Modern Microsurgical and Endovascular Treatment of Cerebral Aneurysms

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American Heart Association.

American Heart Association. Get With The Guidelines. Stroke

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Disclosures

- none

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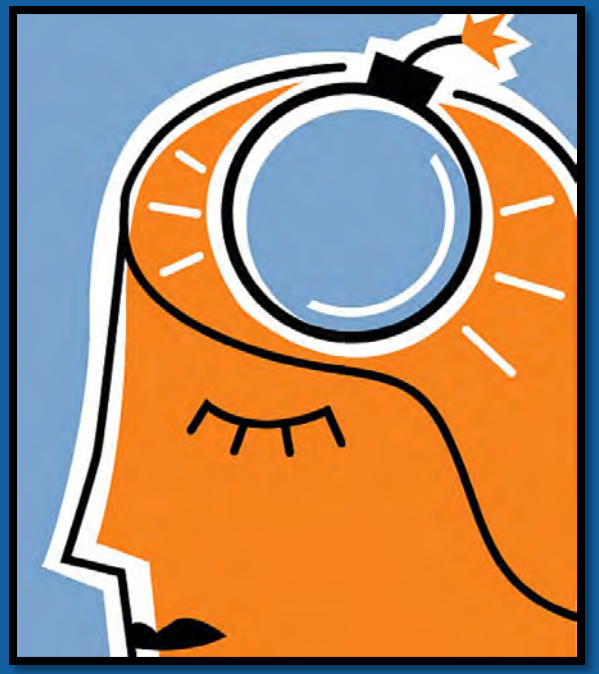
The tragedies of life are largely arterial



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The tragedies of life are largely arterial

Observation risk

- Natural history of unruptured cerebral aneurysms

Treatment risk

- Endovascular treatment
- Microsurgical treatment

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The tragedies of life are largely arterial

- Natural history of cerebral aneurysms
- Evolution of microsurgical treatment
- Evolution of endovascular treatment
- Case examples

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Natural history of cerebral aneurysms

Cerebral aneurysms are present in ~3% of the adult population

Aneurysmal subarachnoid hemorrhage associated with poor prognosis

- 35-40% die
- Less than 50% of survivors return to normal functional status/regain cognitive impairment

aSAH 3-11% of all strokes but results in disproportionate loss of potential life years

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Natural history of cerebral aneurysms

PHASES score

- Risk score developed from pooled analysis of >8000 patients in six prospective cohort studies

	Country	Recruitment period	Inclusion criteria	Imaging used to assess initial aneurysm characteristics	Number of patients
ISUIA[10]	USA, Canada, and Europe	1991–98	Saccular aneurysm ≥2 mm, mRS <3	Conventional angiography	1691
Juvela et al[11]	Finland	1956–78	Non-fusiform, non-mycotic aneurysm	Conventional angiography	142
SUAVe study[12]	Japan	2000–04	Saccular aneurysm ≤5 mm, mRS <3	MRA, CTA, DSA	374
Ishibashi et al[13]	Japan	2003–06	Saccular aneurysm	CTA	419
Wermer et al[15]	Netherlands	2002–04	Non-fusiform aneurysm ≤5 mm	CTA, DSA	93
UCAS[14]	Japan	2001–04	Saccular aneurysm ≥3 mm, mRS <3	MRA, CTA, DSA, conventional angiography	5720

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

PHASES risk score	n	5-year risk of aneurysm rupture
≤2	429	0·4 (0·1–1·5)
3	779	0·7 (0·2–1·5)
4	543	0·9 (0·3–2·0)
5	982	1·3 (0·8–2·4)
6	1078	1·7 (1·1–2·7)
7	1315	2·4 (1·6–3·3)
8	1118	3·2 (2·3–4·4)
9	625	4·3 (2·9–6·1)
10	388	5·3 (3·5–8·0)
11	384	7·2 (5·0–10·2)
≥12	736	17·8 (15·2–20·7)

Greving et al. Lancet Neurology 2014

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Natural history of cerebral aneurysms

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Natural history of cerebral aneurysms

International Study of Unruptured Intracranial Aneurysms (ISUIA)

- Initial study in 1998, second study in 2003. North America, Europe
- ISUIA 1
  - Retrospective Component (observation arm)

Group 1 (727)
No prior history of SAH

<u>Rupture rate</u>
< 10 mm 0.05% per year
> 10 mm 1% per year
≥ 25 mm 6% in first year

Group 2 (722)
History of prior aSAH

<u>Rupture rate</u>
< 10 mm 0.5% per year
> 10 mm 1% per year
≥ 25 mm insufficient data

- Prospective Component (surgical arm)

Overall surgical morbidity and mortality higher than previously reported:

At 1 month, 13.6 – 17.5%
At 1 year, 13.1 – 15.7%

Wiebers et al. NEJM 1998. Lancet 2003.

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Natural history of cerebral aneurysms

ISUIA 1 conclusions:

- Aneurysm location and size impact rupture risk
- Prior history of rupture increases current rupture risk for smaller aneurysms
- Risk of surgical treatment may be higher than risk of observation for most aneurysms

ISUIA 1 criticisms:

- Over 1/3 of aneurysms included in study were extradural carotid aneurysms which do not cause subarachnoid hemorrhage
- Significant selection bias (patients treated within 30 days of aneurysm diagnosis were excluded)
- Significant microsurgical advances have occurred since ISUIA 1 surgical arm and reported M&M likely outdated

Natural history of cerebral aneurysms

ISUIA 2

Prospective observational study

Location	RUPTURE RATE BY ANEURYSM SIZE				
	<7 mm		7-12 mm	13-24 mm	>25 mm
	Group 1	Group 2			
Cavernous carotid artery	0	0	0	3.0%	6.4%
Anterior circulation*	0	1.5%	2.5%	14.5%	40%
Posterior circulation†	2.5%	3.4%	14.5%	18.4%	50%

Overall surgical morbidity and mortality: 10-12.6%

Overall endovascular morbidity and mortality: 7.1-9.8%

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Natural history of cerebral aneurysms

ISUIA 2

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Natural history of cerebral aneurysms

ISUIA 2 conclusions:

- Aneurysm location and size impact rupture risk
- Prior history of rupture increases current rupture risk
- Surgical MM improved with time (microsurgical advancements)
- Endovascular MM may be lower but much lower rates of complete occlusion (only 55%)

ISUIA 2 criticisms:

- Significant selection bias (patients selected for treatment excluded from natural history)
- Short follow-up period
- **Most aneurysms that present as ruptured aneurysms are smaller than 7 mm**

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Natural history of cerebral aneurysms

TABLE 3. Literature Review, Proportion of Ruptured Aneurysms < 5 mm

Author	Publication year	Location	Patients	Enrollment start	Enrollment finish	<5 mm (%)
Lee[44]	2015	Korea	200	2012	2014	47
Froelich[27]	2016	Australia	131	2010	2015	49
Dolati[28]	2015	Canada	123	2008	2012	37
Zhao[29]	2014	China	766	2006	2013	51
Kashiwazaki[16]	2013	Japan	851	2003	2011	28
Tahir[17]	2009	Pakistan	55	2004	2007	24
Nahed[19]	2005	USA	152	2001	2004	33
Taylor[20]	2004	USA	127	1998	1999	33
Forget[21]	2001	USA	245	1996	2000	35
Shiue[22]	2011	Australia	432	1995	1998	22
ISAT[25]	2002	Intl	2143	1994	1997	52
Horiuchi[23]	2006	Japan	2577	1988	2002	39
Osawa[24]	2001	Japan	2055	1988	1998	38
Ohashi[18]	2004	Japan	280	1984	2001	26
Inagawa[45]	2010	Japan	285	1980	1998	24
Kassell[12]	1983	Intl	676	1980	1987	13
Rosenorn[13]	1993	Denmark	908	1978	1983	18
Sundt[14]	1982	USA	644	1969	1981	23
Mccormick[15]	1970	USA	54	1970	1970	4

Bender et al. Neurosurgery 2018

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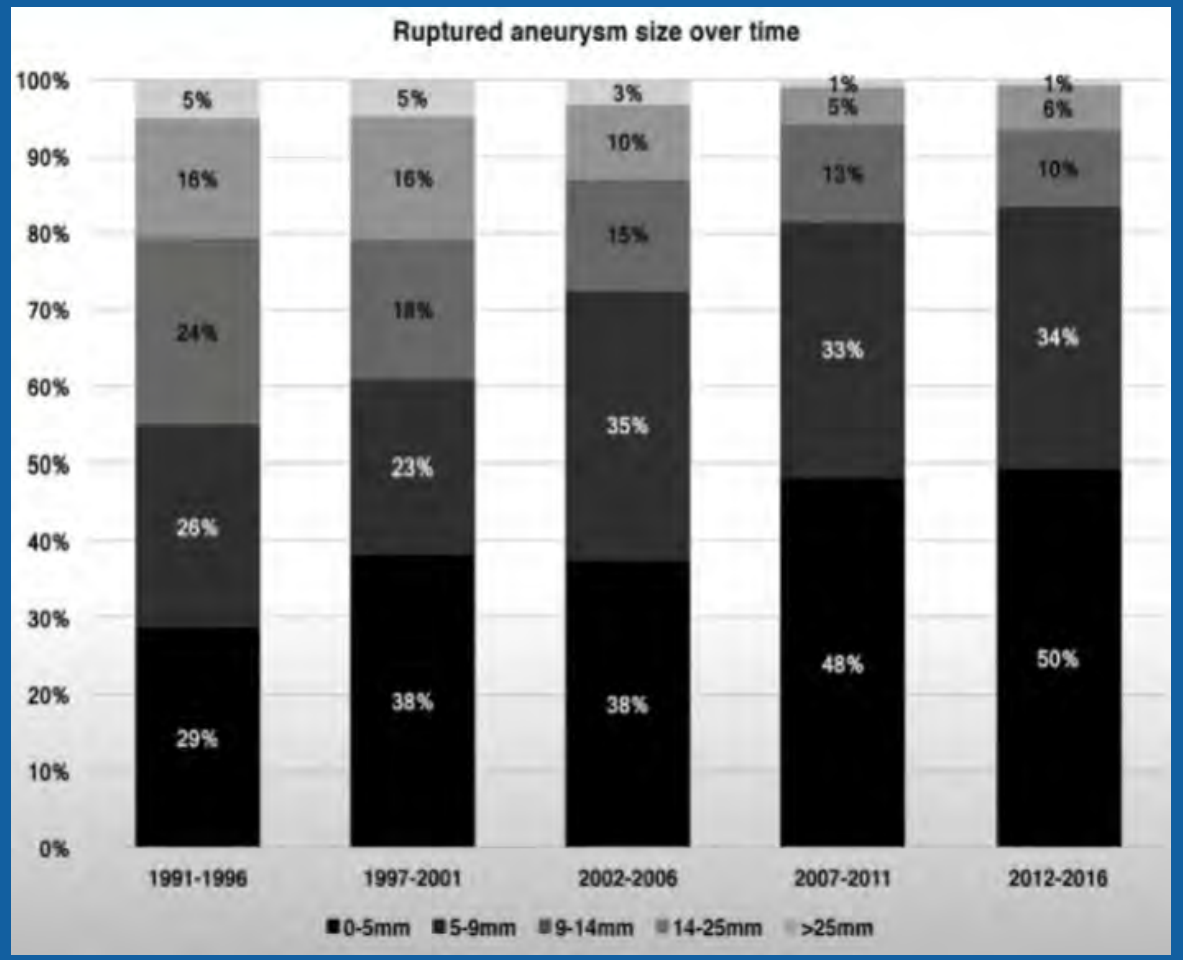
Natural history of cerebral aneurysms



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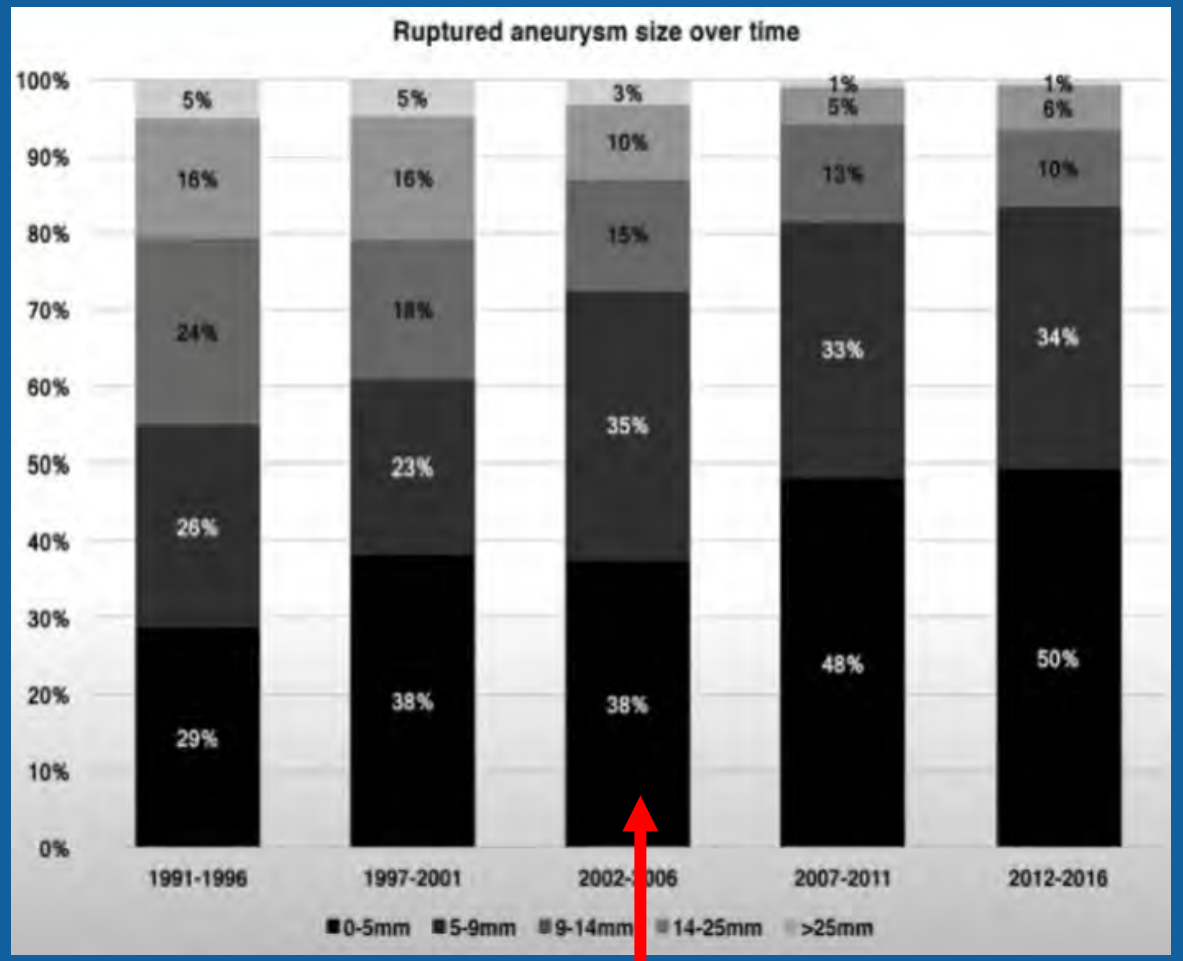
Natural history of cerebral aneurysms



ISUIA 2 publication

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Natural history of cerebral aneurysms

Unruptured Cerebral Aneurysm Study of Japan (UCAS)

- NEJM 2012
- Largest Prospective Cohort Study to date, 5720 patients

Table 3. Annual Rate of Rupture According to Size and Location of Aneurysm.

Location of Aneurysm	Rate of Rupture per Aneurysm per Year (95% CI)				
	3–4 mm	5–6 mm	7–9 mm	10–24 mm	≥25 mm
			percent		
Middle cerebral artery	0.23 (0.09–0.54)	0.31 (0.10–0.96)	1.56 (0.74–3.26)	4.11 (2.22–7.66)	16.87 (2.38–119.77)
Anterior communicating artery	0.90 (0.45–1.80)	0.75 (0.28–2.02)	1.97 (0.82–4.76)	5.24 (197–13.95)	39.77 (9.95–159.00)
Internal carotid artery	0.14 (0.04–0.57)	0	1.19 (0.30–4.77)	1.07 (0.27–4.28)	10.61 (1.49–75.3)
Internal carotid–posterior communicating artery	0.41 (0.15–1.10)	1.00 (0.37–2.66)	3.19 (1.66–6.12)	6.12 (1.66–6.13)	126.97 (40.95–393.68)
Basilar tip and basilar-superior cerebellar artery	0.23 (0.03–1.61)	0.46 (0.06–3.27)	0.97 (0.24–3.89)	6.94 (3.74–12.90)	117.82 (16.60–836.43)
Vertebral artery–posterior inferior cerebellar artery and vertebrobasilar junction	0	0	0	3.49 (0.87–13.94)	0
Other	0.78 (0.25–2.43)	1.37 (0.34–5.50)	0	2.81 (0.40–19.99)	0
Total	0.36 (0.23–0.54)	0.50 (0.29–0.84)	1.69 (1.13–5.93)	4.37 (3.22–5.93)	33.40 (16.60–66.79)

Table 2. Risk Factors Associated with Rupture of Cerebral Aneurysms.*

Risk Factor	Hazard Ratio (95% CI)	P Value
Female sex	1.54 (0.99–2.42)	0.05
Age ≥70 yr	1.21 (0.81–1.78)	0.34
Hypertension	1.41 (0.96–2.07)	0.08
Hyperlipidemia	0.54 (0.28–1.03)	0.06
Daughter sac	1.63 (1.08–2.48)	0.02
Largest dimension of aneurysm		
3–4 mm	Reference	
5–6 mm	1.13 (0.58–2.22)	0.71
7–9 mm	3.35 (1.87–6.00)	<0.001
10–24 mm	9.09 (5.25–15.74)	<0.001
≥25 mm	76.26 (32.76–177.54)	<0.001
Location of aneurysm		
Middle cerebral artery	Reference	
Anterior communicating artery	2.02 (1.13–3.58)	0.02
Internal carotid artery	0.43 (0.18–1.01)	0.05
Internal carotid–posterior communicating artery	1.90 (1.12–3.21)	0.02
Basilar tip and basilar–superior cerebellar artery	1.49 (0.78–2.83)	0.23
Vertebral artery–posterior inferior cerebellar artery and vertebrobasilar junction	0.68 (0.16–2.87)	0.60
Other	1.48 (0.61–3.60)	0.39

The UCAS Japan Investigators. NEJM 2012.

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Natural history of cerebral aneurysms

UCAS criticisms:

- Significant selection bias again (6697 total aneurysms, 3050 were surgically repaired and excluded from natural history analysis)
- Homogeneous population may limit generalizability

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Natural history of cerebral aneurysms

Making sense of it all

Location

High risk:
- Acom
- Pcom
- Basilar tip

Intermediate risk:
- MCA

Low risk:
- Cavernous ICA
- VB junction
- Ophthalmic/paraophthalmic ICA

High risk features

- Dome irregularity or daughter sac
- Interval growth on serial imaging

Lifetime Rupture Risk

$$1 - (1 - annual\ rupture\ risk)^{life\ expectancy\ in\ years}$$

Ex: 4 mm Acom in 50 year old man
Annual rupture risk 0.9%

$$1 - (1 - 0.009)^{30} = 23.8\%$$

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Microsurgical treatment

- Modern meta-analysis suggests mortality of 1.7%, morbidity of 6.7%
- Complete occlusion 91.8%

Hackenberg et al. Stroke 2018.

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Microsurgical treatment

1960s and early 1970s, clips were stainless steel (not MRI compatible)

Modern aneurysm clips are titanium

Aneurysm clips implanted after 1985 are MRI compatible

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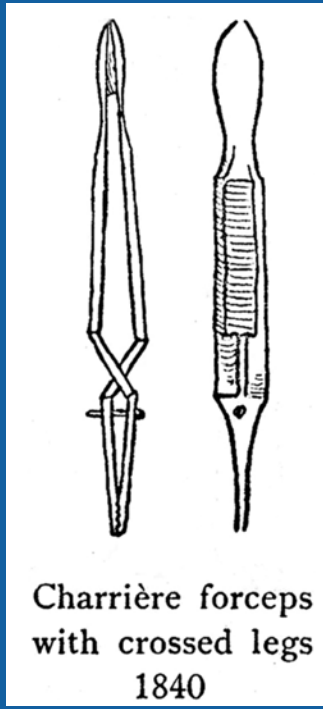
Microsurgical treatment



Charrière forceps with crossed legs 1840

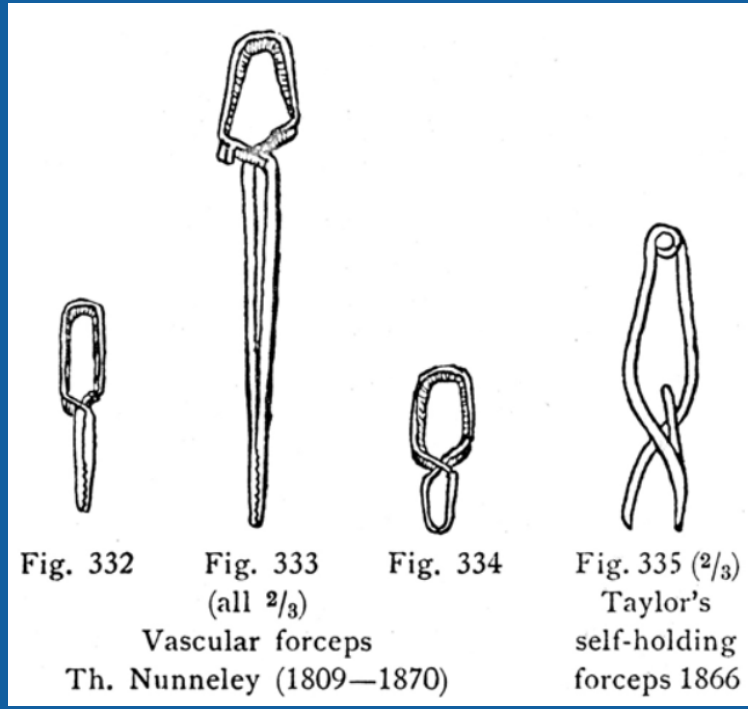


Fig. 332 Fig. 333 (all 2/3) Fig. 334 Fig. 335 (2/3)

Vascular forceps Th. Nunneley (1809—1870)

Taylor's self-holding forceps 1866

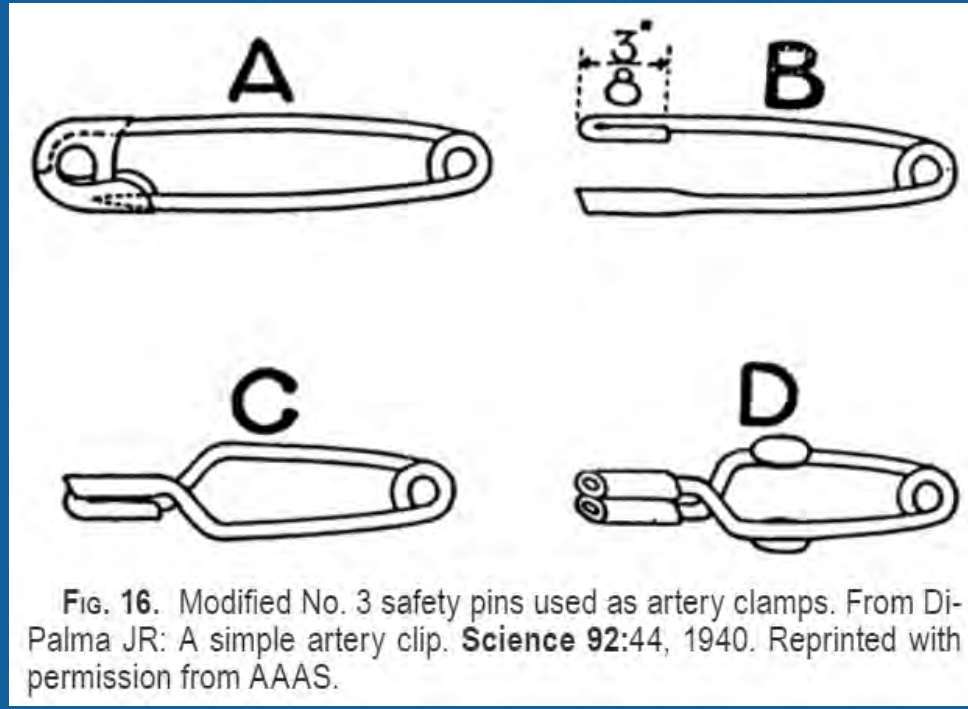


Fig. 16. Modified No. 3 safety pins used as artery clamps. From Di-Palma JR: A simple artery clip. **Science 92**:44, 1940. Reprinted with permission from AAAS.

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Microsurgical treatment

FIG. 3. Mayfield stainless-steel aneurysm clip. Photograph by Robert Ander (2011) from the author's collection.

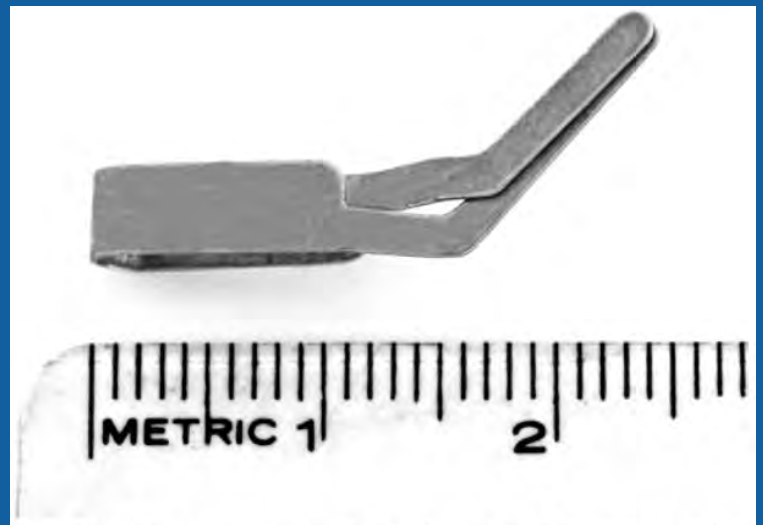

FIG. 2. Schwartz aneurysm clip. Photograph by Robert Ander (2011) from the author's collection.

FIG. 6. McFadden aneurysm clip. Photograph from the author's collection.

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Microsurgical treatment

Item No.		Blade length mm	Maximal opening mm	Closing force N	g
FT822T		10.0	5.6	1.96	200
FT850T		6.7	5.4	1.96	200
FT851T		9.0	5.6	1.96	200
FT830T		7.0	7.2	1.96	200
FT832T		9.3	7.2	1.96	200
FT833T		11.3	8.2	1.96	200
FT746T		7.0	5.7	1.96	200

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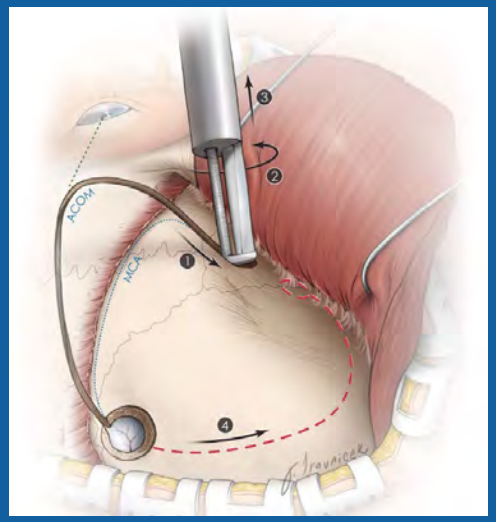
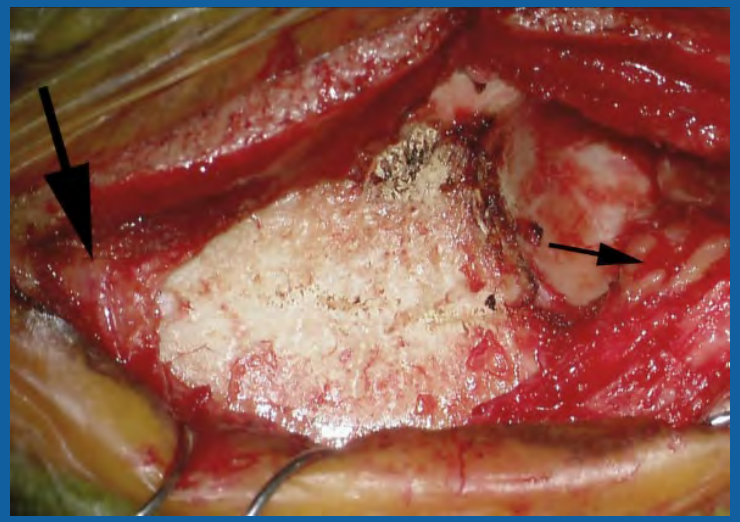
Microsurgical treatment





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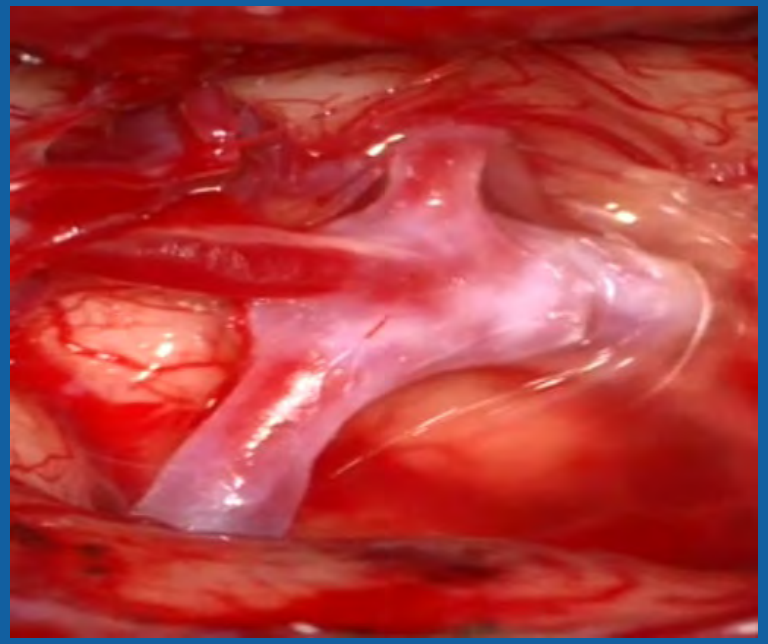
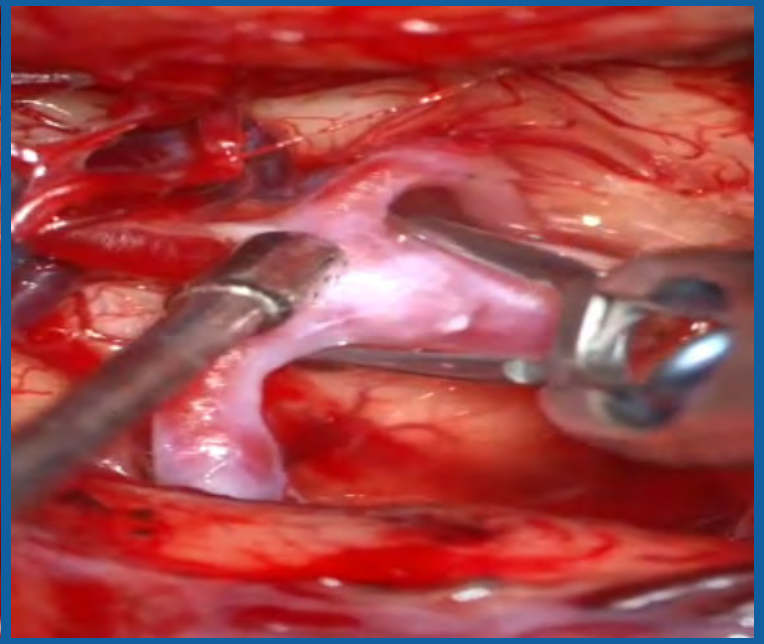
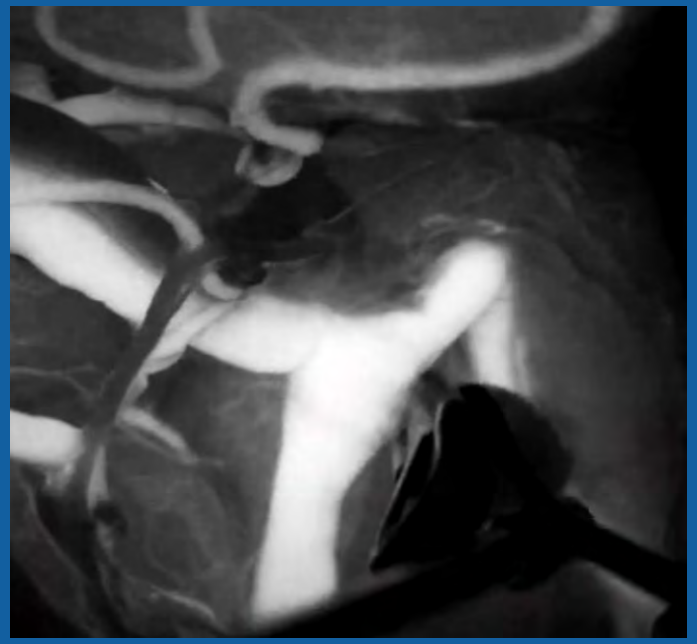
Microsurgical treatment







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Endovascular treatment

- Modern meta-analysis suggests mortality of 2%, morbidity of 4.8%
- Complete occlusion 86.1% initially
- Recanalization rate 24.4 to 34.6%
- Retreatment rate of 9.1%

Hackenberg et al. Stroke 2018.

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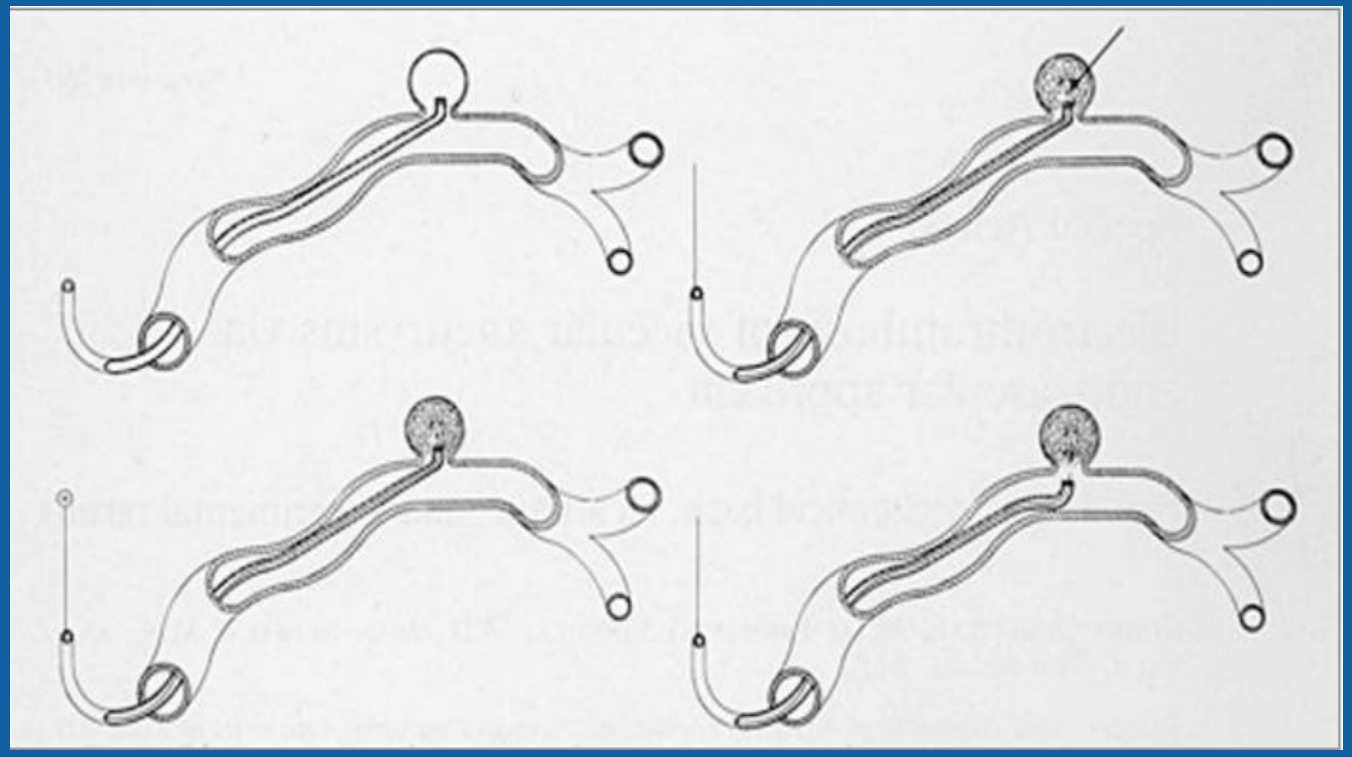
Endovascular treatment



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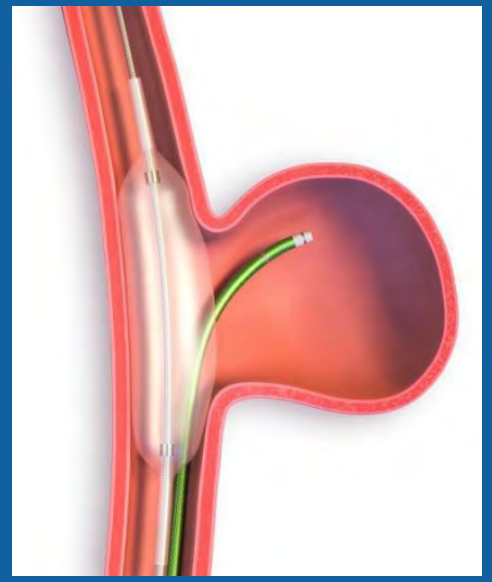
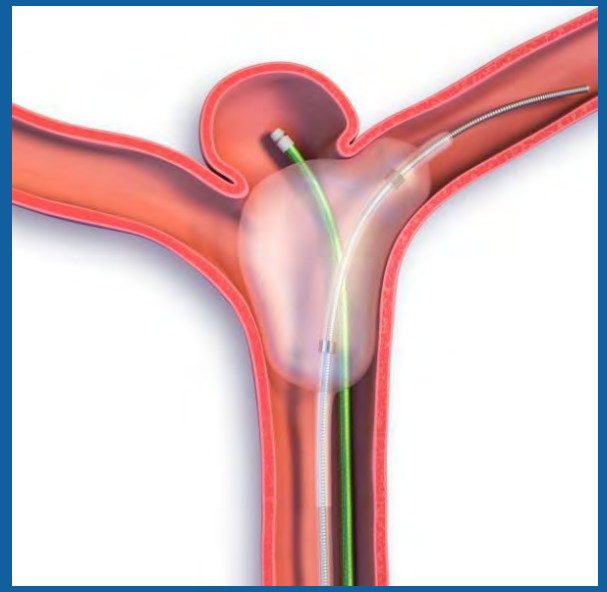
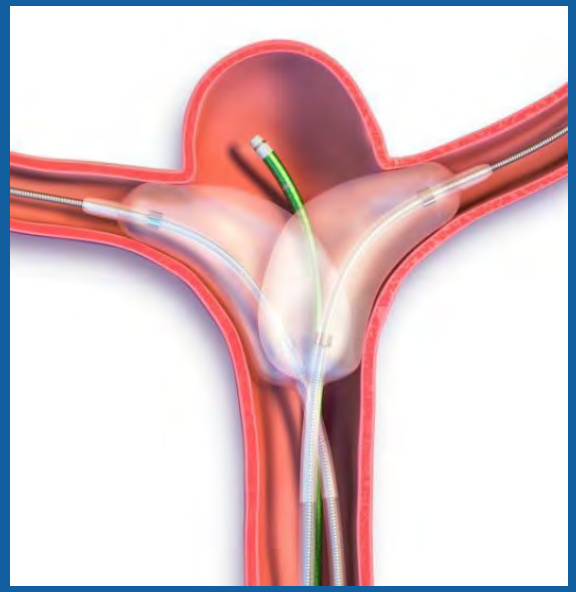
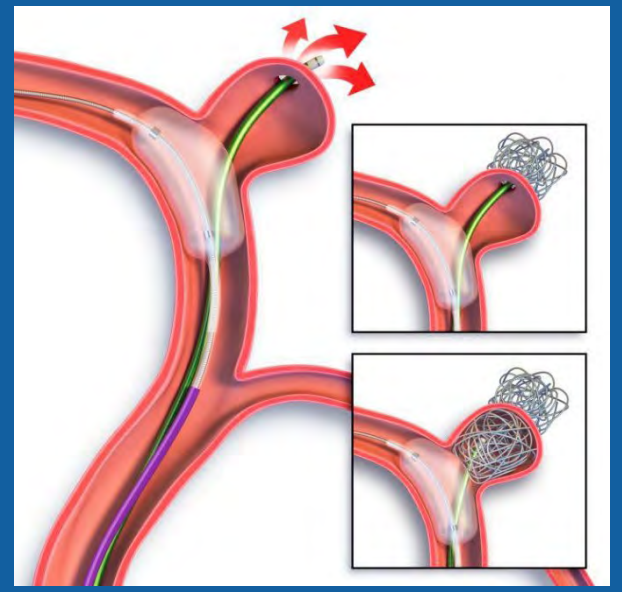
Endovascular treatment

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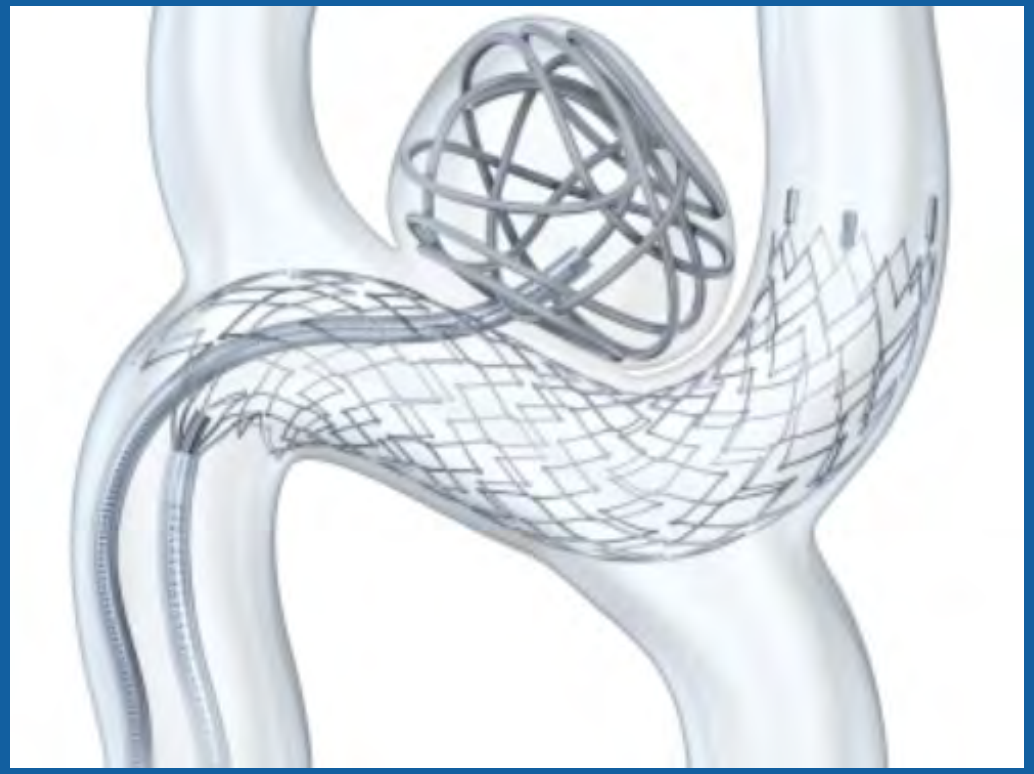
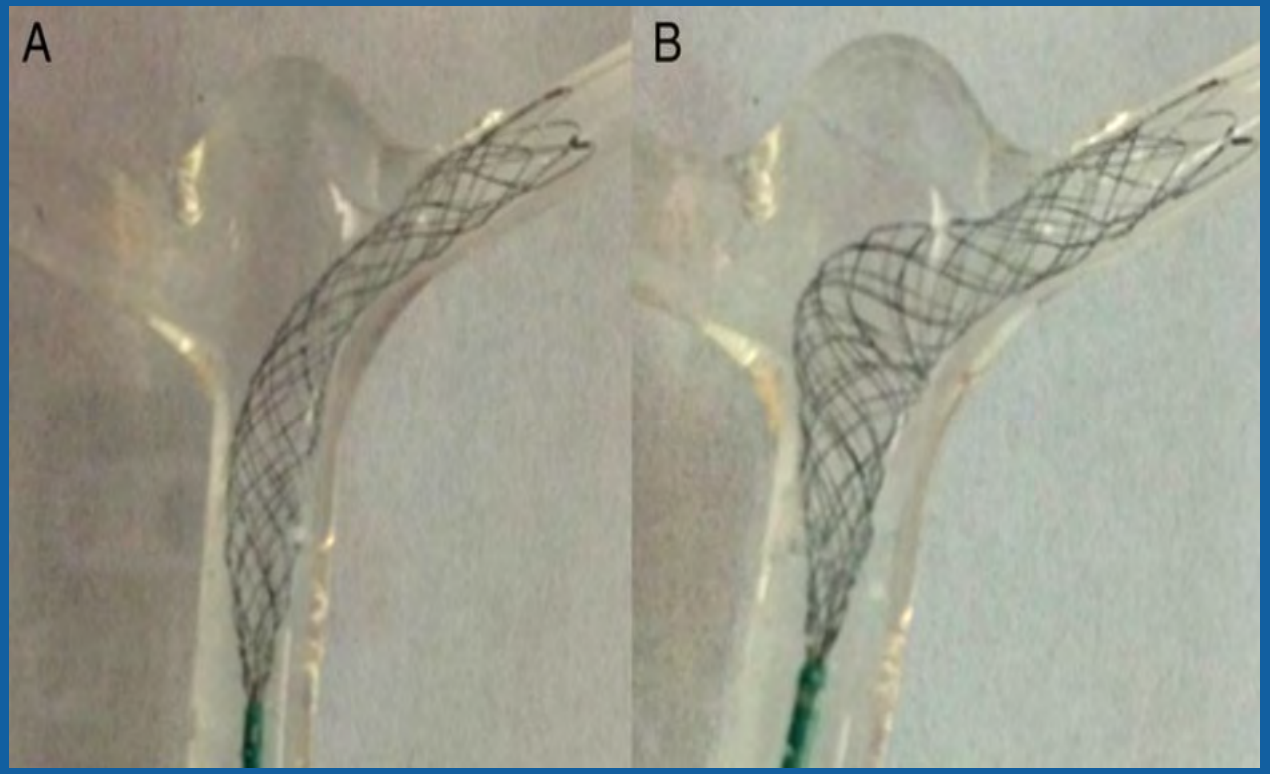
Endovascular treatment





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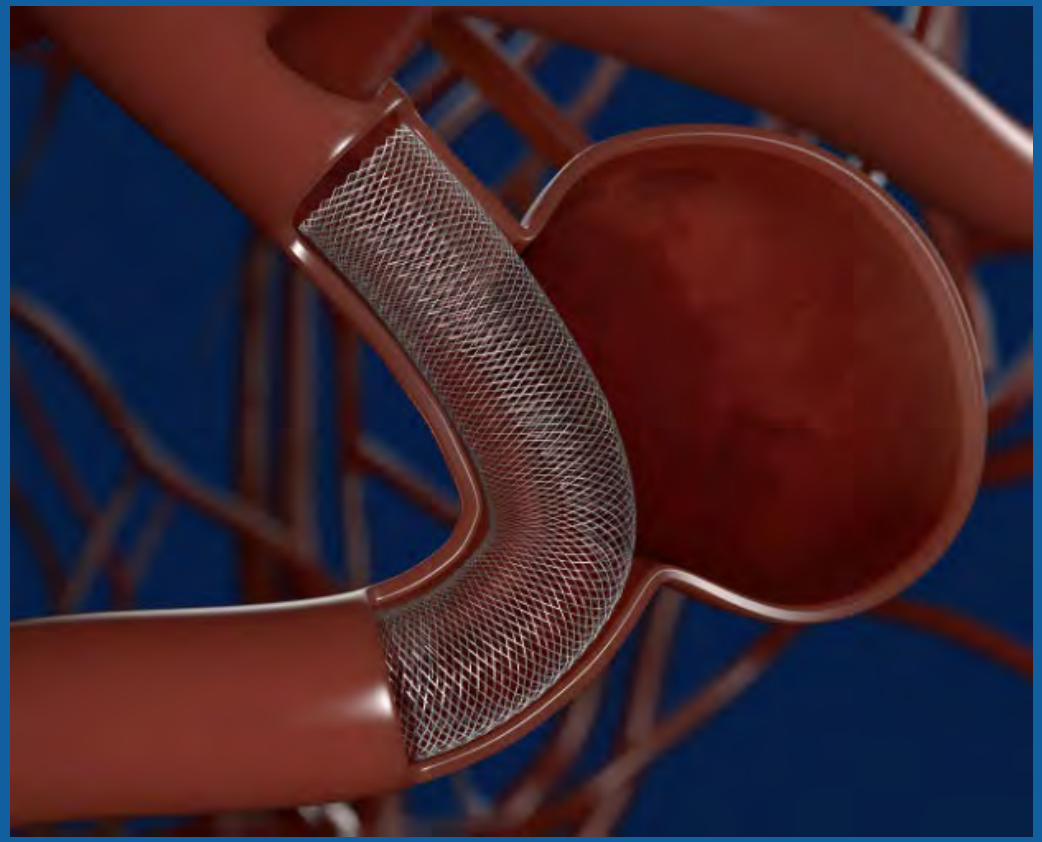
Endovascular treatment



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Management of Unruptured Cerebral Aneurysms

Observation

- Rupture rate estimated 1-1.4% per year
- True rupture rate likely higher given selection bias in natural history studies

Microsurgical clipping

- mortality of 1.7%, morbidity of 6.7%
- complete occlusion 91.8%
- Retreatment less than 5%

Endovascular treatment

- mortality of 2%, morbidity of 4.8%
- Complete occlusion 86.1% initially
- Recanalization rate 24.4 to 34.6%
- Retreatment rate of 9.1%

Hackenberg et al. Stroke 2018.

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A Pragmatic Randomized Trial Comparing Surgical Clipping and Endovascular Treatment of Unruptured Intracranial Aneurysms

T.E. Darsaut, J.M. Findlay, M.W. Bojanowski, C. Chalaala, D. Iancu, D. Roy, A. Weill, W. Boisseau, A. Diouf, E. Magro, M. Kotowski, M.B. Keough, L. Estrade, N. Bricout, J.-P. Lejeune, M.M.C. Chow, C.J. O'Kelly, J.L. Rempel, R.A. Ashforth, H. Lesiuk, J. Sinclair, U.-E. Erdenebold, J.H. Wong, F. Scholtes, D. Martin, B. Otto, A. Bilocq, E. Truffer, K. Butcher, A.J. Fox, A.S. Arthur, L. Létourneau-Guillon, F. Guilbert, M. Chagnon, J. Zehr, B. Farzin, G. Gevry and J. Raymond

American Journal of Neuroradiology May 2023, DOI: https://doi.org/10.3174/ajnr.A7865

CLINICAL QUESTION:

In patients with unruptured intracranial aneurysms, how does surgical treatment compare with endovascular treatment in terms of treatment efficacy and safety?

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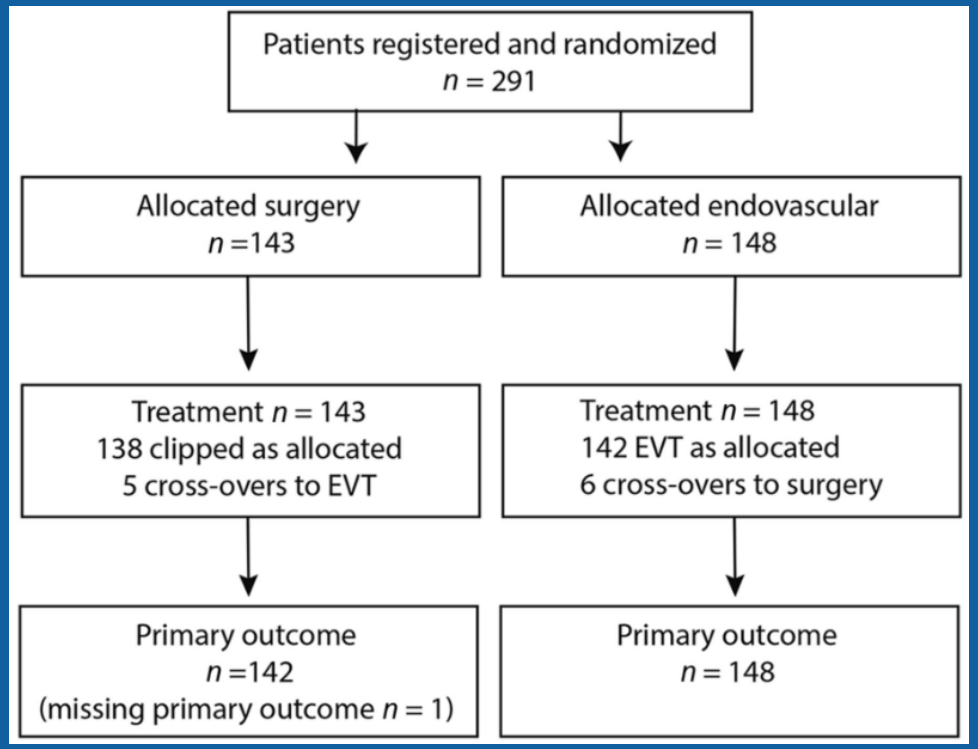
STUDY DESIGN:

Multicenter, randomized, parallel-group, unblinded trial (2010 to 2020)

- 5 Canadian centers, 2 European centers

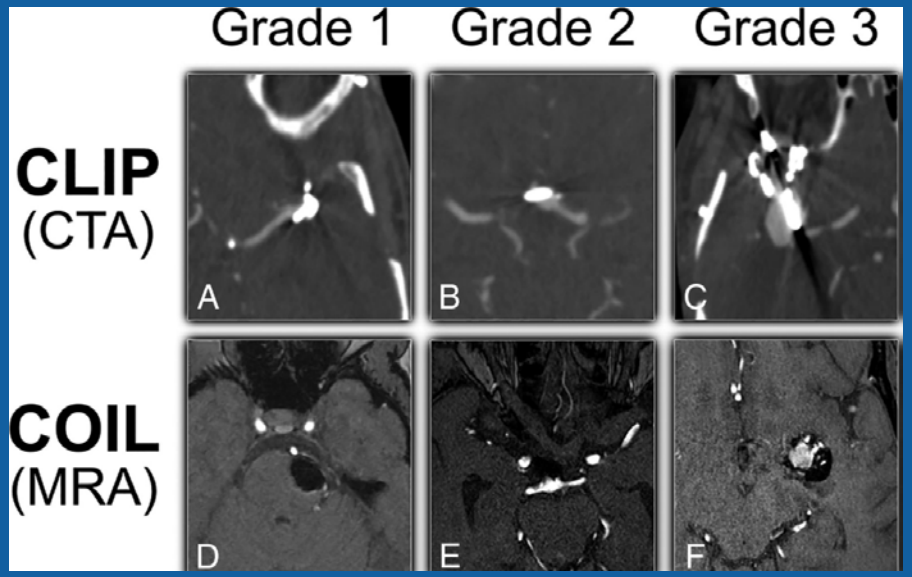


Saint Luke's

STUDY DESIGN:

Primary outcome measure:

- Treatment failure
  - Failure of aneurysm occlusion using allocated treatment technique
  - Intracranial hemorrhage during follow-up
  - Residual or recurrent index aneurysm found on 1 year CTA/MRA/angiogram



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STUDY DESIGN:

Secondary outcome measures:

- Overall morbidity/mortality at 1 year (mRS > 2)
- New peri-operative neurologic deficit within 30 days of procedure
- Peri-operative morbidity at discharge (mRS > 2)
- Hospitalization lasting longer than 5 days

Saint Luke's

A Pragmatic Randomized Trial Comparing Surgical Clipping and Endovascular Treatment of Unruptured Intracranial Aneurysms

T.E. Darsaut, J.M. Findlay, M.W. Bojanowski, C. Chalaala, D. Iancu, D. Roy, A. Weill, W. Boisseau, A. Diouf, E. Magro, M. Kotowski, M.B. Keough, L. Estrade, N. Bricout, J.-P. Lejeune, M.M.C. Chow, C.J. O'Kelly, J.L. Rempel, R.A. Ashforth, H. Lesiuk, J. Sinclair, U.-E. Erdenebold, J.H. Wong, F. Scholtes, D. Martin, B. Otto, A. Bilocq, E. Truffer, K. Butcher, A.J. Fox, A.S. Arthur, L. Létourneau-Guillon, F. Guilbert, M. Chagnon, J. Zehr, B. Farzin, G. Gevry and J. Raymond

American Journal of Neuroradiology May 2023, DOI: https://doi.org/10.3174/ajnr.A7865

BOTTOM LINE:

Clipping is more effective than endovascular therapy in terms of angiographic results at 1 year for anterior circulation aneurysms, especially MCA.

Clipping also associated with longer hospitalization and greater risk of short-term morbidity, but no difference in long term.

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Management of Ruptured Cerebral Aneurysms

ISAT 2002, 2005, 2015
International Subarachnoid Aneurysm Trial

Primary outcome (1 yr death or dependency) 30.9% clip vs 23.5% coil

Complete occlusion 82% clip vs 66% coil

Heavily criticized for the following reasons:

- **Only 22% of eligible patients were randomized (eligible only if aneurysms were deemed suitable for either clip or coil)**
- **Use of general neurosurgeons instead of cerebrovascular subspecialists**
- **Higher time to treatment in clip group, higher pre-procedure mortality**
- **Centers with best interventionalists contributed the most patients (expertise favored for endovascular)**
- **UK provided 76% of patients, significant erosion of microsurgical training/skill in aneurysm surgery in UK during time of trial**

Molyneux et al. Lancet 2005.

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Management of Ruptured Cerebral Aneurysms

ISAT 2002, 2005, 2015
International Subarachnoid Aneurysm Trial

At 10 years, independent survival 82% coil vs 78% clip

Rebleed risk 2.2% coil vs 0.6% clip

Heavily criticized for the following reasons:

- **Only 22% of eligible patients were randomized (eligible only if aneurysms were deemed suitable for either clip or coil)**
- **Use of general neurosurgeons instead of cerebrovascular subspecialists**
- **Higher time to treatment in clip group, higher pre-procedure mortality**
- **Centers with best interventionalists contributed the most patients (expertise favored for endovascular)**
- **UK provided 76% of patients, significant erosion of microsurgical training/skill in aneurysm surgery in UK during time of trial**

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Management of Ruptured Cerebral Aneurysms

BRAT 2012, 2015, 2018
Barrow Ruptured Aneurysm Trial

Primary outcome (1 year death or dependency) 34% clip vs 23% coil

Retreatment at 1 year: 3% surgery vs 7% endovascular

At 6 year follow-up:

No significant difference in primary outcome (41% clip, 35% coil)

Posterior circulation aneurysms: coil group better than clip group (poor mRS 31% coil vs 63% clip)

Complete obliteration 96% clip, 48% coil

Need for retreatment: 5% clip, 16% coil

Spetzler et al. J Neurosurg 2018.

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Management of Ruptured Cerebral Aneurysms

BRAT 2012, 2015, 2018
Barrow Ruptured Aneurysm Trial

At 6 year follow-up:

No significant difference in primary outcome (41% clip, 35% coil)

Posterior circulation aneurysms: coil group better than clip group (poor mRS 31% coil vs 63% clip)

Complete obliteration 96% clip, 48% coil

Need for retreatment: 5% clip, 16% coil

At 10 year follow-up:

No significant difference in primary outcome (51% clip, 53% coil)

Posterior circulation aneurysms: coil group better than clip group (poor mRS 45% coil vs 74% clip)

Complete obliteration 93% clip, 22% coil

Rate of fatal re-hemorrhage: 0% clip, 2.4% coil

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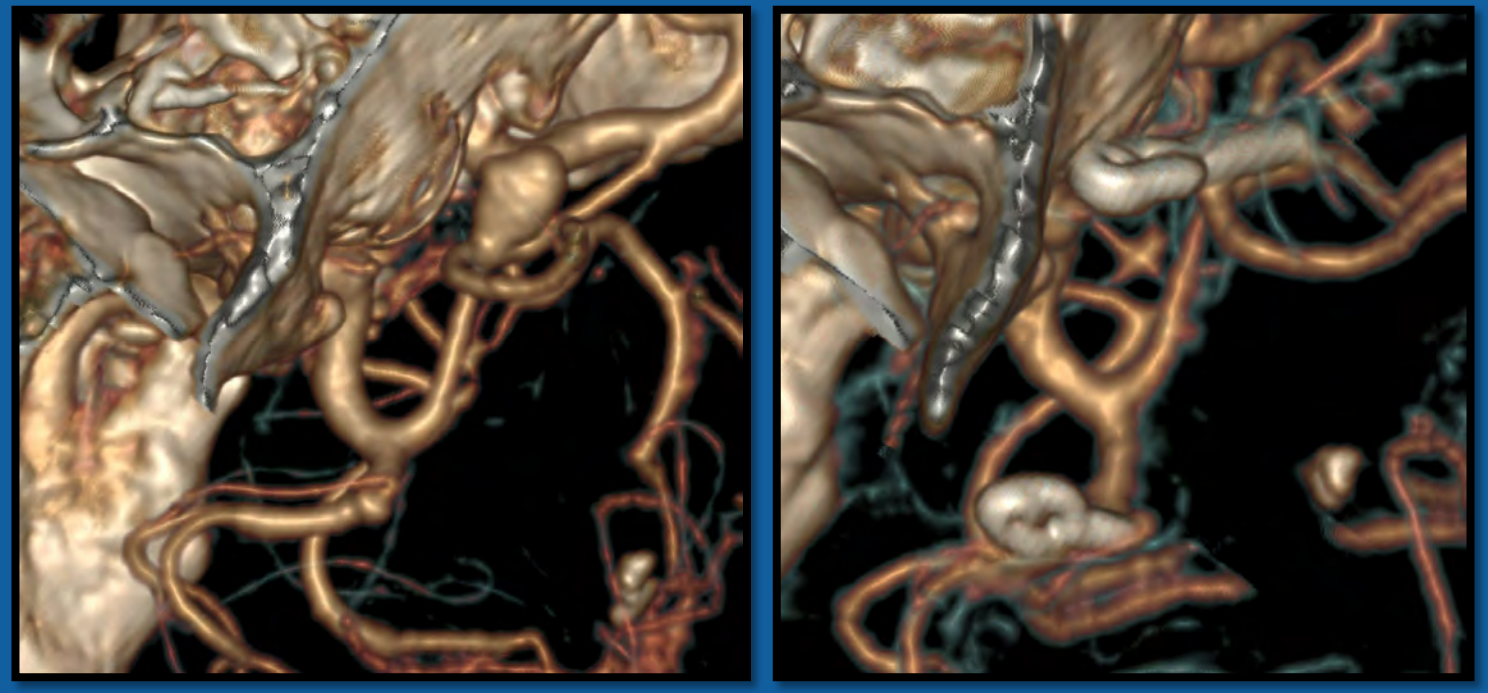
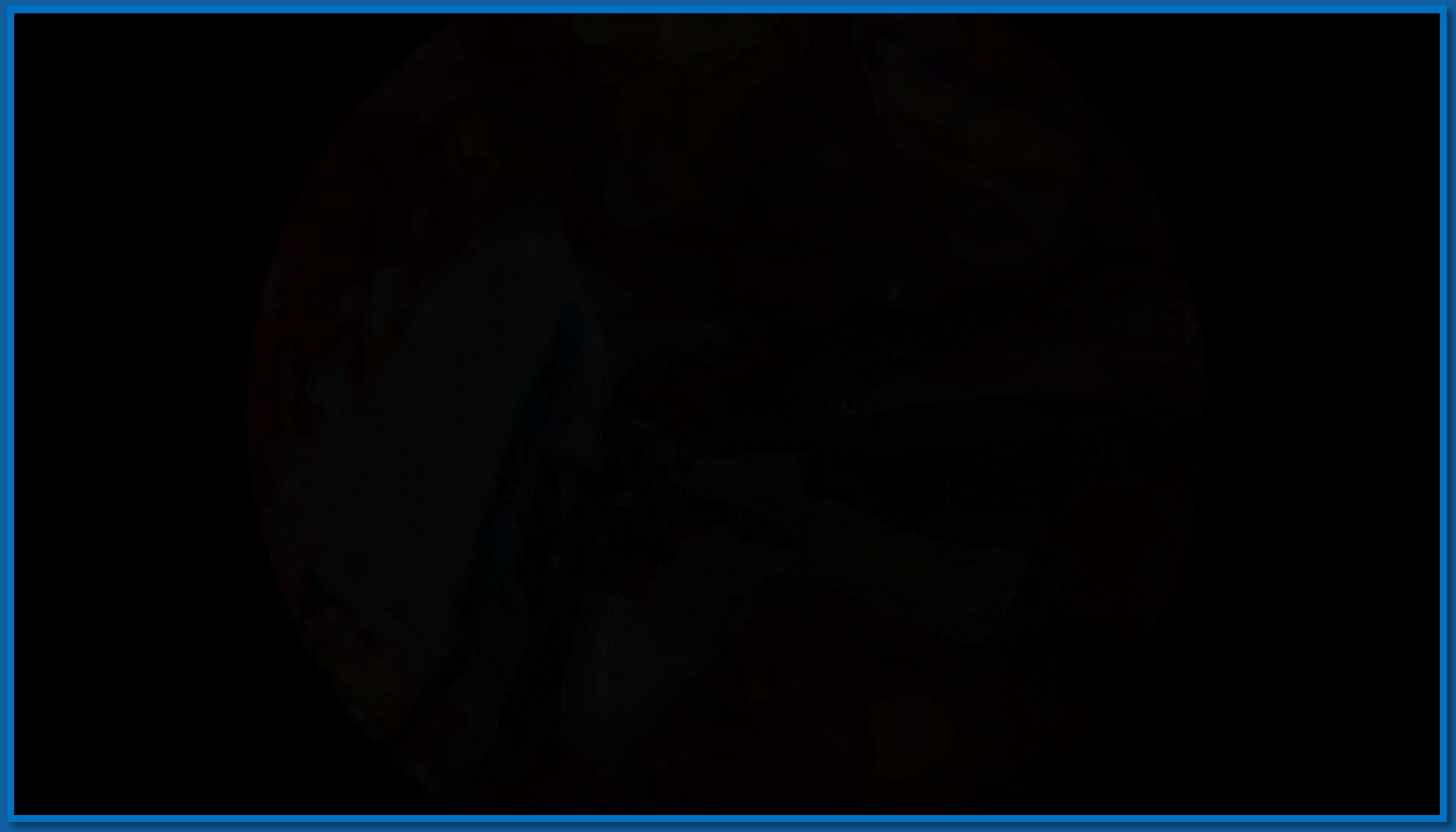
Unruptured aneurysm clipping

74 year old man with incidentally discovered large 9 mm acom aneurysm and 2 mm left anterior temporal MCA aneurysm. Significant proximal arterial tortuosity.



Saint Luke's

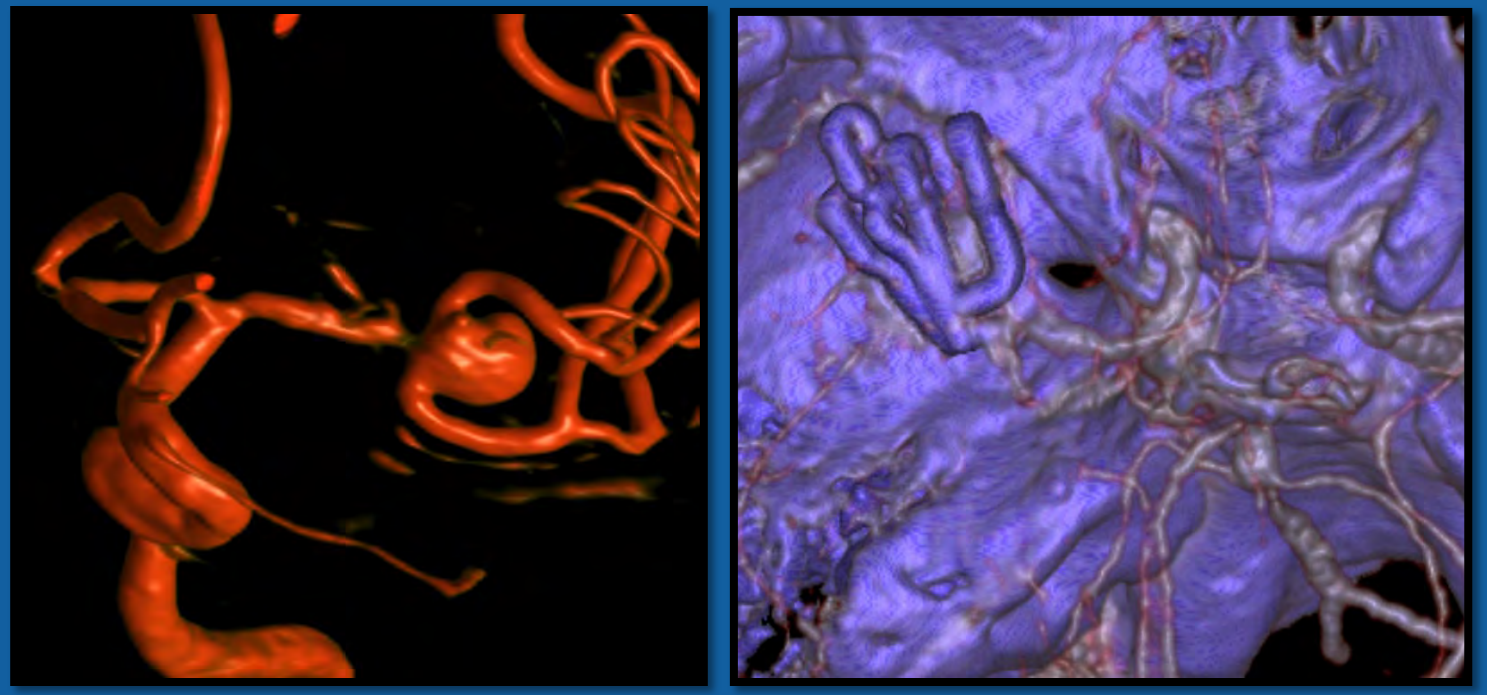
Unruptured aneurysm clipping



Saint Luke's

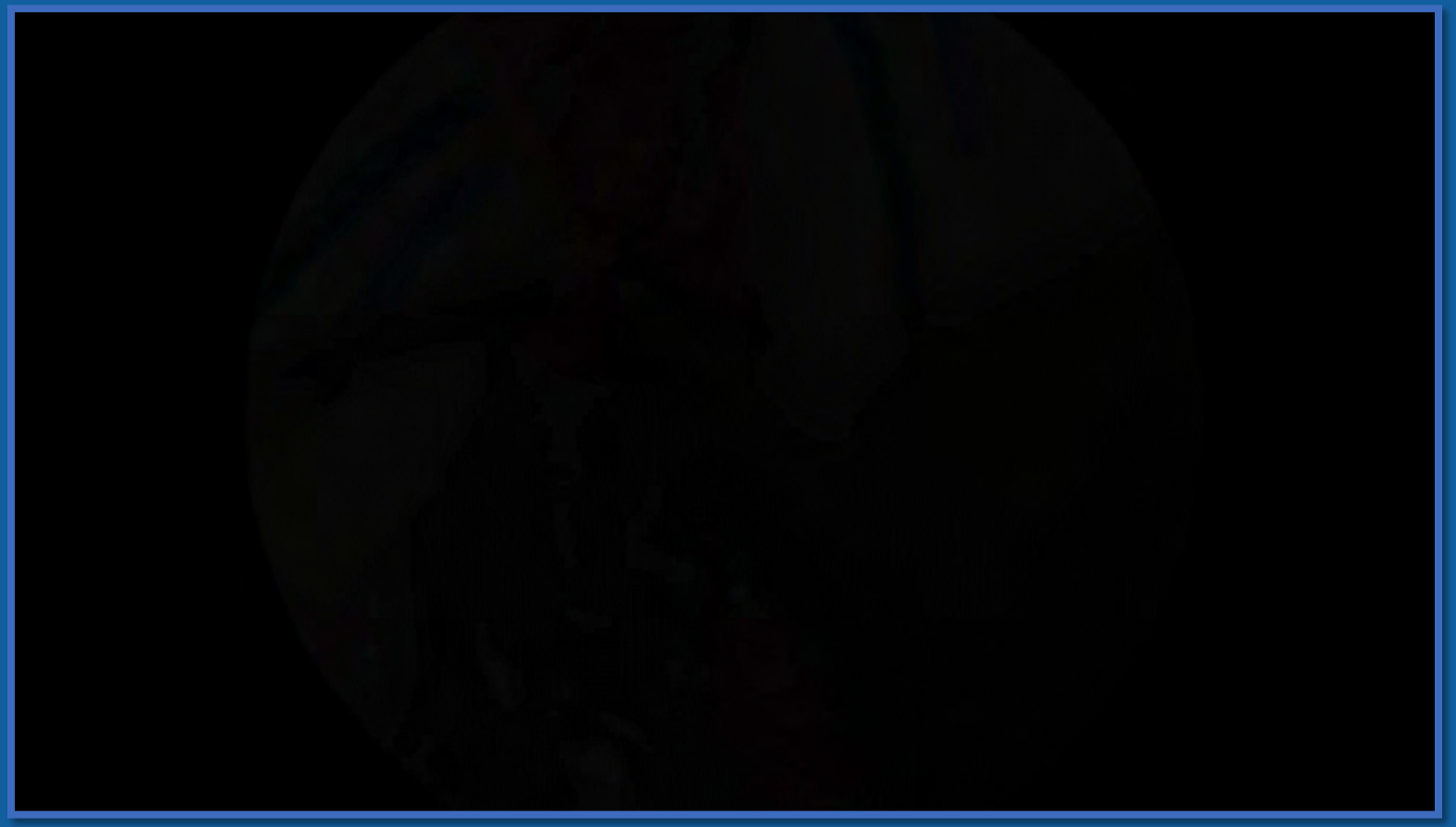
Unruptured aneurysm clipping

67 year old woman with incidentally discovered 10 mm wide necked irregular L MCA aneurysm. Significant proximal arterial tortuosity.



Saint Luke's

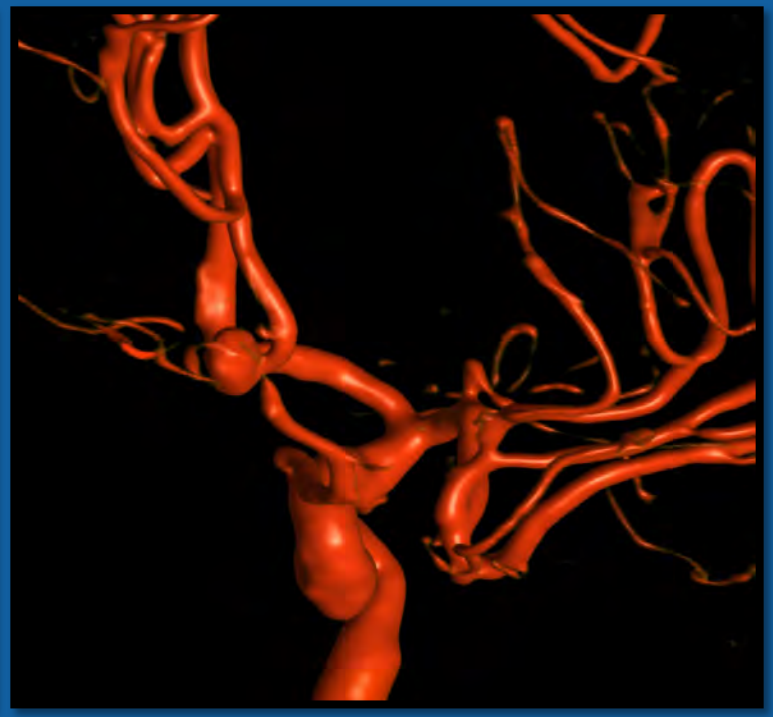
Unruptured aneurysm clipping

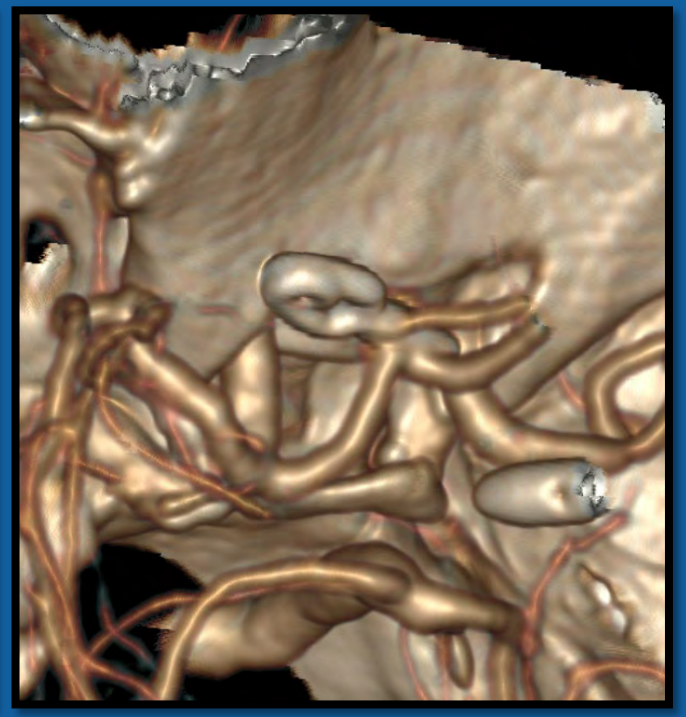


Saint Luke's

Ruptured aneurysm clipping

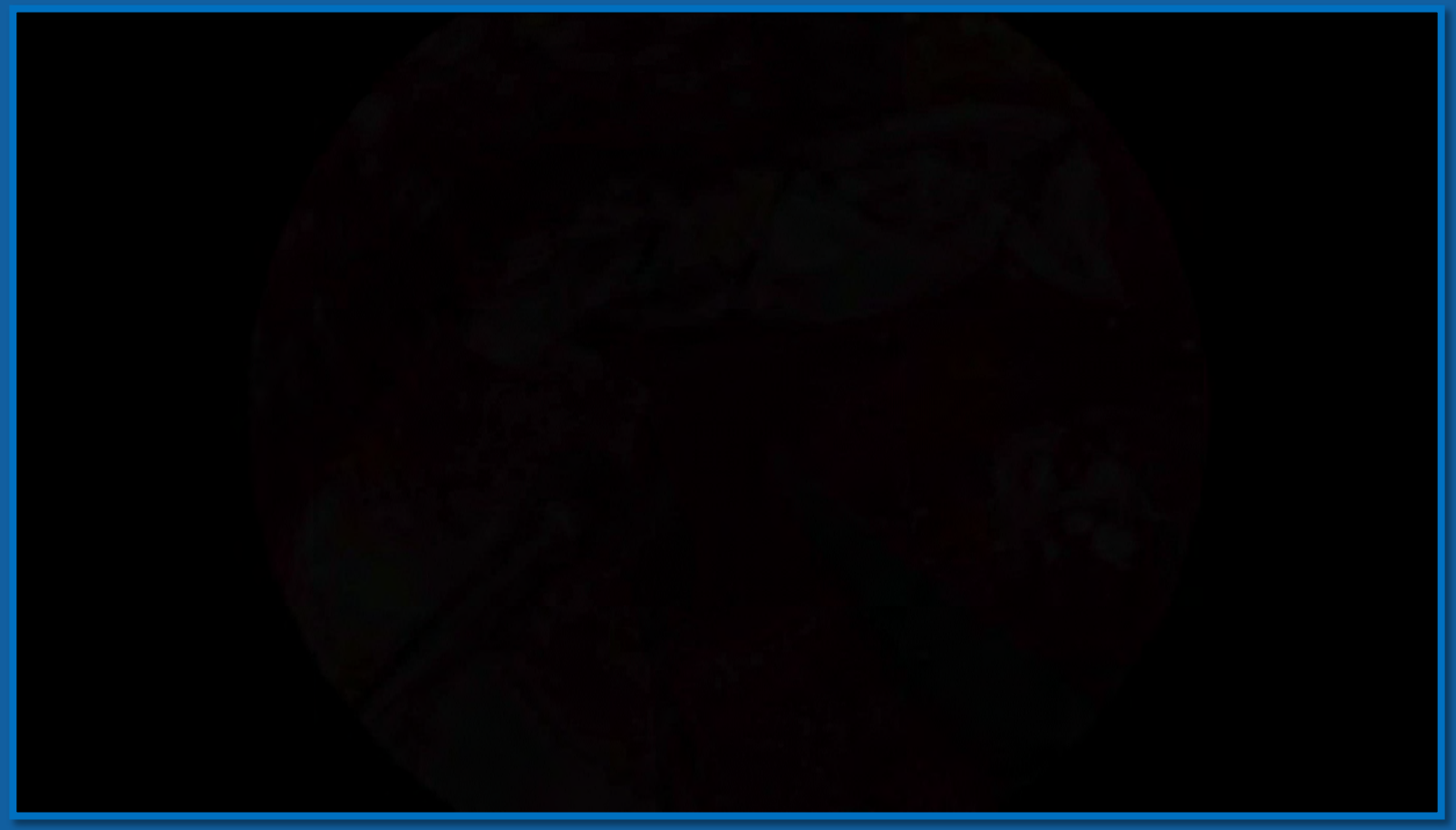
59 year old woman with HH3mF4 aneurysmal subarachnoid hemorrhage from 5 mm wide necked ruptured acom aneurysm.





Saint Luke's

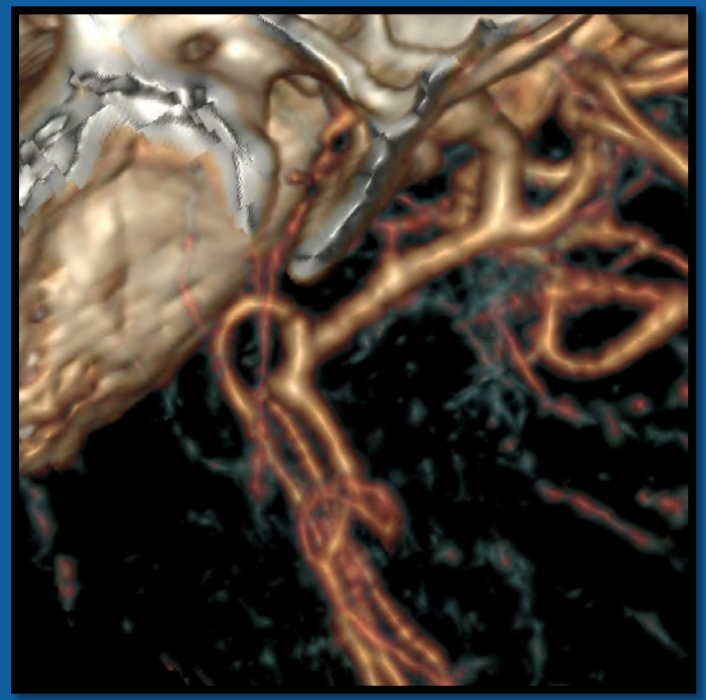
Ruptured aneurysm clipping

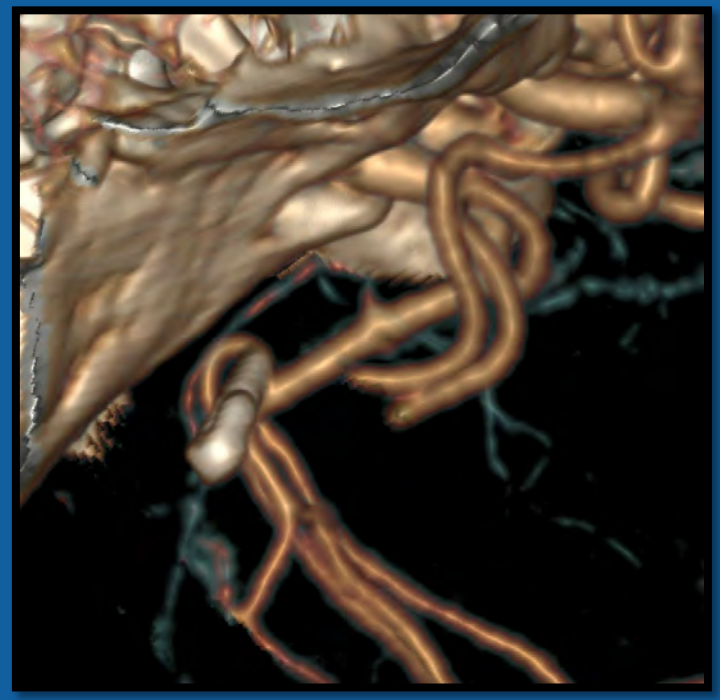


Saint Luke's

Ruptured aneurysm clipping

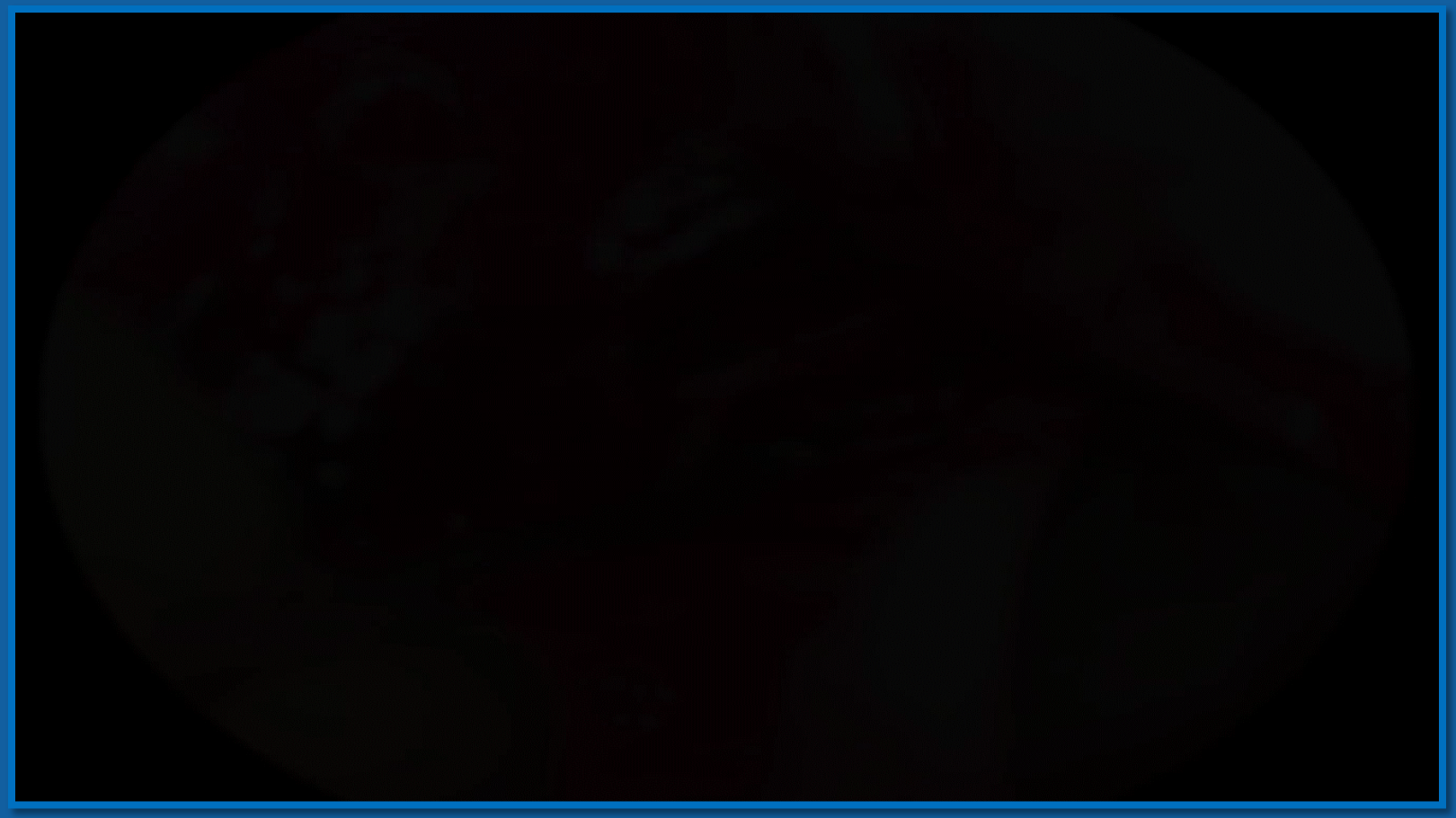
65 year old woman with HH4mF4 aneurysmal subarachnoid hemorrhage from 3 mm L MCA bifurcation aneurysm.





Saint Luke's

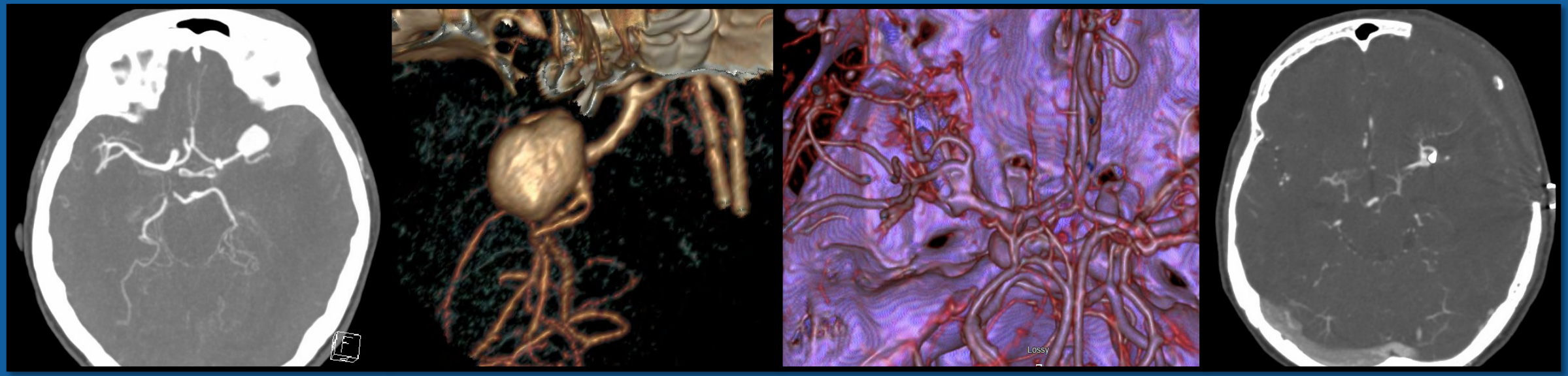
Ruptured aneurysm clipping



Saint Luke's

Ruptured aneurysm clipping

64 year old woman with HH4mF4 aneurysmal subarachnoid hemorrhage from 15 mm L MCA bifurcation aneurysm.



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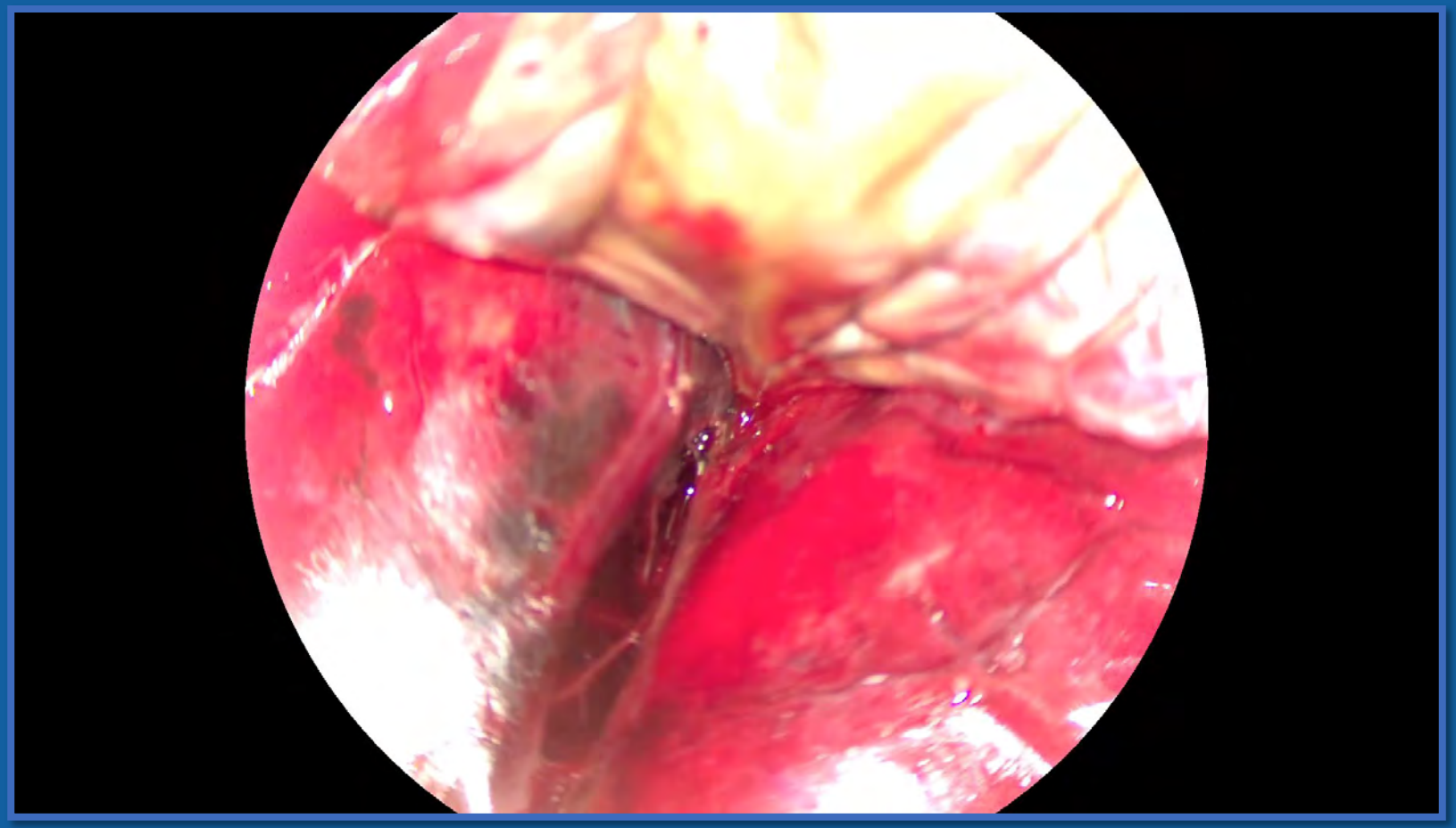
Ruptured aneurysm clipping



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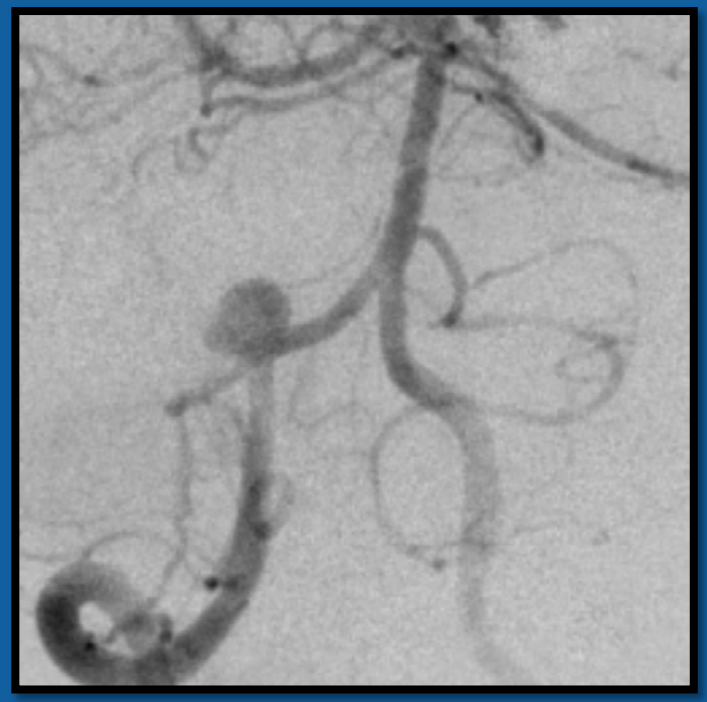
Unruptured aneurysm coiling

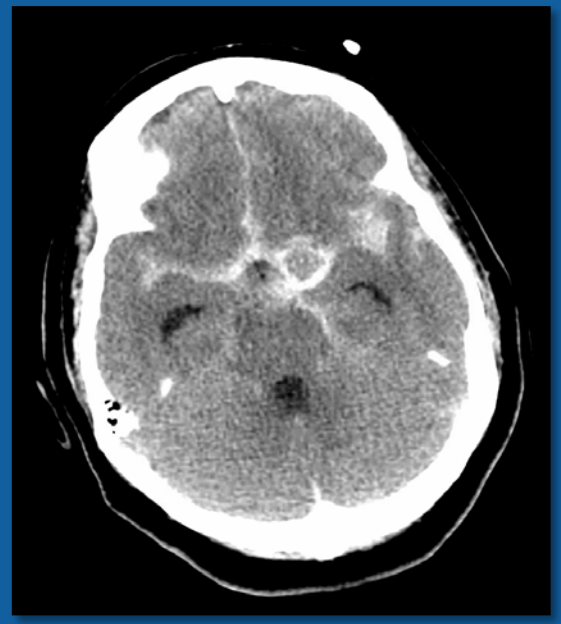
47 year old woman with unruptured wide-necked 7 mm R PICA aneurysm



Saint Luke's

Ruptured aneurysm coiling

60 year old woman with HH4mF4 aSAH secondary to ruptured 13 mm L ICA terminus aneurysm

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Flow diversion

50 year old man with dissecting left vertebral artery aneurysm

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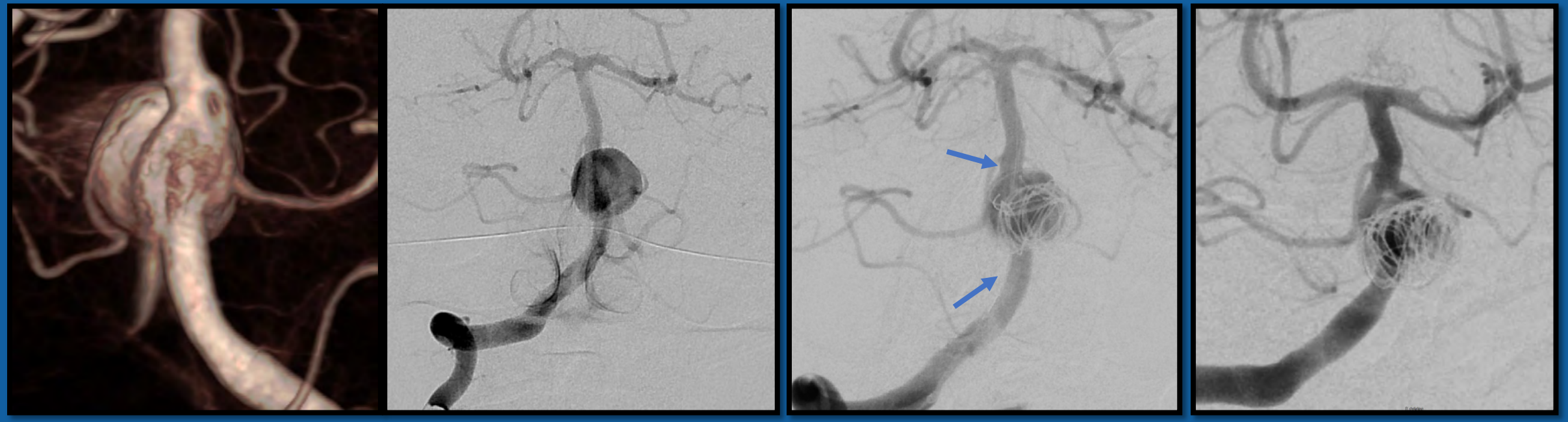
Flow diversion

62 year old woman with 1.6 cm ventral basilar fenestration aneurysm



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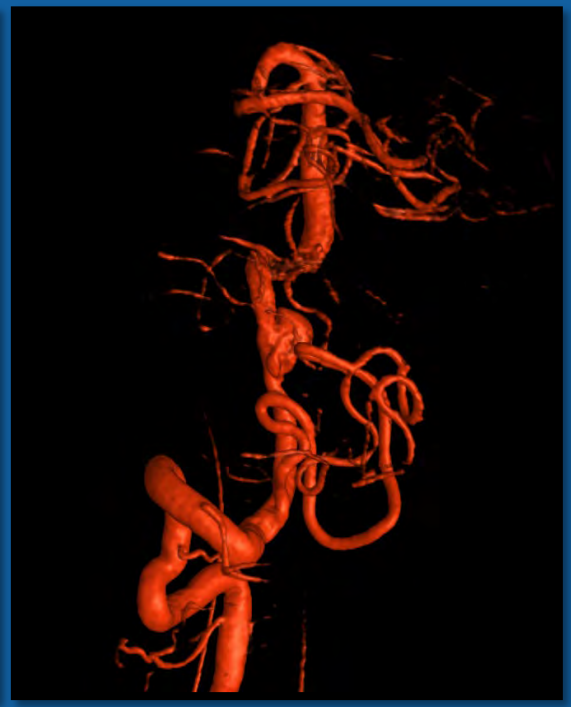
Ruptured aneurysm clipping

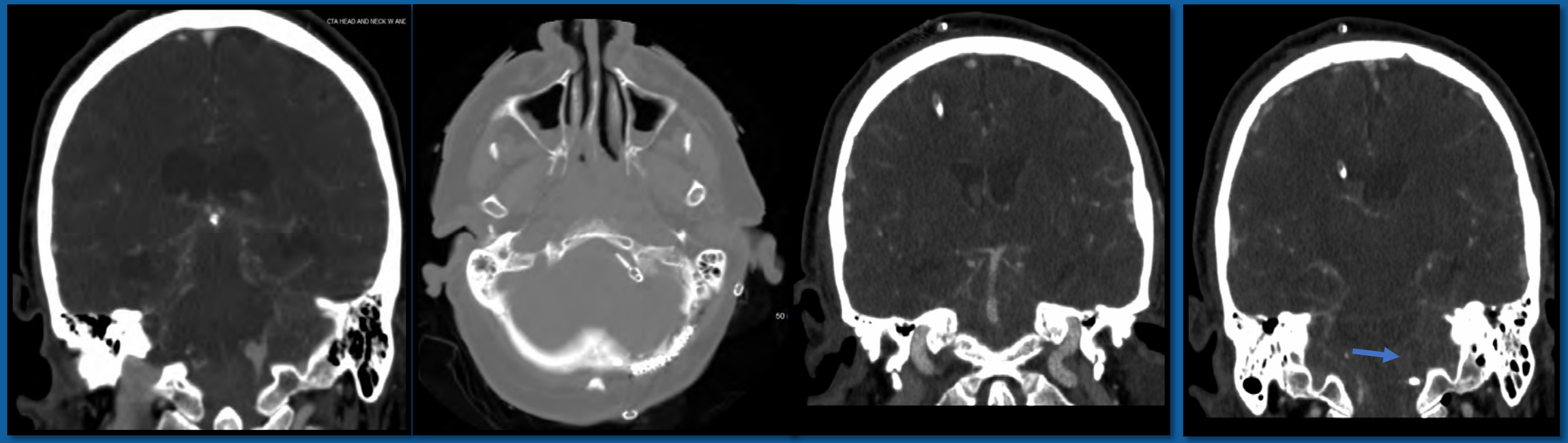
61 year old man with HH3mF4 aneurysmal subarachnoid hemorrhage from ruptured dissecting left V4 segment aneurysm. Endovascular treatment limited by severe proximal tortuosity.

Saint Luke's

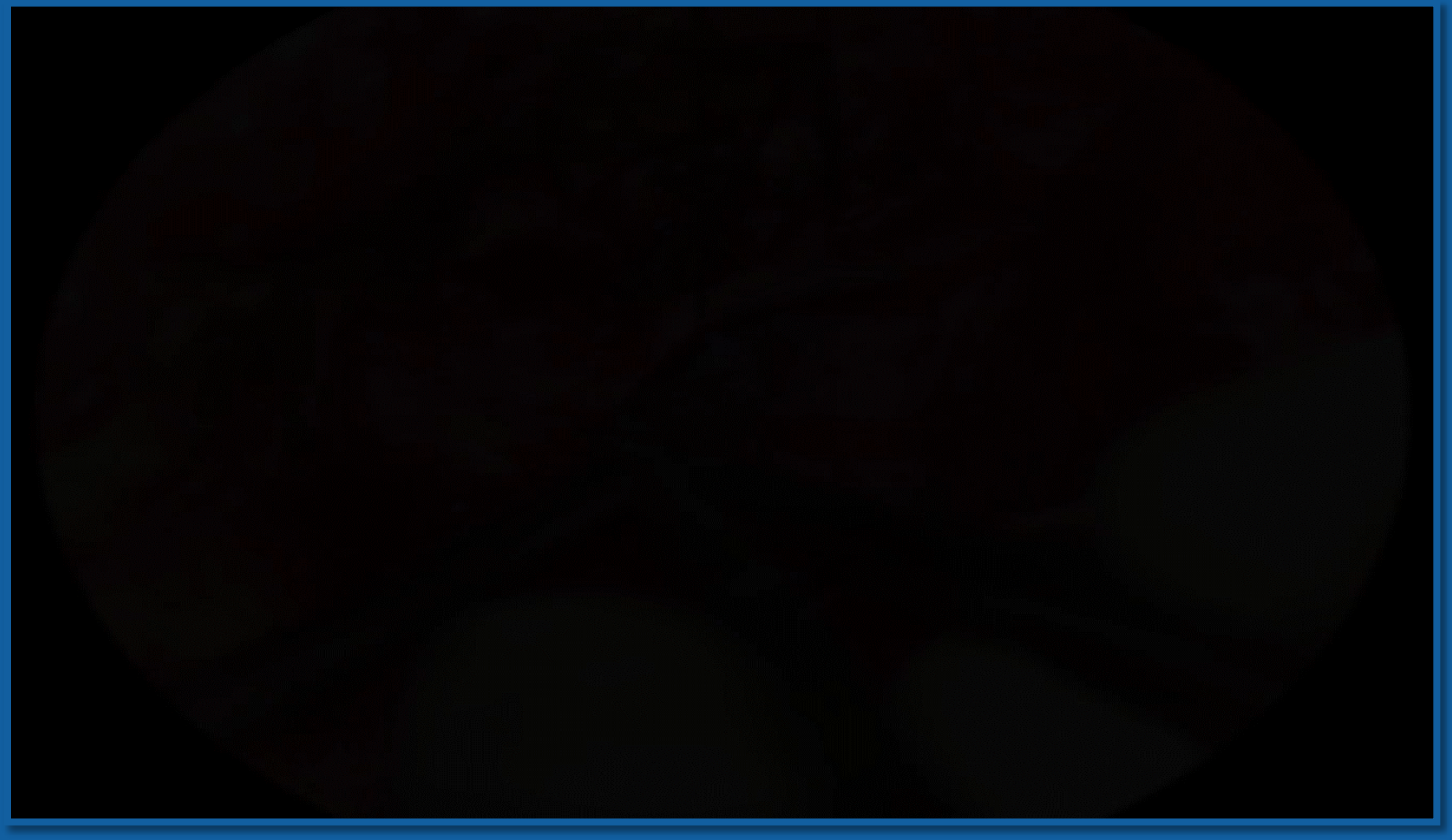
Ruptured aneurysm clipping

61 year old man with HH3mF4 aneurysmal subarachnoid hemorrhage from ruptured dissecting left V4 segment aneurysm. Endovascular treatment limited by severe proximal tortuosity.



Saint Luke's

Ruptured aneurysm clipping



Saint Luke's

Thank you!

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