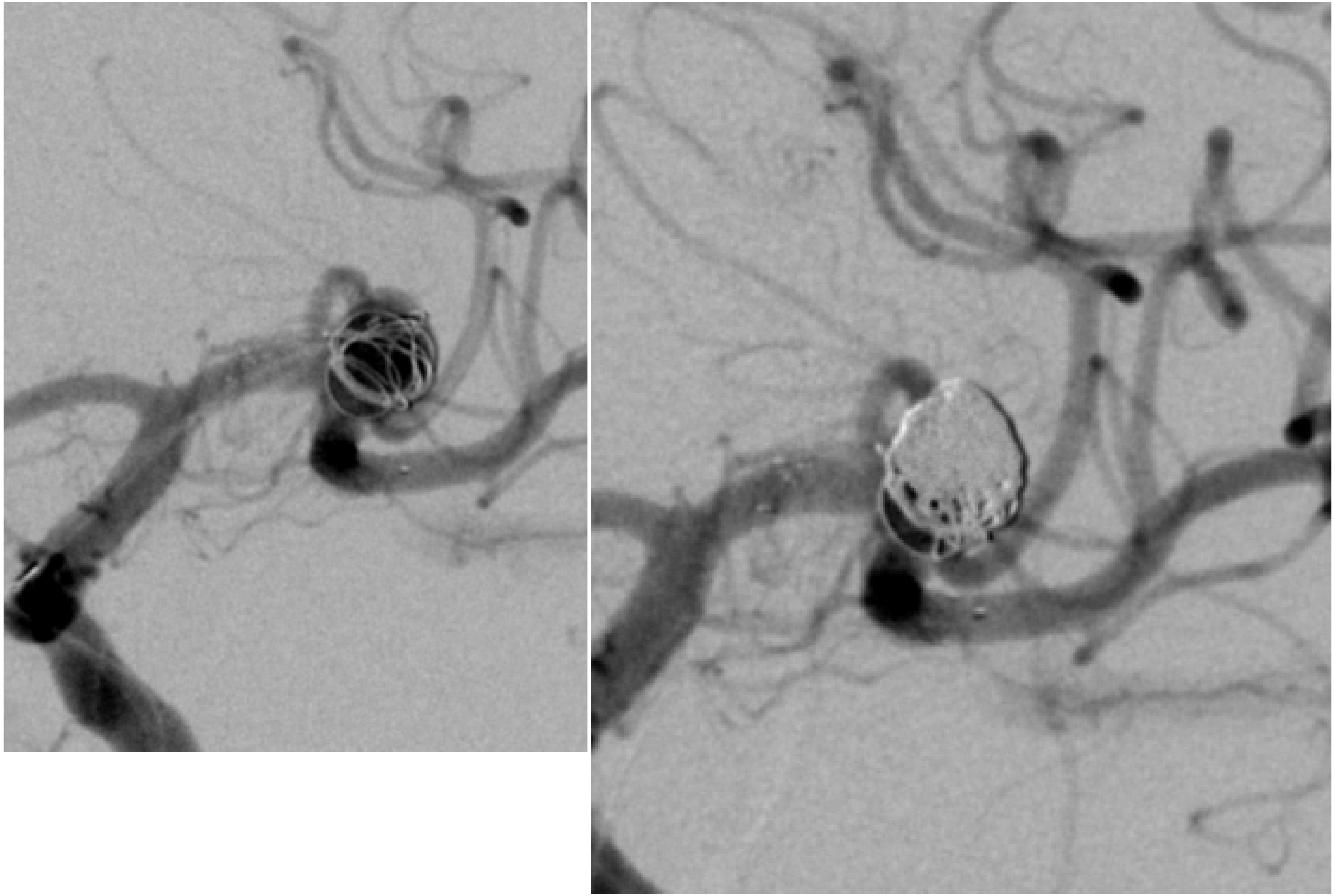

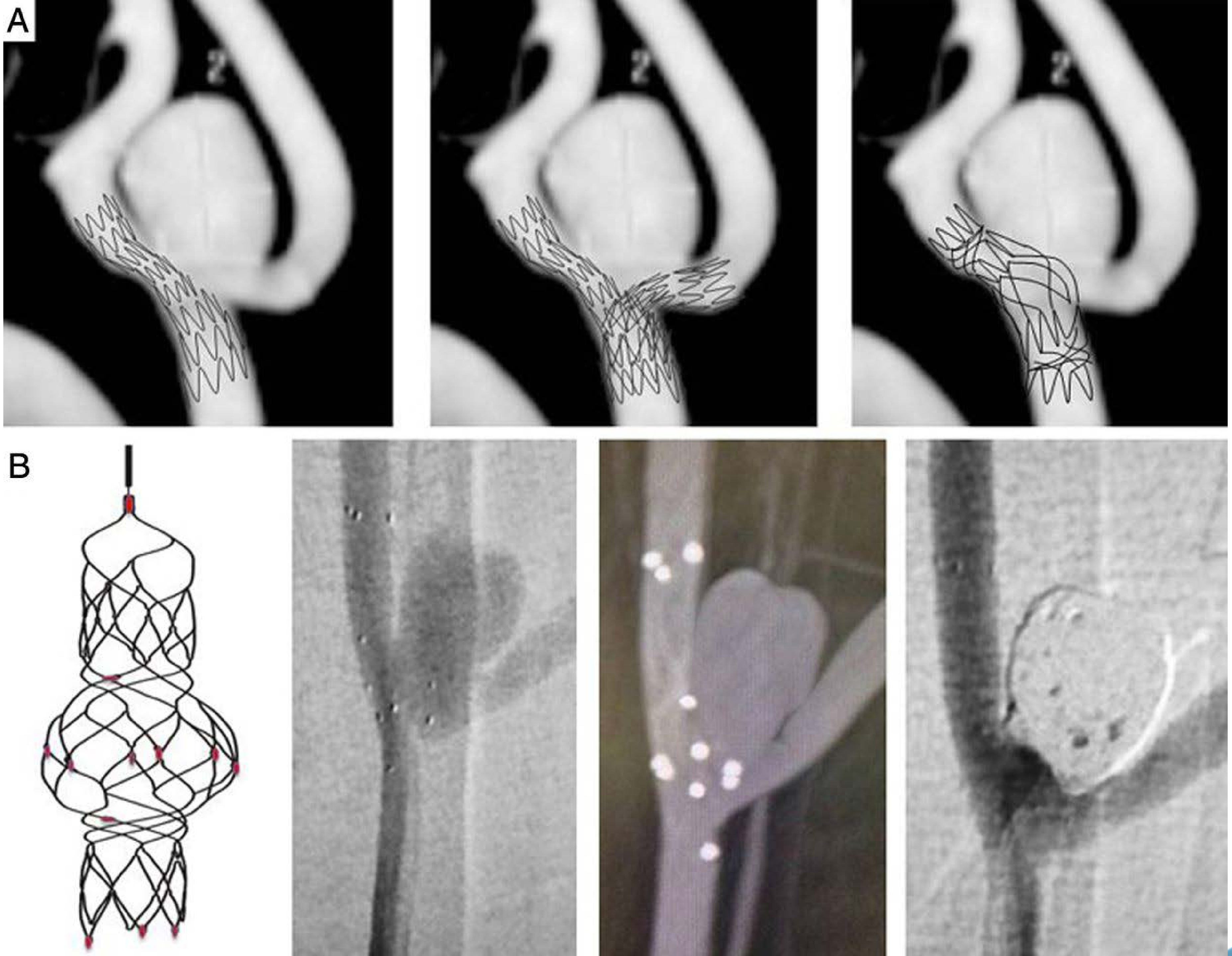
A
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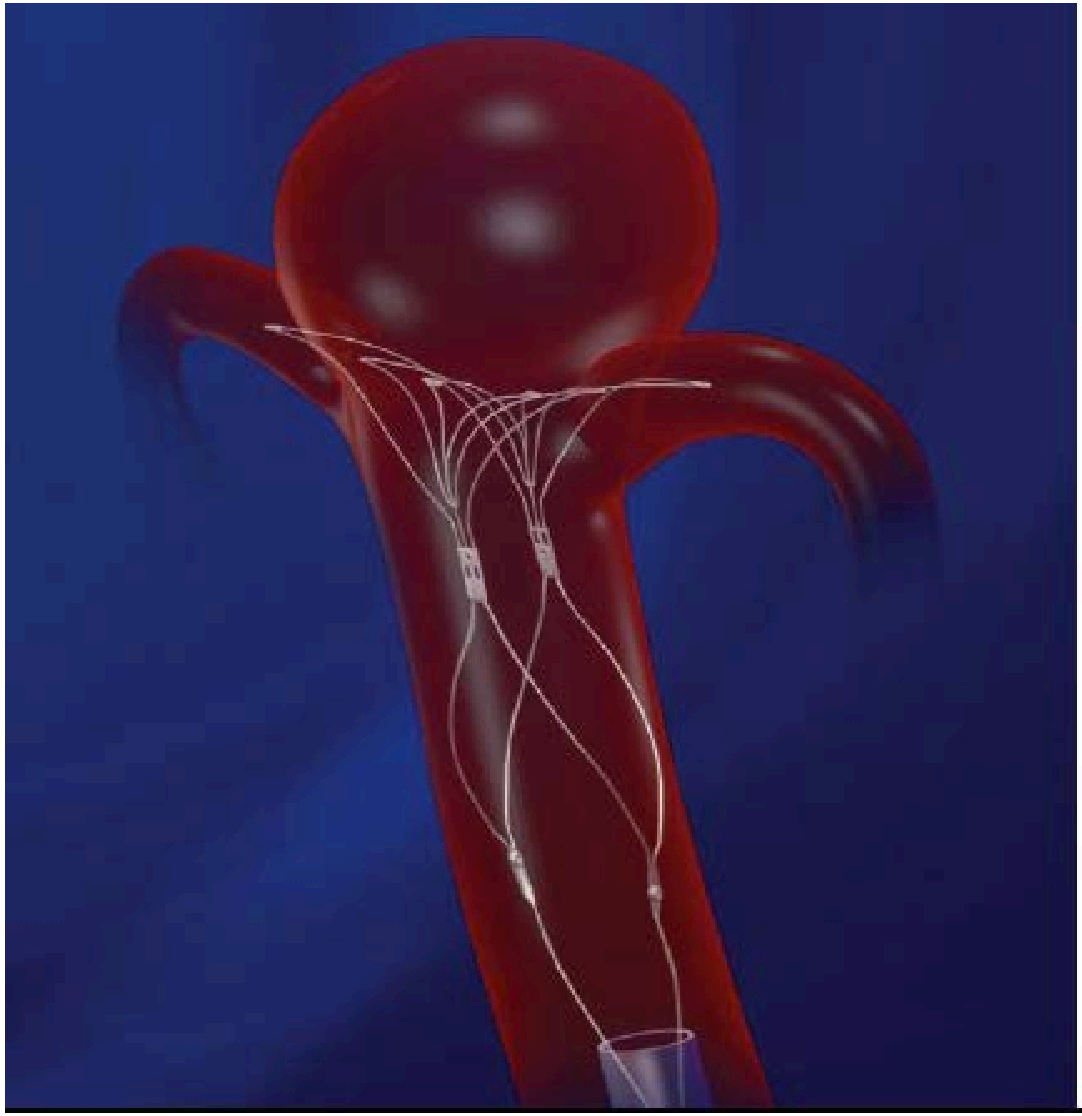
Pulse Rider



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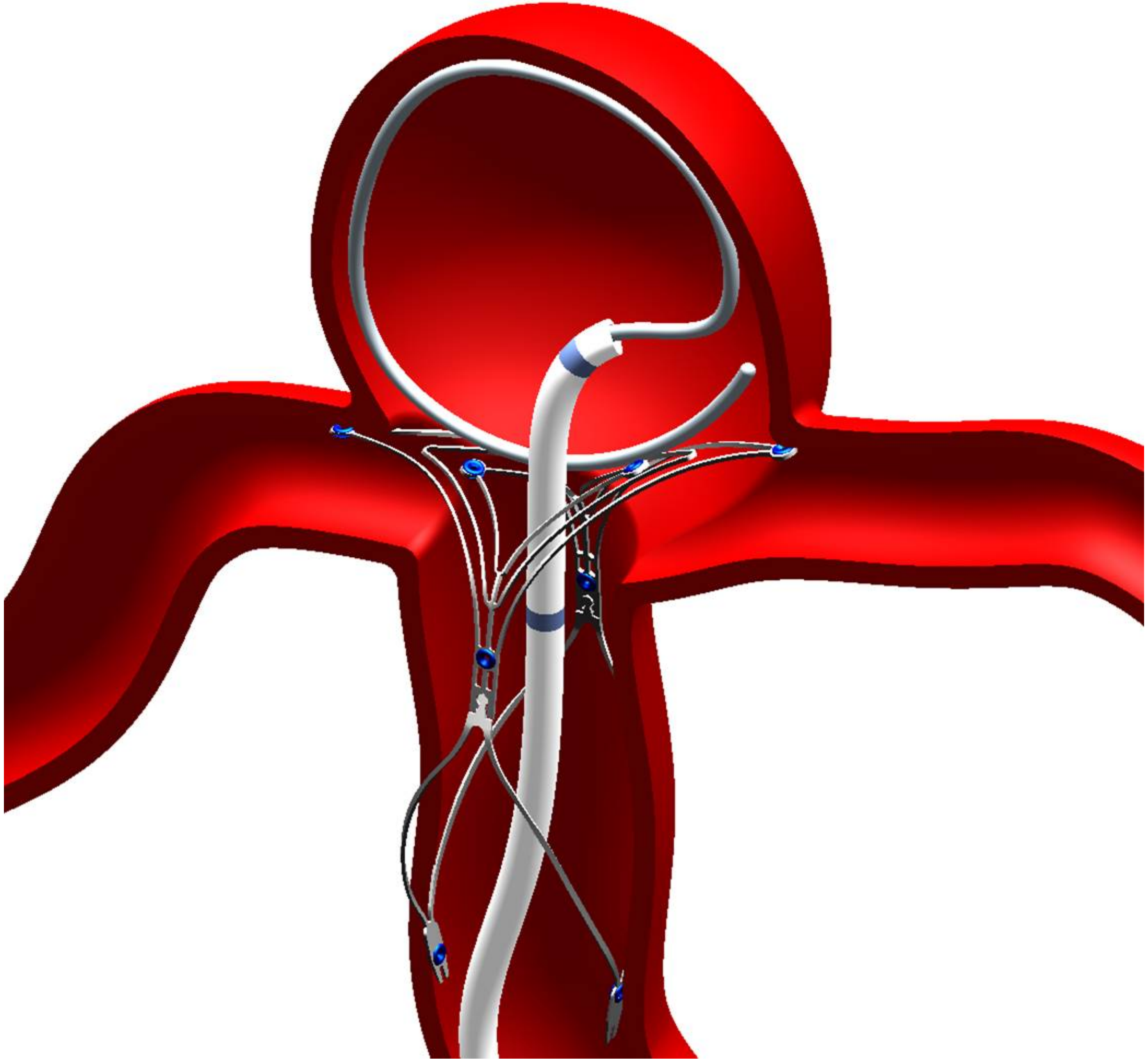

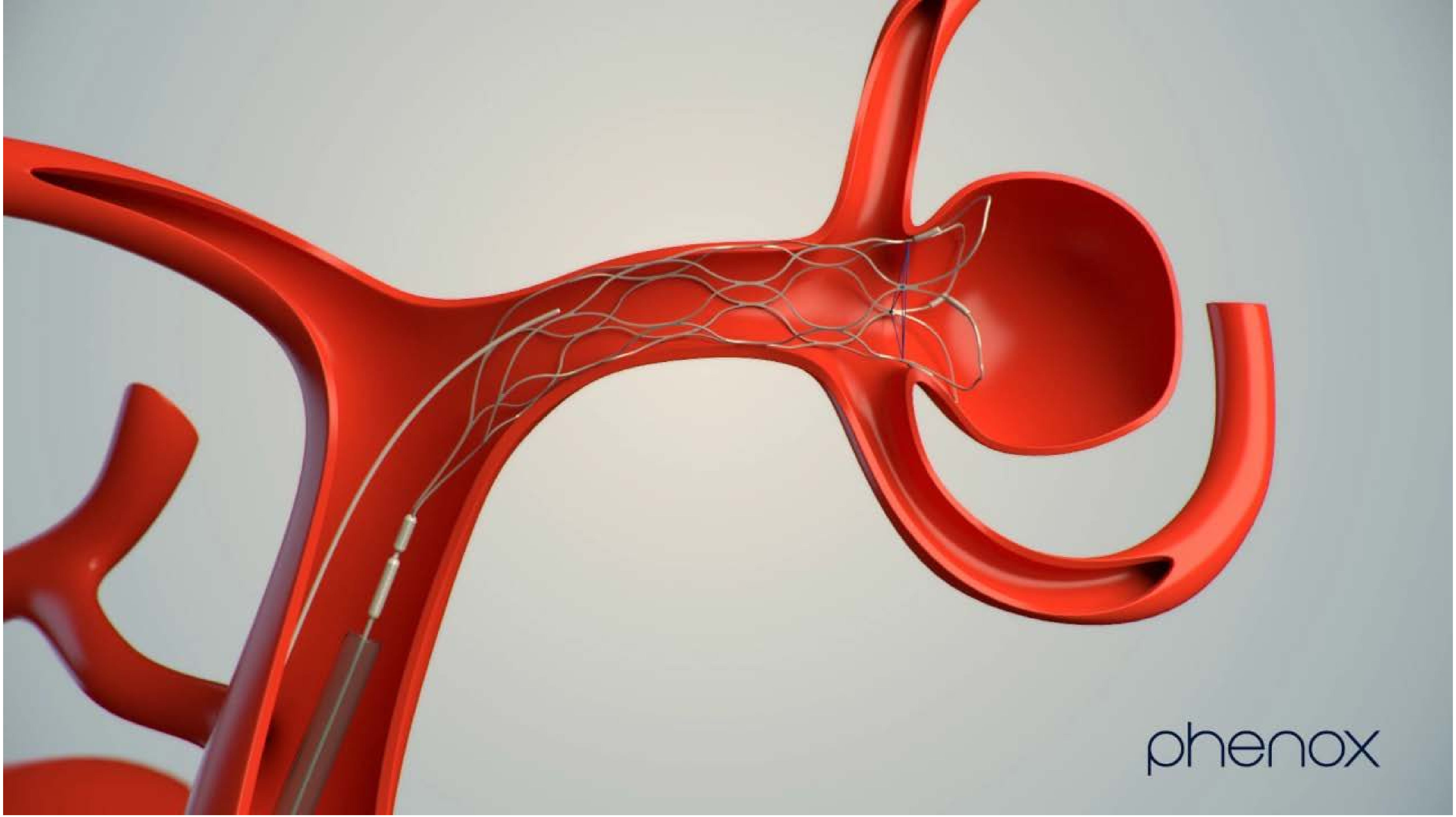

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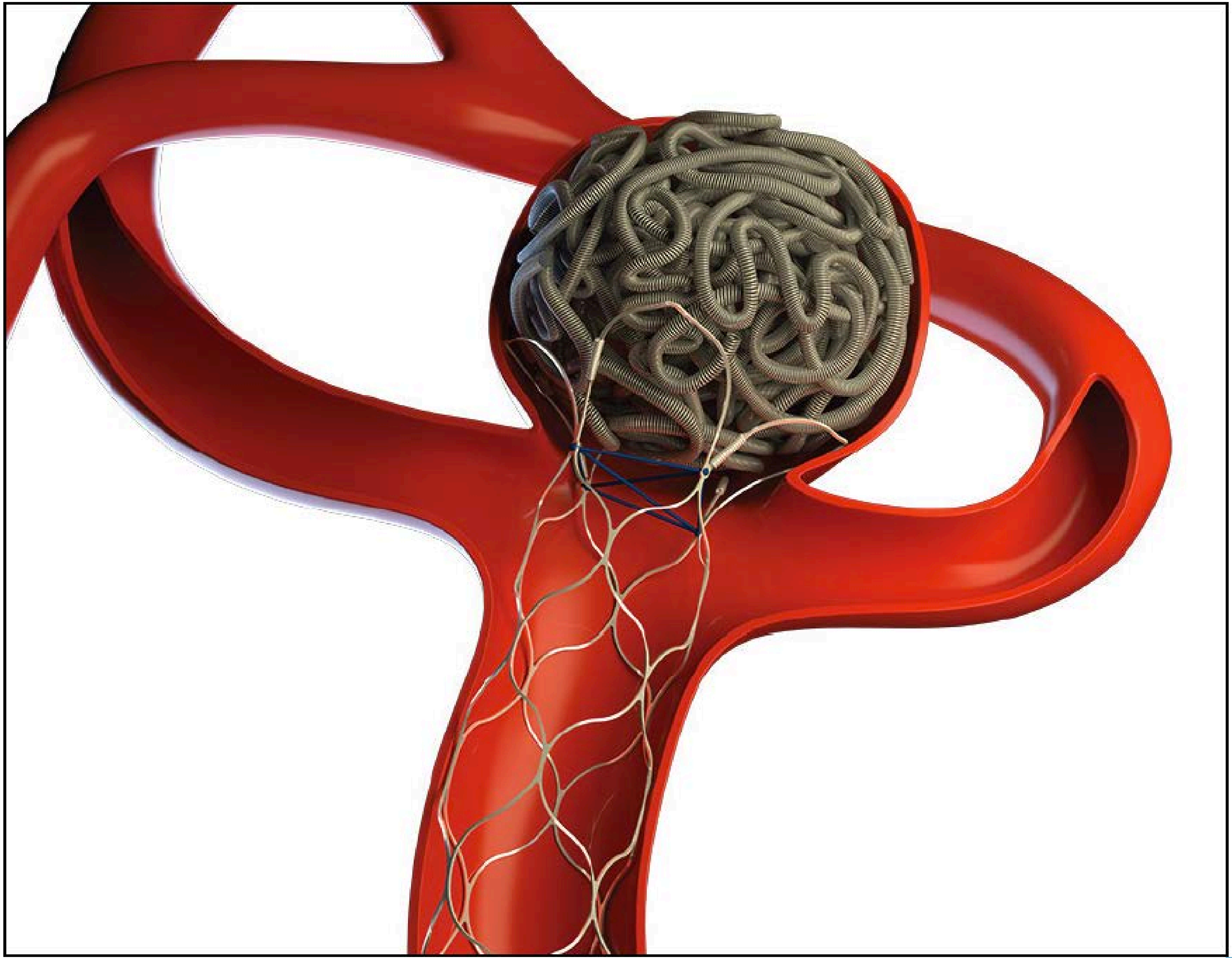

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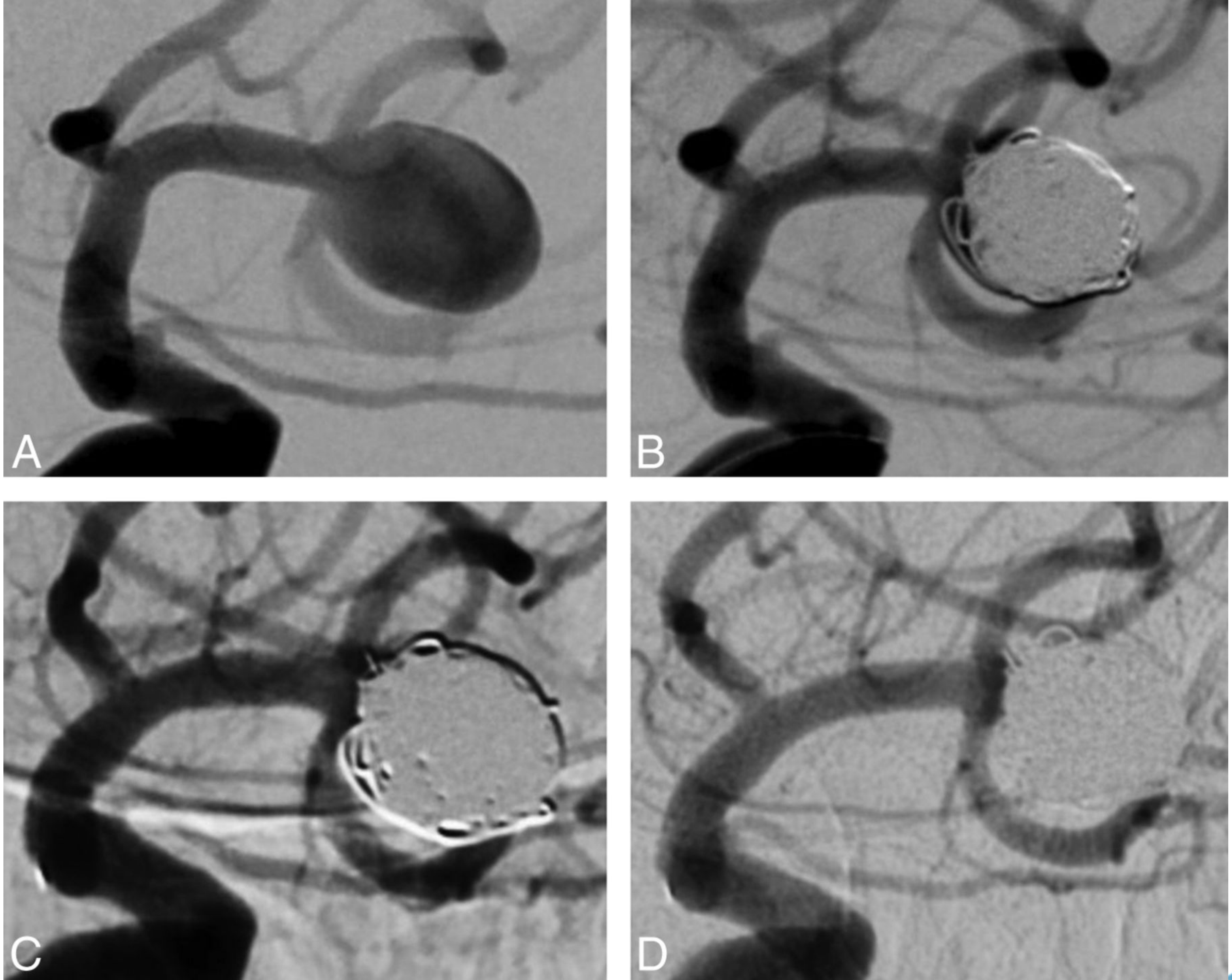

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Cerebral Vasospasm

- Angiographic incidence 40-70%
- Clinical incidence 20-30%
- Usually occurs between PBD 3 and 14
- Highest risk with Fisher grade 3
- Increased incidence with Hunt-Hess grade >2
- Transcranial Doppler (TCD) mean velocities >100 cm/sec
- Progressive neurologic deficit
- Risk of permanent deficit or death 7-10%
- Preventive measures: Nimotop, Lipitor, IV $MgSO_4$, permissive HTN
- Endovascular Rx when medical measures fail

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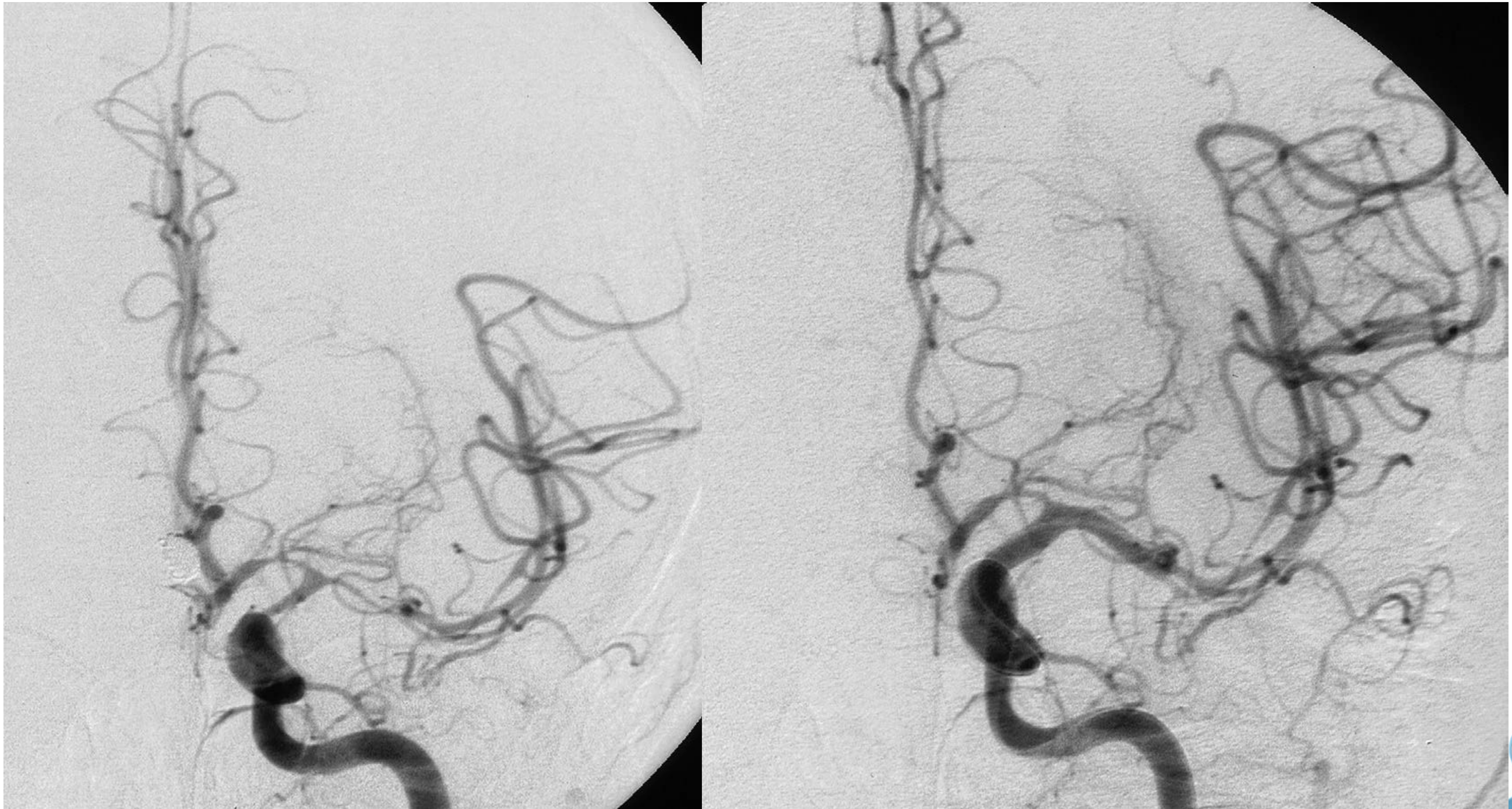
Vasospasm Treatment: IA verapamil followed by balloon angioplasty



Conclusions

- Serbinenko and others laid the groundwork for the endovascular treatment of neurovascular disease in the ‘60’s and 70’s.
- Since the introduction of aneurysm coil embolization by Guglielmi at UCLA in 1991, endovascular treatment has markedly expanded.
- However, the major drawbacks of coil embolization have included recanalization, wideneck/fusiform anatomy, large/giant size, and branch point location.
- The introduction of newer devices including much improved catheter and guidewire technology, intracranial endovascular stents, the Pipeline device, branch point devices, and advanced anti-platelet agents have made endovascular therapies applicable to ever greater numbers of cerebral aneurysms.

Conclusions, continued

- Flow diversion with the Pipeline device has made possible the treatment and cure of large and giant inoperable intracranial aneurysms.
- Although stents and flow-diversion device use is undesirable in acute SAH patients due to the requirement of dual-antiplatelet therapy, possibly within the next 5 yrs., newer stents and the Pipeline device may elude their own anti-platelet agents, obviating systemic therapy.
- The rapid protection of hemorrhagic aneurysms using endovascular techniques has reduced repeat bleeds and has assisted in the effective medical management of SAH.
- The aggressive endovascular management of cerebral vasospasm has contributed to lower stroke and death rates associated with SAH.

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